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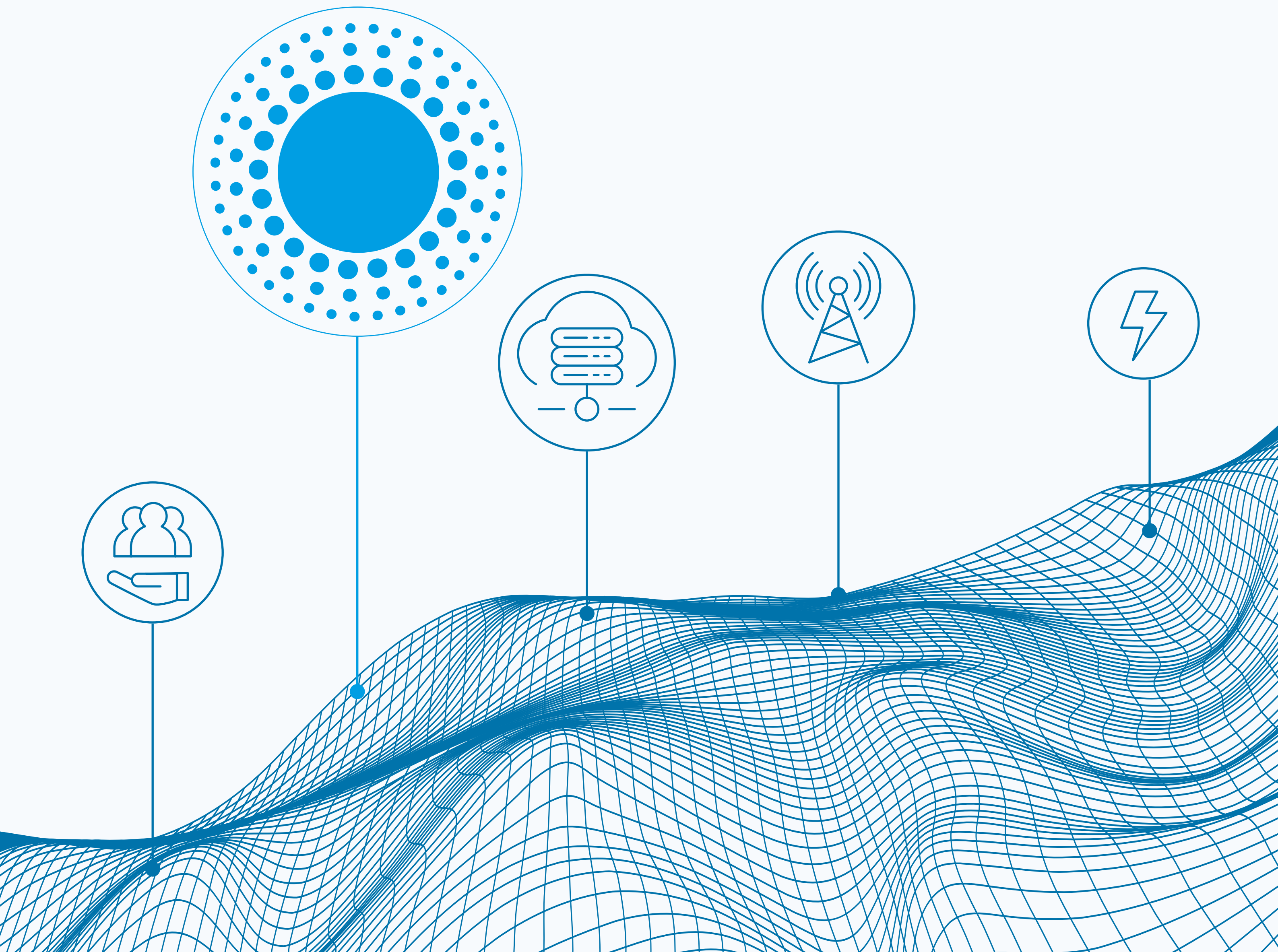
INCREASING SPACE GRANULARITY IN ELECTRICITY MARKETS

INNOVATION LANDSCAPE BRIEF



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ISBN 978-92-9260-128-7

Citation: IRENA (2019), *Innovation landscape brief: Increasing space 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 space granularity in electricity markets

Short term:

Avoid costly re-dispatch and incentivise demand response in areas with high prices

Long term:

Optimise network and generation capacity investments through price signals

Incentivise investments in VRE generation in areas with high prices

Incentivise investments in the grid between areas with high price differences

3 SNAPSHOT

- In the US, ERCOT (Texas) has more than 4 000 pricing nodes, while NYISO (Ney York) has 11 zones. This encourages investments in areas with the highest demand and reduces consumption.
- In Europe, some countries divide their national transmission system into more bidding zones: Denmark (2), Italy (6), Norway (5) and Sweden (4).

