Definition of Key Performance Indicators for the assessment of design options

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Executive summary

Options for the design of market developments required to integrate RES generation into the system and the network and achieve their satisfactory functioning have been described in the reports D3.1 “Developments affecting the design of long-term markets” and D3.2 “Developments affecting the design of short-term markets” available on Market4RES website[1].

The definition of Key Performance Indicators (KPIs) is central to the assessment of the performance of these options. In this report, we specify and describe the KPIs that will be applied when assessing different market design options in the Market4Res project, as well as others to be applied in the real life assessment of options, even when they are not applied in the project due to the limited set of data and resources available.

The set of KPIs defined in the present report relates to main assessment criteria applicable to each type of market development potentially needed. Table 1 shows which types of assessment criteria have been developed for each market design option considered. The specific assessment criteria, e.g. for the type "Efficiency", will however be different for different market design options among those considered.

Table 1: Assessment criteria for pending market developments

	MARKET DEVELOPMENTS	GROUPS OF ASSESSMENT CRITERIA				
		Efficiency	*Effectiveness*	*Robustness*	*Implementability*	*Fairness*
LONG TERM	**CRM**	YES	YES	YES	YES	YES
	RES support LT and ST	YES	YES	YES	YES	YES
	DSM LT and ST	YES		YES	YES	YES
SHORT TERM	**Cross border products**	YES			YES	
	Network representation	YES		YES	YES	YES
	Timing of markets	YES		YES	YES	
	Bidding protocols	YES		YES	YES	
	Balancing	YES			YES	

Within each type of those identified in the table, KPIs defined are summarised in the Tables that are provided at the beginning of the corresponding section. After each summary table, the concept and use to be made of KPIs defined in each section is explained.

Given that KPIs defined are aimed to be of general application, they have not been limited to the ones to be used in the quantitative assessment of design options to be performed within the Market4RES project (within WP4 for 2020 horizon and WP5 for 2030 horizon), but include also additional KPIs that could be used in real life.

[1] See http://market4res.eu/results/reports/.

1 Introduction

1.1 Purpose of this report

This report aims to propose Key Performance Indicators (KPIs) to assess, in a quantitative manner, alternative market design options to achieve a safe, efficient and sustainable supply of load when a large share of the power generation is renewable.

In previous reports within WP3 (D3.1 and D3.2, where D3.1 corresponds to “Developments affecting the design of long-term markets” and D3.2 to “Developments affecting the design of short-term markets”) a range of assessment criteria have been defined, corresponding to each aspect of the functioning of long- and short-term markets studied. These assessment criteria have been gathered into five groups:

- Efficiency: this relates to the achievement of the supply of load at the lowest cost for the system possible that is compatible with constraints on the security of the system and the achievement of climate policy objectives.
- Effectiveness: this relates to the achievement of the objective set for the implementation of the market concerned. For example, it is about the achievement of the RES generation deployment target when assessing the performance of the several RES support schemes considered; or the achievement of the deployment of the required amount of firm capacity when assessing the performance of Capacity Remuneration Mechanisms (CRMs).
- Robustness: this relates to the ability of a market design to deliver a consistent output across the range of situations (reflecting widely varying system conditions) where it may be implemented. Thus, for example, it concerns the ability of a RES support scheme to achieve the deployment of an amount of RES generation that does not vary largely with the existing system conditions (the scenario considered for the future).
- Implementability: this concerns the easiness of implementation of a certain market design option. It relates to aspects like the complexity of this design option and its level of conformity to regulatory principles currently being applied in the target system.
- Fairness: this concerns the ability of a market mechanism to provide an outcome that is perceived as non-discriminatory and acceptable for all groups of stakeholders in the system.

KPIs defined in this deliverable, D3.3, are associated with the qualitative assessment criteria previously defined. Some of the KPIs here defined shall be used to quantitatively assess design options identified as most promising, based on qualitative WP3 analyses within Task 3.1 and Task 3.2. KPIs in this group are suitable to be calculated by the models used in the Market4RES project (WP4 and WP5) to evaluate quantitatively the impact of different market design options. These models are extensively described in WP4 and WP5 reports.

KPIs defined here aim to be of general application and interest, and not only in the context of quantitative analyses in this project. Thus, some of the KPIs defined in this report, corresponding to some assessment criteria discussed in D3.1 and D3.2, cannot be calculated with models applied in WP4 and WP5. These include, for instance, the coherence of market design options with the existing regulation, or the experience with the implementation of a given design option. In addition, some market design aspects qualitatively studied in D3.1 and D3.2 are not quantitatively analysed in WP4 or in WP5, but KPIs defined here also concern them as long as these aspects can potentially be quantitatively analysed. Despite the global aim of this analysis, KPIs not computed in WP4 and WP5 analyses are only briefly explained in this report.

Lastly, the reader should note that performance indicators defined in this report are of a quantitative nature. Thus, those indicators useful to assess the performance of market design options that cannot result in a quantitative measurement of the level of this performance are not discussed here.

The report is organized as follows. Chapter 2 discusses the KPIs proposed for the assessment of long term markets and long term effects of markets in general. These include CRMs, cross-border products, mechanisms for DSM in the long and the short term, and long term effects of mechanisms supporting the participation of RES generation in markets. Chapter 3 discusses KPIs proposed for the assessment of short term tem markets, or aspects of the organization of these markets. These include the representation of the network in these markets, the timing of markets, bidding protocols, balancing markets and short term effects of mechanisms supporting the participation of RES generation in markets. Finally, section 4 concludes.

2 KPIs for Long Term market design options

Options for long-term market design have been identified and assessed in deliverable D3.1 “Developments affecting the design of long-term markets”. In this chapter, quantitative KPIs corresponding to the relevant assessment criteria used in D3.1 are proposed.

2.1 Design and use of Capacity Remuneration Mechanisms

In this section, the KPIs proposed are associated with the qualitative criteria used for assessing the different alternatives for the various aspects of CRMs (Chapter 2 in D3.1). Assessment criteria and the groups of them in section 2.1.1 are defined in chapter 2 in deliverable D3.1. In section 2.1.2, the meaning and application of KPIs proposed are discussed in further detail.

2.1.1 Quantitative KPIs associated with the qualitative assessment criteria

Table 2: KPIs defined for the assessment of CRM schemes

Assessment criteria for CRM		KPIs (quantitative)
Efficiency	Market modelling imperfection costs and marginal cost reflectivity	- Capacity bid prices reflect lack of profitability on the energy market and / or consumer' potential loss of utility (DSR) - Social welfare: Total capacity cost

		- Increase in SoS when set up (loss of load expectation and actual loss of load reduced)
	Cost causality	- Players are remunerated to the extent that they increase SoS - Costs are born by those which cause SoS to be at stake (consumers
	Diversity of products traded in the market	- Number of lead times for trading contracts (possibly infinite if bilateral trading is feasible) - Number of contract durations
	Global coherence of market designs implemented (harmonisation of prequalification criteria, products, timing, gate closure, priority in national vs. cross-border balance etc.)	- Number of differences in product features - Average difference between time of gate closure ahead of real time (lead time) of capacity markets in the several countries of the region. - Is national (local) power balance given priority over that at regional level? - Differences across countries in the set of system agents that qualify for earning capacity payments
Effective-ness		- Missing money - Risk for investors in generation / demand response
Robust-ness		- Price levels in the mechanism in case of overcapacity
Implementability	Coherence with the following regulation and legislation: • Target Model in the short-term • Security of Supply Directive • State Aid Control Legislation	- *[qualitative]* [2]
	Simplicity and transparency	- *[qualitative]*
	Experience with the implementation of a market in other systems	- Number of countries having set up such a type of mechanism
Fairness		- Difference between average prices received by different types of capacities (existing v. new, generation v. DR, conventional v.

[2] KPIs in grey and italic cannot be evaluated by models.

		renewable…) - Differences across countries in the set of system agents that qualify for earning capacity payments

2.1.2 Definition and explanation of the quantitative KPIs

In this section we describe in more detail the KPIs introduced in the above table. We also provide some remarks about how the modelling tool used within the work package 5 of the project addresses these KPIs.

Efficiency

- **Marginal cost reflectivity**

Prices bid by market agents for their firm capacity should be representative of the marginal costs they incur in supplying this capacity or having it available. Next, we discuss how marginal firm capacity costs bid by agents should be computed for each type of them. Then, we discuss the impact of the application of firm capacity prices, or the corresponding CRMs, on the system social welfare.

Supply. In a long term capacity market, producers and DSR operators will try to get enough revenues to complement those from the other electricity markets to reach a profitability level which justifies (i) if the capacity already exists, both from generation and demand assets, that they do not close or mothball it or (ii) that they invest in a new flexibility of the capacity of generation and demand assets. Consequently, the supply curve, represented in Figure 1, representing the increasing marginal cost of capacity credits for each capacity level, should be made of:

- Bids to sell at any price (that is from 0 €/MW/delivery period) the capacity offered by profitable existing units and DSR facilities (or projects that could be commissioned before the delivery date for capacity);
- Bids to sell at a price equal to their missing profitability (per MW, over the delivery period) in the energy markets (often referred to as "missing money") to avoid mothballing or decommissioning of the corresponding generation plants for existing but not profitable ones.
- Bids to sell at a price equal to the expected gap to achieve the profitability of the corresponding units for the capacity of new generation projects that could be commissioned before the delivery date (per MW over the delivery period).
- Bids to sell at a price equal to their missing profitability (per MW, over the delivery period) in the energy markets (often referred to as "missing money") to avoid mothballing or decommissioning of the corresponding demand side flexibility assets for existing but not profitable ones.

- Bids to sell at a price equal to the expected gap to achieve the profitability of the corresponding demand side flexibility assets for the capacity of new assets that could be commissioned before the delivery date (per MW over the delivery period).

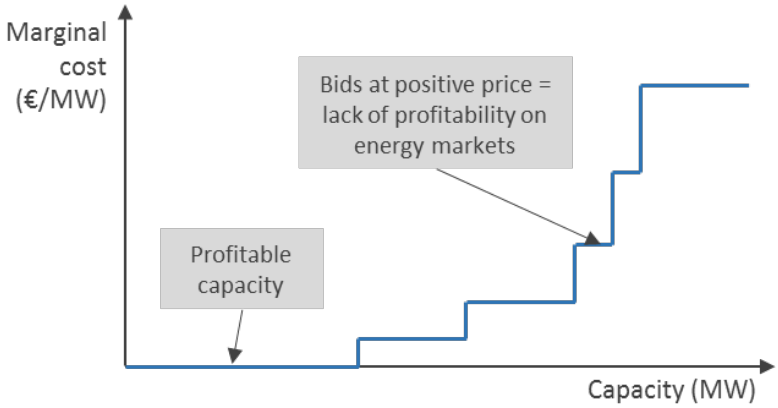


Figure 1: representation of the bid, or offer curve both from generation and demand assets in the firm capacity market

Demand. In such a capacity market demand is only elastic if DSR is able to participate in an implicit way (i.e. in a mechanism that takes into account the fact that by systematically reducing consumption during peak hours, SoS is improved); in this case, the demand curve, which is shown in Figure 2 representing the decreasing marginal utility of capacity credits, should be made of:

- bids at the penalty price for the inelastic part of the reference consumption used to compute the capacity obligation;
- bids at a price equal to the marginal loss of utility of the consumers shed during peak hours for the elastic (in this capacity-related meaning) part of this consumption.

