D6.1.2 Report on the Roadmap for RES penetration under the current Target Model high-level principles (2014-2020)

Part 2: recommendations about other short term market topics

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EXECUTIVE SUMMARY

Introduction

The Work Package 6 (WP6) is the concluding part of the Market4RES project. In this WP, the results from previous work packages are analysed and gathered into a set of conclusions and recommendations. Its major objective is therefore to recommend the steps towards a practical implementation of policy, legislation and regulations for the renewable electricity generation in order to secure a robust evolution of the EU Target Model (TM) beyond 2020.

The present report D6.1.2, as well as the previous report D6.1.1, focuses on the first work stream of the Market4RES project, which addresses the 2020 horizon, both in terms of generation fleet and in terms of possible market designs[1].

The report D6.1.1 was focused on two important aspects of market design studied within Market4RES: RES support schemes and demand response. The present report D6.1.2 is focused on flexibility features of short-term power markets with a specific focus on RES-E integration, within the 2020 framework. The topics addressed within this report are:

- **The flexibility features of short-term markets:** challenges ahead in terms of flexibility on the short-term markets with high RES penetrations, possible options to increase flexibility on the short-term markets, screening of existing measures at international level, features of an ideal short-term market and conclusions regarding the necessary evolution of short-term markets;
- **The features of balancing markets:** current status and challenges ahead in terms of balancing market design, main findings of qualitative and quantitative analyses about balancing market design carried out within Market4RES and perspectives for balancing market design evolution;
- **The timing of short-term markets:** past achievements, current status and challenges ahead in terms of timing of short-term markets, main findings of qualitative and quantitative analyses carried out within market4RES and conclusions about the adequate timing of short-term markets.

Flexibility features of short-term markets

In order to operate an electricity system efficiently, the lowest cost generators available should be used to meet the load, while taking into account grid constraints. In Europe, the foremost objective of market design was to enable trading of electricity across borders, between large national balancing areas. However, renewable sources of energy, with their unique characteristics, create unique challenges in an energy-only market, characterised by a single national price and a day-

[1] Upcoming reports D6.2 and D6.3 will address the second work stream of the project, with focus on longer-term horizons (2030 and beyond) and on long-term energy markets and capacity markets.

ahead market as reference. The performance and outcomes of electricity markets are as a result influenced, amongst others on the short-term markets (day-ahead and intraday).

Inflexibility of the market is a prominent issue, visible mainly through the following three elements:

1. Lower electricity prices and occurrence of negative market prices possibly leading to a lack of available generation capacities;
2. Price volatility;
3. Curtailment of wind and/or solar production.

To improve a power system's flexibility, options can be classified into two categories: on the one hand, regulatory flexibility options can be envisaged (that require **regulatory intervention**) or on the other hand, one can opt for technology-based flexibility options (that require **financial investments** on the supply side, demand side or in storage).

Regulatory flexibility options include Capacity-remuneration mechanisms (CRM) favouring flexible electricity sources; Market coupling of the day-ahead and intraday markets; Near-real time trade and increasing transparency; Shorter scheduling periods for fulfilling the day-ahead and intraday contracts; Shorter dispatch intervals; Allow trade in intra-day markets; Focus on improving forecasting techniques; Create a level playing field for different types of generation units; Remove barriers for RES & DR aggregators supply of ancillary services to fully unlock flexibility; Expose consumers to price fluctuations in day-ahead markets; Inform the public about the benefits and risks of renewable energy.

Technology-based flexibility options include: Increase the flexibility of conventional plants; Invest in monitoring of demand; Invest in electricity storage; Increase network capacity; Invest in electric vehicle (EV) and the corresponding infrastructure; Invest in research, technology and software that facilitates the development of markets for flexibility.

To adapt the short-term markets to low-carbon power systems with high shares of wind and solar power, high temporal and geographical resolution are key. Still, no radical change in the European target model for short-term markets is recommended: the target model should be adopted and implemented as soon as possible. For detailed implementation issues, it is advised that one builds on already existent features and market design, and gets inspired by the identified best practices to identify the market rules that are best adapted to European local conditions. Most importantly, well-functioning intra-day markets must be promoted, with high liquidity, cross-border trades, and implicit pricing on transmission constraints.

Main features of balancing markets in a context of high RES-E penetration

At present, very heterogeneous structures and patterns exist when drawing the different parameter settings characterising national balancing markets in Europe (market structures, market rules, operational procedures and prequalification criteria).

The Market4RES project has studied two aspects of balancing market design:

- **The detailed design of balancing markets.** Different options for the procurement of balancing services, the calculation of imbalance prices to be applied to balancing responsible parties (BRPs) and the level of coherence achieved between balancing and other short-term energy markets can lead to a poor or a bad design in terms of RES integration in the market.
- **The cross-border integration of balancing markets in Europe.** It could potentially bring about savings in the order of hundreds of millions of Euros in system operation costs. Among other benefits, it would make possible an efficient increase in the amount of RES generation that can be integrated in the system.

Today, a great diversity of arrangements and a lack of harmonization of market designs exist for balancing reserve and balancing energy provision and activation across Europe.

A qualitative assessment of different aspects of the balancing market design has been done within the project and is summarized in Table 1 below.

Table 1: Summary of the assessment of balancing arrangements

Competition among BSPs			
Procurement of balancing capacity and balancing energy products	Joint	Separated	
	Poor	Good	
Procurement of upward and downward balancing capacity products	Joint	Separated	
	Poor	Good	
Existence of technology-specific products	Yes	No	
	Poor	Good	
Minimum bid size	Large (> 5MW)	Medium (1MW-5MW)	Small (≤1 MW)
	Poor	Poor to fair	Good
Pricing of balancing products	Pay-as-bid	Marginal	
	Poor to fair	Good	
Adequate incentives on BRPs			
Imbalance pricing system	Dual	Single	Combined
	Poor to fair	Fair to good	Good
Settlement period	Long (1 hour)	Average (30 min.)	Short (15 min.)
	Poor	Fair	Good
Efficiency in balancing actions			
Balancing & intraday trading (ID)	Preventive balancing actions	All balancing actions after ID	
	Poor	Good	
Balancing & congestion management (CM)	CM affects imbalances	CM is treated separately	
	Poor	Good	

A quantitative analysis has also been carried out to validate possible future balancing market mechanisms. From the results of the analysis on future balancing market mechanisms the following conclusions can be drawn:

- The **symmetric (joint)** procurement of positive and negative balancing capacity increases total generation costs and total procurement costs, increases procurement exchanges between German TSOs, and is a poor design for RES integration.
- **Common procurement** of balancing capacity by all balancing areas reduces total generation costs and total costs of procurement.
- **Shorter time frame** of block products reduces average implicit allocation of transmission capacity between balancing areas, reduces total generation costs and total procurement costs, and is a good design to integrate RES in balancing markets.

The perspectives for future balancing market design evolution will be based on the harmonization process tackled by ACER and ENTSO-E with the EU Network Code on Electricity Balancing (NC EB). Still, this top-down approach is rather slow: up to 10 years of negotiation, development and implementation will be needed between the first scoping of ACER Framework Guidelines on EB in October 2011 and the implementation of all provisions of the NC EB.

A complementary bottom-up approach is needed: this is why TSOs have engaged into several cross-border pilot projects, with the purpose of testing the feasibility of the European model, evaluating the associated implementation impact and reporting on the experience gained.

Some research is also needed about cross-border balancing market integration and participation of distributed energy resources.

The debate on balancing market design, which the Market4RES project has contributed to (mostly from a perspective of RES integration), is therefore far away from being closed.

Timing of short-term markets features

There is a large number of parameters characterizing the timing of electricity markets. The most relevant ones are the time parameters of energy markets (lead time, scheduling horizon, time step, session interval), the time parameters of reserve markets and the gate closure, i.e. the timing of the frontier between energy market and reserve use.

The combination of different settings of those parameters for day-ahead and intraday markets can lead to multiple designs.

Within the current implementation of the Target Model, Day-Ahead market (DAM) outcomes are available around 14:00 CET for the next day. It is followed by a continuous intraday market in which trade can occur till at least one hour before real time. For intraday, the co-existence of complementary regional intraday auctions is allowed, as long as they do not hinder the functioning of the European continuous market.

Still, sticking to the status quo in terms of day-ahead market timing is questionable, due to the increased RES penetration leading day-ahead market outcomes to be less and less representative of real-time situation.

A qualitative assessment has been carried out by market4RES, focusing on the timing of the first market (currently the DAM), the timing of intraday market, the timing of the (last) gate closure before real-time and the timing of the reserve markets.

- Regarding day-ahead processes (pre-coupling, coupling and post-coupling), all the tasks involved by the pre-coupling should be pushed to take place as late as possible. Regarding the coupling process, the efficiency is increased as the total time needed to conduct the associated tasks is shortened. However, coupling needs to be conducted in a robust and secure manner.
- Regarding the timing of intraday markets, the results of this assessment are summarized by Table 2 below.

Table 2: Qualitative assessment of continuous, discrete and hybrid timing of intraday markets

		Continuous	Discrete	Hybrid
Efficiency	*Flexibility to trade*	Very Good	Fair	Good
	Liquidity	Fair	Very Good	Good
	Efficiency of the dispatch	Fair	Good +	Good +
	Pricing cross-border capacity	Fair	Very Good	Good
Implementability		Very Good	Good +	Good +

- Regarding the timing of reserve markets, a combination of long-term, day-ahead and shorter-term procurement would maximize the value of existing non-flexible sources, while taking advantage of the potential of variable renewable generation to participate in the market.
- Finally, regarding the timing of the gate closure, bringing the gate closure time closer to real time allows a more efficient participation of RES-E given the improvement of forecast accuracy at shorter times and closer to delivery, while reducing the timeframe during which the System Operator can manage system security.

A quantitative study has also been carried out to assess the impact of bringing the day-ahead market closer to real time. The main findings of the study are as follows:

- Bringing closer the day-ahead market to real time only a few hours is not worthy, because the small reduction in the wind and solar forecast error does not reduce generation dispatch costs.
- Day-ahead market has to be very close to real-time to cause a reduction in the forecast errors high enough to produce benefits in the operation of the power system.

