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Methodological improvements of Resource Adequacy Assessments

Work package 2
Final Report 1

Overview of existing methods to determine demand side response (DSR) potentials

Study on behalf of the
German Federal Ministry for Economic Affairs
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Overview of existing methods to determine demand side response (DSR) potentials

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List of Abbreviations

BRP	Balancing responsible party
DAM	Day ahead market
DSR	Demand side response
EENS	Expected energy not served
ERAA	European resource adequacy assessment
EVA	Economic evaluation assessment
LOLE	Loss of load expectation
MR	Market response
Penta-Forum	Pentalateral Energy Forum
RAA	Resource adequacy assessment
TSO	Transmission system operator
UCED	Unit commitment and economic dispatch
VRE	Variable renewable energy

1 Introduction

Resource adequacy assessments (RAAs) are performed to assess the overall adequacy of power systems to meet current and projected electricity demand. RAAs can be used to identify potential resource adequacy issues and to develop mitigation measures to ensure and maintain a reliable electricity supply over the period covered by the RAA.

Demand side response (DSR) can support the adequacy of power systems. By reducing electricity consumption of end-users through load shedding or load shifting during periods of supply scarcity, the need for dispatchable power plants, storage and transmission capacity can be reduced. Furthermore, by shifting electricity consumption to periods of high electricity generation from variable renewable energy (VRE) resources such as wind or solar, DSR can support the integration of VRE significantly.

By reducing the need for investments in new generation, storage and transmission capacity and limiting curtailment of VRE, DSR can lead to considerably cost savings for the electricity supply. An accurate representation of DSR within RAAs is therefore crucial when assessing the current and future resource adequacy of power systems and developing mitigation measures for potentially identified resource adequacy issues that contribute to the social welfare.

The objective of this report is to provide the basis for the development of recommendations and guidelines for DSR potential assessments that aim to provide input for RAAs conducted by member countries of the Pentalateral Energy Forum (Penta-Forum) and beyond. The report provides an overview of existing methods used to determine DSR potentials and assesses the suitability of selected methods to provide necessary inputs to represent DSR appropriately within RAAs. Recommendations and guidelines for DSR potential assessments that provide input for RAAs in the Penta-region and beyond will be formulated in a in a separate report that follows the report at hand.

In Chapter 2 of the report at hand, the most important DSR terminology and use cases are introduced and the minimum requirements for DSR resource assessments to serve the needs of RAAs are highlighted. Afterwards in Chapter 3, an overview of existing methods used to determine DSR potentials is presented and the most relevant methods are described in more detail. In Chapter 4, the suitability of most relevant existing methods to serve RAAs is evaluated and their strengths and weaknesses discussed. Finally, in Chapter 5, conclusions are drawn and a short outlook on the subsequent report (recommendations and guidelines) is provided.

2 Analysis framework

This chapter establishes the framework for DSR potential assessments which could be used to provide input for RAAs. We first introduce the most important terms and DSR use cases. Afterwards, we describe the requirements for DSR representation within RAAs based on ACER's decision on the methodology for the European Resource Adequacy Assessment (ERAA). Based on these principal considerations, we draw conclusions for the minimum requirements of DSR potential assessments to serve RAAs in the Penta-region and beyond.

2.1 Terminology and DSR use cases

Demand-side response (DSR) is defined in Article 2 of the Directive (EU) 2019/944 as "the change of electricity load by final customers from their normal or current consumption patterns in response to market signals, including in response to time-variable electricity prices or incentive payments, or in response to the acceptance of the final customer's bid to sell demand reduction or increase at a price in an organised market".[1]

DSR is a subset of demand side management and can be categorised into implicit and explicit DSR (see Figure 2-1).[2]

- **Implicit DSR**, or "price-based" DSR**,** refers to consumers' response to price signals to reduce their electricity expenses. The change of demand by final customers from their typical consumption patterns can be triggered by static (e.g. time-of-use tariffs) or dynamic (i.e. real-time pricing) electricity tariffs and can be self-directed or directed by an energy service provider.
- **Explicit DSR,** or "incentive-driven" DSR, can be traded on different markets or participate in classical load control programs similar as other dispatchable resources. Market participation of this DSR type is often facilitated by aggregators. Explicit DSR is activated by a control signal, making it a dispatchable resource from a system operation perspective.