2 KEY ENABLING FACTORS

- Advanced computational power and optimisation modelling software
- Clear and transparent pricing methodology

WHY INCREASE SPACE GRANULARITY?

High shares of VRE deployment, in particular wind, might constrain transmission networks.

INCREASING SPACE GRANULARITY IN ELECTRICITY MARKETS

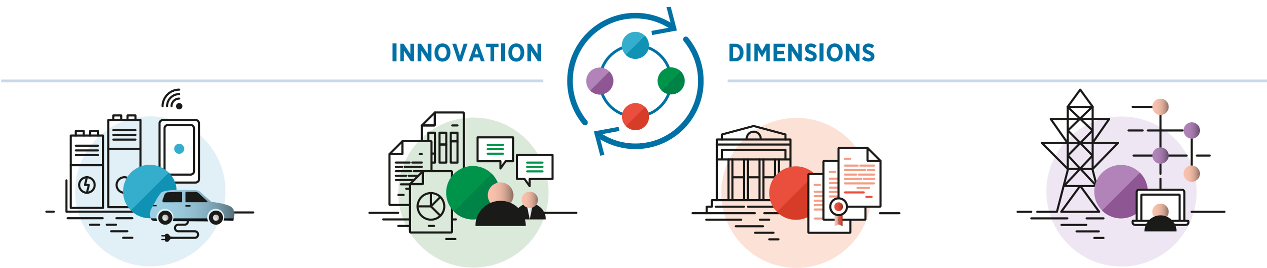
Zonal and nodal pricing reflectgridcongestions.
Increasing space granularity in electricity markets can help **reduce re-dispatch costs** and **drive investments** where most needed.

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 a key market design innovation of increasing space granularity in electricity markets (using nodal or zonal pricing), which addresses the variability and uncertainty of VRE share in the grid. As the share of VRE increases in the overall energy mix, congestion in the transmission network is likely to increase as well. Electricity price formation at different points of the transmission system reflecting congestion can help to reduce the re-dispatch need and can incentivise transmission grid investments in right locations.

The brief is structured as follows:

I. DESCRIPTION

As the share of VRE increases in the energy mix, it may lead to an increasingly constrained transmission system. Price formation at a granular spatial level can reflect this condition and send the necessary price signals in order to avoid or reduce costly re-dispatch, incentivise demand response, and encourage generation capacity investment in the right location of the network.

When referring to space granularity in electricity markets, there are two fundamentally different market designs, as described below (IRENA, 2017).

- Nodal pricing: Nodal pricing refers to prices paid for electricity consumed or generated at a given transmission node. Under this option, transmission constraints are explicitly observed while determining the optimal dispatch of the system and deriving the locational marginal prices. Nodal pricing better depicts the technical and economic effects of the network on the price of electricity as it implicitly includes the impact of grid losses and transmission congestion (IRENA, 2017). For example, several independent system operators (ISOs) in the United States use nodal prices from which are derived the locational marginal price (LMP).

- Zonal pricing: A pricing zone is defined as the largest geographical area within which market participants are able to trade energy without capacity allocation, i.e., an area where grid congestion is assumed to be low. These zones are defined by the regulator and/or the transmission system operator (TSO) and hence the price differentials between the zones reflect the grid congestion between the zones. Such bidding zones represent, for example, the cornerstone of the pan-European electricity market, whereby electricity is traded across bidding zones, based on available transmission capacities calculated by TSOs, while the electricity traded within a bidding zone is considered unrestricted by transmission capacity. While in most cases a bidding zone corresponds to national borders, there are countries that divide their power system into more zones. Italy, for example, has divided the national transmission system into six geographical bidding zones (GME, n.a).

