METIS Technical Note T3

Market module configuration for study S12

Focus on day-ahead, intraday and balancing markets

METIS Technical Notes
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1. INTRODUCTION AND BACKGROUND

1.1. GOAL OF THE DOCUMENT

This technical note has been prepared by Artelys and Thema Consulting and accompanies the study *METIS Study S12 – Assessing Market Design Options in 2030*. This document aims at providing information on the market design options that have been modelled and compared using METIS. In particular, the document details the difference between market design initiative (MDI) options in terms of input data. We describe the way the current market arrangements are represented in the baseline and how the policy measures included in the MDI options are modelled in METIS.

This document also contains a review of the current practices of day-ahead, intraday and reserve markets, which were used as a basis for the modelling work.

1.2. DOCUMENT STRUCTURE

The present document is organised as follows:

Section 2 provides an overview of the policy measures - denoted Actions - aimed at tackling market distortions, improving the functioning of short-term markets and enhancing regional cooperation. The way policy measures are grouped into coherent policy packages (MDI options) is then presented.

Section 3 is dedicated to presenting the measures related to RES curtailment and RES participation in reserve procurement. **Section 4** focuses on measures related to the intraday markets and on the use of interconnection capacities. **Section 5** focuses on reserve dimensioning and procurement, and on risk sharing. **Section 6** focuses on DSR deployment and its participation in reserve procurement.

Each of these sections is split in two subsections: the first one describes the current market practices, and is partly based on an EC report on current functioning of electricity markets[1], while the second one presents the METIS representation of the MDI options and the data that is used to describe the implementation of policy options.

[1] See the report *Electricity Market Functioning: Current Distortions, and How to Model Their Removal, COWI (2016).*

2. OVERVIEW OF MODELLED MARKET DISTORTIONS

The *METIS Study S12* aims at providing quantitative estimates - using METIS models (see *METIS Technical Note T2 - METIS Power Market Models* for more details) - of the impacts of four policy options of market design development of increasing levels of ambition, which have been designed by the European Commission by grouping policy measures into coherent packages. The MDI policy options are listed below:

- **Baseline** – Current market arrangements
- **Sub-option 1a** – Reducing current inflexibility
- **Sub-option 1b** – Better market interconnection
- **Sub-option 1c** – Pull all flexible resources into the market
- **Option 2** – Fully integrated EU market

Common assumptions

The baseline and all the MDI options share a number of common assumptions:

- **Liquid markets:** Although it is not currently the case in each and every Member State, the study assumes that 2030 day-ahead, intraday and balancing markets are fully liquid. The study also assumes that all the electricity is traded on the market (implicitly assuming that all bilateral contracts are based on the market price).
- **Bidding, price caps and clearing**: The study assumes that actors bid according to their marginal cost (marginal cost bidding) for power and reserve markets. In addition, the study does not take into account a price cap in day-ahead, intraday and balancing markets, meaning that the price can reach the value of loss of load, which is set to 15 k€/MWh. The market clearing method is Single Marginal Pricing.
- **Network representation:** A NTC description of the European power network with National bidding zones is used in this study. As such, it does not capture costs related to internal congestion within Member States.
- **Balancing products:** The following balancing products are included in the analysis: harmonized 30sec for FCR, 5min for aFRR and 15min for mFRR.
- **Activation cost of balancing:** The activation cost of balancing energy is assumed to have two components: a fixed activation cost and the variable cost (fuel costs). The fixed activation cost has been estimated by comparing historical balancing costs to the corresponding costs of electricity. This analysis suggests producers add a mark-up of around 8€/MWh to their variable cost. Competitive pressure would likely drive this mark-up down. This effect has not been modelled.
- **Replacement Reserves:** Although replacement reserves are not explicitly represented in METIS, it is assumed that some of the loss of load situations in intraday would be avoided provided it is profitable to invest in and run flexible power plants (60k€/MW/y, 180€/MWh) during the would-be loss of load hours. The share of loss of load that is avoided through these investments is interpreted as being provided by replacement reserves. This is reflected as a post-treatment of the simulation results for intraday markets, where loss of load costs are partially replaced by the corresponding replacement reserve costs.
- **Reserve dimensioning:** The dimensioning of reserves is based on a probabilistic approach. As such, it does not take into account that some countries currently use the deterministic approach.
- **Demand-side Response**: The level of participation of DSR capacities in reserve procurement and balancing markets is optimised. The dispatch of DSR in the day-

ahead power market is however not modelled[2], although it is partly taken into account by the consumption profiles. Indeed, the hourly power demand profiles that are used in the study are based on ENTSO-E's TYNDP 2014 published datasets, which take demand-side flexibility into account (e.g. domestic hot water, electric heating, electric appliances). However, given the level of details published by ENTSO-E, it was not possible to model the dynamic adjustment of the demand to external signals. As a consequence, the study primarily focuses on the savings generated by pulling DSR resources into reserve procurement and balancing markets, and may therefore underestimate the value of DSR.

In particular, this study does not capture the impact of the following market design measures:

- Measures on investments: The installed capacities (NTC, DSR, generation) are input data based on the PRIMES EUCO27 scenario or the COWI report on DSR (see below). Even though revenue distributions and investment risks can be assessed within METIS (for instance in the METIS Studies S16 and S18), the impact on investments and decommissioning is not modelled.
- Measures on network tariffs and retail markets
- Measures to reduce Gate Closure Time: As METIS uses an hourly granularity, the impact of such measures is out of the scope of the model.[3]
- Measures to mitigate market power or improve market liquidity.
- Market clearing approach (uniform pricing vs pay as bid)
- Measures to strengthen balance responsibility and to ensure prices invoiced for imbalances are the same as the marginal price for balancing service remuneration
- Flow-based market coupling and measures related to the redesign of bidding areas.

Option-specific assumptions

An overview of the Actions aimed at tackling market distortions, improving the functioning of short-term markets and enhancing regional cooperation that are modelled in the different policy options is given in next table. For each of these Actions, several options are considered in the different MDI policy packages. A detailed presentation of the options can be found in the subsequent sections along with a description of current practices.

Action	Topic	Description of the options
1	DSR deployment	Three levels of demand-side response (DSR) deployment are considered. The three levels (a, b and c), with increasing capacities, are based on COWI BAU and PO2 scenarios[4] and presented in Section 6.
2	RES priority dispatch and curtailment cost	Two options are considered for renewable energy sources (RES): a. Penalty for solar PV and wind power curtailment, priority dispatch for biomass b. No penalty or priority dispatch for solar PV, wind and biomass

[2] This will be the focus of future work on the METIS Demand Module.