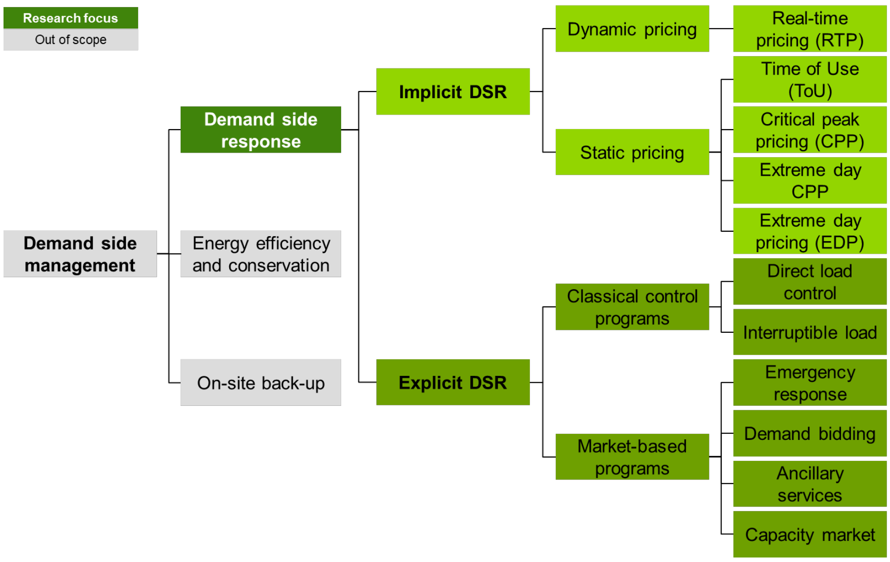

Figure 2-1: Implicit and explicit DSR as subset of demand side management.[2]

[1] EU-Directive (EU) 2019/944 Article 2.

[2] Own illustration based on Albadi, M. H., El-Saadany, E. F. (2007)

DSR can support the adequacy and flexibility of power systems from a long-term system planning and short-term system operation perspective. Figure 2-2 shows the time spectrum of the two DSR use cases. The limit between the use cases is somewhat blurred. Implicit DSR based on time-of-use tariffs, real-time-pricing and critical peak pricing can contribute to adequacy and flexibility of power systems due to the price elasticity of end-users and can be incorporated into system planning at different time scales. Explicit DSR, which represents dispatchable flexibility resources, can contribute to adequacy and system operation at virtually all time scales. This includes capacity and ancillary service programs that involve load reduction commitments made ahead of time, demand bidding in day-ahead and intra-day markets as well as emergency, interruptible and direct load control programs.

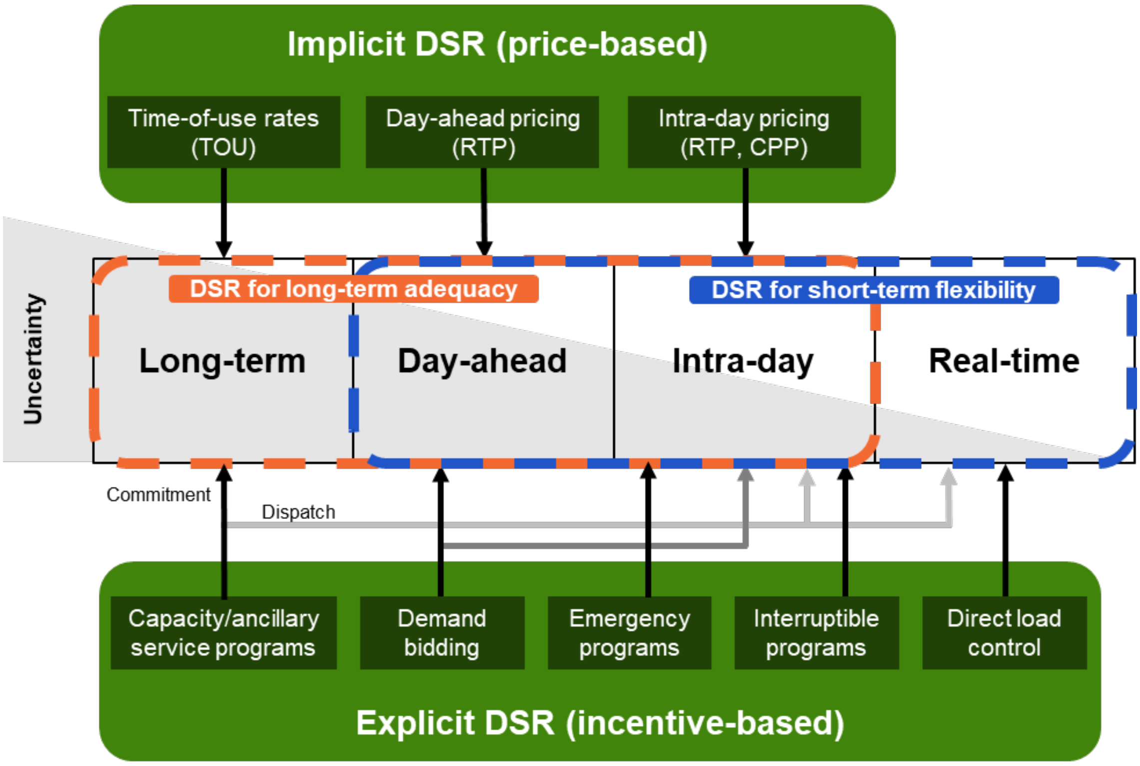

Figure 2-2 Time spectrum of the DSR use cases.[3]

DSR can function in the form of load shedding and load shifting (see Figure 2-3). Load shedding and load shifting can both support resource adequacy as electricity demand can be reduced during periods when available generation capacity and storage resources would not be able to meet projected demand.

- **Load shedding** refers to a reduction of demand for a certain time during scarcity periods which is not compensated for at a later stage.
- **Load shifting** refers to a shift of demand to an earlier or later time. It can support both, the adequacy of the power system and the integration of VRE into the system. To support adequacy, electricity demand during high (residual) demand periods is shifted to periods of low (residual) demand. To support the integration of VRE, electricity demand is shifted to periods of high VRE availability, i.e. to periods with low residual demand to limit curtailment of electricity.