- Bringing day-ahead markets too close to real-time would not be possible for some power systems due to the lack of flexibility of their generation fleet. If the day-ahead market is very close to real-time, some generation units will not be able to start-up or shut-down in the required time and therefore, they will be automatically out of the market.
- Other power systems with more flexibility of their generation mix, like the Nordic ones, may consider this option.

In conclusion, considerable progress has been made during the recent years in terms of day-ahead market integration. Having the day-ahead gate closure brought to noon in most European countries results from a long harmonisation process. Now, since most day-ahead markets in Europe are coupled through a single price coupling algorithm, the day-ahead gate closure must be the same in all countries. Moving it away from noon would therefore need to be based on very strong arguments applicable to all these countries. From the Market4RES project point of view, the increased RES penetration, occurring in all Member States, should be dealt with preferably by improving the functioning of the intraday markets.

Conclusion

In the present report D6.1.2, we have summarized and drawn conclusions from a significant part of the work done within the Market4RES project since 2014.

Within the first work stream of the project (focused on short-term objectives regarding power market design), the report D6.1.1 [1] had provided the project's views about two topics of utmost importance in terms of market development: RES support schemes evolution up to 2020 and demand flexibility deployment. With the present report D6.1.2, we are closing the first work stream of the project by providing the project's vision about the necessary flexibility of short-term markets, allowing for the integration of high share of renewable sources.

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ABBREVIATIONS

ACER	Agency for the Coordination of Energy Regulators
aFRR	Frequency Restoration Reserves with automatic activation
BRP	Balance Responsible Party
BSP	Balancing Service Provider
CACM	Capacity Allocation and Congestion Management
CAISO	California Independent System Operator
CRM	Capacity Remuneration Mechanism
CWE	Central-West Europe
DAM	Day-Ahead Market
DER	Distributed Energy Resources
EC	European Commission
ENTSO-E	European Network of Transmission System Operators for Electricity
EV	Electric Vehicle
EVI	Electric Vehicles Initiative
FCR	Frequency Containment Reserves
FG EB	Framework Guidelines on Electricity Balancing
FRR	Frequency Restoration Reserves
IEA	International Energy Agency
ISO	Independent System Operator
HT	Haupttarif
mFRR	Frequency Restoration Reserves with manual activation
MIBEL	Mercado Ibérico de Electricidade
MISO	Midcontinent Independent System Operator
NC EB	Network Code on Electricity Balancing
NT	Nebentarif
PCR	Price Coupling of Regions
PX	Power Exchange
RES	Renewable Energy Sources
RES-E	Renewable Energy Sources for Electricity
RR	Replacement Reserves
SO	System Operator
TM	Target Model

TLC	Trilateral Coupling
TSO	Transmission System Operator
TYNDP	Ten Year Network Development Plan
VRES	Variable Renewable Energy Sources
WP	Work Package

GLOSSARY

General terms

EU Target Model (TM)

The EU Target Model consists of a market design for the management of cross-border power exchanges at each timeframe (i.e. forward, day-ahead, intraday and balancing) and a coordinated approach to capacity calculation (see for example [1] for more details).

Market4RES project

Workstream 1	**"Short-term action objectives (2016 → 2020)":** Assuming the current generation fleet as an input and current implementation status of the target model, the focus is on determining appropriate, yet novel, instruments (and their subsequent accompanying national energy policies) for increased renewable electricity generation in support of the 20/20/20 targets;
Workstream 2	**"Long-term action objectives (post 2020 → 2030)":** Assuming the future generation fleet (beyond 2020) as a result of current market designs, and taking into account possible future changes in market design beyond the existing TM, the focus is on developing necessary additions or complementary instruments to the current design, which will induce investment incentives and phase out support schemes in the long term without compromising system adequacy or security of supply.
Work package 2	Opportunities, challenges and risks for RES-E deployment in a fully integrated European electricity market
Work package 3	Novel market designs & KPIs
Work package 4	Appropriate new market instruments for RES-E to meet the 20/20/20 targets
Work package 5	Modelling of electricity market design & Quantitative evaluation of policies for post 2020 RES-E targets
Work package 6	Conclusions & Recommendations & Procedure Guidelines

1 INTRODUCTION

1.1 Concluding Market4RES: focus on the first Work Stream of the project

The Work Package 6 (WP6) is the concluding part of the Market4RES project. In this WP, the results from previous work packages are analysed and gathered into a set of conclusions and recommendations. Its major objective is therefore to recommend the steps towards a practical implementation of policy, legislation and regulations for the renewable electricity generation in order to secure a robust evolution of the EU Target Model (TM) beyond 2020.

The Market4RES project addresses market design issues via two separate work streams:

- **Work Stream 1:** Assuming the current generation fleet as an input and current implementation status of the target model, the focus is on determining appropriate, yet novel, instruments (and their subsequent accompanying national energy policies) for increased renewable electricity generation in support of the 20/20/20 targets;
- **Work Stream 2:** Assuming the future generation fleet (beyond 2020) as a result of current market designs, and taking into account possible future changes in market design beyond the existing TM, the focus is on developing necessary additions or complementary instruments to the current design, which will induce investment incentives and phase out support schemes in the long term without compromising system adequacy or security of supply.

In the present report D6.1.2, the focus is on the first work stream of the project. It therefore addresses the 2020 horizon, both in terms of generation fleet and in terms of possible market designs. It deals with the flexibility of short-term energy markets. It complements the report D6.1.1 which is focused on the evolution up to 2020 of RES support schemes and demand response.

Upcoming reports D6.2 and D6.3 will address the second work stream of the project, with focus on longer-term horizons (2030 and beyond) and on long-term energy markets and capacity markets.

1.2 Purpose and structure of this report

We have already delivered the first part of the roadmap for RES penetration under the current Target Model high-level principles, dealing with RES support schemes and demand flexibility (see D6.1.1, May 2016, [1]). This first part was based on:

- Parts of outcomes of WP2 of the project, which has studied the opportunities, challenges and risks for RES-E deployment in a fully integrated European electricity market;
- Parts of outcomes of WP3 of the project, which has analysed novel market designs covering many aspects of the electricity system;
- Outcomes of WP4 of the project, which has studied in a quantitative manner the impacts on short-term markets of different options regarding RES support schemes and demand response, at the 2020 horizon.

The purpose of the present report D6.1.2, which forms the second part of this roadmap, is to address flexibility features of short-term power market with a specific focus on RES-E integration, within the 2020 framework. For that, we use the work carried out in previous WPs of the Market4RES project: again, some outcomes of WP2 and WP3 are reminded; and some of the results from the WP5 quantitative studies are also used[2].

The specific topics that are addressed in the present report are:

- **The flexibility features of short-term markets (Chapter 2)**: first, the challenges ahead in terms of flexibility on short-term markets with high RES penetrations are explained, with a particular focus on empirical case analyses carried out in the Market4RES deliverable D2.3 [2]; then, possible options to increase flexibility on the short-term markets are presented together with a screening of existing measures at international level; afterwards the features of an ideal short-term market are presented and some conclusions are made regarding the necessary evolution of short-term markets.
- **The features of balancing markets (chapter 3)**: first, the current status and challenges ahead in terms of balancing market design are summarized (see Market4RES deliverables D2.1 [3] and D2.2 [4]); second, the results of the qualitative analysis carried out in the report D3.2 "Developments affecting the short-term markets" [5] are summarized; afterwards, the main findings from the quantitative study "Validation of possible future balancing market mechanisms" carried out in WP5 (see [7] and [8]) are put in perspective. The combination of the qualitative and quantitative analyses allows for giving perspectives for balancing market design evolution.
- **The timing of short-term markets (chapter 4)**: along the same lines, the past achievements, current status and challenges ahead in terms of timing of short-term markets are summarized (see [3] and [4]); the results of the qualitative analysis carried out in [5] are summarized; afterwards, the main findings from the quantitative study "Impact of changing the timing of markets" carried out in WP5 are put in perspective. The combination of the qualitative and quantitative analyses allows for giving recommendations about the adequate timing of short-term markets.
- **Chapter 5** summarizes the conclusions of the present report and explains the articulation with other Market4RES WP6 deliverables.
- In **Chapter 6** a list of 29 references is given covering the two topics addressed by this report.

[2] The framework of the analyses carried out in WP5 corresponds to a 2030 setting. Still, market design aspects of short-term markets studied within WP5 are also applicable within a 2020 setting.

2 FLEXIBILITY FEATURES OF SHORT-TERM MARKETS

2.1 Challenges ahead in terms of flexibility on the short-term markets with high RES penetrations

In order to operate an electricity system efficiently, the lowest cost generators available to meet the load should be used, while taking into account grid constraints. In Europe, the foremost objective of market design was to enable trading of electricity across borders, between large national balancing areas. However, renewable sources of energy, with their unique characteristics, create unique challenges in an energy-only market, characterised by a single national price and a day-ahead market as reference. The performance and outcomes of electricity markets are as a result influenced, amongst others on the short-term markets (day-ahead and intraday).

The Market4RES deliverable D2.3 [2] assessed empirically the challenges and issues with respect to renewable penetration trends for the short-term electricity markets, as well as for the medium and long-term electricity markets through a selection of case studies covering three different market regions with different RES-E penetration levels in the European electricity market (the Nordel system, Central-Western European system and the Iberian system).

As widely discussed and emphasized in that deliverable, inflexibility of the market is a prominent issue, visible mainly through the following three elements:

1. Lower electricity prices and occurrence of negative market prices possibly leading to a lack of available generation capacities;
2. Price volatility;
3. Curtailment of wind and/or solar production.

2.1.1 Lower electricity prices and occurrence of negative market prices

As shown in Figure 1, the empirical analysis of day-ahead electricity market (DAM) prices in the selected European jurisdictions highlights the fact that renewable penetration is negatively correlated with the day-ahead electricity prices.