[3] For countries with 30min or 15min intraday gateways, generation plan updates within the hour (every 15 or 30 minutes) will be included in the mFRR activation.

[4] See the report "Impact Assessment support Study on downstream flexibility, demand response and smart metering", COWI (2016).

3	Biomass reserve procurement	Two options are considered for the participation of biomass in reserve procurement: a. Biomass does not participate in FCR and FRR b. Participation of biomass (the absence of priority dispatch is a prerequisite)
4	Coal/lignite commitment in day-ahead markets	Two options are considered for coal and lignite commitment: a. The day-ahead commitment decision (i.e. which plants are turned on or off) for coal and lignite power plants cannot be refined during the intraday timeframe b. Coal and lignite power plants can re-optimise their commitment in intraday (provided they respect a number of technical constraints)
5	Increase balance responsibility	Incentivising RES producers to respect their production planning by making them financially responsible for the imbalances they cause will encourage them to improve their generation forecasts. Two options are considered: a. h-2 forecasts are used for demand, wind and PV generation for reserve dimensioning and generation of imbalances. b. h-1 forecasts are used for demand and PV, while 30 min forecasts are used for wind. This will lead to lower imbalances and lower reserve requirements.
6	Intraday coupling	Auctions for interconnections capacity can either be explicit, meaning that the flows are assumed to be fixed in h-4, or implicit, in which case flows can be updated until h-1. Two options are considered: a. Auctions are mostly explicit, except in specific areas, based in current practices. b. Auctions are implicit for all interconnections. In any case, the reserve procured at day-ahead remains fixed during intraday.
7	Normalized approach for reserve sizing	Two options are considered for automatic frequency regulating reserve (aFRR) sizing: a. Fixed reserve size computed as 0.1% and 99.9% centiles of imbalance distribution over the year. While some Member States have different reserve needs depending on demand variation, this option considers that the reserve size is constant over the whole year for all MS. b. Variable reserve size depending on the hour of the day and wind energy forecasts. The reserve need is computed as the 0.1% and 99.9% centiles of imbalance conditional distribution
8	Reserve procurement methodology	Reserve can be procured either at day-ahead (which is modelled as a joint optimization of power and reserve day-ahead procurement) or on a fixed basis per year (in which case reserve is provided by base-load units). The options are: a. Current practices (data based on COWI, 2016[1]), b. Day-ahead procurement
9	Joint or separate up/downward reserve	Two options are considered for upwards and downwards reserve: a. Joint procurement according to current practices (data based on COWI, 2016[1]). b. Independent procurement of upwards and downwards reserves.
10	Use of NTC	To model the process of interconnection allocation, three options have been considered: a. National transmission system operators (TSO) have an important security margin. PRIMES EUCO27 net transfer capacities (NTC) are reduced by 5%. b. Collaboration between TSOs reduces the need for security margins. The full PRIMES EUCO27 NTC values

		are used. c. The introduction of supranational entities will result in a further reduction of the security margins, leading to an increase by 5% of the PRIMES EUCO27 NTCs.
11	Risk sharing for reserve dimensioning	To represent that risk sharing can reduce the needs for national reserve, three options are considered. Reserve is sized using a probabilistic approach: a. At national level b. At regional level c. At EU level In order to ensure MS can face similar security of supply risks when less reserves are procured (options b and c), interconnections have to be reserved for mutual assistance between MS.
12	PV, wind, waste and RoR reserve procurement	Two options are considered: a. PV, wind, waste and hydro RoR (run-of-the-river) do not participate in FCR and FRR b. Participation of PV, wind, waste and hydro RoR

Table 1: Overview of the options modelled in METIS

The MDI policy packages that are considered in the S12 study are defined by the following combinations of options:

Action	**Topic**	**MDI policy packages**				
		Baseline	**Sub-option 1a**	**Sub-option 1b**	**Sub-option 1c**	**Option 2**
1	Level of DSR deployment	a	b	b	c	c
2	RES priority dispatch	a	b	b	b	b
3	Biomass reserve procurement	a	b	b	b	b
4	Coal/lignite must-run at intraday	a	b	b	b	b
5	Balance responsibility	a	b	b	b	b
6	Intraday coupling	a	a	b	b	b
7	Time granularity of reserve size	a	a	b	b	b
8	Reserve procurement methodology	a	a	b	b	b
9	Joint/separate up/downward reserve	a	a	b	b	b
10	Use of NTC	a	a	b	b	c
11	Cooperation for reserve dimensioning and risk sharing	a	a	b	b	c
12	PV, wind, waste and hydro RoR reserve procurement	a	a	a	b	b

Table 2: Overview of MDI policy packages and corresponding METIS options

Sensitivities

In addition to the four MDI options introduced above, some sensitivities have also been studied:

- **Sensitivity to CO_2 price**: Sub-option 1a has been simulated with various levels of CO_2 price from PRIMES EUCO27 value (38.5 €/tonne) to 60 €/tonne, to assess its effect on CO_2 emissions in a system without priority dispatch.
- **Sensitivity to the order of measures**: This sensitivity attempts to assess if benefits attributed to policy measures can depend on the order in which they are introduced. The sensitivity focuses on the measures introduced between 1a and 1b, i.e. the improvement in reserve procurement rules and overall regional cooperation (reserve, intraday, NTC) and the measures introduced between 1b and 1c, i.e. DSR and RES participation in reserve procurement and balancing services. This is done by creating a scenario 1d, based on Sup-option 1a, but with DSR and RES participation in reserve procurement (Action 1 –option c and Action 12 - option b)

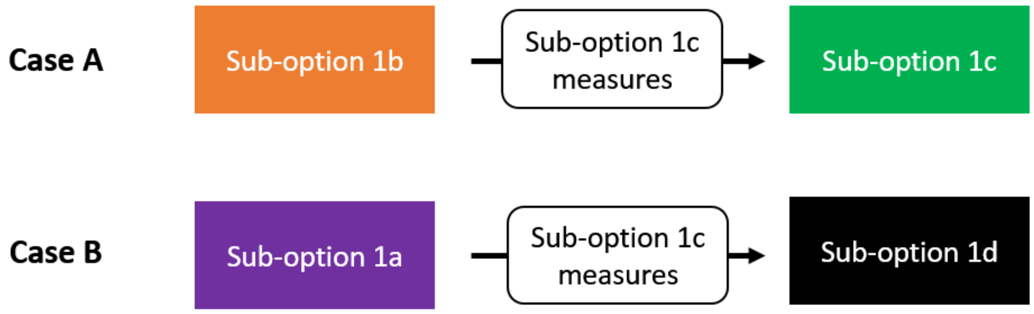

Figure 1 - Sensitivity to the order of policies

3. Priority dispatch, curtailment and RES participation in ancillary services

3.1. Current market practices

3.1.1. Priority dispatch

Priority dispatch implies that TSOs are obliged to schedule and dispatch energy from some generators before others, in an order that might not strictly follow the merit order. Priority dispatch can be considered an indirect support mechanism, and has often been implemented in order make sure that electricity generation from renewable energy reaches the market.