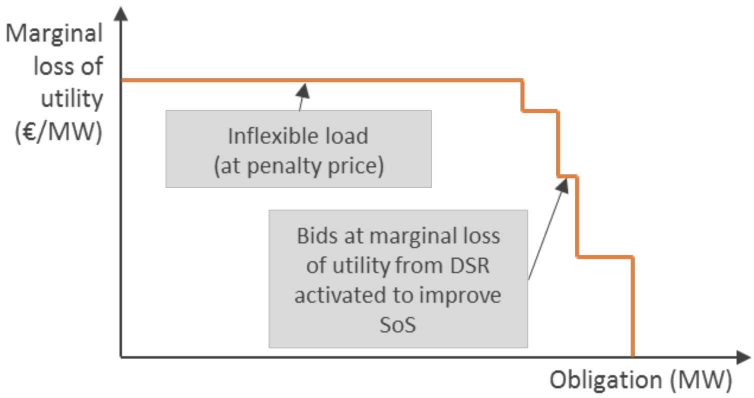


Figure 2: representation of the composition of the demand curve in the firm capacity market

- Impact of the application of CRMs on the social welfare

The firm capacity suppliers' surplus equals the integrated difference between the price at which capacity holders sold their capacity credits and the marginal costs described above.

Conversely, the capacity buyers' surplus equals the integrated difference between the marginal utility described above and the price at which they bought capacity credits.

The social welfare (or the sum of the two above surpluses) is maximized if the marginal cost of capacity equals the marginal utility of capacity credits to buyers i.e. the marginal utility loss associated with consuming less during peak hours. This requires the market to ensure that this price emerges so as to avoid "activating" (in fact keeping functioning or investing in) capacities, to serve demand that, at a price equal to the corresponding supply cost, would better not consume during peak hours.

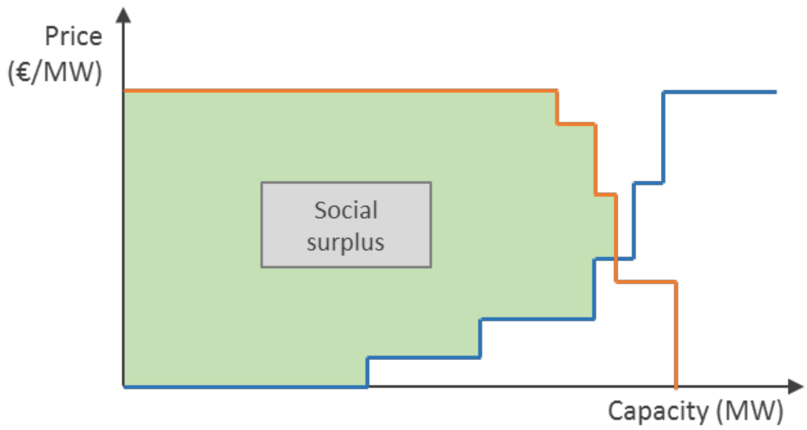


Figure 3: computation of the theoretical social welfare from supply and demand curves

This vision of social welfare, as represented in Figure 3, is, however, static and theoretical, implying that market players have, years in advance of delivery year, perfect information on:

- The capacity needs of consumers (or suppliers) during the delivery year and their marginal utility at this time,
- The availability and marginal cost (which depends on the wholesale energy market conditions) of the capacity of holders of this capacity during the delivery year.

The economic efficiency of the mechanism should therefore be measured by how close it gets to the theoretical maximum social welfare under the realized total obligation and capacity availability scheme, assuming perfect anticipation. In other words, the mechanism should trigger the correct signals to keep the cheapest capacities in operation (or build them) to ensure the targeted level of security of supply (some parts of the demand may require a level of SoS below this criterion and this is reflected by the elastic part of the demand curve).

Besides, CRMs applied may probably have an impact on the short term operation of the system. If two different market designs, corresponding to different types of CRMs, drive exactly the same investments, it can be said that both CRMs are equally efficient in the long term. If, besides this, both mechanisms drive the same short term offers by agents as if no CRM were in place, the architecture with CRM would be equally efficient to one without CRM, which would involve that both CRMs does not influence short-term prices and is, therefore, efficient in the short term as well.

However, different CRMs (or more generally different overall market designs) may lead to different electricity mixes. For instance, the CRMs (and their precise design) may (should) have an impact on the risk taken by firm capacity owners. This is especially true for owners of peak capacity under CRM contributing to their revenue to a larger extent than to revenues of base-load plants. This would alter the relative fixed costs of the different technologies and, in turn, the quantities of each type of asset in the mix.

Being the merit order different, the short-term prices may also differ from one design to the other. Therefore, it is not possible to assess the social surplus impact of CRMs by themselves without considering the social surplus impact on the wholesale electricity market. Consequently, studies aimed at comparing different CRM should measure the total social welfare in the whole electricity market, including the difference between the marginal utility and marginal cost of the electricity which was actually produced and consumed and the marginal utility and marginal cost of ensuring SoS through a capacity mechanism.

Computation of social welfare

As explained above, the total social welfare should, in principle, be used to compare market designs involving different CRMs. Total social welfare is not easily computable: whereas production costs are relatively easy to calculate, consumers' marginal utility is much less. However, as we will be comparing several market designs, absolute social welfare may not be required and we may be settled with:

- either a social surplus computed as the producers' surplus (price minus production costs) plus a "capped" consumers' surplus, i.e. a surplus assuming an arbitrary cap on consumers' utility, which must be kept at the same value across all simulations. A fair value for this cap may be the "value of lost load" which is used to express security of supply in monetary terms;
- or the total costs of the power system in simulations where we assume no elasticity of demand (or that the elasticity of demand is transferred to the supply curve).

It should be noted that CRMs may have an impact on the risks taken by agents even in the particular case where two different CRMs lead to the same electricity mix (at least, on average).

Alternative KPIs measuring the efficiency of CRMs

Computing the social welfare impact of each CRM is very challenging, since it involves estimating the value of lost load for demand (VLL), which has always been deemed very difficult, or, alternatively, the truth utility of energy for demand. Then, one may obtain a first indication of the efficiency of prices resulting from its application by comparing prices paid to firm capacity providers according to this scheme with the marginal "profitability gap" of these providers in the system. Thus the closer is the ratio of the former to the latter to 1, the more efficient prices applied may be deemed to be in the regarding their long term effects.

- Cost causality

Cost causality is key for the efficiency (and even the effectiveness) of a mechanism, since it reflects to which extent market agents who have some physical levers to affect firm capacity needs are those who bear the cost of firm capacity provision. In this way, they can arbitrate between the marginal cost of activating these levers and the market price of capacity.

The mechanism ensures cost causality if:

- The costs are born by the agents benefitting of security of supply (i.e. the consumers to a larger extent, the whole system, to a lower extent, as well, if the benefits of SoS for the integrity of the system are factored in) and up to their willingness to pay for SoS (i.e. until their marginal utility to consume during peak periods, in the case of consumers, or their marginal benefits from preserving the integrity of the system and being able to carry out their activities, weighted with the probability that a supply disruption affects the integrity of the system, in the case of all system agents), which implies that the mechanism should let consumers specifically, and all agents in general, express this preference through an elastic demand curve.
- The mechanism design lets demand and supply reveal their actual marginal utility and cost (respectively);
- The price paid to producers and DSR operators actually reflects the value of the marginal increase in SoS resulting from the availability of their capacity during peak price hours. In these periods, all available units (no matter whether they produce or not) and certified demand response (no matter whether it is activated or not) participate in ensuring SoS to the same extent, therefore they should be remunerated at this same price.

Assessing cost causality

Cost causality is ensured if:

- Capacity prices reflect the marginal cost of SoS, which must be higher or equal than the marginal capacity cost (in the capacity market, i.e. the marginal profitability gap in the wholesale electricity market of units providing firm capacity) of those generation units or demand response facilities having been dispatched to provide firm capacity during the delivery period.
- Conversely, firm prices are lower than the marginal utility of consumers from the load that is served.
- Consumers, or suppliers, and possibly also generators to the extent they are benefiting from avoiding a decrease of the integrity of the system, as argued above, who are responsible to different degrees for the firm capacity needs of the system, are paying firm capacity prices resulting from the market (which must be adapted to their differing contribution to capacity needs).

- Diversity of products traded in the market

In such long term mechanisms as CRM, agents may have very different anticipations of the real-time situation and also different hedging strategies. There is therefore an economic benefit to have multiple products in the market so that everyone finds the product fitting its own needs. However, having a large number of standard products could also hinder liquidity and result in higher transaction costs. Instead, it may be useful to have few standard products and to let market players exchange OTC in a tailored way.

Assessing diversity of products traded in the market

Number of different lead times for trading contracts (possibly infinite if bilateral trading is feasible); number of different contract durations.

- **Global coherence of market designs implemented**

In order to assess the coherence among CRMs applied in the several systems, the number and relevance of differences in features among products defined in these national and local markets should be determined. Products traded in all these markets should be coherent and, to the extent possible homogeneous. This also concerns the average difference between the time of gate closure ahead of real time (lead time) of capacity markets in all these local systems in the region. The smaller this difference, the more compatible CRMs applied across Europe will be.

Another prerequisite to create a regional integrated capacity market concerns the ability of foreign agents to guarantee the provision of firm capacity in a certain third system. Providing this guarantee involves that these agents are allowed to operate their capacity to secure supply in this third system instead of their own one. In other words, as far as these agents are concerned, local supply should not be given priority over the supply to this third country.

Lastly, the differences across countries in the set of system agents that qualify for earning capacity payments may affect the extent to which a level playing field is achieved in the capacity market and, therefore, the efficiency of the outcome of the application of a CRM.

Effectiveness

A CRM is effective if:

- SoS is ensured at a level corresponding to the publicly-set SoS criterion, or at a lower level for consumers who choose to stop consuming during peak net demand hours (where net demand is computed as demand less of available intermittent generation capacity), but on a voluntary and remunerated basis) ➔ SoS can be checked for this.
- All the needed capacities are profitable but not over-remunerated ➔ economic viability (revenues less costs) for all types of plants
- Risk for investors in peaking units is properly mitigated so that there is no underinvestment in this type of technologies ➔ fraction of revenues of peaking plants already defined in the long term.

Assessing effectiveness

All three criteria listed above can be numerically computed based on the output of dispatch models.

Robustness

A CRM is robust if it stops conveying a signal encouraging the deployment of capacity when the system is in overcapacity and strong enough incentives to invest in new capacity occur when capacity becomes scarce. In the first case, the marginal benefit of installing new capacity (or maintaining unprofitable ones) is nil because it brings the system to a sub-optimal high level of SoS. Therefore, the price in the CRM should fall to zero, letting the system behaving just as if there were no CRM.

Assessing robustness

In case of overcapacity, the firm capacity price tends towards zero (it may stay higher if the overcapacity was not obvious long time before the delivery period: in this case, the market agents may have already traded capacity at non-zero prices as part of their hedging strategy). When capacity becomes scarce, capacity price should become higher than zero and attractive enough to attract capacity.

Fairness

In a fair CRM, the same price will be paid for two capacities which participate to SoS to the same extent, no matter their technologies (RES, thermal, DSR, etc.) or whether they pre-exist or are brand new. It should also comply with the rules of the internal energy market, i.e. not favour domestic capacities over foreign European capacities.

