Dialogue on a RES policy framework for 2030

Issue Paper No. 5

Electricity markets and RES integration – Key challenges and possible solutions

Authors:

Arthur Henriot, Andrés Delgadillo,
Jean-Michel Glachant;
European University Institute

March 2015

A report compiled within the European IEE project **towards2030*-dialogue***
(work package 5)

www.towards2030.eu

Intelligent Energy - Europe, ALTENER
(Grant Agreement no. IEE/13/826/SI2.674882)

1 Introduction

As the share of intermittent RES (such as wind turbines and solar PV) increases significantly, their deployment challenges the operation of power systems, and impacts the role played by electricity markets that have not been designed to handle the features of intermittent RES. First of all, intermittent RES feature a variable output that depends on the availability of the resources they are based on (wind does not always blow and sun does not always shine). This variability is worsened by the low-marginal costs of intermittent RES. This means that intermittent RES are willing to generate whenever they can, but only when they can. Second, this output is also difficult to predict accurately, as the output of intermittent RES depends on complex meteorological phenomena. Third, the best generation sites for intermittent RES such as wind turbines are often located far away from consumption centres, creating the need for significant investment in the transmission system. On the opposite, some resources like solar PV are mostly integrated at the distribution level, creating new kinds of flows from low-voltage level to high-voltage level. Fourth, the development of intermittent RES is still driven by support mechanisms and isolated from most market-signals.

It is therefore clear that electricity market design must be revamped to integrate intermittent RES. On the one hand, electricity markets must cope with the changes in the operation of power systems that are created by the deployment of intermittent RES: new time-definitions must fit RES variability, the day-ahead horizon is not adapted to RES predictability, and existing zones do not reflect the congestion patterns corresponding to the location of intermittent RES. On the other hand, intermittent RES cannot remain at the margin of power systems, and must be more closely integrated into electricity markets.

2 Challenges for electricity market design in the context of RES integration

In this paper, four key challenges for electricity market design in the context of RES integration are identified. First, there is a need to ensure resources adequacy in the long-term. This challenge emerged as the profits of conventional generation assets have eroded under the pressure of intermittent RES with "zero" marginal-costs in combination with a scenario of overcapacity and low demand due to overinvestment of utilities and the financial crisis. It is then not guaranteed that the assets being decommissioned will be replaced, especially as the deployment of RES is driven by uncertain support policies rather than market-signals. Second, it is crucial that the flexible resources required to cope with RES variability are in place and incentivised to operate flexibly. Third, electricity market design must ensure efficient expansion of the transmission and distribution network, as significant investments are needed to connect intermittent RES. This challenge is made more difficult by the lack of coordination between network investments and generation investments, especially when the generation investments are driven by uncertain policies. Fourth, while the traditional organisation of power systems was based on a centralised operation of a set of large plants adjusting their production to follow load variations, system operation at the distribution level will be increasingly challenging with the development of distributed resources. The causality relationship between the features of intermittent RES and the four key challenges are illustrated in Figure 1.

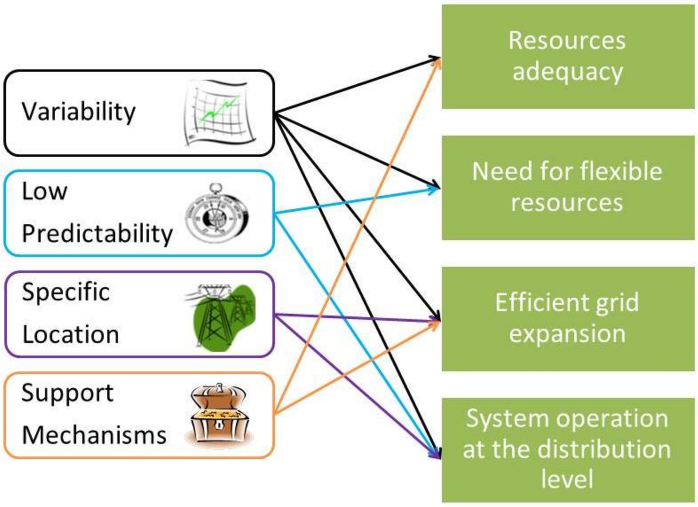

Figure 1. Causality relationship between RES features and key challenges for electricity markets.