To consider load shedding and shifting within RAAs, several techno-economic parameters must be assessed to describe the flexibility characteristics of the respective DSR resource

[3] Own illustration based on DOE (2006)

and its competitiveness against other flexibility options. This includes, inter alia, the available volume (MW), temporal availability, maximum duration of activation, maximum shift time, minimum lead time, minimum time until next activation and activation costs.[4] [5]

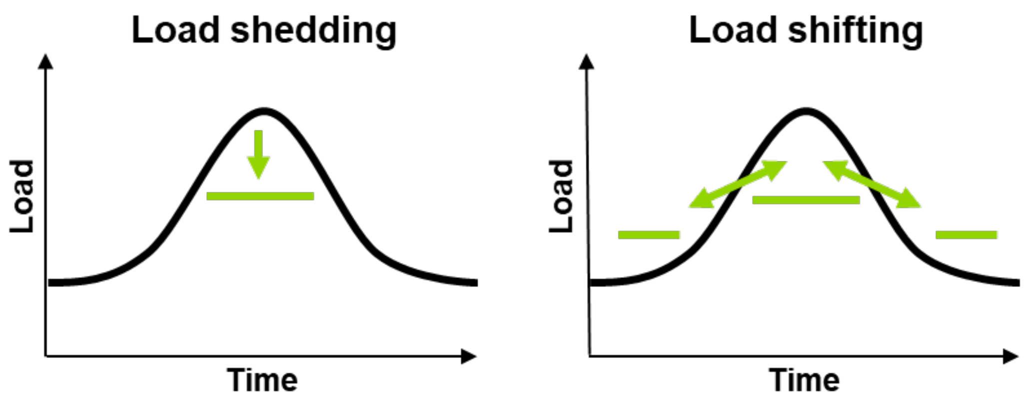

Figure 2-3: DSR categories load shifting and load shedding.

DSR potentials are typically categorised into theoretical, technical, economic and achievable potential (see Figure 2-4).[6] The respective categories can be used to describe the existing and future DSR potentials. Only the load shedding and load shifting potential that takes into account technical, economic and implementation barriers, i.e. the achievable potential, is available to support resource adequacy of power systems. In theory, the achievable DSR potential of today is equal to currently utilised DSR capacity.[7]

Changes in regulatory frameworks or compensation mechanisms, however, can rather easily shift technical DSR potentials to the realm of economic or achievable potential, especially at the 10-year horizon that is in focus of RAAs. Therefore, authorities that are responsible to prepare RAAs face the challenge to acknowledge on the one hand that some of the current technical DSR potential might become achievable DSR potential during the period covered by the RAA while on the other hand not overestimating the achievable potential in each of the individual years covered by the RAA.

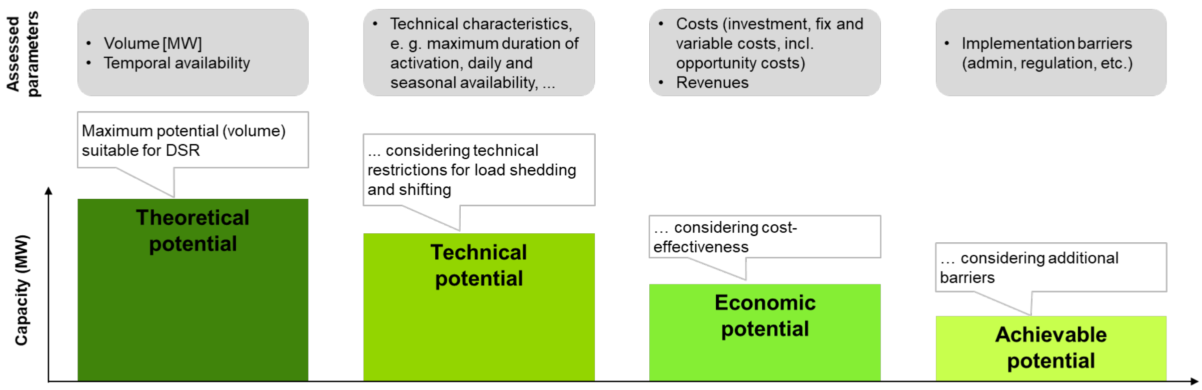

Figure 2-4: Different categories of DSR potentials.[8]

[4] TenneT (2020)
[5] Müller, T., Möst, D. (2018)
[6] Dranka G., Ferreira, P. (2019)
[7] A clear standardised term definition is lacking. The achievable potential is sometimes further categorised into subcategories or different nomenclature are used, e.g. realizable, feasible or market potential.
[8] Own illustration based on Dranka, G., Ferreira, P. (2019).

2.2 ACER's requirements for DSR representation within the ERAA

In its decision on the ERAA methodology, ACER specifies how to consider DSR when assessing the resource adequacy of the future European power system.[9] The ERAA methodology and the specific requirements for the representation of DSR and battery storage[10] within the assessment should be considered in the development of guidelines for DSR potential assessments within the Penta region.