A fair CRM is, therefore, market-wide, technology neutral (although it weighs the different technologies according to their relative marginal participation to SoS) and also offers an equivalence for capacities that are located in another price area (implicitly or explicitly if the interconnections' management rules allow for it to happen).

Lastly, existing differences across countries in the set of system agents that qualify for earning capacity payments may affect the fairness of the CRM applied, since not all agents may be treated in the same conditions.

Assessing fairness

Fairness can be measured by the differences between the average prices received by all types and technologies of capacities, corrected to take their relative participation to SoS into consideration.

It can also be measures, regarding the extent to which a level playing achieved, by the amount of capacity of agents in the market that do not qualify to earn capacity payments.

2.2 Long-term effects of support mechanisms to RES generation

In this section, the KPIs proposed correspond to the qualitative criteria used for assessing the different alternatives for RES support schemes (Chapter 3 in D3.1).

2.2.1 Quantitative KPIs associated with the qualitative assessment criteria

Table 3: KPIs defined for the assessment of RES support mechanisms with respect to their long term effects

Assessment criteria for RES-E participation		KPIs (quantitative)
Efficiency	(Marginal) cost reflectivity	- Difference between the revenues of RES generation in long term markets for this generation, plus other revenues of RES generation, and long term RES generation costs (compute the sum of all revenues minus sum of all costs, for the amount of RES generation to be installed according to the long-term objectives set, over a given period). Unit: €. - Liquidity of long term markets for RES: Volume of Market Orders (for RES vs. total). Unit: %.
	Liquidity	- Total traded volume over a given period in long term markets for RES (Unit = MWh) - Market depth of long term markets (min, max, average of volumes, unit = MWh) over a given period - Where applicable, bid & ask spread (min, max, average, unit = €/MWh)
	Diversity of products traded in the market	- Number of products existing in the market, which cannot be computed with models.
	Market transparency	- For OTC the transparency is lower than for an Exchange. Cannot be determined in quantitative terms, probably.
	Technology targeting	- Level of technology targeting, i.e. focusing on the support of certain RES technologies
	Coherence in the implementation of a scheme across systems	- This should measure whether a scheme can be implemented at regional level to promote an equal treatment of generation in all systems of the region
Effectiveness		- Difference (both positive and negative differences are to be avoided) between the target amount of RES generation capacity to be installed and the actual amount of RES generation capacity installed. Positive and negative differences are considered separately.

Robustness		- Sensitivity of difference between prices in long-term markets plus other revenues and long term costs with respect to a change in the scenario. - Sensitivity of the amount of RES generation installed with respect to a change in the scenario.
Implement-ability	Simplicity of the market	- *N/A*
	Experience with the implementation of a market in other systems	- Number of countries where it has been applied before. Not to be computed in quantitative analyses based on models.
	Applicability to other time frames and contexts (scalability, replicability)	- *N/A*

2.2.2 Definition and explanation of the quantitative KPIs

In this section, we describe in more detail the KPIs introduced in the above table. One relevant issue to take into account is that RES support schemes must be technology oriented, since they aim to drive the installation (production) of immature technologies, not the level of reduction of CO2 emissions.

Efficiency

- **(Marginal) Cost reflectivity**

Two main KPIs have been identified in order to assess the (Marginal) Cost reflectivity of the different options for support schemes of RES generation.

The first KPI involves assessing the **difference between the total income of RES generation** (revenues earned in long-term markets for RES + other revenues of RES generation) **and total costs of this RES generation** (CAPEX and OPEX) over a certain period, for the amount of RES generation to be installed according to the long term objectives set. A big positive difference means that the RES generation has most likely been overly subsidised, while a big negative difference means that the RES support scheme is not able to support a viable business case for the required amount of RES generation.

The second KPI involves measuring the **liquidity in the long-term market brought by RES operators.** This can be calculated by computing the ratio of the overall volume of offers submitted by RES operators to the total volume of orders submitted to the market, and is expressed as a percentage. A large share means that RES operators bring liquidity into the long term markets, which in turns facilitates the price discovery around the system marginal costs. On the contrary, a small share implies that RES operators are neither contributing to, nor benefiting from, the liquidity of the long term market. Consequently, it is questionable whether the market adequately reflects the system marginal costs.

- **Level of technology targeting**

RES support must aim to achieve the deployment of immature technologies to drive their development. Then, a support scheme is more efficient the more capable it is to target specific technologies. This shall be measured by whether or not support using the scheme concerned can be targeted at a specific technology or group of technologies.

- **Liquidity**

Liquidity is a term widely used to characterize the ability and facility to transact on a given market. Here, the liquidity of long term markets brought about by a RES support scheme is being assessed. However, liquidity is typically used as a generic term without proper measurement. In order to quantify the liquidity of a given market, the following indicators are proposed:

- Total traded volume, over a given period, in long term markets for RES (Unit = MWh). Measuring the total traded volumes means measuring the volume of trades that have been transacted on a market. This gives an indication of the appeal of a market, since markets with high volumes of transactions are likely to be attractive markets.
- Also the impact of the use of a RES support scheme on the liquidity of other long term markets that are not RES specific is to be computed. Thus, for example, one can measure how the total volume of RES generation offers into firm capacity markets has changed due to the deployment of a RES support scheme (Unit = MW, or MWh, depending on the type of capacity product being traded).
- Market depth of long term markets, both those for RES generation and general ones, over a given period (min, max, average of volumes, unit = MWh). The market depth is a measure of the total volume of offers that is available for trade. Indeed, at a given moment, taking a snapshot of an order book, the total volume available for trading (i.e. the total number of unmatched orders – whether in a continuous or in an auction market) gives a rough estimate of how much additional volume is available, should, for example, a trader need additional volumes for some reason. Consequently, a deep market is a much more attractive market. To analyse market depth over a given period (as opposed to using a snapshot), the typical approach is to use minimum, maximum and average values. In this case, all snapshots, or trading periods, should be considered.
- Where applicable, bid & ask spread (min, max, average, unit = €/MWh). Bid and ask spreads is only relevant for continuous markets, which normally are not long term ones. Thus, this KPI is less relevant in the context of the assessment of long term impacts of RES support schemes. At a given moment (snapshot), the bid & ask spread is computed as the difference between the price of the best bid and the best ask orders. In case the bid and ask spread is high, it can be assumed that the market price at this very moment is not precise (it lies somewhere between the best bid and the best ask prices), and consequently, the price for closing a position is at best unknown, at worth expensive. On the contrary, when the bid & ask spread is low, closing a position can always be done at defined price. Therefore, a low bid & ask spread is a good measure of the attractiveness, and therefore the liquidity, of a continuous markets.

- **Diversity of products traded in the market**

The diversity of products traded in the market can be determined in terms of the number of products that exist in it. This may not be measurable with the use of models, but can be quantified in reality.

- **Coherence in the implementation of a scheme across systems**

This should measure whether a scheme can be implemented at regional level to promote an equal treatment of generation in all systems of the region.

Effectiveness

The effectiveness of a subsidy scheme involves determining to what extent it achieves the installation of the amount of RES generation corresponding to the predefined target. Therefore, by calculating the difference between the target and actual amounts of RES generation capacity (GW) installed, one will have a direct measure of the effectiveness of a given market design option in reaching a given RES penetration level.

In case the difference is large, one should distinguish between positive and negative differences:

- In the case that a positive difference between the target and the realized amount of RES exists, the targeted amount of RES capacity has not been reached. This probably means that the scheme does not pay RES generation enough to attract a large enough amount of it, or the risk associated with revenues is too high for the remuneration level established.
- In the case that a negative difference exists, the corresponding scheme should probably be seen as inefficient. Indeed, although a scheme which delivers above expectations should, a priori, be regarded as highly effective in attracting generation, it is also likely that the application of this scheme has led to a larger amount of subsidies paid than needed (assuming that the extra amount of RES generation installed beyond the target is not needed).

Robustness

The robustness of a scheme shall measure the ability of this scheme to deliver consistent results across a multiplicity of situations, or scenarios. Lack of robustness would involve the need for authorities to tune the design of the scheme in each case, i.e. to modify their implementation parameters to make it well suited to each specific situation, or scenario, so as to obtain the desired outputs from it. Thus, this feature can be assessed with respect to several dimensions depending on the type of results whose consistency across scenarios one is assessing. Some are discussed next:

- Robustness of a market regarding its marginal cost reflectiveness: this is to be computed as the sensitivity (change in monetary values) with respect to a change in the scenario of the difference between prices in long-term markets plus other revenues and long term RES costs.

- Robustness regarding the effectiveness of a market: this shall be computed as the sensitivity with respect to a change in the scenario of the global amount of RES generation installed, measured in equivalent MWh of electricity expected to be produced by it.

2.3 Regulation of demand participation in long term and short term markets

In this section, the KPIs proposed correspond to the qualitative criteria used for assessing the different alternatives for demand participation in long-term markets (Chapter 4 in D3.1) and short-term markets (Chapter 7 in D3.2).

2.3.1 Quantitative KPIs associated with the qualitative assessment criteria

Table 3: KPIs defined for the assessment of demand participation mechanisms

Assessment criteria for DSR		KPIs (quantitative)
Efficiency	Impact on social welfare and Marginal cost reflectivity	- Difference between the short-term net welfare associated with flexible demand resulting from the application of each DSR scheme and the long-term implementation costs. - Proxy to the previous KPI based on the reflectivity of market price signals of the marginal supply cost and marginal utility in the dispatch.
	Cost causality	- Share of the surplus earned by consumers (and share earned by aggregator)
	Liquidity	- Volume of bids and flexible energy or capacity exchanged in the relevant market
Robustness & replicability		- *[qualitative]* [3]
Implementability	Feasibility	- *[qualitative]*
	Compatibility & Simplicity	- *[qualitative]*
	Implementation costs	- *[hard to assess from a quantitative point of view]*
	Level of use of public funds	- Amount of subsidies and funds originating from a public service obligation required for the system to work
	Scalability	- *[qualitative]*

[3] KPIs in grey and italic cannot be evaluated by models.

Fairness	Competition	- *Qualitative: access to consumers for agents other than their retailer (supplier)* - *Quantitative: economies of scale*
	Confidentiality	- *[qualitative]*
	Allocation of implementation costs	- Non-shed consumers' surplus increase

2.3.2 Definition and explanation of the quantitative KPIs

In this section we describe in more detail the KPIs introduced in the above table.

Efficiency

- **Impact on social welfare and Marginal cost reflectivity**

In European electricity markets, only the biggest consumers have direct access to the wholesale market and can, therefore, express directly in the market the utility that the electricity they consume has for them. The price signal in the retail market associated with the electricity bought by consumers is traditionally much less sophisticated (often due to rudimentary consumption metering technologies), which prevents them from expressing their consumption preferences. Market arrangements allowing demand participation in the short and long term markets try to give consumers this power so as to recreate the actual demand curve and avoid using expensive generation technologies when some consumers' utility to consume is lower than the marginal system supply cost. Therefore, design options to enable DSR should aim to increase the social welfare by allowing the marginal utility that electricity has for consumers at a given moment to be reflected in the market prices. Bids by consumers can be placed on the demand side ("I will consume if I pay less than…") or on the supply side ("Although I had planned to consume a certain amount of energy, which I have paid, I will not consume (a certain amount of) it if I am paid at least…"). Bids by consumers submitted through the corresponding DSR mechanism should, therefore, reflect the utility that each block of energy consumed has for consumers.