2.1 Resources adequacy

Intermittent RES are the first resources dispatched when they are available in the electricity market because they have very low variable costs. This causes changes in the power dispatch and market prices: i) More expensive generation units from other resources are pushed out from the power dispatch, and ii) the electricity prices are lower in average because the price in a competitive power market is set to the marginal cost of the most expensive unit dispatched. Under these conditions, the revenues of conventional generation (which is still needed as backup when the variable output of intermittent RES is low) are reduced and depend increasingly on high prices at times of relative scarcity.

Another important issue is that the development of intermittent RES has been made possible by a wide range of support schemes (Batlle et al. ,2012). However, the modifications to these schemes have created considerable uncertainties for both intermittent RES (whose return depends directly on these schemes) and conventional generation (whose value is impacted by the further development of intermittent RES capacity). The instability of these support schemes is also a hindrance to the provision of adequate investment signals by wholesale markets.

Given these features of electricity markets with high penetration of intermittent RES, it is not clear whether investment in generation assets will be sufficient in the future. Will a revenue stream based on a small number of uncertain energy peak prices be attractive enough to investors? Will these high prices be politically accepted? And how can the wholesale electricity markets provide adequate investment signals in the long-term?

2.2 Need for flexible resources

The output of intermittent RES is variable and not predictable, an increasing share of intermittent RES leads to higher and new needs for flexibility, which is defined as the ability of a given resource to adjust its production or consumption within a given timeframe. This includes the ability of a generation unit to start-up and quickly ramp-up or ramp-down, to cycle frequently, and to operate at low minimum loads.

The provision of flexibility in power markets faces several challenges. Different ways to provide flexibility can impact the range of flexibility providers, and therefore the costs of flexibility as well as the allocation of costs and revenues between the participants. As the need for flexibility is increased to cover the variations of intermittent RES, some market signals are required to reflect this need for flexibility in power markets and to remunerate the flexibility providers. Furthermore, the maximum need for flexibility will be more significant than the average variations. This implies that the revenue stream for flexible capacity will be based on revenues at times of extreme events, and the compatibility of such a revenue stream with the business-model of flexible resources should be assessed.

Another challenge in the power markets is to solve the flexibility measurement problem (i.e. to define and estimate the needs for flexibility), and the flexibility provision problem (i.e. to meet these needs efficiently). It is also important to consider that the flexibility needs and resources may vary significantly across Europe, and to ensure the compatibility of the different mechanisms in the member states.

2.3 Efficient grid expansion

Significant investments in the transmission network are necessary in order to cope with the high variability, low predictability, and specific location of intermittent RES. According to the Ten-Year Network Development Plan (TYNDP) made by ENTSO-E, RES development is the major driver for grid development until 2030 (ENTSO-E, 2014).

ENTSO-E estimates that the required capital expenditures in electricity networks are between 110 and 150 billion of euros. These investments must be made in most cases by regulated transmission system operators (TSOs), which receive a guaranteed return on their asset base. However, this is not sufficient to guarantee that such volumes of investments will be achievable. As TSOs traditionally finance their capital expenditures by emitting debt, the gearing of these companies is already high today. The increase in tariffs that would be required for TSOs to achieve such levels of investment without losing their investment grade (and therefore without losing access to low interest rates) might not be accepted by consumers. Investment in the network would then not be financially sustainable in the long-term (Henriot, 2013).

This challenge is made more difficult by the lack of coordination between network investments and generation investments, especially when there is high uncertainty on the evolution of the generation mix as a result of RES development. Thus, this coordination problem between network investments and generation investments creates greater risks for TSOs.

2.4 System operation at the distribution level

The traditional operation of power systems is based on a system where large generation units adjust their production in order to supply the electricity demand. Energy flows from these large generation units to consumers through transmission and distribution networks. However the large amount of intermittent RES connected to the distribution grid is changing this vision of operation and planning of power systems.

As the share of distributed generation increases, it becomes a source of technical challenges for system operations, but also of new solutions to ensure the reliability of power systems. It is therefore important to ensure that the electricity market design will deliver the right incentives for an efficient participation of distributed intermittent RES. As Distribution System Operators (DSOs) change the way they operate the distribution networks from passive operation to active system management, the role of DSOs vis-à-vis TSOs, and vis-à-vis the market must be reconsidered.