Figure 2-5 provides an overview of the ERAA modelling framework. Resource adequacy is analysed through a Unit Commitment and Economic Dispatch (UCED) model. The UCED model is used to assess the probabilistic resource adequacy metrics Expected Energy Not Served (EENS) and Loss of Load Expectation (LOLE) over a ten-year period.

For each year of the study period, the economic dispatch of available supply, storage and DSR resources in the day-ahead market (DAM) is optimised to meet demand in each considered model zone and time-step (min. hourly). During economic dispatch optimization, unit commitment constraints of resources, transmission constraints between zones and uncertainties regarding the availability of resources and climate conditions are considered. Uncertainties of outages and climate conditions are addressed through Monte Carlo simulations. Results of the UCED model serve the Economic Viability Assessment (EVA). The EVA is used to model market entries and exits of resources and therefore determines which resources are ultimately available in the DAM in each year of the study period.

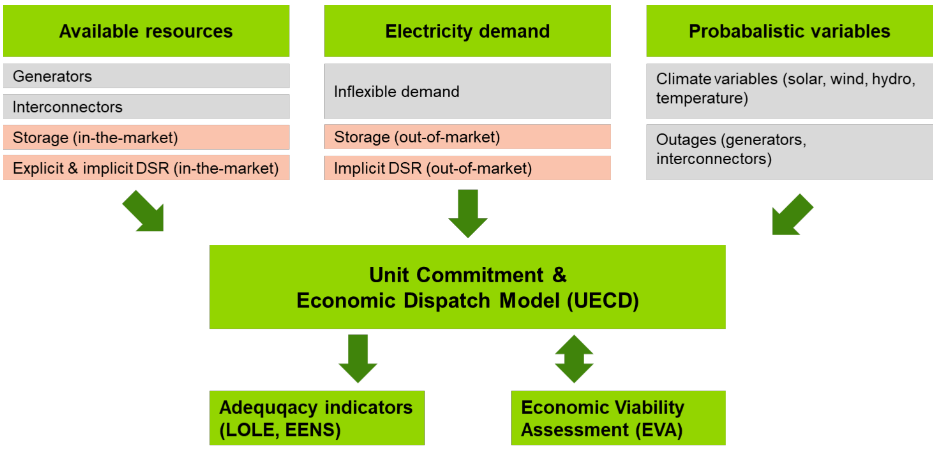

Figure 2-5: High-level overview of the ERAA modelling framework.

According to ACER, for each considered market zone and year of the RAA, potentials for load shedding and load shifting based on implicit and explicit DSR shall be considered:

- **Implicit DSR** shall reflect the demand elasticity of the DAM based on real-time electricity tariffs of final customers. In case implicit DSR is not directly linked to the DAM prices through real-time pricing, implicit DSR (e.g. facilitated through time-of-use tariffs) shall be considered "out-of-market", that is to say as not participating in the DAM, when developing the electricity demand time-series as input for the UCED model. Small-scale batteries are considered as "out-of-market" because these assets are typically managed behind the meter. Peak shaving from "out-of-market" batteries shall be considered when developing the electricity demand time-series.

[9] ACER (2020)

[10] We consider small-scale stationary batteries and battery electric vehicles (BEV) as part of the demand side. However, batteries are mentioned here explicitly as ACER addresses batteries separately (ERAA, Art. 3.5 (b)).

- **Explicit DSR** participating in the DAM ("in-the-market") need to be structured in different price and volume bands, each characterised by a i) maximum activation capacity, ii) maximum activation duration, iii) unit activation price and iv) technical activation and energy constraints. Large-scale batteries need to be modelled as "in-the-market" considering energy storage, state of charge, maximum charging/discharging capacity and round-trip efficiency.

ACER provides two options to determine DSR capacities active in the DAM and therefore available to support adequacy of the system:

- Endogenously within the EVA of the RAA, or

- exogenously as fix input parameter for the RAA.

The former option requires DSR potential and initial installed capacity for various activation prices as input for the RAA modelling framework to allow the EVA to define the installed capacity based on market entry and exit of DSR. In the latter option, the available DSR capacity in the DAM is defined exogenously, i.e. outside of the RAA.

The selected option determines what type of DSR potential needs to be assessed as input for the RAA. When the available DSR capacity is defined exogenously, the 'achievable' DSR potential is to be assessed as an input for the RAA modelling framework. Whereas, when the economic viability of DSR is determined endogenously within the EVA, rather the 'technical' potential, together with techno-economic parameters for individual DSR types, is needed as input for the RAA.

In any case, for both options specified by ACER it is crucial to consider economic and non-economic implementation barriers as accurate as possible to avoid an over- or underestimate of available DSR capacity in the period covered by the RAA.

2.3 Minimum requirements for DSR potential assessments to provide input for RAAs

Based on the above principal considerations, the following minimum requirements must be met by a methodology that assesses DSR potentials as input for RAAs in the Penta-region:

- Implicit and explicit DSR need to be reflected

- Load shedding and load shifting potentials both need to be considered

- Maximum available DSR potentials (volume) in each hour for each market zone for a ten-years study period need to be assessed

- Technical parameters determining the flexibility characteristics of individual DSR potential types need to be assessed

- Information on investment, fixed operational and variable activation costs of individual DSR potential types which determine the rank in the merit order of available flexibility options and their economic viability needs to be provided.