While PV and wind often benefit from priority dispatch, other technologies might be subject to priority dispatch as well: biomass plants, plants using indigenous resources, cogeneration plants, etc. Such positive discriminations for indigenous fuels and renewable generation is allowed under the Third Energy Package, the Renewable Energy Directive, and the Energy Efficiency Directive. Besides priority dispatch, exemptions from technical requirements and/or balancing costs, and participation in re-dispatch are other measures that are commonly implemented by Member States to offer support to selected technologies.

Priority of connection and dispatch is a common tool in several member states[1].

- About 25% of the EU MS have priority of connection for RES technologies
- About 40% of the EU MS have priority dispatch for RES
- In about 25% of the EU MS, RES generation benefits from some form of favourable exemption (e.g. auto-consumption, balancing responsibility)

In approximately half of the EU MS, a form of priority dispatch for RES can be identified. In some countries, some limited information is available in which exemptions are mentioned for specific technologies.

3.1.2. RES Curtailment

In case of imbalances, and in case these cannot be covered by balancing markets, the TSOs may have to curtail generation when supply exceeds the demand. In an ideal world, curtailment decisions would be based on costs, taking into account start-up costs and other considerations.

Priority dispatch may in practice imply that some resources cannot be used by the TSO when re-dispatching of the system, i.e. priority dispatch can prevent the curtailment of renewable resources, even when this is the most cost-effective measure from an overall system cost point of view. In particular, as long as the price zone delimitation is inefficient, such priority can potentially imply substantial costs.

There are two types of reason for curtailment:

- **Oversupply**: After exhaustion of market resources, there may still be an excess of supply. In this case, the TSOs have to curtail generation in order to balance the system.
- **Local grid issues**: There may be some local grid issues related to curtailment. The TSO may need certain units in certain areas in operation for grid stability and security reasons. In this case, the TSO may ask a certain plant to operate at a certain level while curtailing generation somewhere else in the system.

In general, (involuntary) curtailment rules are not transparent, neither when it comes to under what circumstances TSOs conduct curtailment, nor when it comes to the curtailment order (which plants are curtailed first). Curtailment practices are even more challenging to describe, as curtailment occurs very seldom (or never) in many Member States. Ideally, involuntary curtailment should only be carried out as a measure of last resort.

RES is given priority in curtailment situations in the following Member States[1]:

- Austria
- Belgium: The TSO is responsible for the minimization of the curtailment of RES
- Denmark
- Germany (RES and CHP), but a voluntary contractual agreement may limit priority for RES
- Luxembourg
- Hungary: RES curtailment only in case of emergency
- Poland (although not priority in practice)
- Spain (RES curtailed after conventional generation)

On the contrary, RES curtailment is quite common in Ireland.

In general, possible specific curtailment rules apply in 40% of the EU MS but do not specifically relate to negative prices. Curtailment decisions are mostly based upon technical criteria (grid issues) although the occurrence of negative prices, as well as the action of curtailment, might imply in certain countries some kind of compensation for subsidies or missed production.

3.2. METIS IMPLEMENTATION AND INPUTS

In METIS, the current market practices and potential improvement in the fields of priority dispatch, curtailment and RES participation in ancillary services are implemented in Actions 2, 3 and 13, as described below.

3.2.1. BIOMASS PRIORITY DISPATCH AND PARTICIPATION IN BALANCING SERVICES (ACTION 3)

In METIS, biomass is split in two components (assets). The first asset corresponds to waste-based generation and is modelled in all MS as a flexible source in all options. Its variable cost is assumed to be low (3.6€/MWh, based on PRIMES EUCO27 assumptions) and its generation can be curtailed without penalty. Its capacity is assumed to be 22% of the total biomass capacity. This figure is based on the ratio between European municipal and industrial waste capacities over the total biomass capacities in 2013, using Eurostat[5] 2013 figures and is applied to all countries.

The remaining 78% of biomass capacity correspond to conventional biomass fleets. The modelling choice has been to consider this part as:

- Must-run in all MS in option a
- Flexible in all MS in option b. In this case, this part of the biomass fleet can participate in balancing markets in all MS.

In both options, biomass produces at a high generation cost (around 100€/MWh, taking into account an efficiency of 30% and a high fuel cost of around 33€/MWh depending on the MS, based on PRIMES EUCO27 assumptions).

[5] See Eurostat database on: http://ec.europa.eu/eurostat/fr/data/database

3.2.2. PV, WIND AND HYDRO RUN-OFF-THE-RIVER CURTAILMENT (ACTION 2)

In METIS, wind, solar and hydro RoR generation are modelled as flexible generation fleets, able to produce up to a maximum, specified by an hourly time series based on climate data, with low variable costs (0 €/MWh for PV and RoR, 0.5 €/MWh for wind based on PRIMES EUCO27 data). To take into account current distortions related to priority dispatch, two options are considered.

Option a (baseline) takes into account the current priority dispatch practices. Curtailment is one of the solutions available to the model to ensure that the demand-supply equilibrium is enforced for each of the considered timeframes (balanced market clearing for day-ahead, intraday and balancing). Priority dispatch is modelled by penalizing curtailment at a level of 10€/MWh. This penalty has been chosen so that RES curtailment is the measure of last resort, after all other assets have been shut down[6].

In option b, i.e. for all the considered MDI options but the baseline, this penalty is eliminated to reflect the removal of priority dispatch.

The penalty factor should not to be interpreted as any payment RES producers would receive to compensate for the curtailment of their generation assets. As METIS adopts a system point of view, it does not model cash flows between the different market players.

3.2.3. PV, WIND, HYDRO RoR AND WASTE PARTICIPATION IN ANCILLARY SERVICES (ACTION 12)

In S12, two possibilities are considered for the participation of RES in ancillary services.

In option a, corresponding to current practices[7], PV, wind, waste and hydro RoR fleets cannot participate in FCR, aFRR or mFRR reserve procurement. In option b, PV, wind, waste and hydro run-of-the-river fleets can participate in all reserves. In this case, each fleet can participate in downwards reserves procurement up to its day-ahead forecasted generation, while it can participate in upwards reserve procurement depending on its current generation and the maximum generation profile (based on solar irradiation, wind and water inflow data, respectively).