3 Design elements to cope with these challenges

This section describes three toolboxes of market design elements that could contribute to solving the four main challenges: a revamped wholesale market design, additional coordination tools, and solutions based on the deployment of distributed resources. These three toolboxes are partial substitutes and complements, but a mix of these tools must be picked and implemented to address the key challenges of RES integration for electricity market design.

3.1 The wholesale market design

3.1.1 Which paradigm for RES integration

There are two paradigms in the literature to analyze the concept of RES integration, the "melting-pot" and "salad bowl" paradigms (Henriot and Glachant, 2013). In the "melting-pot" paradigm, intermittent RES and conventional generation are integrated under uniform market arrangements, as the costs of intermittent RES are reduced by their large-scale deployment. The "salad bowl" paradigm is based on the axiom that RES integration must address structural discrepancies between intermittent RES and conventional generation. Even if the costs of generating electricity using intermittent RES get low enough to compete with dispatchable thermal generators, there will still be fundamental differences between intermittent RES and conventional generation. Thus, the rules are adapted to the specificities of each set of technologies.

It is sometimes argued that intermittent RES generators have incentives to generate electricity whenever the resource is available, and it is therefore pointless to expose them to more accurate price-signals. "Melting-pot" integration would hence increase the risks and transaction costs for intermittent RES, without fostering more efficient investment and operation, while "salad bowl" integration would reduce these risks. Although, this argument makes sense when the priority is to develop significantly the share of RES in the generation mix, these risks do not disappear with "salad bowl" integration, but are instead transferred to conventional generators and consumers.

The main obstacle to the "melting-pot" integration is the absence of dynamic retail pricing. Without a dynamic retail pricing, consumers cannot distinguish the time when energy is produced at low cost by available intermittent RES. Their consumption, that matches an average tariff, is too high at times when RES are not available. It leads to an overcapacity of conventional generation compared with the optimal generation mix. When dynamic retail pricing is implemented, consumption is lower at times when RES are unavailable, and conventional generation only partially substitutes the production of intermittent RES. Therefore, dynamic retail pricing allows market mechanisms to achieve the optimal generation mix and ensure efficient integration of intermittent RES.

3.1.2 Evolution of products exchanged

The second facet of wholesale market design relates to the evolutions required to manage the power system efficiently when this power system features a high share of intermittent RES. These evolutions include:

- Shorter-time units will be needed to reflect the variability introduced by intermittent RES and remunerate flexible resources adequately. A finer temporal granularity of prices is essential to provide the appropriate price-signals to investors in flexible resources and cope with the flexibility challenge.
- Refined and dynamic space-units could help tackling efficiently the grid expansion challenge. Although, intermittent RES generation plants are not completely free in their locational decisions. Locational signals would give the proper signals to the location of new generation plants, and they would encourage the users to select sites that reduce the costs of network expansion.

- Higher differentials between extreme prices would be needed to reflect the value of energy at times of scarcity or abundance and encourage the development of flexible resources. Price-caps should be high enough to allow peaking units to recover their fixed costs, and to avoid a "missing-money" problem. Negative prices should be low enough to handle efficiently the non-convexities of power plant generation costs.
- The consistency between the different markets from day-ahead to real-time should be improved to match the needs of intermittent RES that are poorly predictable. As exchanges will take place closer to real-time due to the low-predictability of RES, the role of the day-ahead market will lose its significance and intraday and real-time balancing markets will become increasingly important.

These evolutions will not be easy to implement and they might have negative secondary effects. Non-convexities of thermal generators might be more difficult to handle with shorter time-units, while redefining space-units would have significant redistribution effects that could lead to acceptability issues. Finally, there would be a large number of products as a result of smaller time and space units in a set of parallel markets (day-ahead, intraday, real-time and reserves markets), which could be a source of liquidity and complexity issues.