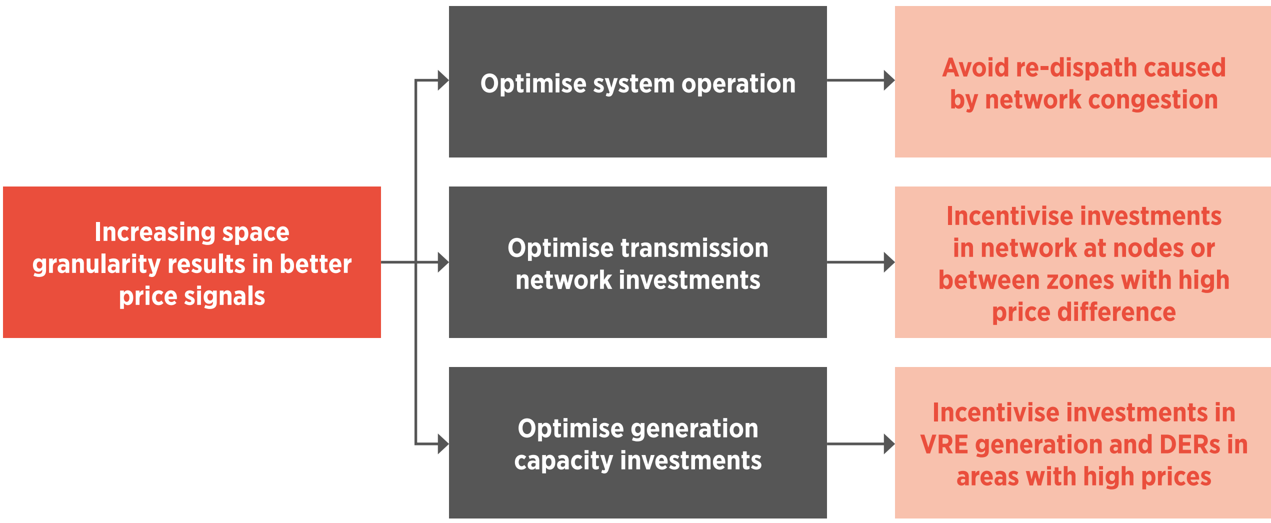
With increasing penetration of VRE, transmission networks are expected to become more congested between areas with relatively high renewable generation units and demand centres. Increased space granularity in electricity markets can help provide better market signals to the system operator and generators, incentivising investments in high-priced zones. "Several issues are to be taken into account when estimating the benefits of these two approaches: the efficiency of the resulting price signals (both in the short and long term), the computational burden and implementation costs, the hedging complexity and the impact on the liquidity of long-term markets and geographical consumer discrimination (IRENA, 2017).

While nodal pricing may be more challenging to implement, it is deemed to be more efficient than zonal pricing because the spatial granularity is lower and reflects better transmission system constraints. However, in cases in which only specific transmission network lines are congested, zonal pricing might be efficient. Also, larger bidding zones are believed to increase liquidity and competition, and zonal prices represent a more stable signal for investors and tend to be less discriminatory for consumers (IRENA, 2017).

II. CONTRIBUTION TO POWER SECTOR TRANSFORMATION

Increasing space granularity by implementing either nodal or zonal pricing would result in price signals that could direct investments towards assets located where the transmission system would benefit the most and, therefore, relieve system constraints in a cost-efficient manner. Furthermore, such price signals can better direct investments towards renewable generation assets in locations with high prices, thereby reducing the overall costs of electricity for consumers. Contributions of increased space granularity in the electricity market to the power sector transformation are depicted in Figure 1.

Figure 1: Key contributions of increased space granularity



Optimise system operation

Both zonal and nodal electricity pricing are used to reflect network congestion. While nodal pricing reflects highly congested nodes, for zonal pricing congestion is reflected in the price difference between two neighbouring zones (i.e., the cross-zonal price differential is an indicator of the congestion at a given border between two zones). Therefore, increasing the space granularity in electricity markets either via nodal or zonal pricing helps locate congestion in the transmission system, which can be accordingly considered by TSOs in their operational procedures to avoid costly re dispatch after the market is cleared.

Moreover, on the demand side of the market, having more granular markets from a geographic point of view could shift peak demand, provided the necessary incentives are in place, such as time-of-use tariffs with locational signals incorporated. Demand-side response would therefore help reduce the network congestion in a particular area.

Optimise transmission network investments

Nodal and zonal pricing also act as drivers to identify grid reinforcement opportunities where these are needed the most. Areas (zones or nodes) with low electricity prices indicate abundant supply and relatively lower demand, whereas areas with high prices indicate relatively high demand and scarce supply. More transmission capacity between such areas would lead to price convergence. This is particularly relevant for integrating VRE into the grid either by a) deploying VRE in areas where there is relatively high demand and low supply or by b) expanding the transmission network so that the VRE is supplied to the areas where demand is higher than in the area where the generation units are located. Such grid reinforcements between zones or nodes would avoid curtailments of abundant VRE generation in areas with high solar and wind potential and relatively low demand.