[6] In very specific conditions, some generation units can be maintained online to avoid an expensive shutdown-start-up cycle. In such conditions, the clearing price is given by the RES penalty (-10€/MWh).

[7] In theory, as shown in Table 3 below, RES can currently participate in several balancing markets. However, in practice, RES only participates marginally in reserve procurement.

4. INTRADAY COUPLING AND USE OF NTC

4.1. CURRENT MARKET PRACTICES

4.1.1. MARKET STATUS

A significant number of MS (eight) have not implemented intraday market trade, although implementation is planned in five of them (see Figure 2). In the countries where an intraday market is implemented, liquidity appears to be quite low. Low liquidity is an indicator that the market is not functioning adequately. Note that possible exemptions of RES for balancing responsibility might also affect their (non-) involvement in the intraday timeframe.

4.1.2. INTRADAY COUPLING

Market coupling is not wide-spread, although more or less organized cross-border coupling and exchange does exist. However, the XBID project is expected to increase and improve intraday market coupling. The XBID project (*Cross-border Intraday Project*) would allow continuous implicit trading, involving France, Belgium, Luxembourg, Netherlands, Germany, Switzerland, Austria, GB, Denmark, Sweden, Finland, and Norway, Austria, Portugal, Italy and Spain. According to the current plans, the XBID project is supposed to go live in Q3 2017.

As of today, intraday market coupling (implicit auctioning) is in place in the following regions:

- EPEX: Germany, Austria, France, Switzerland
- Nord Pool Spot ElBas: Denmark, Sweden, Finland, Norway, Baltics, Netherlands, Belgium, Germany
- MIBEL: Spain, Portugal

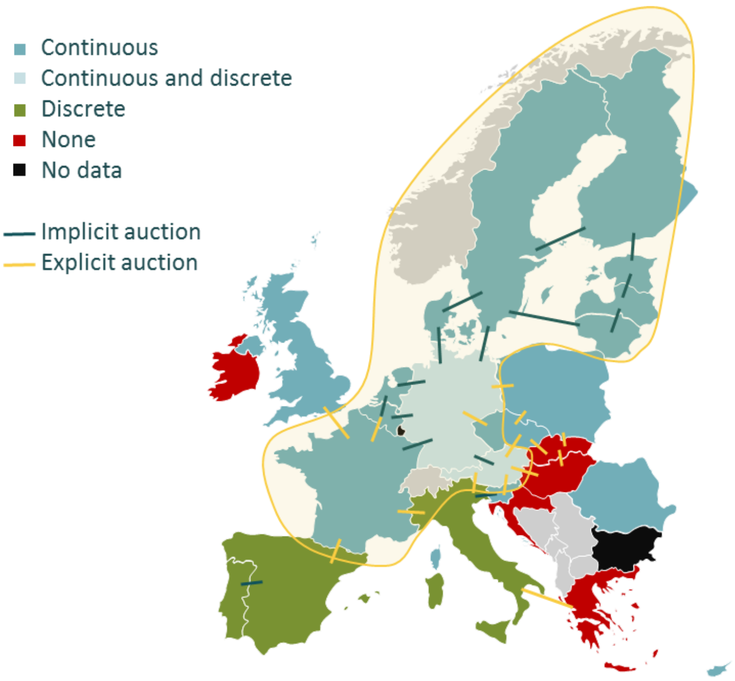

Figure 2: Intraday market mechanisms (colours) and the coupling mechanisms (lines) (source: COWI, 2016[1]).

4.1.3. EXPLICIT INTRADAY CAPACITY AUCTIONING IN GENERAL

On a number of European interconnections, explicit intraday auctioning mechanisms have been implemented, as shown in Figure 2. The figure shows which MS have domestic intraday markets and whether trade is continuous or discrete. Moreover, it shows the interconnections with implicit intraday auction, and the interconnections with explicit auctions. For example, between Belgium and France, there are explicit auctions taking place every two hours (rolling auctions).

4.1.4. EXPLICIT INTRADAY CAPACITY AUCTIONING IN CEE

The explicit auctions occur six times a day, each for four hours. Market participants may submit bids in the period between 6 hours and 2.5 hours before the first auctioned hour (i.e., 9 to 5.5 hours before the last hour in each four-hour block). The offered capacity is updated until gate closure (2.5 hours before the first hour). Capacity is then allocated on a first come first serve basis, and capacities are allocated free of charge. The market is however organized as "rights-with-obligation", meaning that acquired capacity comes with the obligation to use the capacity. Even for some of the other markets, there appears to be some bilateral intraday trading.

4.2. METIS CONFIGURATION AND INPUTS

In METIS, the current market practices and potential improvement in the fields of intraday coupling and use of interconnection capacity are modelled as Actions 6 and 10, as described below. Another market distortion of intraday markets which concerns coal and lignite commitment, Action 4, is also described in this section.

4.2.1. INTRADAY COUPLING (ACTION 6)

In S12, two options related to interconnection reallocation are considered.

In option a, corresponding to current market practice, Germany, Austria, France, Switzerland, Denmark, Sweden, Finland, Norway, Baltics, Netherlands and Belgium intraday markets are coupled meaning that flows in this area can be adjusted up to h-1. Spanish and Portuguese markets are also coupled. For all other interconnections, auctions are assumed to be explicit. Since the bids can be submitted in the period between 6 hours and 2.5 hours (see above), it is assumed that the bids occur at h-4 meaning that flows cannot be altered after h-4.

In option b, intraday markets are supposed to be coupled at an EU level, meaning that all auctions are implicit, and all flows can be adjusted up to h-1.

4.2.2. USE OF NTC (ACTION 10)

The improvements of the interconnection allocation process, for instance via the introduction of new algorithms for better cross-border utilization or through an improved cooperation at a regional or EU level, tend to lead to a reduction of interconnection security margins and consequently to a higher available capacity being available for exchanges (arbitrage and reserve sharing)[1]. Three options, which represent the impact of policy measures, have been considered:

- In option a, the regional cooperation is relatively low (the Guideline on Electricity Balancing is assumed to be adopted). As a result, the PRIMES EUCO27 NTC values are assumed to be reduced by 5% in all market timeframes.
- In option b, the increase level of regional cooperation (TSOs dimension and procure of reserves at the regional level) induces a greater level of coordination amongst TSOs. It is assumed that the full PRIMES EUCO27 NTC values are available in all market timeframes.

- In option c, the introduction of a supranational entities (in particular responsible for the dimensioning and procurement of reserves at an EU level) results in better coordination amongst TSOs and in a reduction of security margins, assumed to lead to an increase by 5% of the PRIMES EUCO27 NTCs in all market timeframes.