Demand response, however, has a set up cost (for instance, installing remote control devices). Then, the short term increase in surplus out of the application of DSR options is not enough to compare merits of several options: long-term costs should also be taken into account.

Assessing the impact on social welfare and marginal cost reflectivity

<u>Social welfare</u>

Market design options to enable DSR should be compared according to their impact on the total social welfare. A possible KPI to compare options concerns the difference between the short-term net welfare associated with flexible demand resulting from the application of each DSR scheme and the long-term implementation costs of this DSR scheme. In order to compute this KPI, demand needs to be divided into flexible one, potentially affected by the application of DSR schemes, and non-flexible demand that is never to be affected. The short-term net welfare associated with flexible demand for each DSR option is to be computed as the difference between the overall utility that electricity has for the fraction of flexible demand that is covered when applying this DSR scheme and the short-term (variable) cost of producing power covering this demand. The long-term implementation costs of a DSR scheme corresponds to the cost of the long-term measures (mainly the installation of DSR and communication equipment) required to apply this scheme and the long term effects on system costs of the application of this scheme (mainly the impact of this scheme on generation investment costs).

Marginal cost reflectivity

Marginal cost reflectivity is relevant, in addition to social welfare, because it reflects the efficiency of price signals, which may have not been fully reflected yet in social welfare yet but may do in the further future. Thus, it is also relevant to measure the marginal cost reflectivity gap of market signals resulting from the application of each DSR scheme net of the long term marginal cost of deployment of this scheme. The marginal cost reflectivity gap of market signals is to be computed as the sum, over all hours in the considered time horizon of the analysis, of the absolute values of the difference between the utility that electricity has for the first unit of load not served in the system (or the corresponding area) and the marginal supply costs in this area (deemed to represent the market price). The long term marginal cost of deployment of a DSR scheme is computed as the extra cost of long term measures implemented to apply this DSR scheme to an extra unit of power along the considered time horizon plus the difference between the variabilized unit investment cost of marginal generation in the scenario where this DSR scheme is in place and the reference scenario where no scheme is implemented.

A complementary measure of the impact on social welfare of the application of a DSR scheme concerns the sharing of the short term surplus resulting from the use of this scheme between the flexible consumers and the aggregator. The larger the share of the short term consumer operation surplus resulting from the application of a DSR scheme that the aggregator keeps for himself, the less efficient the level of deployment of DSR by the corresponding consumer will be, since benefits earned by this consumer will be less reflective of true benefits produced by this scheme (and therefore, the CBA of DSR investments conducted by the consumer will be biased).

- Cost causality

Flexible consumers are the ones largely incurring the cost of implementing DSR schemes (costs of the required DSR equipment, for example). Hence, they should be the ones largely benefiting from the application of these schemes. Then, the cost causality of a DSR option depends on the surplus sharing arrangements made between the shed consumers and their supplier or aggregator (i.e. the party in charge of bidding DSR in the market).

Assessing cost causality

Cost causality can be measured by how the surplus is divided between the shed consumers and the supplier or aggregator: the more surplus is appropriated by the latter, the less cost causal the option is.

- Liquidity

Assessing the impact of DSR on liquidity

The impact of market design options for demand participation in short or long term markets on market liquidity should be measured in terms of the volume of bids and flexible energy and/or capacity exchanged in the relevant market.

Implementability

Assessing the level of use of public funds

This corresponds to the amount of subsidies and funds originating from a public service obligation that are mobilized through a DSR scheme for it to work properly. The level of use of public funds can be more easily measured in a model in which the level of deployment of demand response is set as a parameter. In order for public funds to be mobilized, the deployment of DSR should be set at a level at which this deployment (or at least a part of it) is not profitable and has to be subsidized.

Fairness

Consumers should globally benefit from the price lowering effect resulting from the activation of DSR, since this should lead to less expensive marginal generation units running.

Assessing the cost and revenue allocation

The allocative effect should be measured through the non-shed consumers' surplus increase when compared to the situation without DSR.

2.4 Long-term cross-border products (transmission)

In this section, the KPIs proposed correspond to the qualitative criteria used for assessing the different alternatives for long-term cross-border products (Chapter 5 in D3.1).

2.4.1 Quantitative KPIs associated to the qualitative assessment criteria

Table 4: KPIs defined for the assessment of cross-border products traded in long-term markets

Assessment criteria for cross-border products		KPIs (quantitative)
Efficiency	Market and system modelling imperfection costs	- The size of infeasibilities should be computed as the excess of capacity sold over available capacity. Sold capacity in long term auctions should never exceed the available capacity.
Efficiency	Diversity of products traded in the market • Relevant to assess how different products hedge the preferences and needs of the different agents involved • Optimal design alternatives for the products	- Level of stability of the costs of accessing the grid

	Global coherence of market designs implemented (some long-term cross-border products are claimed to inefficiently affect short-term cross-border trading)	- Fraction of total transmission capacity whose physical use cannot be decided in the short term, because it has already been allocated in the long term through these products.
Implementability	Simplicity and feasibility of the implementation (some cross-border products can lead to problems extremely hard/long to solve, or even impossible solutions)	- Computation time - Feasible/optimal solution possible (in case of modelling)
	Compatibility with existing regional regulation, legislation and policy objectives (NC CACM & FCA are relevant)	- *Whether products considered are already an option within NCs on CACM and FCA.* [4]
	Implementation costs	- *Number of changes required to adjust currently existing long term capacity allocation algorithms and network models: redefinition of congestion areas (e.g. from zones to nodes); changes in the complexity of the algorithm (e.g. whether coordinated allocation of the capacity of all congested corridors is needed).*
	Experience with implementation of a market in other systems	- *Number of systems where these cross-border products are being used.*

2.4.2 Definition and explanation of the quantitative KPIs

In this section the before-mentioned KPIs of Table 4 are described in more detail. The problem within this chapter is that there is no modelling tool available within WP 5 of the project, which can evaluate these KPIs on long-term cross-border products. A very complex modelling tool would be needed, which combines the long-term as well as the short-term and in addition a very detailed resolution of the grid would be necessary. Therefore, the following KPIs can be seen as suggestions for evaluating in further studies.

Efficiency

The category efficiency is divided into three main assessment criteria parts. Firstly, the *market and system modelling imperfection costs* can be measured/evaluated by the size of **infeasibilities**, which should be computed as the **excess of capacity sold over available capacity.** The sold capacity in long term auctions (in the form of these products) should never exceed the available capacity.

Concerning the *diversity of products*, there are two main dimensions to consider. On the one hand, the assessment of how different products can hedge the several involved agents from the risk associated with the volatility of the price paid for accessing the grid is relevant. On the other hand, the coordinated, or coherent functioning of the several hedging products made available is also important. Thus, the **level of stability achieved by agents in the cost of accessing the grid**

[4] KPIs in grey and italic cannot be evaluated by models.

through the products they have acquired is chosen as a first quantitative KPI. In other words, in order to measure how well products are adapted to the hedging needs of agents, it can be checked to which extent the prices paid by agents to access the grid are fixed in the long term through the use of these products. Regarding the second dimension, a suitable KPI can be the difference among the prices paid for the use of transmission capacity by agents having acquired long term cross-border products in different time frames relative to the real time price of the total transmission capacity bought in the long term.

To measure *Global coherence of market designs* the **fraction of total transmission capacity** whose physical use cannot be decided in the short term, because it has already been allocated in the long term through long term products is an important indicator. Thus, financial rights are superior to physical ones in this regard. Including use-it-or-sell-it arrangements in combination with physical rights should help free for its short term allocation the fraction of transmission capacity whose use is committed in the long term but will not be used eventually. However, these clauses do not completely solve the problem created by the use of physical rights, since there may still be a fraction of capacity committed in the long term that is inefficiently used.

Implementability

The assessment criteria implementability is divided into four main parts. The *simplicity and feasibility of the implementation* made of the set of cross-border products issued can be measured by the **computation time** employed by the model to compute the allocation of cross-border products to agents and the final energy dispatch including these products. Another relevant KPI, related to the former, is whether a **feasible/optimal solution** of these problems can be found.

The *compatibility of a market design with existing regional regulation and policy objectives* is very difficult to measure quantitatively. The only possibility is to have a look at the **current deviation** from the initial time line for implementation (see ACER) and whether the **products considered are already an option within the NCs on CACM and FCA.**

The estimation of the *implementation costs* with a model is not possible. C**osts comprise those of all the relevant changes that are required to update the currently existing long term capacity allocation algorithms and network models** if these products are implemented. The considered changes include the redefinition of congestion areas (e.g. from zones to nodes); and changes in the complexity of the algorithm (e.g. whether coordinated allocation of the capacity of all congested corridors is needed).

The *experience with implementation of the market design in other systems* can only be verified by the **number of systems where these cross-border products are being used**. Therefore, the evaluation of cross-border products with a model based on this KPI is also not possible.

3 KPIs for Short Term

Options for short-term market design have been presented and assessed in the report D3.2 "Developments affecting the design of short-term markets". In this chapter, quantitative KPIs corresponding to the relevant assessment criteria used in D3.2 are proposed. Only KPIs that are calculable by the models used within WP4 and WP5 are displayed.

3.1 Network representation

In this section, the KPIs proposed correspond to the qualitative criteria used for assessing the different alternatives for network representation (Chapter 2 in D3.2).

3.1.1 Quantitative KPIs associated to the qualitative assessment criteria

Table 5: KPIs defined for the assessment of possible models for the representation of the network in markets

Assessment criteria for Network representation		KPIs (quantitative)
Efficiency	Marginal cost reflectivity resulting from the granularity of the network model	- Social welfare: producer surplus + consumer surplus+ congestion revenue - Average price level - Ratio of market price to marginal production cost - Redispatching costs - Total generation costs
	Level of coordination of the capacity allocation method applied	- Price convergence / average price differentials between adjacent zones or nodes - Amount of cross-border flows - Social welfare or total generation costs
	Market (network) modelling imperfection costs	- Redispatching costs - RES curtailment - Load curtailment
	Liquidity	- *Bid-ask price spread : difference between the highest price a buyer is willing to pay (bid) and the lowest price a seller is willing to accept for it* [5] - Volume traded within each zone / at each node
Robustness		- Impact of a change from a reference scenario to alternative scenarios (involving for e.g. different levels of fuel prices, RES penetration, demand, etc.) on the indicators defined to study the different market designs for network representation/transmission capacity allocation model
me nt	Computational feasibility	- Computation time

[5] KPIs in grey and italic cannot be evaluated by models.

	Compatibility with existing regulation in Europe	- *Number of deviations from existing regulations in Europe (IEM and other relevant European legislation)*
	Implementation costs	- *IT costs to implement the different network configuration options/capacity models for market participants, TSOs and PXs*
	Possible extension to several time frames	- *Number of timeframes where the system of prices is implementable*
	Simplicity	- *Number of price zones* - *Number of network parameters provided by TSOs to PXs*
	Experience with its implementation	- *Number of countries where the studied network representation models have been implemented* - *% of global electricity generation under each studied network representation model*
Fairness	Distributive effects	- Magnitude of the differences between prices earned by generators and those paid by demand within a region or a country. - Also, price differences among countries and, within countries, among price zones
	Compatibility with the application of single price to small consumers within a region, or country	- *Number of different price zones for small consumers at region/country level*

3.1.2 Definition and explanation of the quantitative KPIs

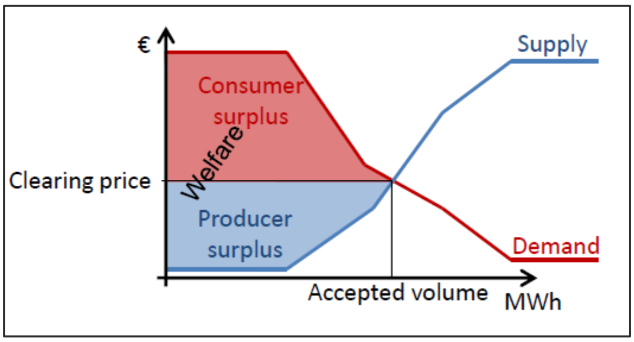
In this section we describe in more detail the KPIs introduced in the above table.