These requirements will be considered when assessing the suitability of existing methods to provide the necessary input for RAAs as well as in the development of new methodological guidelines and recommendations which will be presented in a subsequent report.

3 Overview existing methods to determine DSR potentials

In this chapter, we first describe our approach to identify existing DSR potential assessment methods. Afterwards, we provide an overview of the results of our desk research and group the identified methods according to methodological building blocks. In the last section, we describe the most relevant methods identified within our analysis in some more detail.

3.1 Approach used to identify existing methods

The approach to identify existing DSR potential assessment methods is composed of three steps as shown in Figure 3-1. In a first step a desk research was conducted and a tabular overview of existing DSR potential assessments was developed. Afterwards, with the help of an online survey, experts in the field were asked to complement the desk research and point to further relevant studies. Finally, a workshop was organised in which experts presented empirical studies and underlying DSR potential assessment methods and strengths and weaknesses of selected methods were discussed.

Figure 3-1: Approach to identify existing methods used to determine DSR potentials.

The literature analysed was selected to include recent studies (published within the past five years preferably), a broad range of technologies as well as a good geographic coverage of the Penta region. Overall, 49 studies were considered in the literature review and assessed regarding the methods they use, technological/sectoral as well as geographical coverage, DSR potential type and timeframe. Table A-1 in the appendix offers a full overview of the literature analysed for this report.

3.2 Results of desk research and grouping of identified methods according to methodological building blocks

Figure 3-2 provides an overview of the literature. Most studies we analysed focused on DSR potentials in industry and had a national scope. In most cases, the studies assessed the technical or economic DSR potentials and focused on the status quo rather than a longer-term future.

Sectoral coverage: Within industry, steel, metal, paper, chemistry, cement, and food were the most represented branches. DSR in residential and commercial buildings was second to industry, with heating, ventilation and cooling the most widely covered technologies in this segment. Mobility relates to electric vehicles and studies focusing on storage, Power-to-X or other applications like data centres are summarised in the category ‘Other’.

Geographical scope: Because of the framework of the project, the focus of our desk research was set on the Penta-region although some studies covering other EU-countries and the US were considered too. While nearly half of the studies have a national scope, only 20% have a cross-border coverage.

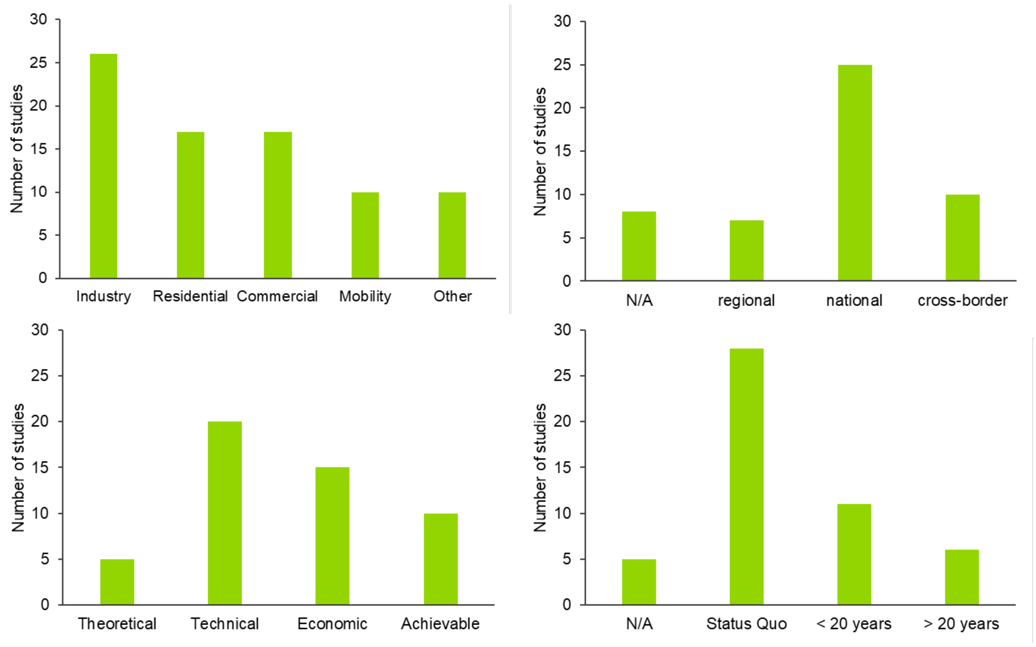

Figure 3-2: Overview of sectors (top, left), geographical scope (top, right), assessed potential type (bottom, left) and time frame (bottom, right) covered by the analysed literature.

Potential type: DSR potential assessment methods show a large heterogeneity in the definition of potentials. While the terms theoretical, technical and economic potential seem to be quite accepted, the literature partly used different names or applied subcategories for the ‘’achievable’ potential (such as ‘accepted’ ‘practical’, ‘realizable’, ‘feasible’ ‘socio-economic’ or even ‘market’ potential).[11] Technical potential is most commonly assessed, but some studies do not specify what type of potential they look at.