4.2.3. Coal and lignite commitment in day-ahead (Action 4)

Two options are considered to reflect the fact that coal and lignite units may enjoy a *de facto* must-run status in some intraday markets,

In option a, which reflects the observed behaviour in some MS, it is assumed that coal and lignite fix their commitment (meaning which plants are turned on or off) at day-ahead in all MS, and that this decision cannot be modified during the intraday timeframe. The production of coal and lignite fleets can still vary between the minimum and maximum power of the plants that are turned on.

In option b, coal and lignite fleets have to update their commitment in intraday in all MS, provided they respect their technical constraints. In particular, the decision to turn on a coal or lignite power plant has to be made up to 6 hours ahead of delivery, depending on the age of the power plant.

5. Reserve dimensioning, procurement and operation

5.1. Current market practices

5.1.1. Balancing market status

Most MS have at least one market based procedure for balancing services, as shown in Figure 3. Croatia is the only MS without any market based mechanisms, as balancing services are currently procured through bilateral contracts with the TSO. In the Baltic States, Poland, and France, there are only market based procedures for tertiary reserves (denoted FRR-M or mFRR).

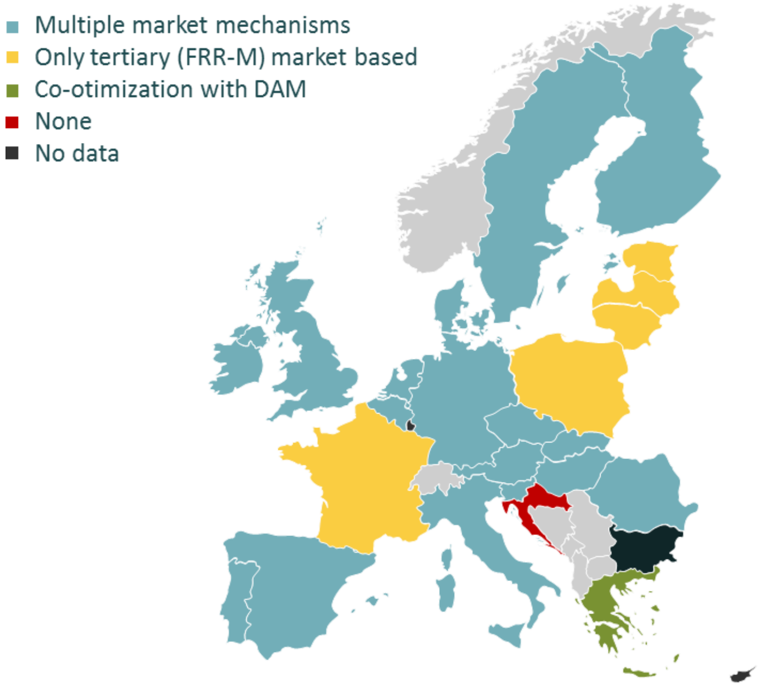

Figure 3: Degree of market-based mechanisms for balancing services (source: COWI, 2016[1])

The extent to which balancing services are procured through market based procedures, however, varies significantly among MS. The variations are due to

- Implementation (e.g., a yearly tendering process versus a daily auction, whether compensation is pay-as-bid or marginal pricing, whether the products for upward/downward balancing are separate, etc.).
- What services are procured through market based procedures (e.g., capacity reserves or energy settlement, and primary (FCR), secondary (aFRR), or tertiary (mFRR/RR))

An overview of the balancing markets are given in the table below. The entries have to be read as follows:

- *Significant obligations:* Some MS have requirements to provide balancing services for certain technologies. In France for instance, there are requirements to provide both FCR and aFRR reserves, and the compensation is a regulated price. Several MS have mandatory provision of primary reserves (FCR) for certain generators. There may be secondary markets to exchange reserves bilaterally, but we ignore such cases as these are far from optimal. In Italy and Portugal, generators are obliged to provide primary reserves without any compensation. There may also be an obligation to participate in the market, which is less strict than the former case, because the market participants are allowed to specify a price associated with a bid, and a market based mechanism is used to determine what bids are accepted.

- *Significant barriers:* There are several barriers to participate. Most commonly demand side response and/or RES cannot participate in balancing markets. If it is indicated "No barriers identified", it is assumed that both RES and DSR may participate in the balancing markets.
- *Procurement frequency:* In the table we indicate whether the procurement frequency is assumed to be "optimal" or not. A procurement is considered "optimal" if a TSO procures reserves frequently. For example, a TSO may contract parts of the reserves e.g. on a yearly basis, but adjusts the reserve according to short-term needs on, e.g., a weekly basis, the sizing of the reserve is considered optimal. However, if a TSO contracts the entire reserve on an annual basis, it can be assumed that the sizing will be sub-optimal. As the need for reserves vary over the year, a TSO procuring reserves on an annual basis only is likely to over-dimension the reserve, in order to account for uncertainty. In MS where the reserves are procured less frequent than monthly, the sizing may be considered non-optimal. Most MSs procure reserves quite frequently. Notable exceptions are Poland, Slovenia, the Netherlands, the Baltics, Finland, and Sweden.

Balancing markets	Significant obligations	Significant barriers	Procurement frequency	Comment
Austria	No obligations identified	No barriers identified	Optimal	
Belgium	Obligation to provide primary reserves for large generators	DSR not (yet) allowed to participate in secondary reserves	Optimal	
Bulgaria	Obligation to participate in the market	No barriers identified	N/A	
Croatia	Obligation to provide primary reserves	Participation DSR in balancing markets not foreseen. Contracts are awarded to generators only	Not applicable	
Cyprus	N/A	N/A	N/A	
Czech Republic	Centrally dispatched generating units are obliged to participate in the market	DSR can only participate in RR	Optimal	
Denmark	No obligations identified	No barriers identified	Optimal	
Estonia	No obligations identified	No barriers identified	Non-optimal	Primary control is conducted by Russia
Finland	No obligations identified	No barriers identified	Non-optimal	TSO owns reserve power plants used in mFRR
France	FCR and aFRR are mandatory, and compensated with a regulated price	No barriers identified	Optimal (FRRm)	Test phase for DSR participation
Germany	No obligations identified	No barriers identified	Optimal	
Great Britain	Mandatory provision of frequency response (not market based compensation) (3-5% droop)	No barriers identified	Optimal (except Short Term Operating Reserve)	Balancing services do not follow ENTSO-E categories
Greece	Dispatchable units hare obliged to participate in the market	DSR not allowed to participate	Optimal	
Hungary	Centrally dispatched generating units are obliged to participate in the market	DSR can only participate in RR, FCR and aFRR only provided by generators	Optimal	
Ireland	Obligation to participate in the market	DSR not allowed to participate	N/A	
Italy	Provision of primary reserves is mandatory for units above 10 MW, and not compensated.	DSR and RES are not allowed to participate	Optimal (FRR)	
Latvia	No obligations identified	DSR not allowed to participate	Non-optimal	Primary control is conducted by Russia