Efficiency

- **Social welfare**

Within the context of cross-zonal flows, the social welfare is a crucial indicator to measure the efficiency of the market architecture. For example, market coupling algorithms (for instance EUPHEMIA) aim at maximizing the social welfare. The social welfare to be measured here corresponds to the implementation of the market outcome. Possible infeasibilities resulting from this are addressed by separate KPIs, related to market modelling imperfection costs.

Within a single market, the social welfare is defined as the sum of consumer surplus and producer surplus. The consumer surplus is the difference between the willingness to pay of each consumer and the price actually paid; symmetrically, the producer surplus is the difference between the market price and the willingness to sell of producers. It can be represented graphically as follows (Figure 4):



Source: Price Coupling of Regions (PCR)

Figure 4: Social welfare within a market

Within a cross-zonal context, where several market areas are interconnected, the social welfare takes into account not only the consumer surplus and the producer surplus within each market area, but also the congestion revenue at the borders between market areas. This can be graphically illustrated thanks to the net export curves (NEC) of each market. The NEC of each market area is constructed from demand and supply curves: to each energy unit potentially exported from or imported to the market area is associated the resulting market price. The total social welfare is illustrated by Figure 5 below with two market areas A and B.

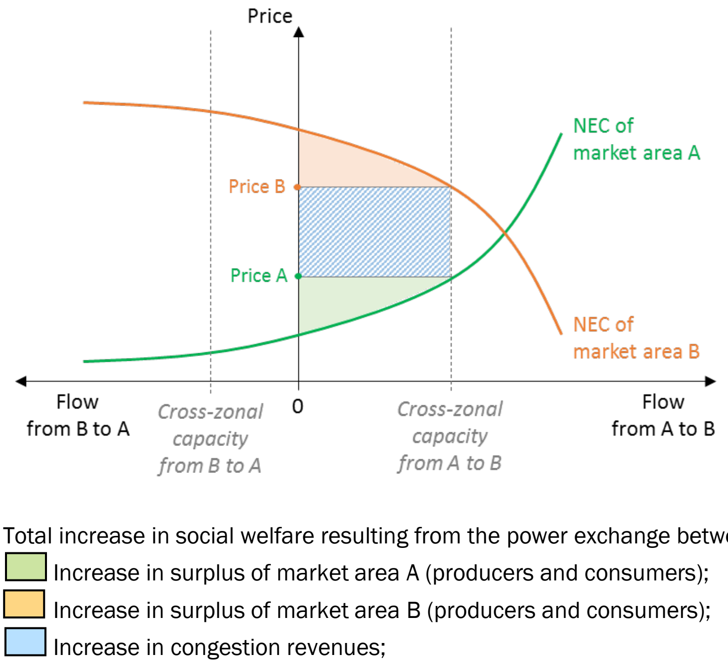


Figure 5: Increase in social welfare resulting from trade

Calculation of social welfare

Most models allow for calculating all components of social welfare: consumer surplus per market area, producer surplus per market area, and congestion revenue per border.

However, many models do not consider the strategic behaviour of market players: rather, the assumption of perfect competition is considered. In particular, producers may be supposed to bid at their marginal cost: this hypothesis tends to inflate the producer surplus.

In addition, the consumers' willingness to pay may be modelled in a very simplified way, with most of the demand at the market maximum price.

- **Average price level**

The average price level, for a given market area, a given market timeframe (day-ahead, intraday…) and a given period of time, is the average value of the prices incurred within this market area during this period of time (in general at the hourly step). Typically, the lower the average price level, the lower the energy supply costs would be, and, therefore, the better.

Calculation of average market prices

Normally, average prices computed refer to the specific time-frame considered in market models, i.e. average day-ahead prices. In addition, as already said, producers may be supposed to bid at their marginal cost: this hypothesis tends to underestimate the average prices compared to real life.

- **Ratio of market price to marginal production cost**

Within each market area or at each node, the ratio of market price as calculated by the model to the marginal costs of the system (i.e. the variable production cost of the most expensive generation unit dispatched) is a measure of the efficiency of the system: the more efficient the system is, the closer this ratio is to 1.

Calculation of the ratio of market price to marginal production cost

Within most models, as those used in WP4 quantitative analyses within the project, producers are supposed to bid at their marginal cost. Therefore, calculating such ratio is not relevant.

- **Redispatching costs**

The redispatching costs are the costs of the actions carried out by the TSO to make the market clearing compatible with network constraints. In principle, the bigger the market areas are, the higher the redispatching costs. The lower the level of these costs, the more efficient the market design is. This should be considered together with the system welfare resulting from the dispatch to compute the overall economic efficiency of the final dispatch.

Calculation of redispatching costs

Redispatching costs may not be calculated by all models used in WP4 and WP5.

- **Total generation costs**

The total generation costs are the short-term costs for generating the electricity, in general at an hourly step. They do not include the fixed costs corresponding to the investments in generation plants; rather, they reflect the variable costs (mainly the fuel costs) and the short-term costs such as start-up costs. Total generation costs are complementary to the social welfare, as illustrated on the figure below.

This indicator applies only to thermal generation: RES generation cost is considered, in general, to be zero. However, they can be compared to the costs for subsidising RES generation: for a given generation fleet, the former are the costs for generating electricity from thermal sources, while the latter are the cost of the generation of RES electricity.

The lower the level of total generation costs, the more efficient the dispatch is. This is shown in Figure 6 below.

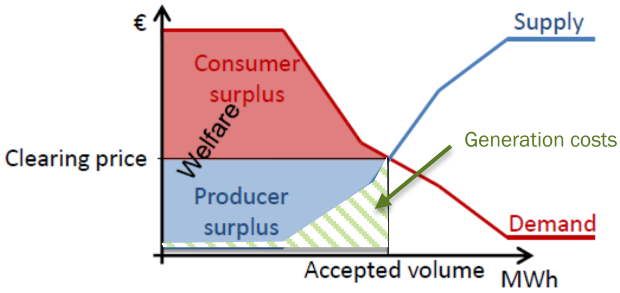


Figure 6: Generation costs within a market

Calculation of total generation costs

Generation costs at the day-ahead stage are calculated within most models for the representation of the functioning of day-ahead markets. The advantage of this indicator is that the demand curve is not needed. Therefore, the fact that demand may be modelled in a simplified way does not impact the quality of this indicator (contrary to social welfare). This is why this indicator is sometimes preferred.

- **Price convergence**

An indicator for price convergence between several zones or nodes can be the number of time steps (in general hours) during which the prices within the different market zones or nodes are equal. Alternatively, it can be the number of hours during which the price difference is lower than a certain amount (for instance 0.10 €/MWh). The higher the level of price convergence achieved, the better use is deemed to be made of trading opportunities and, therefore, the more efficient the scheme is.

Calculation of price convergence indicators

Such indicators can be easily calculated with most models computing prices for each of the several zones defined in the system.

- **Average price differences between adjacent zones or nodes**

The average price difference between two adjacent nodes or zones A and B is the average value, over all time steps (in general hours) included in the period studied, of the difference between the price in A and the price in B. The average can be calculated by using the absolute values of this differences in order to avoid the compensation of negative and positive differences. The lower the level of price differences, the better use is deemed to be made of interconnection capacity and, therefore, the more efficient the design option is.

Calculation of average price differentials

Such indicators can be calculated with most day-ahead models.

- Bid-ask price spread

The bid-ask spread is the difference between the highest price a buyer is willing to pay (bid) and the lowest price a seller is willing to accept for it. In other words, it is the price range between best bid and best ask (definition from EPEX Spot glossary). It is expressed in €/MWh, or in % of the market price.

According to ACER in the Report on the influence of existing bidding zones on electricity markets, *"it is assumed that less market activity (expressed in terms of churn rate) results in higher bid-ask spreads. Bid-ask spread indicators may be considered as a more direct measure of liquidity, as defined at the beginning of this sub-section, because they show the extent of transaction costs resulting from an instantaneous change in a market participant's contractual position. Higher transaction costs incurred in markets with high bid-ask spreads are likely to be passed on to final customers."*

Calculation of bid-ask spread

Such an indicator can only be calculated when models consider the utility value that electricity has for consumers, which is not the case in most models, including most of those used in the project.

- Amount of cross-border flows

The amount of cross-border flows can be regarded border per border, and hour per hour. A single indicator corresponding to a geographic scope covering several borders and a certain period of time could be the cumulated average net cross-border flow, i.e. the sum, over all borders, of the absolute average value, over all hours, of the net cross-border flow. This indicator is a measure of the intensity of cross-border flows during the period studied. The higher the level of flows in aggregate terms, the more use is made of interconnection capacity, which is deemed to be a positive feature of a design option.

Calculation of cross-border flows

Cross-border flows can be computed in all multi-area models for the computation of the market dispatch, where the enforcement of the power balance per area involves the computation of flows among areas, as it is the case in most models used within the project.

- RES curtailment

RES generation output can be curtailed because in excess, taking into account non flexible demand and generation. The average depth (in MWh), the duration (in hours) and/or the total amount (in MWh) of RES curtailment may increase due to a lack of efficiency of the network representation. The lower the level of this, the more efficient the design option is.

Calculation of RES curtailment amount

Most dispatch and unit-commitment models are able to compute the amount of RES-based power effectively injected into the grid. The differences between the gross amount of RES based power available and that injected is the amount of RES based power that is spilled.

- Load curtailment

Load can be curtailed because of insufficient generation and/or insufficient import capacity within a given market area or at a given node. The average depth (in MWh), the duration (in hours) and/or the total amount (in MWh) of load curtailment may increase due to a lack of efficiency of the network representation. The lower the level of this, the more efficient the design option is.

Calculation of load curtailment amount

Most tools for the computation of the day-ahead, or real time dispatch, as well as unit commitment ones, make use of load curtailed as a last resource to achieve the balanced of power in the system or each area. Therefore, they are able to compute the amount of load curtailed in each operation situation considered.

- Volume traded within each zone / at each node

The volume in MWh (or the average depth in MW) of energy traded within a given market area or node is a measure of the level of liquidity in the market. This is also influenced by the model used for the representation of the network. Models with finer granularity may result in lower levels of liquidity in some nodes or areas. The higher the level of this, the more efficient the design option is.

Calculation of the volume traded within each zone / at each node

Most models available do not compute the total amount of energy traded but the optimal set of power generators and loads dispatched. Then, this indicator is difficult to compute.

Robustness

- **Impact of a change from a reference scenario to alternative scenarios**

This is not *per se* an indicator, it is rather a methodology to assess the robustness of a market design option by studying the behaviour of all the other indicators when changing the initial conditions (e.g. different levels of fuel prices, RES penetration, demand, etc.). The lower the size of changes occurring in indicators, the more robust, and better, the design option is.