Timeframe: Most studies analyse the status quo of DSR potentials. This includes studies that use historical or empirical data for calculation without forecasts but also barrier analyses or publications on market design. Among studies that analyses future time periods, a time horizon of up to 20 years is most used.

With regard to the methods used to assess DSR potentials in the literature, these can be grouped through the help of “methodological building blocks”, see Figure 3-3. We used two methodological dimensions to structure our mapping:

- **Top-down vs. bottom-up approaches:** A typical methodological distinction can be made between top-down and bottom-up analyses. While top-down approaches focus on aggregated data sources and simplified modelling (aggregation by technology, industry or markets), bottom-up approaches focus on collecting data and modelling at the level of specific assets or (market) actors.

- **Technical-data vs. market-data based analysis:** Another fundamental differentiation can be made between methods that rely on an analysis of aggregated market data and methods that rely on an analysis of asset or actor specific technical data.

While the distinction between top-down and bottom-up is a widely known separation used in many fields, the distinction between technical-data and market-data based analysis is one we suggest specially for this topic. The tech-data based analyses focus on the potential and characteristics of specific DSR technologies or processes, independently of markets or mechanisms in which they provide flexibility. Market-data based analyses however focus on

[11] Refer to Dranka, G., Ferreira, P. (2019) for further reading on different terms and definitions for DSR potential.

DSR offer and the performance of DSR as revealed on specific markets and mechanisms, without insights into specific technologies.

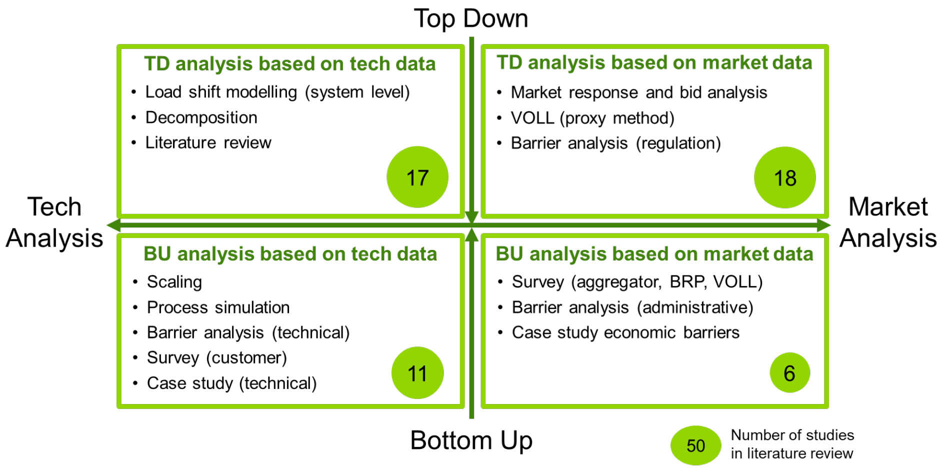

***Figure 3-3: Grouping of identified methods according to building blocks.*[12]**

Our literature review reveals a focus on top-down methods, whereby most studies use a combination of methods to assess DSR potentials. Figure 3-4 to Figure 3-7 specify and briefly describe the methods identified as part of the literature review along the dimensions of Figure 3-3. Four of the methods identified in the literature – decomposition, scaling, market response and surveys – are particularly relevant in our point of view for the assessment of DSR potentials as it would be required for RAAs. They are highlighted in boxes in the following graphs and will be described in more detail in the following section.

The scaling and decomposition method can be used to assess the current and future theoretical DSR potential (volume) which can be used as starting point to determine the load shedding and shifting potentials available to support adequacy. Surveys and market response analyses can provide insights into DSR volumes currently active in the DAM. Furthermore, surveys can provide insights into techno-economic characteristics and implementation barriers of different DSR types which are all important input parameters for RAAs.

Top-down approaches based on tech-data

Decomposition	Load-shift modelling (system-level)	Literature review
Used to determine **theoretical DSR potential** (volume). Potential derived by determining **flexible component** of total load (decomposition) of a process/ appliance. Combined with load time-series to calculate **temporal availability.** Often applied to assess DSR potential in **industry, commercial and tertiary sector**.	**Economic dispatch optimization** for a given power system incl. DSR resources. Can also be combined with an investment model. **Requires** DSR volumes, technological characteristics and costs as **input from other methods.** Applied to **analyse the value of DSR** to support resource adequacy or flexibility of power systems **and its competitiveness** to other resources from a system perspective.	Mainly used to determine **technological characteristics and costs of DSR** to supplement other methods. In some of the analysed references, assumed DSR potentials (volume) are entirly taken from other studies.

Figure 3-4: Overview of identified methods considered as top-down approaches based on tech-data.

[12] Adding up the number in the quadrants adds up to more than the total number of analysed studies, because some studies combine different methodological instruments and were therefore double counted.