Lithuania	No obligations identified	DSR not allowed to participate	Non-optimal	Primary control is conducted by Russia
Luxembourg	N/A	N/A	N/A	
Malta	N/A	N/A	N/A	
Netherlands	No obligations identified	DSR does not participate on equal basis as generation	Non-optimal	
Poland	Centrally dispatched generating units are obliged to participate in the market	Only local entities can provide balancing services DSR does not participate on equal basis as thermal plants	Non-optimal	DSR can participate in emergency reserve. According to the code, balancing market is open to DSR, but complicated procedure
Portugal	Provision of primary reserves is mandatory and not compensated.	No barriers identified	Optimal (FRR)	DSR may participate with interruptible contracts
Romania	All dispatchable units are obliged to participate in the market	DSR does not participate on equal basis as generation	Optimal	Ancillary services auctions when needed
Slovakia	Centrally dispatched generating units are obliged to offer FCR	DSR allowed to participate in RR	Optimal	
Slovenia	Mandatory provision of primary control for units larger than 10 MW	DSR does not participate on equal basis as generation	Non-optimal	
Spain	FCR is mandatory and not compensated.	DSR not allow to participate	Optimal (FRR)	DSR can participate with interruptible contracts Note that pumping storage is not being considered as DSR/DR although it could be characterised as controllable load.
Sweden	No obligations identified	No barriers identified	Non-optimal	

Table 3: Overview of balancing markets

The table above gives a rough indication whether the procurement is conducted yearly or not. There is no detailed information on how often the dimensioning of the size of reserve is conducted. Ideally, the sizing should be done hourly. However, one may use the procurement frequency and granularity as an indicator on the optimality of the sizing, as this is also often suggested as the most likely alternative by country experts (see "Market design: Barriers to optimal investment decisions", (COWI, 2016)). If the procurement is conducted only once a year, the sizing is indeed non-optimal. If the procurement is done weekly, with an hourly or load block solution, the dimensioning is more likely to be close to optimal.

In general, balancing services are mainly dimensioned and procured on a national level. However, the dimensioning of *primary* reserves is to some extent regional, that is:

- A minimum requirement of 3000 MW of primary reserves in the Continental European synchronous grid is required by ENTSO-E, and each country must provide a share proportional to its annual demand
- A minimum requirement of 600 MW of FCR normal operation reserve, and 1200 MW of FCR disturbance reserve is required in the Nordic synchronous grid
- There are no primary reserves in the Baltic region, as primary control is conducted by Russia

Dimensioning of secondary and tertiary reserves (FRR) are based on national assessments. We did not identify any MS conducting a regional assessment of reserve requirements for FRR.

Although reserves are normally procured on a national level, there are some notable regional collaborations on *exchange* of reserves:

- Common FCR market in Austria, Germany, and the Netherlands (and Switzerland).
- mFRR exchange of reserves in France, Spain, and Portugal (each TSO with its own procurement mechanism, no common optimization)
- mFRR exchange of reserves (activation only) in Sweden, Denmark, and Finland (and Norway)

Additionally, there exists a number of bilateral agreements for exchange of reserves with a more limited scope.

The product definitions vary significantly among MS. Differences include the minimum bidding size, price caps, symmetrical versus asymmetrical products, time schedules, marginal pricing versus pay-as-bid compensation, etc.

5.2. METIS CONFIGURATION AND INPUTS

In METIS, the current market practices and potential improvement in the fields of reserve dimensioning, allocation and operation are modelled as Actions 5, 7, 8, 9, 11 and 12. Each of these Actions is described below. More details on the reserve procurement and balancing models can be found in the METIS focus on market models report.

5.2.1. RESERVE PROCUREMENT METHODOLOGY (ACTION 8)

In the study, reserve can be procured either on a fixed annual basis or during the day-ahead market (in the form of hourly products).

If reserve is procured in day-ahead (which is denoted "optimal reserve procurement" in the METIS Study S12), the day-ahead model jointly optimises the power dispatch and the reserve procurement in order to minimise the global cost of the system to ensure the supply-demand equilibrium is met for both power and reserve. In the second case (denoted "suboptimal"), reserve is provided by base-load or mid-merit units (nuclear, coal, lignite, hydro turbines and CCGTs) using a fixed allocation of reserve between these sources. Indeed, when the reserve is fixed for a long duration, it is usually these technologies that provide reserve services. The chosen allocation is based on the average ratios observed when using an optimal procurement in day-ahead.

In option a, MSs can procure the reserve either on a fixed basis or in day-ahead depending on current practices. Inputs for METIS models, constructed with COWI are presented in Table 4.

In option b, the reserve allocation of all MS is optimised during the day-ahead market, jointly with power dispatch.

5.2.2. JOINT OR SEPARATE UP/DOWNWARD RESERVE (ACTION 9)

In some MS, upwards and downwards aFRR reserve are not independent products and have to be procured simultaneously. To model this market distortion and potential improvements, two options are considered.

In option a, upwards and downwards aFRR have to be procured jointly according to current practices. The countries that are impacted are specified in Table 4.

In option b, upwards and downwards aFRR are two separate products in all MS and can be procured independently.

	Action 8 Optimal reserve procurement[8]		Action 9 Separate products for upwards and downwards reserve[9]
	FCR	aFRR	(aFRR)
Austria	yes	yes	yes
Belgium	no	yes	no
Bulgaria	yes	yes	yes
Croatia	no	yes	no
Czech Republic	yes	yes	yes
Denmark	yes	yes	no
Estonia	no	no	no
Finland	yes	yes	yes
France	no	no	no
Germany	yes	yes	yes
Greece	yes	yes	yes
Hungary	yes	yes	yes
Ireland	yes	yes	yes
Italy	no	yes	no
Latvia	no	no	no
Lithuania	no	no	no
Netherlands	yes	yes	yes
Norway	yes	yes	yes
Poland	yes	yes	no
Portugal	no	yes	no
Romania	yes	yes	no
Slovenia	no	yes	no
Slovakia	no	yes	no
Spain	no	yes	no
Sweden	yes	yes	yes
Switzerland	yes	yes	yes
United Kingdom	no	no	no

Table 4: Inputs for Action 8 and 9 in METIS

[8] It is assumed that reserve procurement in Estonia, Latvia and Lithuania will be optimal and asymmetric when these countries will be synchronised with Europe in 2025.