3.2 Coordination tools

An alternative (and/or complement) to wholesale market evolutions is the implementation of a set of coordination tools to ensure efficient investment and operation in power systems featuring a high share of intermittent RES. Generation adequacy policies might be implemented to coordinate the development of generation (or demand-response) assets and solve the resources adequacy issue. The coordination between network investment and operation at the regional scale might require specific tools, such as a European system-management layer, as well as planning at the regional scale and cost-allocation tools. Coordination between network and generation investment to ensure efficient expansion of the grid can be ensured via the development of market facilitators, reforming the payments by generators, and changing the response of TSOs to connection requests and investments needs. Finally, coordination of investment and operation between transmission network operators and distribution network operators will be required to manage efficiently operation at the distribution level.

3.2.1 Coordination between generation assets

Long-term coordination mechanisms are necessary in order to ensure efficient resource adequacy. In a power system featuring a high share of intermittent RES, ensuring resource adequacy is not only about achieving a certain capacity margin, it is also about ensuring that the installed resources are flexible enough to cope with the variations of RES. Therefore, efficient long-term coordination mechanisms will impact on the short-term operation of the power systems.

Generation adequacy mechanisms are one option for fostering long-term coordination. These mechanisms are based on the remuneration of a certain amount of capacity in order to ensure that a minimum amount of capacity is available when it is needed. Currently, there are a number of discussions in Europe about the development of these generation adequacy mechanisms. The diversity of solutions implemented is the logical consequence of the diverse needs, resources and objectives of the member states. It is unlikely that a common scheme could fit to all member states.

However, coordination of national capacity mechanisms at the European level will only be possible if a minimum framework is implemented (Henriot and Glachant, 2014). This framework consists of three tools. The first tool required is a methodology sophisticated enough to take into account partially correlated evolutions of load and RES production across different Member States, and a common set of inputs and scenarios shared by the different stakeholders. The second tool required is a multilateral regulatory framework aimed at allocating responsibility (and the corresponding remuneration) for the delivery of energy when needed. This delivery indeed does not only depend on the availability of the resource committed in the generation adequacy policy, but also on the available capacity of the interconnector and the direction of the flow through this interconnector, which is the result of concomitant conditions in different Member States. A third tool is a method to allocate rights (financial or physical) to consume energy at times of extreme scarcity, while taking into account some solidarity principles. Unless such a framework can be established, generation adequacy policies will remain national patches, with joint consequences on the provision of flexibility.

3.2.2 Coordination between network investment and operation at the regional scale

A well-functioning and efficient transmission network is a prerequisite to a competitive internal energy market. However, transmission system operators have been introduced as entities responsible for managing and expanding the transmission grid within their control zone (that often matches national boundaries). Incentives are conceived by national regulatory authorities to ensure efficiency within these political boundaries that do not reflect the physical reality of the grid (Neuhoff et al., 2013). There are therefore significant asymmetries between the frameworks for intra-TSO transmission investment planning and operation and inter-TSO transmission investment planning and operation (Joskow, 2006). This is a source of inefficiency as it does not allow managing properly the externalities created by the decisions of each TSO on neighbouring power systems. For Zachmann (2013), European welfare maximisation can only be achieved if three coordination tools are implemented at the European level: a tool for coordination of operations, a planning tool to ensure the coordination of investments, and a tool to allocate costs and benefits of network investments at the European scale.

3.2.3 Coordination between network and generation investment

The features of intermittent RES (variability, specific location, and the fact that their development is driven by support schemes) create more challenges for the unsolved issue of coordination between generation and transmission investment. If the targets for RES penetration are to be achieved, significant investment will be needed in the transmission network (ENTSO-E, 2014). Due to the long development and construction time of transmission lines, the TSOs would have to anticipate the development of the generation mix (Rious et al., 2011). Yet, this will lead to high risks of stranded assets for the TSOs if generation assets do not receive strong locational signals.