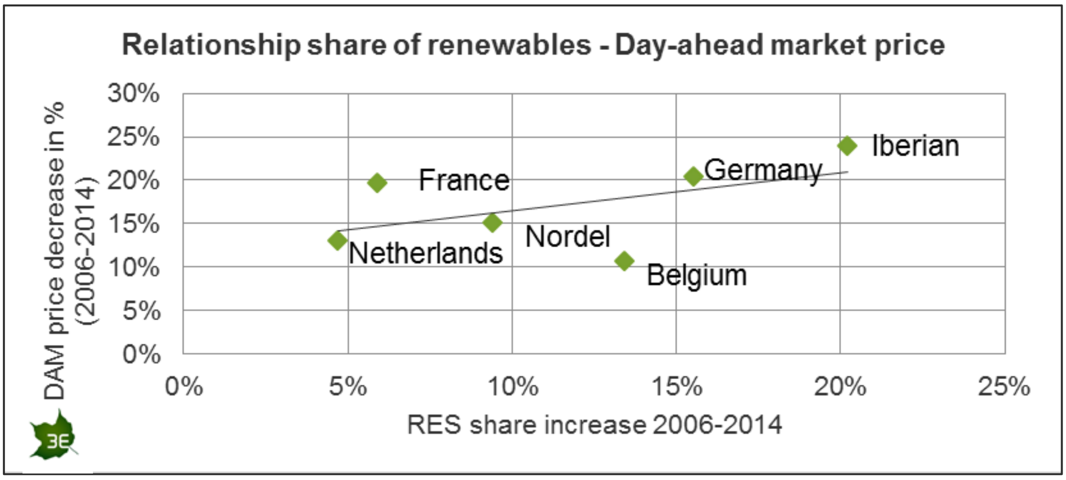


Figure 1: Development of the shares of RES-E compared to the Day-ahead market prices

As a result, renewable energy generation appears to be a driver of the differences in wholesale day-ahead prices. However, prices are influenced by supply relative to demand at specific points in time and will only decrease if capacities are too high relative to demand or if the electricity mix and flexibility of the system do not correspond to the needs of the rising renewable shares and changing consumer patterns [9].

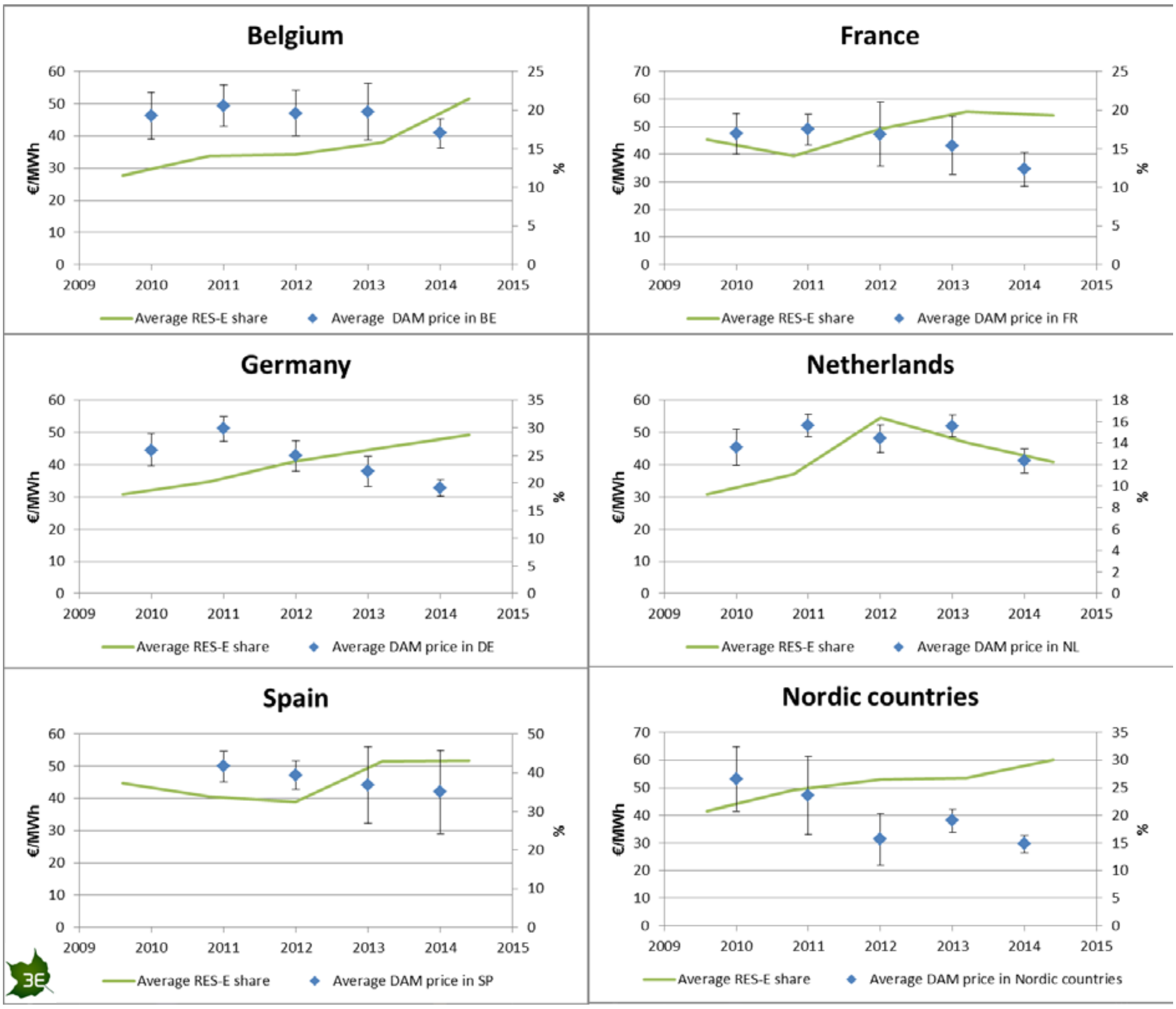
In recent years, several European electricity markets have also seen their prices turn negative when high shares of inflexible generation hit a low demand period.

The occurrence of negative prices on the wholesale markets signals the need for more flexible electricity supply and demand through adaptation of system components, and reinforces the need for better integration of renewable generation sources to the power grid [10].

Another impact of the downward pressure on power prices due to i.e. increasing shares of renewables, is that firm capacities (e.g. conventional fossil-fuel power generation) are having problems to recover their costs. This can lead to reduced flexibility when the installed capacity for controllable units is reduced.

2.1.2 Price volatility

From a purely theoretical point of view, with low interconnection and large shares of varying generation, price volatility increases. Even though, there is no clear correlation between the share of RES-E penetration and the DAM price, it can nevertheless be concluded from the study conducted in deliverable 2.3 [2] that volatility increases when interconnectivity is low (cf. results for Spain in Figure 2, that has low transmission capacity with other countries) and that real price volatility decreases only come with huge investments in infrastructure (cf. results for the Nordic countries, who benefit from large shares of highly flexible hydropower reservoirs), as can be seen in Figure 2 (whereby volatility is represented by the vertical grey segments corresponding to the standard deviation to the average price).



Source: APX, Belpex, Elspot, EPEXspot, OMIE, ENTSO-E

Figure 2: Volatility of the base load price on the Day-ahead market

The transition to a low-carbon economy with high shares of RES-E is likely to increase transmission congestion and forecast errors in the day-ahead timeframe.

Price volatility can be managed for instance through more flexible system operations on a technical side. In countries with a high share of intermittent RES-E, like Germany or Spain, there are already requirements for fault-ride through capacity provision of reactive power, frequency and voltage control, and incentives to minimise deviations exist. In Germany the provision of these services has become mandatory for new power plants. In Spain, there are financial incentives that drive the provision of these services [11].

On the market side, price volatility can be mitigated through demand flexibility. As analysed in Market4RES deliverable 4.3 [6] and also explained in D6.1.1 [1], demand flexibility has a significant impact on average market prices and on the average daily spread (difference between the maximum price of the day within a given market area and the minimum price of the same day and market). In countries facing high price peaks, the impact on the daily spread is most significant. Moreover, demand shift allows decreasing even more the average daily spread, leading to a very significant impact.

If and how varying electricity prices can incentivise the provision of flexibility on an Energy-Only market will be analysed later in this report.

2.1.3 Curtailment of wind and/or solar production

High RES-E generation coupled with low demand can create a need for curtailing renewable capacity. "Curtailment" is an option that some system operators employ as a consequence of constraints in distribution and transmission grids to deal with overabundance of electricity production on the system. Electricity producers can also be shut down for certain periods of time to balance the grid and secure stability of the system when there is, for example, network faults. Curtailment results in economic losses, as the power that could be generated from RES-E at that time goes unused.

Spain in particular makes extensive use of curtailment due to its high wind production levels, lack of interconnection to neighbouring markets, must-run conditions of some non-RES units, and low demand levels at off-peak times. RES-E curtailment events have also happened several times in Germany, where wind power generation is important.

With higher RES-E integration in the market, curtailment will likely (have to) happen more frequently in some markets if other market design elements such as the interconnection capacity and a supportive framework for demand management are not modified.

2.2 Assessment of possible options to increase flexibility on short-term markets and screening of international measures

In what follows, we will first see what options are available to tackle flexibility issues on the short-term electricity markets and screen international practises where relevant, then determine which other features of the short-term market should be adapted in order to operate an electricity system efficiently, and finally conclude with options that could be implemented in Europe by 2020 together with some recommendations.

To improve a power system's flexibility, options can be classified into two categories: on the one hand, regulatory flexibility options can be envisaged (that require **regulatory intervention**) or on the other hand, one can opt for technology-based flexibility options (that require **financial investments** on the supply side, demand side or in storage) [12] and [13].

2.2.1 Regulatory flexibility options

- **Capacity-remuneration mechanisms (CRM)** favouring flexible electricity sources; the preferred design of CRMs will be presented in the upcoming Market4RES deliverable D6.3.