Bottom-up approaches based on tech-data

Scaling	Process simulation	Survey, barrier analysis, case study
Used to determine **theoretical DSR potential (volume)** based on installed capacity and temporal use-pattern of specific processes or appliances. Results for single units **scaled to national level** considering market deployment. Often used to determine theoretical DSR potentials for **electric vehicles and heat-pumps**.	**Detailed simulation** of specific processes/appliances to assess **technical potential** and characteristics (incl. load shifting capabilities). **Results difficult to aggregate** on a country level because many parameters are very specific to a given technology and environment (e. g. isolation characteristics and thermal inertia of the building).	**Stated choice surveys or interviews** (also contingent valuation/ conjoint analysis) to determine a customer's willingness-to-pay, willingness-to-accept and trade-off preferences. **Barrier analysis** to assess technical restrictions given by the operation patterns and limitations of a process. **Case studies** to investigate economic parameters relevant for flexibilisation or to cover special events like power outages or peaking prices.

Figure 3-5: Overview of identified methods considered as bottom-up approaches based on tech-data.

Top-down approaches based on market data

Market response and bid analysis	Value of lost load (proxy-method)	Barrier analysis (regulation)
Evaluates **existing DSR volumes** based on historic market data. **Covers different methods** based on the market bidding and responses on spot market, balancing market or other flexibility mechanisms. Used methods incl. **market response analysis,** bid ladder analysis, analysis of ancillary services, voluntary balancing analysis, elasticity analysis.	Evaluates the **maximum electricity price that customers are willing to pay** to avoid a supply interruption. **Does not allow to determine DSR volume** by itself but can complement other methods. **Use of macroeconomic data** (e. g. GDP, electricity consumption) to estimate **value of lost load**.	Focuses on **regulation framework** in the considered markets. **Does not allow to determine DSR volume** by itself. **Can complement other methods** to get insights regarding achievable DSR potentials.

Figure 3-6: Overview of identified methods considered as top-down approach based on market data.

Bottom-up approaches based on market data

Survey	Case-Study (economic)	Barrier analysis (administrative)
Survey and interviews with **aggregators, BRP and grid connected parties** to get insights in type of DSR resources and their capacity and to infer response patterns and/or perceived barriers of flexibility providers. **Focus on active DSR resources** operating in the market rather than on future potentials.	Investigation of market-related barriers for flexibility providers. **Does not allow to determine DSR volume** by itself but can complement other methods to get insights regarding achievable DSR potentials.	Focuses on **administrative issues** for DSR resources. **Does not allow to determine DSR volume** by itself but can complement other methods to get insights regarding achievable DSR potentials.

Figure 3-7: Overview of identified methods considered as bottom-up approaches based market data.

3.3 Description of selected methods

The following section describes the fours methods identified as particularly promising in more detail:

3.3.1 Decomposition method (Top-Down/Tech-Data)

Use case: The method is often used to approximate the theoretical DSR potential (volume) of entire branches/sectors based on annual electricity consumption.[13] [14] [15] This top-down method uses published aggregated statistical data for entire sectors to calculate current and future potentials.

Functioning of the method: Figure 3-8 shows the functioning of the decomposition method with the help of a flow-diagram. The theoretical DSR potential for individual branches of the industry sector or relevant processes/appliances in the tertiary and residential sector is calculated on an hourly basis using the decomposition method. In the case of industry, annual electricity consumption of a certain branch (e.g., the steel industry) is calculated by multiplying annual production (kt/y) with the average specific electricity consumption required to produce. For the tertiary or residential sector, annual electricity consumption of a certain process (e.g. air conditioning in the tertiary sector) is derived from the share of the specific process in total electricity consumption of the sector. By using typical hourly load profiles and assumptions on full-load hours, the hourly electricity consumption for the respective DSR application is then calculated. The theoretical hourly DSR potential is derived through decomposition, i.e. by assuming a certain share of the electricity consumption is flexible. Future DSR potentials can be approximated by making assumptions on future production as well as on developments for process efficiencies and full load hours.[16]