Lapuerta et al. (2007) realized an overview of the possible tools used to coordinate investment in transmission and generation assets:

- A first set of tools include measures facilitating market transactions and hence the decisions by generators. These measures are: i) the implementation of tradable connection rights, that a generator could sell with its site to a third party, to avoid the wait for reinforcements to the transmission system, ii) higher transparency by publishing information on connection capacity available at each substation, and iii) more drastic policies such as auctioning sites or connection capacity.
- A second set of tools are transmission tariffs. Transmission tariffs can be divided into connection charges (shallow or deep charges) and Use of the System (UoS) charges. Under shallow charges, new users are only charged for the infrastructure required to connect the user. Deep charges cover the cost of both the infrastructure and the necessary network reinforcements. Another alternative for giving locational signals to generators is that transmission tariffs have a G-component, i.e., both generators and loads pay part of the transmission tariff.
- A last category of solutions that could be implemented include reforms in the TSO responses to connection requests and investment needs. One solution is to introduce some discretion in the decision made by the TSOs to connect generators. TSOs should be allowed to refuse connection requests from new generation in

certain parts of the network. An alternative is to give TSOs the possibility of anticipating the development of the network. Rious et al. (2011) show that anticipating the connection of a generator is a source of benefits when the probability that the generator will connect is high, and when it requires significantly more time to build transmission lines than to build generation units.

3.2.4 Coordination between transmission network operators and distribution network operators

The development of distributed resources will give TSOs and DSOs many more options to actively manage the system at the distribution level. However, this creates coordination issues. On the one hand, actions taken by TSOs at the distribution level will impact the flows in distribution networks and could lead to constraints in the transmission grid. On the other hand, there are more complex phenomena occurring at the distribution level and hence out of the TSO observability area.

Therefore, it is necessary to clearly define the relevant products that distributed resources may provided to TSO and DSOs, as TSOs and DSOS might share interest for some of these products in order to manage short-term problems in the grid, maintain quality of service, or reduce losses and investment needs (Pérez Arriaga et al., 2013). It is hence crucial for the system security to coordinate the TSOs with the DSOs and to determine their respective jurisdictions and hierarchy of functions.

3.3 The potential of distributed resources

The last toolbox focuses on tools required to unlock the potential of distributed resources. Indeed, these resources can provide many different flexibility services, contribute to resources adequacy, allow deferral of network expansion, and are needed to actively manage the system at the distribution level. However, an efficient development and management of distributed resources will only be possible if a compatible framework is implemented. The contracts offered by suppliers to their customers and the retail market design must evolve to allow consumers expressing their willingness to pay for electricity and valuing their flexibility. Having a real-time retail market as a base for innovative contracts is a prerequisite to efficient use of the distributed resources (He et al., 2013). Similarly, in order to develop a contribution of distributed resources to efficient grid expansion and management, distribution tariffs should be revamped to reflect the state of the distribution network and the contribution of a certain consumer to local losses and peaks in the distribution network (Ruester et al., 2014).

Apart from changes to the retail market design, an active management of distributed resources will require the development of an adequate set of intermediaries between the consumers and demand response procurers, as well as an adequate set of contracts. These contracts must fit the different needs, technical properties and preferences of the consumers and distributed producers (He et al., 2013).

Finally, it is not clear how the penetration of intermittent RES will impact the operational and capital expenditures of DSOs, and the role of DSOs will have to be revisited. Therefore, it is necessary to ensure that the DSOs receive efficient incentives via their regulatory framework. Whether new services (e.g. ownership and management of metering systems and charging infrastructures, data handling, energy efficiency and flexibility provision) will be provided by the DSOs or by third-parties, there will be a need for stricter unbundling and transparency requirements as DSOs handle more responsibilities.

4 Conclusion

Each of the three toolboxes (the wholesale market design, coordination tools, and distributed resources) can contribute to solving some of the key challenges (resource adequacy, need for flexible resources, efficient grid expansion, and system operation at the distribution level). Of course, they also come with secondary effects that can contribute to worsening other challenges. The development of distributed resources can make grid expansion at the transmission level more difficult to plan; coordination tools such as capacity remuneration mechanisms might distort the provision of flexibility. Table 1 describes the contributions of the three toolboxes to the four key challenges.