- **Market coupling** of the day-ahead and intraday markets of physically interconnected markets, where total supply and demand are matched over different market areas in order to use the existing grid capacity in the most efficient way.
- **Near-real time trade and increasing transparency**: development of an EU-wide system for cross-border intraday trading.
- **Shorter scheduling periods** for fulfilling the day-ahead and intraday contracts: allowing transactions closer to real-time can reduce the need for control power and increase schedule accuracy.
- **Shorter dispatch intervals:** the National Electricity Market in Australia for instance benefits from sub-hourly (5 min.) dispatch intervals which enables system flexibility and improves forecasting accuracy. Short dispatch intervals reduce the need for regulated reserves and ramping, since changes in variable generation and load are more closely matched economically.
- **Allow trade in intra-day markets** close to real-time, which enables to use better RES forecasts. In fact, forecasting accuracy of renewable power production increases as real-time is approached. Wind energy forecasting errors for example can decrease by almost 50% from 36 to 3 hours before delivery. Intraday markets allow balancing by market parties before system operators take actions to solve remaining imbalances. For wind power producers, the intraday market is crucial for correcting forecasting errors and avoiding imbalance penalties.
- **Focus on improving forecasting techniques:** In the United States, several Independent System Operators (ISOs) are using advanced day-ahead weather forecasting techniques to optimise the integration and dispatch of renewables on the power system close to real-time. Most American ISOs now have centralised day-ahead wind power forecasts incorporated in their reliability commitment models which can be used to make better decisions for meeting forecasted demand [14]. In Europe, day-ahead weather forecast has become increasingly sophisticated in regions with high shares of renewables such as Germany and Spain. There is also a lot of research in this field in countries such as Portugal (certainty gain effect on wind power forecasting in the electricity market) and the UK (linking wind power forecasting accuracy to increased trading revenue) [15] and [16].
- **Create a level playing field for different types of generation units**: Wind generators should be subject to the same scheduling and balancing obligations as conventional power plants; this will be further developed in upcoming Market4Res deliverable 6.2. The share of wind power is reaching such levels that they should not be considered as neutral passive units. Renewables must operate as other power plants and participate in maintaining power system stability. Fair and equal treatment of RES is recommended, also taking account of their characteristics when defining products. The European Commission is favourable too to fully integrated renewables into the market. This includes “balancing their portfolio” and contributing to increase system flexibility. “If necessary, existing provisions excluding particular means of power generation from normal market rules have to be revisited” [18]. In the United States, the Midcontinent Independent System Operator (MISO) has developed a “Dispatchable Intermittent Resources Program” which allows wind plants to

submit offers for energy in the real-time market and update them based on sub-hourly forecasts [14]. In Europe, RES cannot bid in real-time markets. The California Independent System Operator (CAISO) has set up a “Participating Intermittent Resource Program” allowing individual wind plants to self-schedule according to shared forecasting techniques [19].

- **Remove barriers for RES & DR aggregators supply of ancillary services to fully unlock flexibility**: Business models for RES aggregation are predetermined to be a key element to facilitate their market integration. New market actors such as energy aggregators will therefore play an important role in future market designs. They will mobilise renewable energy systems, flexible demand, storage, and other technologies. However, important technical, regulatory and legal barriers that prevent the efficient deployment of aggregation should be eliminated and benefits, such as congestion management, portfolio optimization of the BRP, frequency and voltage control and grid losses reduction should be unlocked. RES aggregators are appearing more and more in European countries (examples UK, Belgium, Germany, France, Austria, Italy, Cyprus, Spain and Portugal) whereas there are equally interesting examples in the US and other countries [20].
- **Expose consumers to price fluctuations in day-ahead markets:** Regulators can valorise flexibility by changing energy-based tariffs to flexible tariffs at different rates and time-of use periods. Smart meters can play an important role in implementing these flexible tariffs.
- **Inform the public about the benefits and risks of renewable energy:** Public acceptance towards RE can be improved by informing the public about the benefits and risks of different types of renewable energy.

2.2.2 Technology-based flexibility options

- **Increase the flexibility of conventional plants**, through retrofits of existing plants or opting for more flexible new plants.
- **Invest in monitoring of demand, condition for exposing consumers to price-variation,** and use of **support schemes** (extensively treated in Market4RES deliverable 6.1.1 [1]).
- **Invest in electricity storage.** Storage technologies will likely play a larger role in the energy mix in the future for their flexibility advantage. For example, it has been proven that the business case for storage is already positive in some cases in the US whereas different market actors are investing in large-scale storage in Germany [21].
- **Increase network capacity.** Power system transmission and distribution networks are key enablers of flexibility. Network strengthening is relevant for short-term, mid-term and long-term flexibility as it allows reducing congestion by allowing netting or offsetting changes in generation over larger geographic areas. Sharing existing flexibility resources among regions and countries, also including large existing hydropower reservoir capacity in Nordic area (about 85 TWh in Norway), can help to buffer variable renewable electricity generation in a cost-efficient manner.
- **Invest in electric vehicle (EV) and the corresponding infrastructure.** Countries such as the US, Japan, Norway and Germany already have a considerable stock of electric vehicles (EV)

and the Electric Vehicles Initiative (EVI) expects a significant increase of EV by 2020 [22]. Companies should partner up with regulators to facilitate the construction of charging points and other infrastructure to fully unlock the potential of this market evolution. If deployed at large-scale, EVs can be used as a flexibility source for the power system thanks to their charging and discharging capacity.

- **Invest in research, technology and software that facilitate the development of markets for flexibility.**

2.3 Features of an ideal short-term market

To adapt the short-term markets to low-carbon power systems with high shares of wind and solar power, high temporal and geographical resolution are key. The IEA, in its report "RE-POWERING MARKETS-Market design and regulation during the transition to low-carbon power systems" [23] identifies five high-level principles as best practices:

- **Locational pricing**: differentiating electricity prices by local geographical area is important in order to reflect the differences in electricity generation costs due to the limitation of network capacity. Implementing locational prices implies that the prices are published and the associated financial settlement sufficiently reflects the reality of system operations. As wind and solar power increase the volatility of electricity flows and lead to congestion, efficient locational pricing will be needed. Still, decreasing too much the granularity of network representation (for example down to nodal pricing) also presents serious drawbacks, notably in terms of liquidity, implementation costs, transparency and fairness for small end-consumers, as explained in Market4RES deliverable D3.2 "Developments affecting the design of short-term markets" [5]. A right balance therefore needs to be found in terms of size of bidding zones. A review process of existing bidding zones has been tackled by ENTSO-E with the support of ACER as part of the implementation of the CACM network code. ENTSO-E has developed alternative bidding zones configurations to be assessed, going from the status quo to a 'start from scratch' configuration. The work carried out by ENTSO-E in the bidding zone review process investigates the best delineation of bidding zones that fits the multicriterion of efficiency, price signals, liquidity and security of supply. The first results of the review are expected to be known by end 2016, but work will continue in 2017.
- **Uniform pricing**: as discussed in Market4RES deliverable 3.2 [5], uniform or combined prices to all real-time energy used for balancing should be applied (instead of dual price systems), to reflect the marginal cost of the marginal resource used to balance the system at each location. Under a single-price system, the same imbalance price is applied to BRPs with short and long positions. In principle, uniform prices should lead to well-correlated prices in the intraday and balancing timeframes. Under a dual imbalance pricing scheme, different imbalance prices are applied to BRPs with long and short positions.
- **Administrative reliability pricing**: regulate energy pricing during capacity shortage conditions, i.e. when there is insufficient capacity to meet, in addition to the load, the reserve requirements needed for reliability. Some form of regulation of scarcity prices is

necessary to ensure existence of a market-price during scarcity hours. If markets are well functioning, there will be correlation between prices in markets for procurement of reserves, day-ahead, intra-day, and finally in markets for balancing energy in real time.

- **Intraday liquidity and transparency**: Ensuring liquid (intra-day) markets is important to enhance competition, fight the exercise of market power (MP) and result in prices that are stable. Transparent intraday prices are necessary to inform all market participants about the cost of serving the next megawatt. Thanks to transparent intraday price information, aggregators of distributed resources can adjust their schedule in a decentralised fashion to complement intraday variations caused by increasing shares of renewables. In a system with abundant distributed generation, the continuous update of intraday prices can ensure the price co-ordination of many decentralised resources.

2.4 Conclusions on the flexibility of short-term markets

No radical change in the European target model for short-term markets is recommended: the target model should be adopted and implemented as soon as possible. For detailed implementation issues, it is advised that one builds on the already existent features and market design, and draws from the identified best practises to identify the market rules that are best adapted to the European local conditions.

Most importantly, well-functioning intra-day markets (which, after the day-ahead markets, provide trading possibilities to market parties to balance their positions without the intervention of the system operator) must be promoted, with high liquidity, cross-border trades, and implicit pricing on transmission constraints. The more the market parties can balance through the intraday markets, the less balancing actions are needed to be taken by the system operator to balance the system. The intraday markets should be an extension of the day-ahead markets.

As argued by Glachant [11], the joint operation of balancing markets with other markets like the day-ahead market will become a key source of efficiency. Intraday markets and real-time balancing markets which allows trading after the day-ahead gate-closure, should gain in importance as the share of intermittent RES-E increases and there is a need to balance markets closer to real time at all hours of the day.

Finally, there is a need for tuning the market operation rules (e.g. reducing the lead time after the final gate closure in intra-day markets before real time operation) and improving market integration by the expansion of market and cooperation between TSOs to carry out netting of imbalances (in different directions) between control zones, and to utilize least-cost options for balancing.

3 FOCUS ON THE MAIN FEATURES OF BALANCING MARKETS IN A CONTEXT OF HIGH RES-E PENETRATION

3.1 Background: Current status and challenges ahead for balancing markets

At present, very heterogeneous structures and patterns exist when drawing the different parameter settings characterising national balancing markets in Europe (market structures, market rules, operational procedures and prequalification criteria). [3]

The different balancing markets within the time frame of balancing service provision are mainly determined by maturity and activation mechanism of balancing capacity. According to the new nomenclature proposed in the Network Code on Electricity Balancing (NC EB, [24]), the following categories are recommended:

- **Frequency Containment Reserves (FCR)**: means the Operational Reserves activated to contain System Frequency after the occurrence of an imbalance. These are operating reserves for constant containment of frequency deviations from nominal value in the whole synchronously interconnected electricity system. Operating reserves have activation time up to 30 seconds and are activated automatically and locally.
- **Frequency Restoration Reserves (FRR)**: means the Active Power Reserves activated to restore System Frequency to the Nominal Frequency and for Synchronous Area consisting of more than one LFC Area power balance to the scheduled value. These are operating reserves to restore frequency to nominal value after electricity system imbalance. Activation up to 15 minutes, typically managed by an automatic controller (in this case called "**aFRR**"). However, depending on product and country, FRR can also be activated manually (in this case called "**mFRR**").
- **Replacement Reserves (RR)**: means the reserves used to restore/support the required level of FRR to be prepared for additional system imbalances. These are operating reserves used to restore the required level of operating reserves to be prepared for a further electricity system imbalance. This category includes operating reserves with activation time from 15 minutes up to hours. They may be contracted or subject to markets.