Impact of a change from a reference scenario to alternative scenarios

The impact on the system operation of a change in the scenario is normally computed by solving the system dispatch, or unit commitment, problem for all the scenarios to be compared.

Implementability

- **Computation time**

The computation time of each market design option is the number of hours, or minutes, needed to calculate the dispatch volumes and prices. The lower the level of this, the more efficient the design option is.

- **Number and relevance of deviations from existing regulations in Europe (IEM and other relevant European legislation)**

The number and relevance of deviations from existing regulations, or, in other words, the number and impact on the system functioning of changes to be done to the existing regulation to make it compliant with the market design options under study, could be a measure of the implementability of this option. It could be calculated, for instance, as the number of articles to be changed in the current Network Codes weighted with the expected impact of these changes on the operation and development of the system, as well as on prices and emissions. Thus, non-relevant changes would be omitted and only the most relevant ones would be considered when determining whether this design option is easily implementable. The lower the level of this, the better the design option is.

- **IT costs to implement the different network configuration options**

A way to assess the implementability of a market design option for network configuration is to assess the IT costs to implement it, for the different players involved: TSOs, Power Exchanges (PXs), and market participants.

For TSOs, such costs would need to be detailed to their regulators, since passed through network tariffs. For PXs and market participants, assessing these costs may be quite difficult, and the actual costs would probably be confidential. The lower the level of this, the better the design option is.

- **Number of timeframes where the system of prices is implementable**

The implementability of a network representation model could be assessed along four timeframes: long-term, day-ahead, intraday and (close to) real-time. The larger the number of timeframes when a design option can be implemented, the better the design option is.

- **Number of price zones / Number of network parameters provided by TSOs to PXs**

Counting these figures is a way to roughly assess the simplicity of each network representation option. It is also related to computation time: the more parameters are needed, the higher the computation will be.

- **Number of countries where the studied network representation models have been implemented / Percentage of global electricity generation under each studied network representation model**

Calculating these indicators would provide a guidance about the implementability of a given network representation option. The larger the number of countries where the option has been implemented, the better the design option is.

Fairness

- **Magnitude of the differences between prices earned by generators and those paid by demand within a region or a country**

The difference among the prices earned by the several generators (in case of a pay-as-bid mechanism), and the differences among prices paid by the several consumers within the same region or country is a measure of the fairness of the market design and is also conditioned by the features of the network model employed. The lower these differences are, the fairer the corresponding option is deemed to be.

Calculation of the differences between prices earned by generators and those paid by demand

Pay as bid mechanisms cannot be modelled with the day-ahead module of most models, since they are designed to model marginal pricing ones. Therefore, such indicator cannot be calculated in all these cases.

- **Price differences among countries, as well as those among price zones within each country**

Differences occurring in prices applied in the several countries and several price zones of a region, both to consumers and generators, may raise concerns about the fairness of these prices. In principle, the smaller these differences are, the fairer the corresponding option is deemed to be.

Calculation of the differences in prices among countries and zones

As for the previous indicator, prices, and therefore their differences, can be computed with most models available if these prices are marginal, while they cannot be easily computed when pay-as-bid prices are applied.

3.2 Timing of short term markets

In this section, the KPIs proposed correspond to the qualitative criteria used for assessing the different alternatives for the timing of short-term markets (Chapter 3 in D3.2).

3.2.1 Quantitative KPIs associated to the qualitative assessment criteria

Table 6: KPIs defined for the assessment of possible options for the design of the sequence of markets implemented in the short term

Assessment criteria for Timing of markets		KPIs (quantitative)
Efficiency	Efficient price signals	- Ratio of short-term market price to real-time marginal production cost
	Market modelling imperfection costs (Many of these costs are incurred, in the first place, by the SO)	- Re-dispatch costs - RES curtailment - Load curtailment
	Liquidity	- Bid-ask price spread: difference between the highest price that a buyer is willing to pay (bid) and the lowest price that a seller is willing to accept for it - Volume traded for each market segment (day-ahead, intraday…)
	Ensure the availability of a complete set of time frames to trade the products and Global coherence of markets	- Price differential between subsequent markets for the same product - Total social welfare - Flexible generators surplus
Robustness	Robustness against different scenarios	- Impact of a change from a reference scenario to alternative scenarios (involving for g. different levels of RES penetration and electric vehicle penetration) on the indicators defined to study the different market designs for the timing of markets
Implementability	Compatibility of the design alternatives with the Capacity Allocation and Congestion Management and the Balancing Network Codes	- *Number of deviations from initial time line of CACM and Balancing Network codes* [6]
	Simplicity of the market sequence	- *Number of subsequent markets* - *Computation time*
	Implementation costs	- *IT costs for PXs to implement the different configurations*

[6] KPIs in grey and italic cannot be evaluated by models.

	Experience with the implementation of a market in other systems	- *Number of countries where the studied timing of short-term markets have been implemented* - *% of global electricity generation under each studied network representation model*

3.2.2 Definition and explanation of the quantitative KPIs

In this section, only the KPIs that have not been described previously, or not described in a manner taking into account the different options for the timing of short-term markets, are detailed. Those KPIs that have been included in Table 6, but are not described next have already been defined in previous sections, namely section 3.1 on KPIs for the assessment of network representation models. The reader should notice that welfare and other related indicators referred to in sections 3.1 and 3.2 are associated with energy markets, while those indicators related to social welfare in section 2.1 refer to the dispatch of capacity markets.

Efficiency

- **Ratio of short-term market price to real-time marginal production cost**

This ratio could be calculated for each market segment (day-ahead, intraday, reserve). For market segment based on bilateral transactions (for instance continuous intraday), an average value for the market price is needed. The lower this ration is, the closer prices applied are to real costs incurred in the delivery of the product, and therefore the more efficient this option is.

- **Volume traded for each market segment (day-ahead, intraday…)**

Comparing the volume traded within each market segment for the different market design options considered is a way to measure the efficiency of the option. Larger volumes reflect a higher liquidity level and therefore more efficiency of an option.

- **Price differential between subsequent markets for the same product**

The same product (for instance the delivery during one hour of one electricity unit at a given date and time) can be traded in different market segments (day-ahead, intraday…). In the absence of changes in system conditions, the price differential in €/MWh between the different segments, or the ratio between each price and a reference price is a measure of the efficiency of each market segment. The larger this difference is, the less efficient markets have been in arbitraging this difference, and the less efficient the outcome of markets can be expected to be. A distinction must, thus, be made between changes in prices due to changes in system conditions and those price differences caused by inefficient arbitraging. The latter can be better determined when no relevant change in system conditions occurs between the clearing of one market and the other.

- **Total social welfare**

Measuring the total social welfare would be, in theory, a useful indicator to compare different options regarding the timing of short-term markets. The larger the social welfare, the more efficient an option should be. Measuring, in practice, the resulting social welfare in markets based on bilateral transactions (such as continuous intraday) may be more difficult, since a centralized clearing process is not conduct in the latter. However, based on the final schedule of generators and consumers and their main features, which must be made available to the SO, computing a good estimate of the social welfare should be possible.

- **Flexible generators surplus**

Calculating the surplus of flexible generators is a way to measure how efficiently a market design values the flexibility. Anything else being equal, more flexible generators should be able to earn larger revenues than less flexible ones. However, as explained for the social welfare, this may not be feasible in practice for continuous markets.

Implementability

- **Number of subsequent markets**

The number of subsequent markets (for instance the number of intraday auctions) is a measure of the simplicity of the market design. The larger this number is, the more complex the sequence of markets is, and therefore the more difficult it is to implement.

3.3 Bidding protocols

In this section, the KPIs proposed correspond to the qualitative criteria used for assessing the different alternatives for the bidding protocols (Chapter 4 in D3.2).

3.3.1 Quantitative KPIs associated to the qualitative assessment criteria

Table 7: KPIs defined for the assessment of the several bidding protocols and pricing rules applied

Assessment criteria for bidding protocols		KPIs (quantitative)
Efficiency	Marginal cost reflectivity	- Difference between market price and marginal supply cost - Number of limitations to bid at desired price - Use of complex conditions y agents - Features that allow flexibility in the procurement and delivery of products, such as portfolio offers - Number of agents
	Market modelling imperfection costs	- Existence of the need of extra incomes for agents. - Infeasibilities resulting from the ex-post simulation of system operation for market results
	Diversity of products traded in the market	- Number of products - Number of markets
	Market transparency	- Clear Rules and behaviour - Central platform for the publication of information with easy access

		- Access to aggregate data - Access to results - Access to bids - Delay in data accessibility
Robust-ness	Products and pricing rules prove to be robust against different potential penetration levels of RES-E	- % of energy in each market depending on scenario - % of energy in each product depending on scenario - % change of average price depending on scenario - % change of price profile depending on scenario
Implementability	Feasibility of the implementation of a market	- *% of countries with liberalized electricity market with similar implementation* - *Duration of the implementation*
	Compatibility with existing regional regulation	- *Number of incompatible rules* - *Number of rules that are compatible but need to be adapted* - *Number of new rules that need to be developed.* - *Number of new markets or products*
	Simplicity of the market	- *Number of steps to make a bid* - *Number of markets available to sell the energy in.* - *Number of times a period can be traded* - *Back-up procedures to bid*
	Implementation costs	- *IT and staff extra costs for PX* - *IT and staff extra costs of TSO* - *IT and staff extra costs for agents* - *IT and staff costs during testing period.*
	Experience with the implementation of a market in other systems	- *Number of countries with similar implementation*

3.3.2 Definition and explanation of the quantitative KPIs

Next, the KPIs defined in Table 7 for the quantitative assessment of bidding protocol options and pricing ones in short term markets are explained regarding the main idea underlying them and their use. Those KPIs in Table 7 that are not explained next have been already defined in previous sections.

Efficiency

- **Marginal cost reflectivity**

Difference between market price and marginal supply cost in each area or node of the network. Market prices should reflect marginal supply costs to induce efficient operation decisions by agents. Then, the lower this KPI, the better.

Number of limitations to bid at desired price: In a market free of any distortion, any should be free to bid at the desired price, which should reflect its generation cost. Thus, any limitation to that bid, like minimum or maximum prices to bid, are potentially limiting this freedom, impeding the actual cost to be reflected in the bid. The lower this KPI is, the better.

Use of complex bids by agents: Agents must be able to reflect their different conditions and realities, possibly resulting in specific operation constraints. A sufficient range of complex conditions must be displayed, although only when used by agents. Complex conditions add complexity to bidding process. Therefore, only complex conditions used by agents are desirable. This KPI can be computed as the percentage of bids using complex conditions, or per complex condition, the KPI could be the share of bids using that condition. The higher this KPI is, the better.

Features that allow flexibility in the procurement and delivery of products, such as portfolio offers. Different agents may have different circumstances and, although it is almost impossible to represent them all, flexibility is desired. Portfolio agents will surely appreciate them, and considering that the electric system naturally favours portfolios, this is an important characteristic. This KPI could be Boolean, with a desirable value of 1 that would mean that portfolio offers are allowed.

Number of agents: A high number of agents ensures liquidity and competition. A market where a larger number of competitors exists should lead to prices getting closer to marginal costs. This applies both to buyers and sellers. Therefore, the higher this KPI is, the better.