[9] Due to the lack of data for Bulgaria, Greece, Ireland, Norway and Switzerland, reserve procurement in these countries is assumed to be asymmetric.

5.2.3. NORMALIZED APPROACH FOR RESERVE SIZING (ACTION 7)

Action 7 aims at taking into account the current methodology for aFRR sizing and how it could be improved.

In option a, the sizing of aFRR is fixed throughout the year. It is computed as the 0.1% and 99.9% centiles of imbalance distribution over ten years of historical data. Reserve size is supposed to be constant over the whole year, i.e. it does not depend on the hour of the day (and thus it does not take into account the fact that consumption can be lower at certain times during the day), nor does it depend on the wind production level. Therefore the reserve size is assumed to be constant over the whole year in all MS.

In option b, the reserve size varies hourly, depending on whether it is a peak period or not, and, for off-peak hours, depending on the wind forecast. The reserve needs are still computed as the 0.1% and 99.9% centiles of imbalance distribution for each category of hours (conditional distributions).

Note that in both options, the needs of FCR and mFRR do not vary and are fixed throughout the year.

5.2.4. RISK SHARING FOR RESERVE DIMENSIONING (ACTION 11)

Action 11 focuses on risk sharing for reserve dimensioning. Sharing risks at a regional or at a European level allows to decrease reserve sizing, and consequently the use of fewer resources to ensure the same level of security, as long as interconnection capacity is reserved accordingly. To take this possibility into account, three options for reserve sizing are considered. Reserve sizing is done:

- Nationally in all MS in option a,
- At regional level in option b,
- At EU level in option c.

In any case, the dimensioning is done using the hourly probabilistic approach described in Section 5.2.3 (Action 7).

In order to ensure MSs can face similar imbalance risks when less reserves can be procured (options b and c), interconnections have to be reserved for mutual assistance between MSs.

The regions used in the study are shown on Figure 4.

5.2.5. BALANCING RESPONSIBILITY (ACTION 5)

Incentivising RES producers to respect their production planning by making them financially responsible for the imbalances they cause is assumed to encourage them to improve their generation forecasts. It leads to fewer imbalances in real-time and consequently, to lower reserve capacity requirements. To represent this, two options are considered:

- In option a, as is currently the case in some MS, RES producers are assumed not to be financially responsible for the imbalances they cause. In consequence, the quality of the generation forecasts they share with the TSOs is rather poor. TSOs therefore need to procure reserves accordingly. TSOs are assumed to use h-2 demand, PV and wind forecast errors for the computation of reserve sizing and for imbalances.

- In option b, it is assumed that RES producers become financially responsible for the imbalances they cause, and are incentivised to provide better forecasts. TSOs are therefore more confident in the forecast they receive and can lower the size of their reserves. We assume that h-1 forecasts errors are used for demand and PV, while 30 min forecasts errors are used for wind.

Region 1
Austria
Belgium
Czech Republic
Denmark
France
Germany
Hungary
Luxembourg
Netherlands
Poland
Slovakia
Slovenia
Switzerland

Region 2
Estonia
Finland
Latvia
Lithuania
Norway
Sweden

Region 3
United Kingdom
Ireland

Region 4
Portugal
Spain

Region 5
Bosnia and Herzegovina
Bulgaria
Croatia
Cyprus
FYR of Macedonia
Greece
Italy
Malta
Montenegro
Romania
Serbia

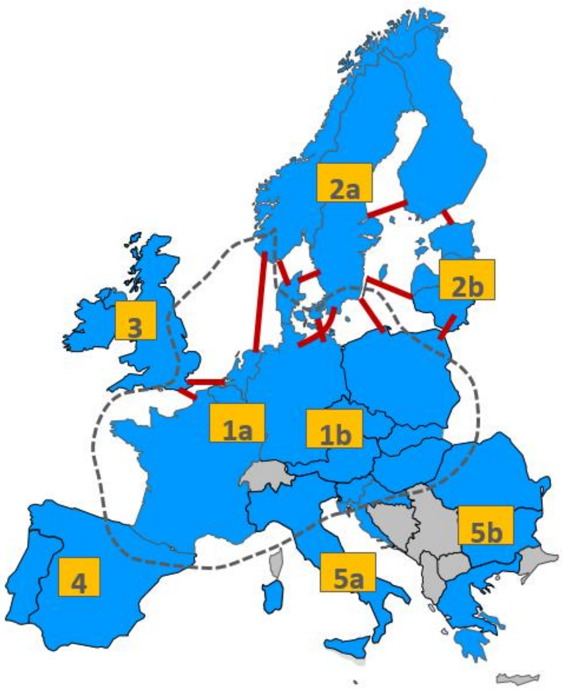

Figure 4: Regions used for cooperation in reserve sizing and procurement

6. DSR DEPLOYMENT AND PARTICIPATION IN ANCILLARY SERVICES

6.1. CURRENT PRACTICES

DSR participation in ancillary services

Traditionally, the generation side has provided ancillary services. In recent years, a number of MSs have allowed the demand side to participate in the provision of such services.

In around 50 percent of MSs, demand participates on an equal basis to generation in balancing energy markets.

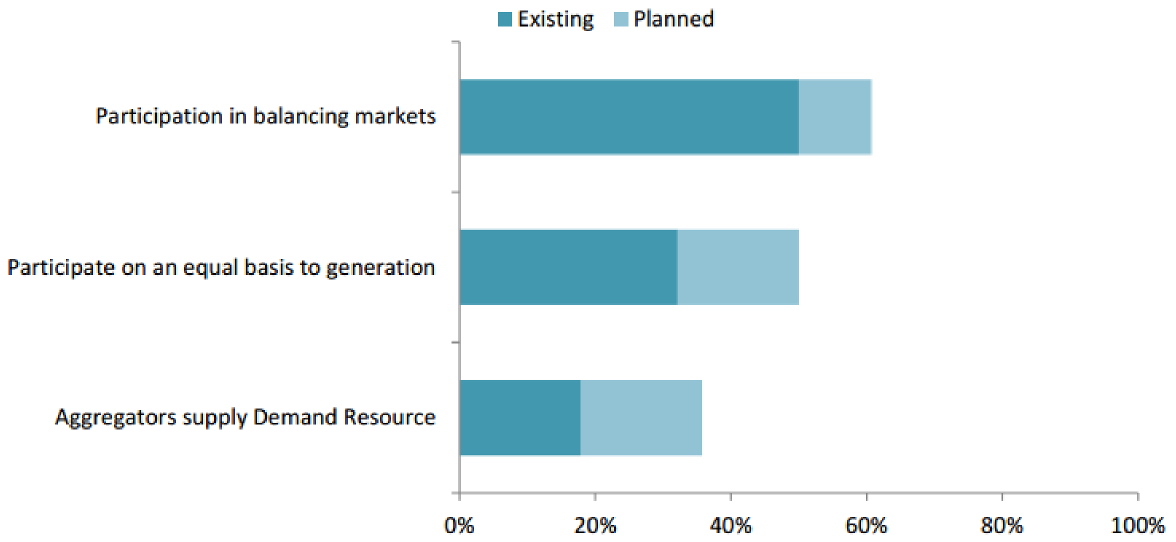

Figure 5 : Demand participation in balancing energy markets (% of Member States). Source: ACER (2014).