The Market4RES project has studied two aspects of balancing market design:

- **The detailed design of balancing markets**. Different options for the procurement of balancing services, the calculation of imbalance prices to be applied to balancing responsible parties (BRPs) and the level of coherence achieved between balancing and other short-term energy markets can lead to a poor or a bad design in terms of RES integration in the market [5]. This is further discussed in sections 3.2 and 3.3 below (qualitative and quantitative assessments of different balancing market design options).
- **The cross-border integration of balancing markets in Europe**. It could potentially bring about savings in the order of hundreds of millions of Euros in system operation costs. Among other benefits, it would make possible an efficient increase in the amount of RES generation that can be integrated in the system. Integrating RES generation requires

having available a large enough amount of flexible resources to be able to balance changes in the power output available from variable RES generators. [4]

Today, a great diversity of arrangements and a lack of harmonization of market designs exist for balancing reserve and balancing energy provision and activation across Europe. The main differences include the different kinds of balancing services, the different balancing market architectures (central dispatch, self-dispatch portfolio based and self-dispatch unit based); different parameter settings (timeframe of products, gate closure times, minimum bid sizes, etc.). [3]

Fully harmonizing all aspects of balancing markets for the purpose of cross-border integration of these markets and RES integration into these is not foreseen by ENTSO-E. For example, regarding the imbalance settlement period and the imbalance price, the supporting document to the NC EB reads: *"In respect of the Imbalance Settlement Period, a Cost-Benefit Analysis shall demonstrate whether harmonisation is beneficial and how best to achieve it. Regarding Imbalance Price, the NC EB describes marginal pricing as the preferred methodology, unless a different pricing method is proven to be more efficient in the long run".* [25]

Also, cross-border integration of balancing markets raises the issue of reserving cross-border transmission capacity for balancing purposes. According to the NC EB [24], such reservation should be possible only if socio-economic efficiency is proven: *"Each TSO shall have the right to reserve Cross Zonal Capacity for the Exchange of Balancing Capacity or Sharing of Reserves when socio-economic efficiency is proved [...] using one of the following approaches: (a) co-optimisation process; (b) market-based reservation process; and (c) reservation based on economic efficiency analysis"*. It was indeed requested by ACER in its Framework Guidelines on Electricity Balancing [27] that *"the Network Code on Electricity Balancing shall forbid TSOs to reserve cross-border capacity for the purpose of balancing, except for cases where TSOs can demonstrate that such reservation would result in increased overall social welfare and provide a robust evaluation of costs and benefits"*.

3.2 Qualitative assessment of balancing market design options

3.2.1 Aspects of the balancing market design studied within Market4RES

Three main aspects of the balancing market design have been considered and analyzed by the Market4RES project (see deliverable D3.2 [5]):

- **Procurement of balancing services.** A high enough level of competition and flexibility shall be achieved, leading to an increase in the efficiency and safety of system operation. Possible options for reserve procurement include:
    - A. Separated versus joint procurement of balancing capacity and balancing energy products;
    - B. Separated versus joint procurement of upward and downward balancing capacity products;
    - C. Existence of technology-specific products;
    - D. Minimum bid size requirements/possibility of aggregation of individual bids;

E. Pricing of balancing products: marginal versus pay-as-bid pricing.

- **Calculation of imbalance prices to be applied to balancing responsible parties (BRPs).** Adequate incentives for BRPs shall be provided, to either keep a balanced position or to help the system to restore its balance. Possible options for imbalance settlement include:
    A. Single / dual / hybrid pricing;
    B. Length of the settlement period.
- **Level of coherence achieved between balancing and other short-term energy markets including cross-border congestion management schemes.** Possible options include:
    A. Intraday trading versus preventive balancing actions;
    B. Level of interaction among balancing prices and actions in other markets (including congestion management).

3.2.2 Qualitative assessment of the options studied

Within [5], the different options have been assessed in terms of efficiency towards the achievement of a well-functioning cross-border European balancing market. Here, efficient balancing arrangements are considered to be the ones that provide adequate incentives for BSPs to invest in (balancing) capacity and for BRPs to support the system balancing in real time. It is also important to point out that the integration of European balancing markets depends not only on the harmonization and standardization of balancing arrangements but also on the existence of adequate arrangements related to transmission capacity allocation and models for cross-border balancing purposes. Such arrangements are being dealt within the Network Code on Electricity Balancing [24] recently approved by ACER [26].

Regarding the procurement of balancing reserves:

- **Separated procurement of balancing capacity and balancing energy products is a preferable market design option** when compared to joint procurement of products. Joint procurement of capacity and energy products may limit or even prevent the participation of renewable producers and other small players since, in general, the gate-closure for capacity products have long lead-times.
- **Separated procurement of upward and downward balancing capacity would contribute to increase the balancing market efficiency.** Joint procurement of upward and downward balancing capacity may impose barriers to the participation of renewable generators since variable RES mostly is able to provide downward balancing capacity.
- If a competitive and efficient integrated balancing market is to be achieved, all potential providers should be allowed to participate in all balancing markets as long as they comply with the technical requirements for balancing service provision, meaning **there should be no technology–specific products.**
- To foster the participation of small units in balancing markets, **smaller minimum bid size should be required and the aggregation of several units should be facilitated.** It should be noted that aggregated forecasts are more accurate, which could lead to a more reliable participation of renewable producers in balancing markets.

- **Compared to pay-as-bid pricing, marginal pricing should lead to more efficient balancing markets.** Pay-as-bid pricing provides incentives to market parties to submit bids as close as possible below the resulting market price, whereas marginal pricing gives incentives to bid at marginal costs. Pay-as-bid pricing can lead to inefficiencies, among other things because small players do not have possibilities to forecast prices.

Regarding the imbalance settlement arrangement options:

- In general, **the shorter the imbalance settlement periods are the more cost-reflective the calculation of imbalance prices will be.**
- **Under adequate balancing arrangements, single imbalance pricing leads to higher efficiency in electricity balancing.** While under single pricing BRPs that support the system balance are settled as balancing service providers, dual pricing is generally implemented to incentivize all BRPs to follow their schedules regardless the system imbalance direction - i.e. to not create a short position if they expect the system imbalance to be long and vice-versa. In principle, this goes against the concept of passive balancing according to which BRPs are incentivized to actively respond to the system balance state very close to real time operation. However, in the presence of market distortions, single pricing could provide incentives to BRPs to worsen the system imbalance. Therefore, the Market4Res project recommends that, **whenever the system imbalance cannot be anticipated (i.e. both upward and downward reserves are activated within a settlement period), a dual imbalance pricing system based on the price of activated reserves is implemented** (see [5] pp. 77-82).

Regarding the global coherence among market designs implemented:

- Intraday and balancing markets are closely related since the more (or less) BRPs adjust their schedules through the former, the less (or more) balancing actions will be needed in real time. According to ACER [26], **only imbalances occurring after the closure of the intraday market should be balanced by TSOs within the balancing market timeframe.** This can be explained by the fact that preventive balancing actions may compromise liquidity in the intraday market (by moving bids from this market to balancing markets) and, at the same time, increase balancing costs (which could have been minimized through intraday trading).
- While the Network Code on Electricity Balancing [24] emphasizes the right of TSOs to activate balancing energy bids for ensuring operational security and, consequently, for congestion management purposes, it establishes that **bids activated for purposes other than balancing must not determine imbalance volumes and/or prices.**

Table 3 below provides a summary of the qualitative assessment of the balancing market design options studied in [5].

Table 3: Summary of the assessment of balancing arrangements

Competition among BSPs			
Procurement of balancing capacity and balancing energy products	Joint		Separated
	Poor		Good
Procurement of upward and downward balancing capacity products	Joint		Separated
	Poor		Good
Existence of technology-specific products	Yes		No
	Poor		Good
Minimum bid size	Large (> 5MW)	Medium (1MW-5MW)	Small (≤1 MW)
	Poor	Poor to fair	Good
Pricing of balancing products	Pay-as-bid		Marginal
	Poor to fair		Good
Adequate incentives on BRPs			
Imbalance pricing system	Dual	Single	Combined
	Poor to fair	Fair to good	Good
Settlement period	Long (1 hour)	Average (30 min.)	Short (15 min.)
	Poor	Fair	Good
Efficiency in balancing actions			
Balancing & intraday trading (ID)	Preventive balancing actions		All balancing actions after ID
	Poor		Good
Balancing & congestion management (CM)	CM affects imbalances		CM is treated separately
	Poor		Good

3.3 Quantitative study validating possible future balancing market mechanisms carried out with the EDisOn+Balancing model

Within the Market4RES project, a quantitative analysis has been carried out to validate possible future balancing market mechanisms. The assumed installed capacities and other economic and technical parameters are based on the reference 2030 scenario, corresponding to ENTSO-E "Green transition scenario" (TYNDP 2030 Vision 3). Detailed scenario description, as well as a description of the model EDisOn+Balancing developed by EEG, can be found in Market4RES report D5.1 [7].

3.3.1 Specifications of the study

Balancing market mechanisms are considered for the Netherlands, Belgium, Germany (divided into the four German TSOs: TenneT, 50Hertz, Amprion and TransnetBW) and Austria. To get a more complete picture of imports and exports, the neighbouring countries are also considered for day-ahead simulations.