- Market Modelling imperfection costs

Existence of the need of extra incomes for agents: It might be that the market does not provide enough revenue for (some of) the agents to recover their operation costs. That may threat the participation of agents in the market, so some side payments may be needed. The extra incomes would represent the value not provided by the market. The lower this KPI is, the better.

Infeasibilities resulting from the ex-post simulation of system operation for market results: If possible, a simulation of the real operation of the system when implementing market results could be run. Any infeasibility resulting from this simulation would represent an imperfection cost. Thus, when infeasibilities exist, the lower this KPI is, the better. This should be measured as the aggregate size of overflows in the lines of the system for the operation resulting from the market.

- Diversity of products traded in the market

Number of products: As buying agents may have different needs, it will be easier to find a product that suits them better when there is a wide range of products available. Therefore, the higher this KPI is, the better.

Number of markets: Just a as a matter of freedom, it will be always good to have several chances to do something instead of just one. Thus, the higher the number of markets is, the better. The differences between the markets can be related to the moment when they are held, the horizon when they apply, the products that are traded, etc.

- Market Transparency

Clear rules and behaviour: Agents need a clear set of rules to guide their behaviour and the behaviour of other agents, OS, OM and regulator. Rules should be fair, but even if they are not, agents must foresee how other agents can behave legally. The quantitative KPI that can be used is the number of formal questions asked and/or reports requesting some clarification issued by agents. The lower this KPI is, the better.

Central platform for the publication of information with easy access: Access to data is key for transparency. Being able to know what anyone has done at any moment will boost competition as well as limit illegal behaviour. Information should be easily reachable and a central platform will help. This KPI level should vary depending on whether all those conditions are fulfilled or not, being better when all of them are considered.

Access to information: which is divided in 4 sections

- **Access to aggregate data**
- **Access to results**
- **Access to bids**
- **Delay in access to information:** This KPI will be better when there is more information accessible. Finally, there may be some confidentiality period before data is accessible. According to point 4, the KPI should increase when data is available earlier. This KPI is not measurable with models but its importance is enormous. Therefore, there should be a KPI (even as a Boolean) referring to these dimensions of transparency.

Robustness

- **Products and pricing rules prove to be robust against different potential penetration levels of RES-E**

Variability of % of energy in each market across scenarios: when the scenario changes, will the energy be traded in the same way, and more specifically, in the same markets? It may occur that the outcome of short-term markets becomes too volatile, and low-risk agents may prefer long-term forward markets. If so, how large are the differences in the relative amount of energy that is traded in short term markets for different scenarios?. If the variation is large, it might mean that the bidding protocols do not result in robust results, although logic should be taken into account. Maybe some changes are reasonable. If there are no illogical changes, the model is robust.

Variability of % of energy traded in each product across scenarios: Same as above, referred to product.

Changes of average price across scenarios: Same as above, referred to price.

% change of price profile across scenarios: Same as above, referred to price profile. The above mentioned KPI referring to price might not be enough to characterize the market. Two hours of 29 and 31 €/MWh and 10 and 50 €/MWh have both an average of 30€/MWh, but do not reflect the same behaviour of an electricity market regarding its robustness. Therefore, it must be studied if the profile of prices change, and what part of that change is deemed not reasonable considering the energy mix (not justified by the mix). Differences in peak/floor price, number of hours above/below a certain threshold, etc.

Implementability

- **Feasibility of the implementation of a market**

% of countries with liberalized electricity market with similar implementation: It is important to know how many of the countries with similar characteristics (i.e. liberalized market) have implemented a similar solution. This can help to avoid certain errors in the implementation of this format of bids. The higher the value is, the easier the implementation is supposed to be.

Duration of the implementation. All changes are difficult, but longer ones are worse. The shorter the duration of the implementation, the better.

- **Compatibility with existing regional regulation**

Number of incompatible rules: The lower this KPI is, the better.

Number of rules that are compatible but need to be adapted: The lower this KPI is, the better.

Number of new rules that need to be developed: The lower this KPI is, the better.

Number of new markets or products: The lower this KPI is, the better.

- **Simplicity of the market**

Number of steps to make a bid: Placing a bid in the market should be as easy as possible. The lower this KPI is, the better.

Number of markets available to sell the energy in: The more markets available to sell the energy, the easier it should be to sell it. Therefore, the higher this KPI is, the better.

Number of times a period can be traded: Just like the above KPI, the higher, the better.

Back-up procedures to bid: It is a good idea to have a back-up bid in case problems arise. It does not have to be necessarily mandatory to have a back-up bid, but it is good to have the chance. This would be a Boolean KPI, with desirable value of 1.

- **Implementation costs**

IT and staff extra costs for PX: The lower, the better.

IT and staff extra costs for TSO: The lower, the better.

IT and staff extra costs for Agents: The lower, the better.

IT and staff costs during testing period: The lower, the better.

- **Experience with the implementation of a market in other systems**

Number of countries with similar implementation: The higher the number of countries, the better.
General design principles for balancing mechanisms in a context of high RES-E penetration

3.4 Balancing markets

In this section, the KPIs proposed correspond to the qualitative criteria used for assessing the different alternatives for balancing markets (Chapter 5 in D3.2).

3.4.1 Quantitative KPIs associated to the qualitative assessment criteria

Table 8: Overview of KPIs for design principles for balancing mechanisms

Assessment criteria	KPIs (quantitative)

Assessment criteria		KPIs (quantitative)
Efficiency	Optimal Pricing of balancing products • Pay-as-bid • Marginal pricing	- Marginal cost reflectivity: Ratio of the price of products to the marginal cost of providing the corresponding balancing capacity or energy.
	Efficiency of the imbalance settlement design: • Imbalance prices (dual, single or combination, average or marginal) • Imbalance settlement period	- Ratio of price to the sensitivity of system balancing costs with respect to changes in this agent's imbalance. - Difference between the revenues of SO from the payment by BRPs and the payments made to BSPs (this should be as small as possible in order not to produce a surplus that is then inefficiently allocated)
	Liquidity (e.g. minimum bid size, possibility of aggregation, intra-TSO vs. cross-border, offer separately upward and downward products, gate closures for capacity bids, possibility of offering balancing energy without providing capacity, effect of technology specific products)	- Average price levels per balancing product - *Number/characteristics of market participants (entrants vs. incumbents vs. cross-border)* [7] - *Number/characteristics of types of bids*
	Market transparency (not only ex-post clearing results, but also merit-order bid curve)	- *Lead time for data publication* - *Online availability*
	Global coherence of market designs implemented (harmonisation of prequalification criteria, products, timing, gate closure, priority in national vs. cross-border balance etc.)	- *Number of different sets of pre-qualification criteria, timing of markets, gate closure times, priority schemes across Europe. The lower this number, the more coherent the schemes are.* - Overall revenues in all kinds of markets of BRPs: Compatibility of the participation in balancing markets as service provider or BRP with the participation in other markets, like energy ones.
Implement-ability	Compatibility with existing regional regulation, legislation and policy objectives (Framework Guidelines, Network Codes of EB and LFC&R, etc.)	- *Deviation from designs and time lines proposed by FG EB (ACER)*

3.4.2 Definition and explanation of the quantitative KPIs

In this section, the before-mentioned KPIs of Table 8 are described in more detail. In addition, some remarks are provided about how the modelling tool used within work package 5 of the project can be used to compute these KPIs.

[7] KPIs in grey and italic cannot be evaluated by models.

Efficiency

Social welfare cannot be measured for balancing markets alone, but for the whole set of markets organized as a whole. Then, assessing the efficiency of balancing markets separately probably requires setting more specific measures of the efficiency of price signals used for the specific products traded in these markets, considering the context where these signals are derived. This is our purpose when defining the set of KPIs proposed here.

The overall assessment criteria economic efficiency is split into five sub-criteria. One of them is the *efficiency of the pricing scheme of balancing products*; pricing schemes can be either pay-as-bid or marginal pricing. The associated quantitative KPI is **marginal cost reflectivity**, which is the ratio of the products price to the marginal cost of providing the corresponding balancing capacity or energy. When comparing pay-as-bid and marginal pricing, the fact that the average price is lower under pay-as-bid does not mean that pay-as-bid is more efficient. Here it should be assessed whether prices of products reflect their marginal supply costs. Products should be priced according to their market value, which is related to the cost of providing an extra unit of them.

The *efficiency of imbalance settlement designs*, comprising the imbalance prices and settlement period defined ex-ante, can be measured ex-post as the **ratio of the unit price paid for imbalances to the sensitivity of system balancing costs** with respect to changes in the corresponding agent's imbalance. When comparing single and dual pricing, or average vs. marginal, prices paid should be deemed cost-reflective to the extent that they correspond to the impact on system costs of the changes in the system variable being priced. Then, prices paid by agents should be as similar as possible to the sensitivity of system balancing costs with respect to an increase in the imbalance by these agents. The performance of dual pricing and single pricing can be also assessed according to the **difference between the revenues** of System Operators (SOs) from the payments made by Balancing Responsible Parties (BRPs) and the payments made to Balancing Service Providers (BSPs). This difference should be as small as possible in order not to produce a surplus to be inefficiently allocated afterwards.

The *liquidity of the balancing market* is influenced by features of this market like:

- the minimum bid size, the possibility of aggregation of bids,
- the possibility to offer separately up- and downward products,
- whether gate closures for capacity bids are close to real time,
- the possibility of offering balancing energy without providing capacity,
- or the effect of the use of technology specific products.
- the ability for external bids to be issued into the market.

Market liquidity is intimately linked by aspects of the market functioning like the **number and homogeneity of market participants** (entrants vs. incumbents vs. cross-border) and **types of bids.** However, it is difficult to assess these features of a market using a model, or by its results. Instead, the **average price levels and/or the overall amount of balancing capacity and energy**

costs of several market designs implemented can be compared to determine their level of liquidity. An increase in the number of market participants, and therefore, the level of competition in the market, should result in lower average prices and overall payments for upward balancing capacity and energy and higher ones for downward balancing capacity and energy. Having products with a large number of characteristics shall probably decrease the level of liquidity in the market since it leads to market fragmentation according to, for example, where in the electricity system (e.g. on which voltage level, etc.) the services are delivered in case of activation (when having in mind aggregators in the future), or which type of technology is behind the different bids/activations (e.g. primary fuel type for generation, or type of storage technology). Some kind of "diversity" of market participants can be described in a market, but it is unlikely to be determined by a model.

Features like the **lead time for data publication** and **online availability** of results can be hardly determined with the help of a model, so it is not possible to compute the level of *market transparency* with models.

The *global coherence of market designs* concerns the harmonisation of prequalification criteria, balancing products being traded, the timing of markets and gate closures, and the avoidance of priority schemes applied to national vs. cross-border bids. The **heterogeneity of local markets in terms of these features** cannot be evaluated using models. This can be determined ex-ante via assumptions only or through direct observation of real life markets. The lower the number of different features of markets, the more coherent the markets schemes applied are geographically speaking. The compatibility of the participation of agents in balancing markets, as Balancing Service Providers (BSP) or Balancing Responsible Parties (BRP), with their participation in other markets – like energy ones – can be measured by the ability of **revenues or payments faced by BSPs/BRPs, due to the balancing services they provide or they have to buy, not to be negatively affected by an increase in the participation of these agents in other markets.** If, for example, the participation in energy market of BRPs rises significantly balancing costs faced by them, because of the limitations of existing balancing markets, then this balancing market design is less appropriate than another one, where balancing costs faced by the same BRPs are lower. Also, the other way around, the larger the reduction of revenues in energy markets caused by the participation of BSPs in balancing markets, the less efficient this market scheme may be.