Optimise generation capacity investments

Zonal and nodal prices can also incentivise investments in generation assets and demand-side response in areas with higher prices, where demand is relatively higher than other areas. On the supply side, this could either result in investments in utility-scale renewable power plants or the deployment of distributed energy resources (DERs) such as solar rooftop installations, combined heat and power plants, electricity storage units, etc. Therefore, electricity could be provided from local sources during peak hours.

III. KEY FACTORS TO ENABLE DEPLOYMENT

Advanced computational power and optimisation modelling software

Increased space granularity and introduction of zonal or nodal pricing in electricity markets requires introducing a detailed network representation in dispatch modelling. While system and market operators should have state-of-the-art hardware and software, including optimisation modelling tools with high computational power, they also need access to a highly skilled workforce capable of modelling and operating the power system.

Clear and transparent pricing methodology

As electricity markets become more complex and their processes become more automated, regulators need to ensure there are clear and transparent methodologies for price formation, regardless of the chosen market design. A clear and transparent methodology builds confidence among market participants. Moreover, combatting insider trading and market manipulation via regulatory oversight strengthens the trust of market participants.

Nodal pricing in California is calculated based on the economic theory that matches the demand and supply of power. Mathematically, it is computed with an objective function to minimise the total system costs subjected to match demand and supply, adhering to all operational constraints. This computation is done at each node of the transmission network (CAISO, 2005).

IV. CURRENT STATUS AND EXAMPLES OF LEADING INITIATIVES

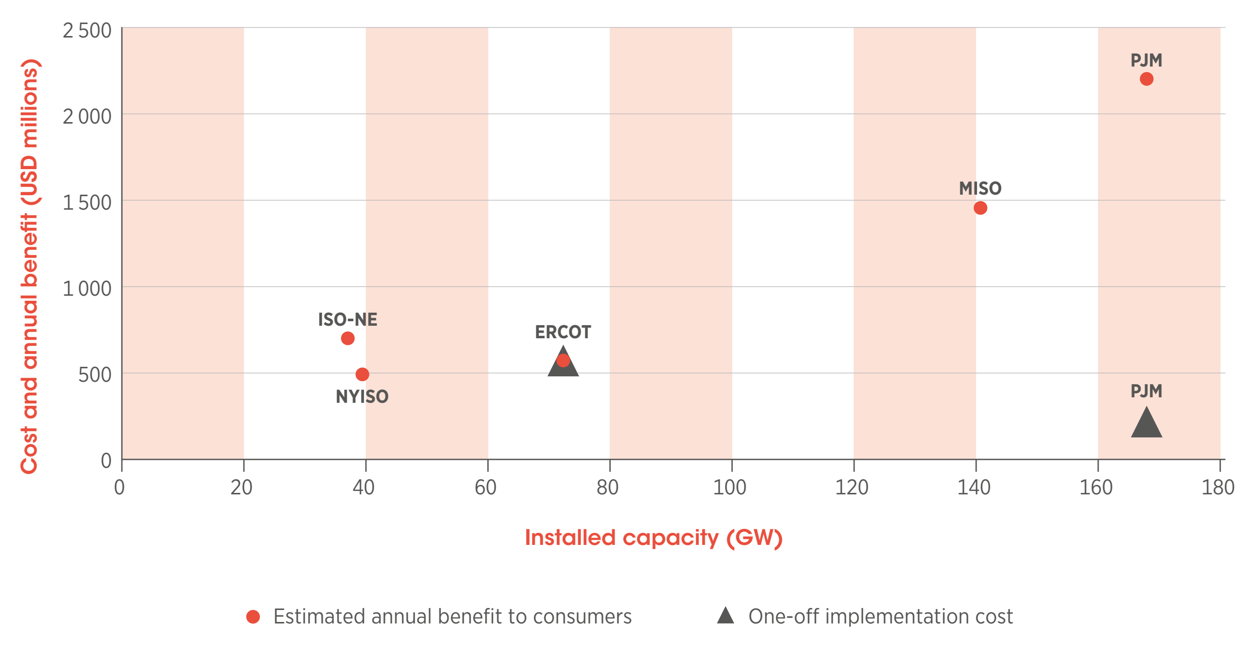
Locational pricing in the United States

Distributed energy resources (DERs) are expected to transform New York's power system. The New York Independent System Operator (NYISO) aims to reform the power market to enable higher participation of DERs, which are mainly renewable energy sources, in the power grid. Currently, NYISO provides real-time prices at the zonal level (updated every five minutes). Zonal pricing however may not necessarily reflect sub-zonal conditions. To enable higher DER participation and to provide more economically efficient DER benefits, NYISO will provide more granular pricing (NYISO, 2017a). The granular pricing data is expected to encourage investments at the most economically efficient transmission location (NYISO, 2017b). NYISO, as part of its Distributed Energy Resources Roadmap for New York's Wholesale Electricity Markets, is planning to provide real-time prices on nodal locations calculated for every five minute block. Currently, NYISO is piloting the roadmap at a few nodes at selected locations (NYISO, 2017b).