Table 4 gives an overview of the analysed scenarios. The reference case reflects the current arrangements of balancing markets in Germany and Austria. For Case A to F the differences compared to the reference case are mentioned only. The focus of these cases is, on the one hand, to analyse the impacts of joint procurement of up- and downward balancing capacity and the timing of these products. On the other hand, the influences of separated procurement of up- and downward balancing capacity and timing of products combined with common procurement by all TSOs are analysed.

Table 4: Defined scenarios for studying possible future balancing market mechanisms.

Scenario	Description
Reference case	• for all balancing regions/areas the same market designs • **separated** procurement of balancing capacity and energy products • **separated** procurement of up- and downward balancing capacity products • **week-ahead** procurement of Peak, Off-Peak and Weekend aFRR products in Austria, and Haupttarif (HT: Mo-Fr 8:00-20:00) and Nebentarif (NT: Mo-Fr 0:00-8:00 and 20:00-24:00, Sa-So) aFRR products in Germany, Belgium and the Netherlands • daily procurement of 4h products for mFRR (like in Austria) • imbalance settlement period of 15 minutes • balancing capacity can be **only exchanged** between German TSOs/balancing areas
Case A	• **day-ahead** procurement of Peak, Off-Peak and Weekend aFRR products in AT, and HT and NT aFRR products in DE, BE and NL
Case B	• **joint** procurement of up- and downward balancing capacity products
Case C	• **joint** procurement of up- and downward balancing capacity products • **day-ahead** procurement of Peak, Off-Peak and Weekend aFRR products in AT, and HT and NT aFRR products in DE, BE and NL
Case D	• **day-ahead** procurement of Peak, Off-Peak and Weekend aFRR products in AT, and HT and NT aFRR products in DE, BE and NL • balancing capacity can be **exchanged** between all TSOs/balancing areas
Case E	• **12 hours-ahead** procurement of Peak, Off-Peak and Weekend aFRR products in AT, and HT and NT aFRR products in DE, BE and NL • balancing capacity can be **exchanged** between all TSOs/balancing areas
Case F	• **1 hour** products in all countries • balancing capacity can be **exchanged** between all TSOs/balancing areas

3.3.2 Main findings of the study

From the results of the analysis on future balancing market mechanisms the following conclusions can be drawn:

- The **symmetric (joint)** procurement of positive and negative balancing capacity
    - o increases total generation costs and total procurement costs (see Case B and C in Figure 3),
    - o increases procurement exchanges between German TSOs,

- o is a poor design for RES integration, due to the fact that e.g. wind farms cannot use their full electricity generation in order to be able to provide also upward balancing capacity.
- **Common procurement** of balancing capacity by all balancing areas
  - o reduces total generation costs and total costs of procurement (see Case D to F in Figure 3).
- **Shorter time frame** of block products
  - o reduces average implicit allocation of transmission capacity between balancing areas (see Figure 4),
  - o reduces total generation costs and total procurement costs (see Case D to F in Figure 3),
  - o is a good design to integrate RES in balancing markets, because the shorter the product length is, the more efficient RES can bid into the market.

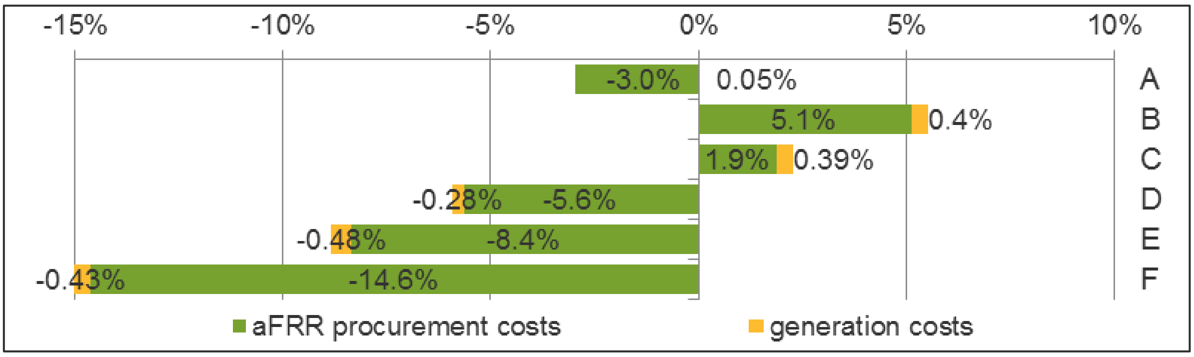


Figure 3: Differences of aFRR procurement costs and generation costs compared to reference case.

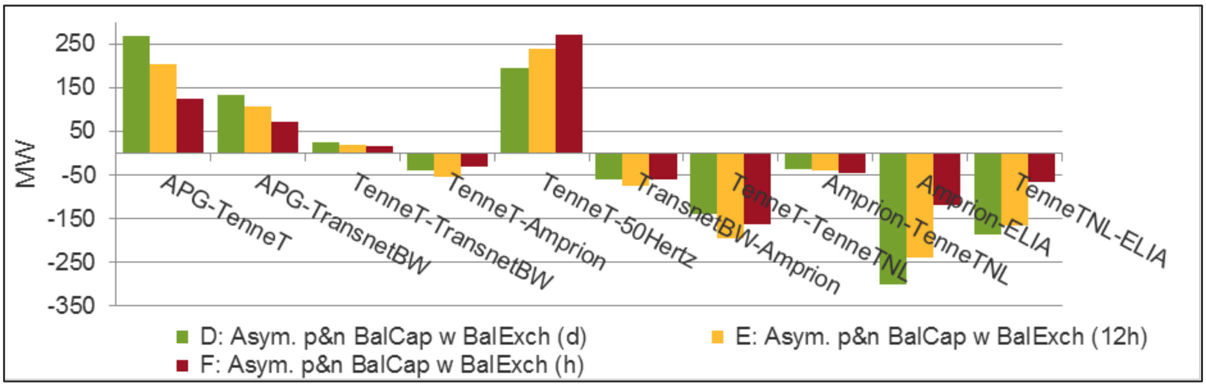


Figure 4: Average allocated transmission capacity for positive balancing capacity for Case D to F, positive value means A to B (A-B) and negative vice versa (in MW).

Detailed description of scenarios and the corresponding results can be found in Market4RES report D5.2 [8].

3.4 Perspectives for balancing market design evolution

Balancing electricity systems is one of the core activities of TSOs, and has strong links with the security of the power system. The way balancing is done within each country is the result of a long history, taking into account national specificities such as the structure of the national generation fleets. Balancing markets have initially not been designed to be integrated at cross-border level, nor to integrate high RES shares. Integration of distributed energy resources (DER) such as small RES units and consumers in balancing markets is also a challenge.

Progress is therefore rather slow, as illustrated by the date of the first scoping of ACER Framework Guidelines on EB in October 2011 to ACER recommendation for adoption of ENTSO-E Network Code on Electricity Balancing (NC EB) in July 2015. Afterwards, the NC EB should be prepared by experts from the European Commission before it enters the Comitology process, through which it should become European law[3]: as far as the authors know, the comitology process should start in autumn 2016. In addition, once the NC EB entries into force, TSOs will have between 1 and 4 years to implement some of the NC EB requirements[4]. Up to 10 years of negotiation, development and implementation will therefore have been needed. The degree of harmonization to be achieved after this decade is also not finally determined yet.

However, improving the functioning of electricity markets is urgently needed, and the NC EB does not provide detailed design for all kinds of balancing services. This is why TSOs have engaged into several cross-border pilot projects, with the purpose of:

- Testing the feasibility of the European (target) model and intermediate steps established in the ACER Framework Guidelines on Electricity Balancing (FG EB);
- Evaluating the associated implementation impact;
- Reporting on the experience gained. [5]

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[3] See ENTSO-E and EC websites for details about comitology: https://www.entsoe.eu/major-projects/network-code-development/electricity-balancing/Pages/default.aspx and https://ec.europa.eu/energy/en/topics/wholesale-market/electricity-network-codes.

[4] NC EB article 13.1, *"No later than two years and six months after the entry into force of this Network Code, all TSOs using Replacement Reserves shall implement the regional integration model for the Replacement Reserves"*.
NC EB article 15.1, *"No later than four years after the entry into force of this Network Code, all TSOs using Frequency Restoration Reserves with manual activation shall implement the regional integration model for the Frequency Restoration Reserves with manual activation"*.
NC EB article 17.1, *"No later than four years after the entry into force of this Network Code, all TSOs using Frequency Restoration Reserves with automatic activation shall implement the regional integration model for the Frequency Restoration Reserves with automatic activation"*.
NC EB article 19.1, *"No later than two years after the entry into force of this Network Code, all TSOs in the Synchronous Area Continental Europe shall implement the regional integration model for Imbalance Netting Process"*.
NC EB article 21.1, *"No later than three years after the entry into force of this Network Code, all TSOs shall harmonise: (a) the main features for Imbalance calculation […]; and (b) the main features to calculate the Imbalance Price"*.
NC EB article 29.2, *"No later than one year after entry into force of this Network Code, all TSOs shall develop a proposal for a list of Standard Products for Balancing Capacity and Standard Products for Balancing Energy for Frequency Restoration Reserves and Replacement Reserves."*.

[5] See more details at https://www.entsoe.eu/major-projects/network-code-implementation/cross-border-electricity-balancing-pilot-projects/Pages/default.aspx.

As illustrated by Figure 5 below (source ENTSO-E [28]), each pilot project is focused on one specific area ranging from Imbalance Netting, Replacement Reserve, manual Frequency Restoration (mFRR), automatic Frequency Restoration (aFRR) to Frequency Containment Reserve (FCR).