Implementability

To assess the implementability of a balancing market design, meaning *compatibility with existing regional regulation, legislation and policy objectives* (Framework Guidelines, Network Codes of EB and LFC&R, etc.) the only possibility is to have a look at the **deviation between the concerned market scheme and path of implementation and the designs and timelines proposed in the Framework Guidelines or Network Codes on Energy Balancing by ACER.**

3.5 Short term effects of RES support schemes

In this section, the KPIs proposed correspond to the qualitative criteria used for assessing the short-term effects of RES support schemes (Chapter 6 in D3.2).

3.5.1 Quantitative KPIs associated to the qualitative assessment criteria

Table 9: KPIs defined for the assessment of the short term effects of RES support schemes

Assessment criteria for participation of RES-E generators in short term markets		KPIs (quantitative)
Efficiency	(Marginal) cost reflectivity	- Difference between overall revenues earned by RES generation and the short term marginal value of energy produced by these generators. - Occurrence of negative prices - Volume of RES based Market Orders (for RES vs. total)
Efficiency	Cost causality	- *N/A*
Efficiency	Liquidity	- Total volume of offers by RES generators traded in the short term market over a given period - Short term market depth (min, max, average) over a given period - Where applicable, bid & ask spread (min, max, average)
Efficiency	Global coherence (spatial and temporal)	- Difference in RES-support per MWh in different countries.
Robustness		- Changes in the efficiency of the support mechanism in the short term (inversely proportional to the aggregate difference between prices earned by RES generation and short term marginal supply costs) with changes in the system conditions (among scenarios or operation hours).
Implementability	Compatibility with existing regulation/principles and markets	- Number and relevance of changes to be made to existing regulation to adapt it to the considered scheme.
Implementability	Relevance of barriers faced by RES operators for their participation in markets	- *Difficult to assess quantitatively*
Implementability	Level of use of funds from the public (State/local government) budget	- Amount of funds from the public budget being used. Needs to be determined beforehand, which costs are covered by public funds.
Implementability	Cost efficiency	- Level of global earnings of RES generation in all markets and through all schemes implemented, including support ones, per unit of RES generation installed.
Fair-ness	Stability of support payments	- *Difficult to assess quantitatively*

3.5.1 Definition and explanation of the quantitative KPIs

In this section, the KPIs defined within Table 9 for the assessment of RES support schemes with respect to their effects in the short term are explained in text including the idea underlying these KPIs and how to use them.

Efficiency

- **(Marginal) Cost reflectivity**

Three main KPIs have been identified in order to assess the short term (Marginal) Cost reflectivity of the different options for support schemes of RES generation.

The first consists of assessing the **difference between overall per unit energy revenues earned by RES generation and the short term marginal value of energy produced by these generators.** The short term marginal value of energy produced by RES generators correspond to the overall costs incurred by the system in the short term (operation timeframe) in order to supply one extra MWh of energy of the same type in the corresponding node or area. These costs certainly include marginal energy production costs and the cost of extra emissions (mainly, CO2 ones) caused when supplying this extra unit of energy. But marginal supply costs to be considered here, which should drive RES revenues in the energy market, may, or may not, also include the extra payment required to achieve that the extra unit of energy supplied in the considered node or area is produced by the concerned RES generation technology. This mainly depends on whether the production of a certain amount of energy by RES generators of each type defined (technology, or group of technologies) has been set as an objective of system operation in the timeframe concerned (the dispatch timeframe) in order to accelerate the development of immature RES generation technologies.

- If producing a certain amount of energy in the short term (i.e. in the timeframe of the dispatch) using certain, immature, RES generation technologies is deemed necessary to achieve a sufficiently rapid development of these technologies, then, energy production by these technologies should be supported by the minimum extra payment required to reach the aforementioned short term level of production. In this case, minimum RES energy support payments required by this generation to achieve its energy production objective would make part of the short-term value for the system of energy produced by these technologies, together with local marginal variable production and emission costs.
- However, the acceleration of the development of these, immature, technologies to be supported may need to be driven by the installation of a sufficient amount of capacity of them, or by the production of a certain amount of energy by these technologies in a longer timeframe than the dispatch one (for example, a certain amount of electrical energy needs to be produced by these technologies over the whole year). Then, support to these technologies should be linked to the installation of generation capacity of these technologies or to the achievement of the overall, long-term, energy production objective,

respectively. Then, support payments should not be considered part of the short-term marginal value for the system of energy produced by these technologies.

The second KPI consists of measuring the **occurrence of negative prices**, and can be simply computed as the number of hours with negative prices over a given period. Negative prices – assuming they are caused by RES subsidies (as opposed to the unlikely cases of incompressible traditional generation) – evidence an inefficient market reaction to a given subsidy scheme. This subsidy forces overproduction of RES-based energy that is offered and sold in the market at a price largely below its variable production cost.

The third KPI is the **volume traded in the short term market that is brought by RES operators.** This can be calculated by computing the proportion of the volume of offers submitted by RES operators over the total volume of orders submitted to the market, and is expressed as a percentage. A large share means that RES operators bring liquidity into the market, which in turns facilitates the price discovery around the system marginal costs. On the contrary, a small share implies that RES operators are neither contributing to, nor benefiting from, the liquidity of the market. Consequently, it is questionable whether the market adequately reflects the system marginal costs.

- **Liquidity**

Liquidity is a term widely used to characterize the ability and facility to transact on a given market. However, liquidity is typically used as a generic term without proper measurement. The liquidity of a market is intimately linked to the reliability, or stability, of prices resulting from this market. This, in turn, depends on the volume of offers in the market and the variability of this volume. Liquidity of existing markets (energy and capacity ones) may be affected by RES support schemes applied. This is because some RES support schemes encourage agents to participate in markets, while other schemes do not because, when applied, they make revenues of agents independent of market conditions. In order to quantify the liquidity of a given market, the following indicators are proposed:

- **Total volume of offers by RES generators** traded over a given period in short term markets (Unit = MWh). A RES support scheme that results in a large participation of RES generation in short term markets is encouraging the participation of these generators in short term markets. Measuring the total traded volumes means measuring the volumes of trades that have been transacted on a market. This gives an indication on the appeal of a market since markets with high volumes of transactions are likely to be attractive markets.
- **Short term market depth** (min, max, average of volumes offered in the market, unit = MWh) over a given period. The short term market depth is the measure of the total volume that is available for trade in the short term. Indeed, at a given moment, taking a snapshot of an order book, the total volume available for trading (i.e. the total number of unmatched orders – whether in a continuous or in an auction market) gives a rough estimate of how much additional volume is available, should e.g. a trader need additional

volumes for some reason. Consequently, a deep market is a much more attractive market. To analyse market depth over a given period (as opposed to using a snapshot), the typical approach is to use minimum, maximum and average values.

- Where applicable, **bid & ask spread** (min, max, average, unit = €/MWh). Bid and ask spreads is only relevant for continuous markets. At a given moment (snapshot), the bid & ask spread is computed as the difference between the price of the best bid and the best ask orders. In case the bid and ask spread is high, it can be assumed that the market price at this very moment is not precise (it lies somewhere between the best bid and the best ask prices), and consequently, the price for closing a position is at best unknown, at worst expensive. On the contrary, when the bid & ask spread is low, closing a position can always be done at a defined price. Therefore, a low bid & ask spread is a good measure of the attractiveness, and therefore the liquidity, of continuous markets.

Robustness

As for the long term effects of RES support schemes, the robustness of the effects on system efficiency produced by these schemes can be measured along several dimensions. Thus, when measuring the robustness of the impact of a RES support scheme on the marginal cost reflectiveness of short term markets, one may be measuring how differences between marginal short term energy revenues of RES generation and short term marginal supply costs change with changes in the system conditions (among scenarios or operation hours).

Implementability

- **Compatibility with existing regulation/principles and markets**

This is to be measured as the number and relevance of changes to be made to existing regulation to adapt it to the considered RES support scheme. This is not a KPI to be computed with the help of models.

- **Level of use of funds from the public (State/local government) budget**

This corresponds to the amount of funds from the public budget that are being used to support RES generation. For most RES generation support schemes, support can either be drawn from the public budget or from electricity tariffs. Thus, the level of use of public funds concerns an implementation decision more than the features of most specific support schemes. This has been considered within the short term, but could perfectly be dealt with in the long term discussion of support schemes.

- **Cost efficiency**

Analogously to the case of the amount of public funds mobilized through an scheme, this feature of support schemes has been considered within the short term, but could perfectly be dealt with in the long term discussion of support schemes. Cost efficiency refers to the ability of a scheme to achieve the objectives set for it, in terms of the deployment of RES generation, while minimizing the overall amount of revenues earned by this RES generation. This KPI is to be computed as the aggregate (sum) of earnings of RES generation in all markets and through all schemes implemented, including support ones, per unit of new RES generation deployed. Note that cost efficiency does not have to do with overall system efficiency, which is measured as the overall net revenues of all agents in the system, and not only RES generation. The cost efficiency of a scheme is closely linked to its implementability because transferring large amounts of funds to RES generation through this scheme is likely to become unpopular, and therefore result in opposition to the implementation of this scheme.

4 Conclusions

In this report, main assessment criteria identified in D3.1 and D3.2 within the Market4RES project have been associated with Key Performance Indicators useful in quantitatively assessing the performance of design options for pending developments in short and long term markets required to integrate massive amounts of RES generation.

For each aspect of the functioning of markets previously defined, KPIs associated with each main assessment criterion are listed in the form of tables. Then, KPIs are described in text to provide the reader with the idea underlying them and explain how they should be used. The basic aim of this report is providing the reader in general, and subsequent WPs in the project, with KPIs they can effectively use to compare the several design options that have been identified within the WP.

Given that the purpose of this report is defining KPIs of general applicability, not only those to be used in WP4 and WP5 analyses within the project are defined and explained. However, the former are given a more relevant treatment than the rest of KPIs defined. Similarly to what has been carried out within previous conceptual analyses, market developments for which KPIs are defined have been classified into long and short term ones, though KPIs for options for the participation of demand in short and long term markets have been jointly discussed in a single section.

For some aspects of system functioning and assessment criteria, several KPIs have been defined. Different KPIs referring to the same criterion aim to assess the performance of market design options, with respect to this criterion, making use of different system variables, and sometimes are related to different dimensions of the performance of these design options.

Annex: Assessment criteria defined for electricity market designs

The following is a table providing which main assessment criteria were identified within Tasks 3.1 and 3.2 for the conceptual assessment of market design options. Based on these criteria, KPIs have been identified, since all KPIs identified are associated with one of these criteria.

Table 10: Assessment criteria for pending market developments

	MARKET DEVELOPMENTS	GROUPS OF ASSESSMENT CRITERIA				
		Efficiency	*Effectiveness*	*Robustness*	*Implementability*	*Fairness*
LONG TERM	**CRM**	YES	YES	YES	YES	YES
	RES support LT and ST	YES	YES	YES	YES	YES
	DSM LT and ST	YES		YES	YES	YES
SHORT TERM	**Cross border products**	YES			YES	
	Network representation	YES		YES	YES	YES
	Timing of markets	YES		YES	YES	
	Bidding protocols	YES		YES	YES	
	Balancing	YES			YES	