Table 1. Potential contribution of each set of solutions to the four key challenges

Challenges	Contribution of wholesale market evolutions	Contribution of coordination tools	Contribution of distributed solutions
Resources Adequacy	✓ Allowing resources to earn scarcity rent ✓ Complementary revenues from well-integrated balancing markets ✓ RES market integration can reduce uncertainty	✓ Better coordination of generation assets can reduce uncertainty and ensure adequacy ✓ Coordination of transmission investment and system operations at the European level allows a more efficient multinational approach to resources adequacy	✓ Distributed resources and demand response can contribute actively to resources adequacy 👎 But ensuring a stable revenues stream to assets that will be only used as back-up of distributed resources might prove challenging
Need for flexible resources	✓ Cost- reflection and remuneration of flexibility value	✓ The development of flexible resources can be ensured by procurement through dedicated mechanisms 👎 BUT it might be more restrictive and hence more expensive than a market-based procurement	✓ Distributed resources and demand response can also be a source of flexibility
Efficient grid expansion	✓ Stronger locational signals in the wholesale market might reduce the need for grid expansion	✓ Coordination tools between generation and transmission assets as well as between the different transmission operators allow more efficient grid expansion	✓ The development of distributed resources might reduce the need for grid expansion 👎 BUT it creates higher risks of stranded transmission assets as consumers "leave the grid"
System operation at the distribution level	✓ Cost-reflection and transparency in the system costs might induce the development of efficient distributed solutions	✓ Coordination tools between transmission and distribution network operators will be needed to handle local issues efficiently.	✓ The development of distributed resources will give many options to system operators at the distribution level

Some of these solutions are partially substitutes: the coordination of generation investments can for instance be ensured by dynamic locational signals in wholesale market prices or by different coordination tools; the recovery of fixed costs of generation assets can be ensured through scarcity pricing or through dedicated capacity remuneration mechanisms; similarly, flexibility remuneration can be delivered via price differentials in the wholesale markets or via dedicated mechanisms.

Some of these solutions are also complementary: melting-pot integration of intermittent RES would not be possible without implementation of dynamic retail pricing and some form of demand-response; system operation at the distribution level can be tackled by active management of distributed resources by aggregators or DSOs, but it will require further coordination between the TSOs and the DSOs.

Acknowledgement

The authors would like to thank Katharina Grave, André Ortner and Christoph Zehetner for his comments and suggestions.

5 References

Batlle, C., Pérez-Arriaga, I.J., Zambrano-Barragán, P., 2012. Regulatory design for RES-E support mechanisms: Learning curves, market structure, and burden-sharing. Energy Policy 41, 212-220.

ENTSO-E, 2014. Ten-Year Network Development Plan.

He, X., Hancher, L., Azevedo, I., Keyaerts, N., Meeus, L., Glachant, J.-M., 2013. Shift, not drift: towards active demand response and beyond.

Henriot, A., 2013. Financing investment in the European electricity transmission network: Consequences on long-term sustainability of the TSOs financial structure. Energy Policy 62, 821-829.

Henriot, A., Glachant, J.-M., 2013. Melting-pots and salad bowls: The current debate on electricity market design for integration of intermittent RES. Utilities Policy 27, 57-64.

Henriot, A., Glachant, J.-M., 2014. Capacity remuneration mechanisms in the European market: now but how? Robert Schuman Centre for Advanced Studies Research Paper No. RSCAS 84.

Joskow, P., 2006. 5. Patterns of transmission investments. Competitive electricity markets and sustainability, 131.

Lapuerta, C., Hesmondhalgh, S., Harris, D., 2007. A Review of TenneT's Connections Policy.

Pérez Arriaga, J.I., Ruester, S., Schwenen, S., Batlle, C., Glachant, J.-M., 2013. From distribution networks to smart distribution systems: Rethinking the regulation of European DSOs. Think Final Report (http://think. eui. eu), European University Institute.

Neuhoff, K., Barquin, J., Bialek, J.W., Boyd, R., Dent, C.J., Echavarren, F., Grau, T., von Hirschhausen, C., Hobbs, B.F., Kunz, F., Nabe, C., Papaefthymiou, G., Weber, C., Weigt, H., 2013. Renewable electric energy integration: Quantifying the value of design of markets for international transmission capacity. Energy Economics 40, 760-772.

Rious, V., Perez, Y., Glachant, J.-M., 2011. Power transmission network investment as an anticipation problem. Review of Network Economics 10.

Ruester, S., Schwenen, S., Batlle, C., Pérez-Arriaga, I., 2014. From distribution networks to smart distribution systems: Rethinking the regulation of European electricity DSOs. Utilities Policy.

Zachmann, G., 2013. Electricity without borders: a plan to make the internal market work. Bruegel Center report (Brussels).