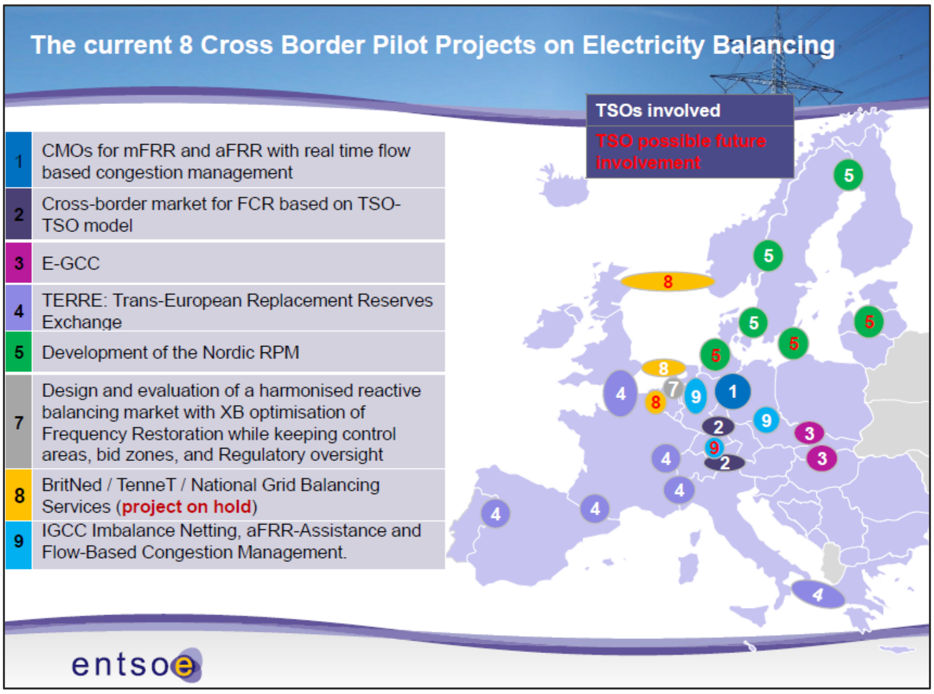

Figure 5: The current cross-border pilot projects on Electricity Balancing

It is expected that the cross-border pilot projects will deliver results progressively up to 2019 and allow for better preparing the implementation of the NC EB by gaining experience about product definitions and pricing mechanisms, identifying and overcoming barriers related to regulatory issues, IT development, interactions with intraday markets and more. Furthermore, in addition to those pilot projects, which are testing implementation issues, some research is still needed about cross-border balancing market integration and participation of distributed energy resources. This is why the FutureFlow project has been selected by the European Commission in 2015, under the Horizon2020 research and innovation programme[6]. With four TSOs of Central-South Europe involved, the project aims at designing and testing comprehensive techno-economic models for open and non-discriminatory access of advanced consumers and distributed generators to a regional balancing and redispatching platform. The creation of such platform is expected to bring about synergetic benefits:

[6] Full project title: "Designing eTrading Solutions for Electricity Balancing and Redispatching in Europe". See project website at http://www.futureflow.eu/.

- For TSOs, through more competition in reserve markets, possible decrease in the total volume of reserves contracted, more efficient congestion management;
- For aggregators, through increased attractiveness and/or profitability growth potential;
- For commercial and industrial consumers, prosumers and distributed generators, through increased profitability of turnover from their assets.

The debate on balancing market design, which the Market4RES project has contributed to (mostly from a perspective of RES integration), is therefore far from being closed.

4 FOCUS ON THE TIMING OF SHORT-TERM MARKETS

4.1 Background: Achievements, current status and challenges ahead for the timing of short-term markets

4.1.1 Options for the timing of short-term markets

As presented in [5], there is a large number of parameters characterizing the timing of electricity markets. The most relevant ones are:

- The **time parameters of energy markets** run by Power Exchanges (PXs), as the day-ahead markets (DAM) and the intraday markets:
    - The lead time, i.e. the interval between the market closure and the delivery of energy;
    - The scheduling horizon, i.e. the total duration of the products traded during a market session;
    - The time step, i.e. the length of the smallest energy products that can be traded;
    - The session interval, i.e. the interval between two market sessions (not applicable for continuous markets);
- Similarly, the **time parameters of reserve markets** run by Transmission System Operators (TSOs);
- The **gate closure**, i.e. the timing of the frontier between energy market and reserve use.

The combination of different settings of those parameters for day-ahead and intraday markets can lead to multiple designs. An option is to concentrate liquidity in a first opening session (typically the day-ahead market) and to complement it with subsequent intraday sessions ranging from a few, spaced sessions[7] to continuous markets[8] if liquidity is high enough.

4.1.2 Timing of short-term markets within the Target Model

The Market4RES project has assessed the target model in terms of timing of short-term market (see deliverable D2.2 [5]).

Within the current implementation of the Target Model, Day-Ahead market outcomes are available around 14:00 CET for the next day. It is followed by a continuous intraday market in which trade can occur till at least one hour before real time. For intraday, the co-existence of complementary regional intraday auctions is allowed, as long as they don't hinder the functioning of the European continuous market.

[7] This corresponds to the market design in Spain and Italy.
[8] This corresponds to the market design in Northern and Central-Western Europe.

For the Day-Ahead timeframe, most national markets are already aligned with the European timings, since a large number of countries are already taking part in the Price Coupling of Regions (see Figure 6, source EPEX SPOT [29]).

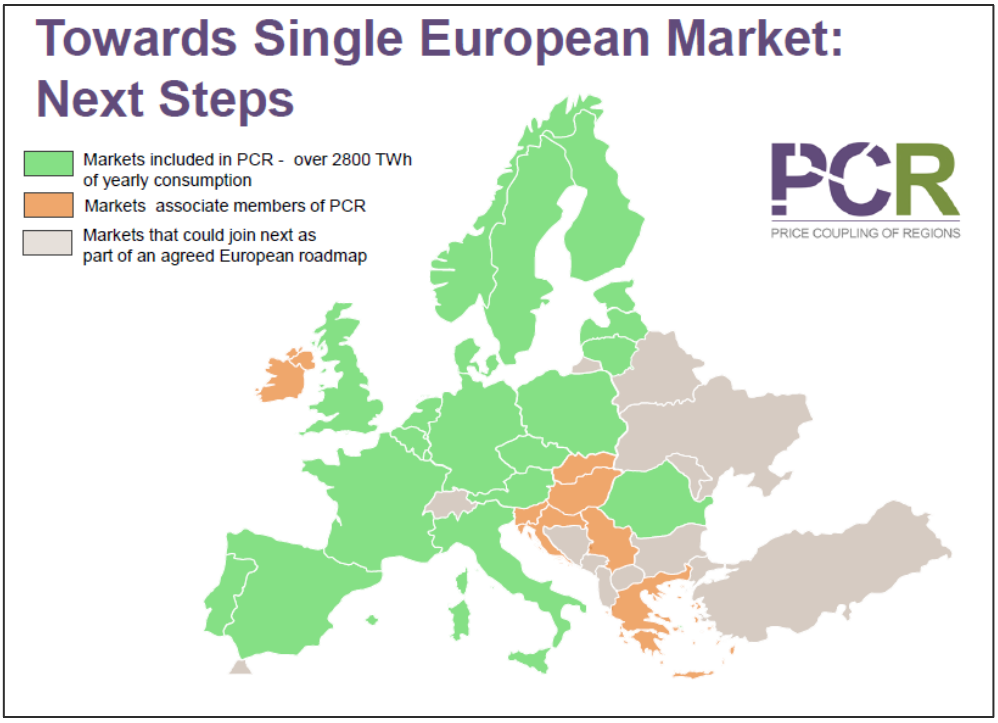

Figure 6: Status of day-ahead market integration through market coupling

The timing established for the market coupling operation is such that market players are able to submit bids and offers until 12:00 CET. Article 47 (§1 and §2) of Regulation (EU) 2015/1222 establishing a guideline on capacity allocation and congestion management[9] indeed reads*: "The day-ahead market gate closure time in each bidding zone shall be noon market time day-ahead […].Market participants shall submit all orders […] before day-ahead market gate closure time"*. [30]

This timing has allowed market players to have reasonable forecasts on the operational conditions of their power plants and on demand forecasts of their consumers. At the same time, it has allowed TSOs to have on time a clear picture of the following day operation and to validate it.

Still, sticking to the status quo in terms of day-ahead market timing is questionable, due to the increase RES penetration leading day-ahead market outcomes to be less and less representative of real-time situation. A possible change in day-ahead market timing is qualitatively assessed in section 4.2 below, and the results of a quantitative study are reported in section 4.3.

[9] This is the formal name of the Network Code on CACM, adopted by Comitology process in July 2015.

For the intraday, solutions are more diverse and the implementation of the European Intraday continuous market is still under way. Nevertheless, according to the guideline on capacity allocation and congestion management [30] (article 59, (§2 and §3), cross-zonal intraday exchanges shall be possible up to one hour before real-time: *"The intraday cross-zonal gate closure time shall be set in such a way that it: (a) maximises market participants' opportunities for adjusting their balances by trading in the intraday market time-frame as close as possible to real time; and (b) provides TSOs and market participants with sufficient time for their scheduling and balancing processes in relation to network and operational security. One intraday cross-zonal gate closure time shall be established for each market time unit for a given bidding zone border. It shall be at most one hour before the start of the relevant market time unit and shall take into account the relevant balancing processes in relation to operational security".*

4.2 Qualitative assessment of the possible options for the timing of short-term markets

Here we refer to the qualitative assessment presented in [5]. The qualitative assessment focuses on the timing of the first market (currently the DAM), the timing of intraday market, the timing of the (last) gate closure before real-time and the timing of the reserve markets.

4.2.1 Timing of day-ahead markets

Presently, in the context of the Price Coupling of Regions (PCR), the timing of three processes concentrate most discussions: **pre-coupling** (involving e.g. nomination of long-term rights, calculation of day-ahead capacities, bid submission…), **coupling** (involving e.g. closing order books, market coupling calculation, portfolio allocation, publication of results…) and **post-coupling** (involving e.g. security checks by TSOs, calculation of intraday capacities, possibility to re-open the order book in case of abnormal prices…).

In general, to maximize efficiency and avoid distortion, all the tasks involved by the pre-coupling should be pushed to take place as late as possible. Regarding the coupling process, the efficiency is increased as the total time needed to conduct the associated tasks is shortened. However, coupling needs to be conducted in a robust and secure manner. Total time to conduct the tasks, under nominal operational conditions, currently takes 42 minutes.

4.2.2 Timing of intraday markets

The major alternative is about having continuous trading or discrete auctions, or possibly a hybrid system based on continuous trading but also including the possibility of complementing the design with discrete auctions to ensure market liquidity.