Investment in transitioning to a nodal pricing system has been recovered within one year of operation by different Independent System Operators (ISOs) in the United States, as illustrated in Figure 2.

Another important example of nodal pricing implemented in the United States is the ERCOT (Electric Reliability Council of Texas) system. In 2003, ERCOT transitioned from a wholesale electric market with four large zones to a marketplace made up of more than 4 000 nodes. This undertaking, called the Nodal Project, improved the efficiency of the grid by increasing the amount of specific information for different locations throughout the state (Choose Energy, 2015). As Figure 2 illustrates, the one-off implementation cost for the Nodal Project in ERCOT equals the annual benefit to consumers.

Figure 2: Costs and benefits of nodal pricing



ISO-NE: Independent System Operator New England; NYISO: New York Independent System Operator; ERCOT: Electric Reliability Council of Texas; MISO: Midcontinent Independent System Operator; PJM: Pennsylvania New Jersey Maryland Interconnection

Note: GW = Gigawatts

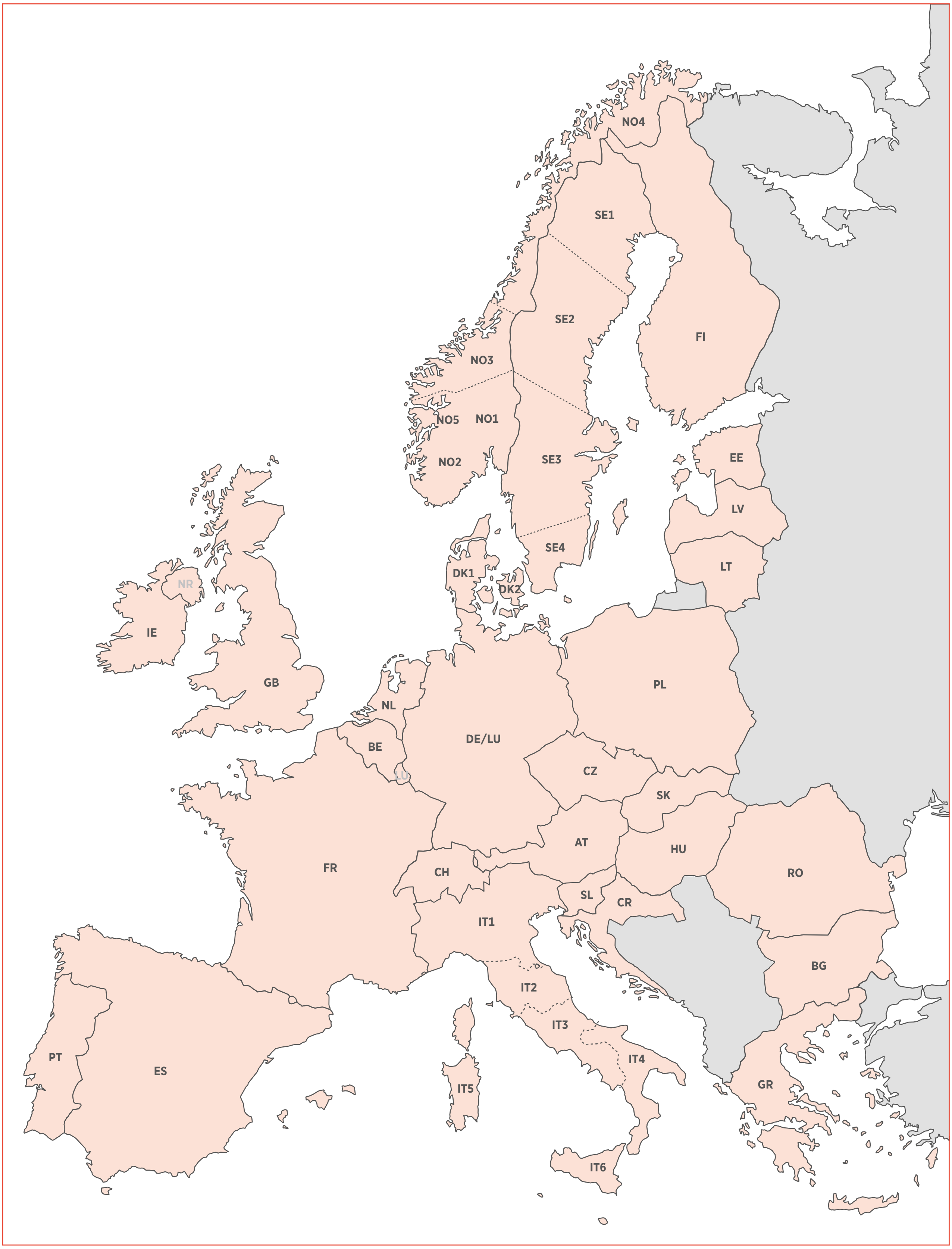
Source: Neuhoff and Boyd (2011)