Demand side participation in other ancillary services such as primary reserves (FCR) is less common. Still, around one third of the Member States allow demand side participation in primary reserves, according to the report "Demand side flexibility: the potential benefits and state of play in the European Union" (ACER, 2014).

6.2. METIS CONFIGURATION AND INPUTS

6.2.1. DSR MODEL AND INPUT DATA

In the METIS Study S12, the level of participation of DSR capacities in reserve procurement and balancing markets is optimised. The dispatch of DSR in the day-ahead power market is however not modelled, although it is partly taken into account by the consumption profiles. Indeed, the hourly power demand profiles that are used in the study are based on ENTSO-E's TYNDP 2014 published datasets, which take demand-side flexibility into account (e.g. domestic hot water, electric heating, electric appliances). However, given the level of details published by ENTSO-E, it was not possible to model the dynamic adjustment of the demand to external signals. As a consequence, the study primarily focuses on the savings generated by pulling DSR resources into reserve procurement and balancing markets, and may therefore underestimate the value of DSR.

In METIS, DSR is divided in three categories, **Industrial DSR** regrouping industrial processes, **Storage DSR** regrouping all storage-based DSR (Electric vehicles, Domestic hot water management, etc.) and **Other DSR** (heating and cooling) which can participate in balancing services. More details on the model used are available in *METIS Technical Note T2 - power market models.*

Installed capacities for these DSR devices are based on a study carried out by COWI for the European Commission[10]. Two modifications of the potentials have however been made, in order to ensure consistency with the PRIMES EUCO27 data:

- Electric vehicles-based DSR has been adjusted to match PRIMES EUCO27 assumptions.
- Other DSR potential has been divided by a coefficient, to reflect that this potential cannot be activated all day long. Since it is estimated that in a typical household, heating and cooling consumptions are usually turned off during half an hour every three hours by demand-response service providers (based on current industrial practices), we have chosen to divide the other potential by 6, since each MW can be turned on one sixth of the time.

6.2.2. DSR DEPLOYMENT (ACTION 1)

The type and capacity of DSR that can participate in reserve procurement depends on the assessed option:

- In option a, industrial DSR can provide balancing services only in countries where it has currently access to the market. Current balancing market specificities are described in Table 5. In this option, storage DSR and other DSR cannot participate in balancing markets. Installed capacities chosen are based on COWI **BAU scenario**.
- In option b, industrial DSR can provide balancing services in all MS. Storage DSR and other DSR cannot participate in balancing markets. Installed capacities chosen are based on COWI **BAU scenario**.
- In option c, all DSR resources can access to balancing markets. In this case, installed capacities are based on COWI **PO2 scenario**.

[10]See the report "Impact Assessment support Study on downstream flexibility, demand response and smart metering", COWI (2016).

	Action 1 DSR participation in balancing markets	
	FCR/aFRR	mFRR
Austria	yes	yes
Belgium	N/A[11]	yes
Bulgaria	yes	yes
Croatia	no	no
Czech Republic	no	no
Denmark	yes	yes
Estonia	no	no
Finland	yes	yes
France	N/A	yes
Germany	yes	yes
Greece	no	no
Hungary	no	no
Ireland	no	no
Italy	no	no
Latvia	no	no
Lithuania	no	no
Netherlands	yes	yes
Norway	yes	yes
Poland	no	no
Portugal	yes	yes
Romania	no	no
Slovenia	N/A	no
Slovakia	no	no
Spain	no	no
Sweden	yes	yes
Switzerland	yes	yes
United Kingdom	N/A	yes

Table 5: Inputs for Action 1 in METIS

An overview of European potentials in each option is given in Figure 6 below.

[11] In countries where DSR can participate only via direct contracts for FCR, namely Belgium, France, Slovenia and United Kingdom, it is assumed that DSR cannot participate in aFRR/FCR markets in option a.

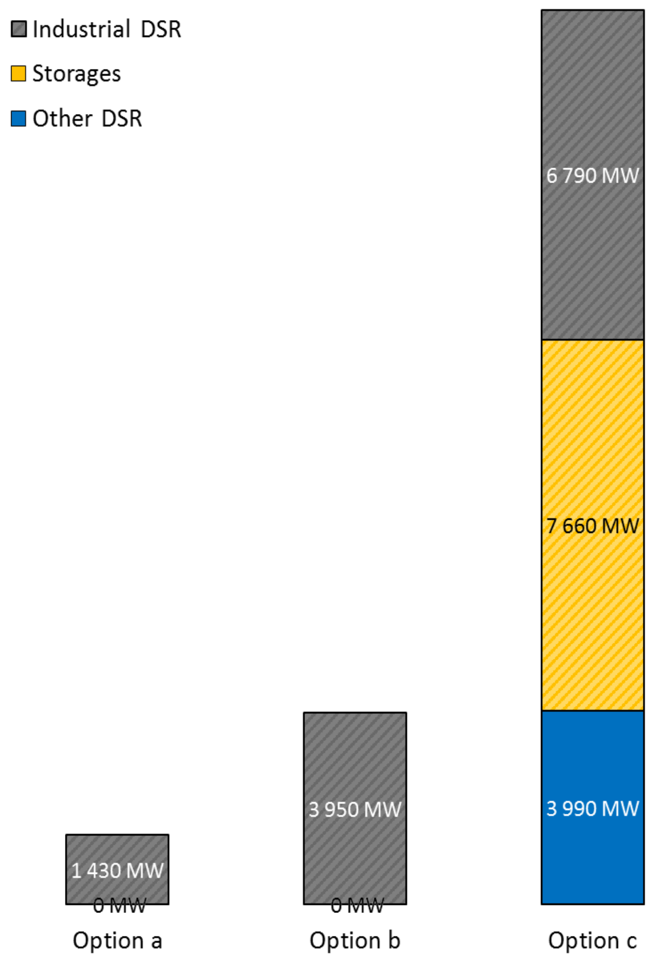

Figure 6: DSR deployment in METIS for Action 1, options a, b and c.