The assessment of each option against efficiency and implementability criteria is summarized in Table 5 below. It can be concluded that continuous trading provides greater flexibility since trading is always possible. However, continuous trading is deemed efficient only at the condition that a certain level of liquidity exists. When this is not the case (as shown in some European PXs), a hybrid solution combining discrete and continuous is the best approach.

Table 5: Qualitative assessment of continuous, discrete and hybrid timing of intraday markets

		Continuous	Discrete	Hybrid
Efficiency	*Flexibility to trade*	Very Good	Fair	Good
	Liquidity	Fair	Very Good	Good
	Efficiency of the dispatch	Fair	Good +	Good +
	Pricing cross-border capacity	Fair	Very Good	Good
Implementability		Very Good	Good +	Good +

4.2.3 Timing of reserve markets

In parallel to the timing of the "energy" products, there are also different possibilities for the timing of ancillary services products: procurement of reserves can occur in the long-term (year/month/week-ahead), in the short-term (a few days ahead), in day-ahead with intraday updates, or a hybrid procurement is possible (e.g. regulatory requirements satisfied on year/month/week-ahead; free bids complement the reserve pool on a day-ahead or intraday timeframe).

Exclusively implementing long-term procurement of reserves clearly restricts variable RES participation due to the limited predictability of its generation. On the other hand, exclusively procuring reserves in the very short-term does not allow the participation of some slower plants. The day-ahead seems to be a reasonable time frame to maximize the value of non-flexible resources.

Considering the variant with intraday updates, market players with variable generation have the option to self-balance their deviations, therefore fewer power plants have to operate in an inefficient partial load mode.

Consequently, a combination of long-term, day-ahead and shorter-term procurement would maximize the value of existing non-flexible sources, while taking advantage of the potential of variable renewable generation to participate in the market.

4.2.4 Timing of the gate closure

Each system has traditionally used different criteria to define the point at which the system operator (SO) takes increasing control of the system so as to ensure security. Today, the gate closure occurs in general around one hour before real time. RES-E adds to the discussions on where to draw this frontier. The two major approaches are:

- **Bringing it closer to real time** to allow a more efficient participation of RES-E given the improvement of forecast accuracy at shorter times and closer to delivery.
- **Keeping it around one hour before real time or even moving it away from real time** to allow the SO to ensure security of supply while also giving further incentives (when coupled with dual imbalance pricing) to improve forecasting tools.

From the efficiency point of view, bringing the gate closure time closer to real time allows a more efficient participation of RES-E given the improvement of forecast accuracy at shorter times and closer to delivery, while reducing the timeframe during which the SO can manage system security. Examples are the Nordic market with gate closure being 45 min before delivery, and in Belgium and the Netherlands where local trading is possible until 5 minutes before real time.

Moving the gate closure away from real time would be inefficient as found by the REserviceS project: *"The functioning of existing day ahead and intraday markets must be improved with shorter gate closure and more cross border integration in order to give VAR-RES producers (short term) opportunities to trade their imbalances. A shorter forecasting time horizon would not only help to set up a level playing field for balancing conventional and variable generation, but would also lower the system operation costs"*. [31]

4.2.5 General conclusion of the qualitative assessment

The timing of markets should be modified to allow their outcome to react faster to changes in system conditions largely caused by renewable generation. Then, day-ahead markets should be called as late as possible (regarding bid submission) while tasks associated with them should be carried out as quickly as possible. In the intraday timeframe, continuous trading, providing greater flexibility, should be implemented, while in those cases where flexibility is not enough this should be combined with (discrete) auctions.

4.3 Quantitative study analysing the impact of changing the timing of short-term markets carried out with the ROM model

Within the Market4RES project, a quantitative analysis has been carried out to assess the impact of bringing the day-ahead market closer to real time. The analysis compares the operation of the power system with the current timing of the day-ahead market with that for the case where the day-ahead market is closer to the real time operation. Detailed input data and model description can be found in Market4RES report D5.1 [7], while complete study results can be found in Market4RES report D5.2 [8].

4.3.1 Specifications of the study

The quantitative analysis of the impact of moving the timing of day-ahead markets closer to real-time has been carried out using the ROM model developed by IIT-Comillas. The main idea is that reducing the time lag between the day-ahead market and real time results in a reduction in the forecast error of wind production and solar production. As a result of this reduction in the forecast error, the amount of operating reserves required by the system operator would also decrease.

The analyses carried out comprise the power system of Spain, while not considering its internal network. The time scope of the analysis is one year (8,760 hours), and the target year considered is 2030. The generation capacity and demand considered are based on the Vision 3 of the TYNDP-2014. RES generation profiles are scaled-up based on the RES profiles obtained in 2013 and on the forecasted installed capacity for 2030.

These analyses take into account both the day-ahead market (unit-commitment) and the real-time simulation of the power system. The up and down reserves required are obtained based on these formulas:

$$UpReserve(h) = \alpha \cdot Demand(h) + MaxUnit(h) + \beta \cdot RES(h)$$

$$DwReserve(h) = \alpha \cdot Demand(h)$$

The up reserve covers the system from the uncertainty in the demand and RES generation and the failure of the biggest unit generating electricity. In this analysis, only the uncertainty coming from wind and solar generation is being considered. The down reserve covers the system only from the uncertainty in the demand.

The methodology employed in the analyses is described with more detail in the report D5.1 [7].

4.3.2 Main findings of the study

From the results of the analysis on moving the timing of markets, the following conclusions can be brought forward:

- Bringing closer the day-ahead market to real time only a few hours is not worthy, because the small reduction in the wind and solar forecast error does not reduce generation dispatch costs.
- Day-ahead market has to be very close to real-time to cause a reduction in the forecast errors high enough to produce benefits in the operation of the power system.
- Bringing day-ahead markets too close to real-time would not be possible for some power systems due to the lack of flexibility of their generation fleet. If the day-ahead market is very close to real-time, some generation units will not be able to start-up or shut-down in the required time and therefore, they will be automatically out of the market.
- Other power systems with more flexibility of their generation mix, like the Nordic ones, may consider this option.
- For systems with limited flexibility, enabling intraday markets may represent a reasonable trade-off between achieving a high level of accuracy in considering the true operation conditions in the market (through these intra-day markets) and making room for less flexible generation to be committed long enough in advance of real time.

4.4 Conclusions regarding the timing of short-term markets

Considerable progress has been made during the recent years in terms of day-ahead market integration. Having the day-ahead gate closure brought to noon in most European countries results from a long harmonisation process. For instance, before the launch in 2010 of the CWE market coupling linking Germany to the Trilateral Coupling (TLC) countries France, Belgium and the Netherlands[10], the day-ahead market gate closure in the TLC markets was 11am, while the German market was closed at noon as was the Nordpool market. At the same time, the MIBEL market (Spain and Portugal) closed at 10am: it moved to noon in 2013 when the market coupling was extended to the Iberian Peninsula.

Now, since most day-ahead markets in Europe are coupled through a single price coupling algorithm, the day-ahead gate closure must be the same in all countries. Moving it away from noon would therefore need to be based on very strong arguments applicable to all these countries.

From the Market4RES project point of view, the increased RES penetration, occurring in all Member States, should be dealt with preferably by improving the functioning of the intraday markets.

[10] **The TLC was launched in 2007. At this occasion the Belgian power exchange Belpex was created: before that, only bilateral exchanges were possible in Belgium in day-ahead.**

5 GENERAL CONCLUSION

In the present report, we have summarized and drawn conclusions from a significant part of the work done within the Market4RES project since 2014.

Within the first work stream of the project (focused on short-term objectives regarding power market design), the report D6.1.1 [1] had provided the project's views about two topics of utmost importance in terms of market development: RES support schemes evolution up to 2020 and demand flexibility deployment; for this we had used outcomes of previous work packages of the project, namely WP2, WP3 and WP4.

With the present report D6.1.2, we are closing the first work stream of the project. Again on the basis of previous project's outcomes (this time WP2, WP3 and WP5), we have provided the project's vision about the necessary flexibility of short-term markets, allowing for the integration of high share of renewable sources. Again, our analyses have been focused on the 2020 horizon, even if the limit before and after 2020 in terms of market design is not that strict.

First, we have discussed some flexibility features of the short-term markets in general (Chapter 2). The discussion has been based on concrete examples regarding short-term electricity price volatility and mid-term price trends. Possible options to increase short-term market flexibility have been put forward, ranging from regulatory to investment-based flexibility options. Finally some features of an ideal short-term market have been proposed.

Second, we have focused on the main features of balancing markets in a context of high RES penetration (Chapter 3). Different options have been assessed, first in a qualitative manner, second in a quantitative manner with the help of a modelling tool developed by EEG. In conclusion we have linked with the current pilot projects which ENTSO-E members are engaged in and with the most recent research projects about the integration of distributed energy resources into cross-border balancing.

Finally, in Chapter 4 we have discussed the timing of short-term markets. We have listed the different parameters characterizing this timing, and discussed different options in a qualitative manner. Regarding the gate closure of day-ahead markets, we have provided the results of a quantitative analysis carried out within the project. We have concluded that the main aspects to be improved and harmonized were about the intraday markets, since the day-ahead markets have already been deeply improved through an integration process launched ten years ago.

Deliverables D6.1.1 and D6.1.2 related to the first work stream of the Market4RES project will be followed by two other deliverables D6.2 and D6.3 related to the second work stream of the project (post 2020), as illustrated by Table 6 below. In particular, the design of intraday markets compatible with high RES penetration levels, will be discussed in D6.2.

Table 6: Organization of concluding Market4RES reports (WP6 deliverables)

Market design aspects	WP6 deliverable	Based on
Workstream 1: short-term objectives		
RES support schemes design up to 2020	D6.1.1	WP2, WP3, WP4
Participation of demand in short-term markets		
Other design features of short-term markets	D6.1.2	WP2, WP3, WP5
Workstream 2: long-term objectives		
New market designs for RES beyond 2020	D6.2	WP2, WP3, WP5
Design of capacity remuneration mechanisms	D6.3	WP2, WP3, WP5
Participation of demand in long-term markets		

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