Zonal pricing in the European markets

Bidding zones represent the cornerstone of the pan-European electricity market. Electricity is traded across bidding zones based on available transmission capacities calculated by TSOs, while the electricity traded within a bidding zone is considered unrestricted and unlimited by transmission capacity. While in most cases a bidding zone corresponds to national borders, some countries have divided their national transmission systems into more bidding zones, including Denmark (two bidding zones), Italy (six geographical bidding zones), Norway (five bidding zones) and Sweden (four bidding zones). Moreover, until 1 October 2018, Austria, Luxembourg and Germany were grouped into a single bidding zone. Following the decision of the Agency for the Cooperation of Energy Regulators (ACER) No. 06/2016 from 17 November 2016, the bidding zones were split into two and a bidding zone border between Germany/Luxembourg and Austria was introduced. Figure 3 illustrates the bidding zone configuration in European wholesale market.

According to ACER, in 2017, the cross-zonal transmission capacity made available for trading on the market was significantly below the "benchmark capacity", i.e., the maximum capacity that could be made available to the market while preserving operational security. On average only 49 % of the benchmark capacity in high-voltage alternating current interconnectors was made available to the market in 2017, which was probably the result of congestion not being properly addressed by the existing bidding zone configuration. Therefore, the relatively low level of available cross-zonal capacity is an indication that structural congestion is located within bidding zones, rather than between bidding zones, in most of continental Europe. Moreover, congestion at bidding zone borders is mostly linked to intra-zonal network lines, rather than to interconnectors. For example, in 2017, congestion was caused within the Central-West Europe (CWE) region 86 % of the time by internal lines and 14 % of the time by interconnectors. Within CWE, over 50 % of these occurrences related to network elements located inside Germany (ACER, 2018).

Figure 3: Bidding zone configuration in European wholesale markets



Source: Adapted from ENTSO-E (2018)

Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.

V. IMPLEMENTATION REQUIREMENTS: CHECKLIST

TECHNICAL REQUIREMENTS	**Software:** • Higher computational power and better system modelling tools • Automation of various processes and information exchange related to both market and system operation
REGULATORY REQUIREMENTS	**Wholesale market:** • A liberalised wholesale electricity market with unbundling across the entire value chain • A defined level of granularity for the implementation of locational marginal pricing or for zonal market design based on technical and socio-economic criteria (*e.g.*, welfare maximisation, transmission system reliability, etc.) • A detailed load flow studies for the identification of key nodes for the implementation of nodal pricing or bidding zone configurations • The development of a transparent pricing methodology • Surveillance of the market to ensure market manipulation does not occur • Regular monitoring of the impact of increasing the geographical granularity on power costs for consumers and publication of the results for broader public awareness
STAKEHOLDER ROLES AND RESPONSIBILITIES	**Regulators:** • Design the rules, in consultation with interested stakeholders (market operators, market participants, system operators, etc.) • Enforce the rules, monitor the market outcomes regularly and adapt the market design, whenever necessary
	Market operators and system operators: • Perform pilots and conduct studies with the regulators and interested stakeholders to assess the space granularity required in the market design

ABBREVIATIONS

ACER	Agency for the Cooperation of Energy Regulators
CWE	Central-West Europe
DER	Distributed energy resource
ERCOT	Electric Reliability Council of Texas
ISO	Independent system operator
LMP	Locational marginal price
NYISO	New York Independent System Operator
TSO	Transmission system operator
VRE	Variable renewable energy

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