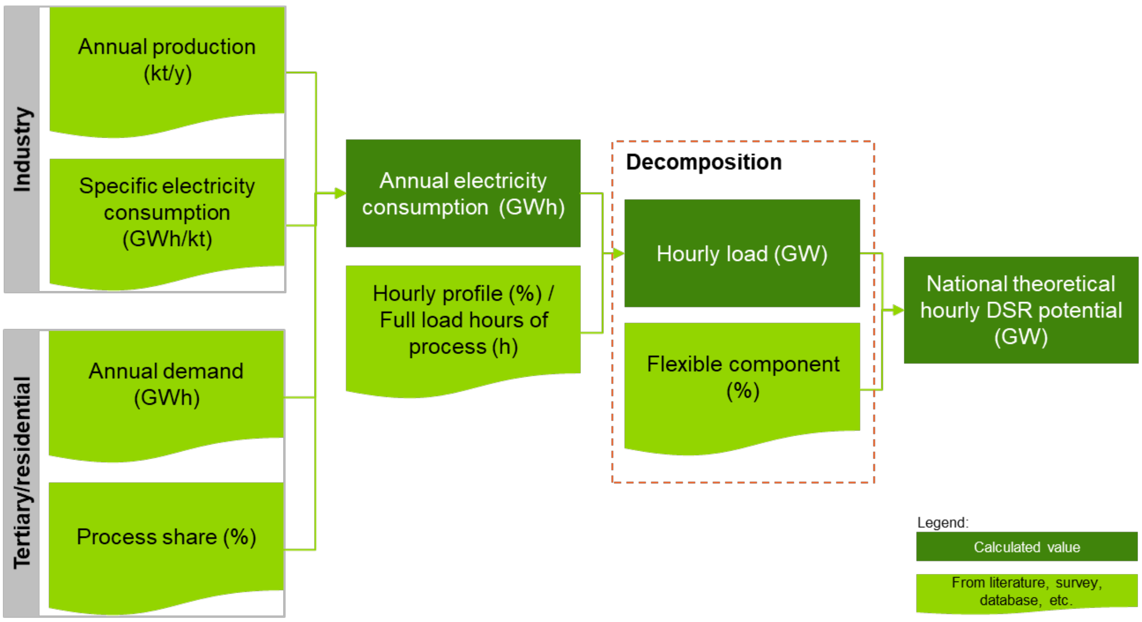

Figure 3-8: Decomposition method to determine national theoretical hourly DSR potential.[17]

[13] Gils, C. (2014)
[14] Gruber, A-M. (2017)
[15] Heitekoetter et al. (2021)
[16] Müller, T., Möst, D. (2018)
[17] Own illustration based on Gils, C. (2014)

Figure 3-9 shows how the technical DSR potential for load shedding and load shifting can be derived from the hourly theoretical DSR potential determined through the decomposition method. Technical characteristics required to determine the technical DSR potential can be derived from literature, surveys, and databases.

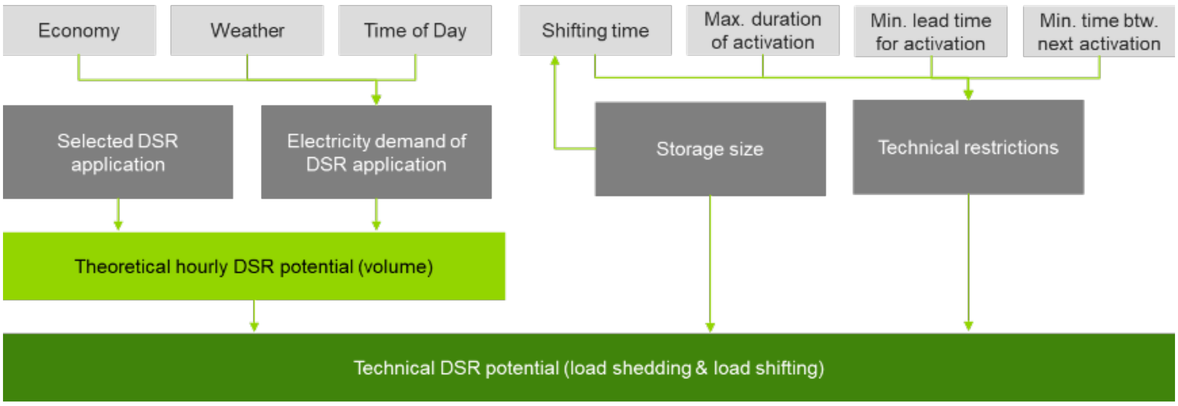

Figure 3-9: Components determining the theoretical and technical DSR potential.[18]

Limitations: Without the combination with other methods, the decomposition method does only allow to determine the theoretical DSR potential (volume). Techno-economic parameters which describe the flexibility characteristics of the respective DSR resource and its competitiveness against other flexibility options must be derived from other methods, e.g. from surveys or literature review. This additional information is a prerequisite to derive the technical and economic from the theoretical DSR potential. The decomposition method only partially allows to distinguish different DSR types – to do so, disaggregated data needs to be available, e. g. figures on production and specific energy consumption per industrial process. This may not always be the case, in particular for niche industries, complex processes or entirely new DSR options that might be available in the future. Furthermore, the heterogeneity of individual processes can't be captured by the method due to the usage of aggregated and representative data.

3.3.2 Scaling method (Bottom-Up/Tech-Data)

Use case: The method is often used to approximate the theoretical hourly potential for a specific appliance, such as electric vehicles or heat-pumps.[19] [20] [21] [22]

Functioning of the method: The scaling method is quite similar to the decomposition method but operates inversely: instead of using a top-down approach based on aggregated sector data, the scaling method calculates the hourly electricity consumption bottom-up for a single asset using asset/technology specific data. Based on the market deployment of the specific asset type, the national theoretical hourly DSR potential is calculated (see Figure 3-10). Future theoretical DSR potentials can be approximated by making assumptions on market deployment and technological development. The hourly technical load shifting potential can be derived as shown in Figure 3-9, i.e. considering technical parameters that constraint a potential load shift.

[18] Own illustration based on Müller, T., Möst, D. (2018)
[19] Ladwig, T. (2018)
[20] ELIA (2021)
[21] Heitekoetter, W. et al. (2021)
[22] Nitsch, J. et al. (2012)

Limitations: A limiting factor of the method – similar as for the decomposition method – is that without additional methods only the theoretical DSR potential can be assessed. The heterogeneity of various DSR options is another limiting factor. Scaling is most suitable for homogenous groups of DSR option (e. g. home appliances, such as heat pumps), which ensures that the analysed technical unit is representative for the entirety of DSR options.

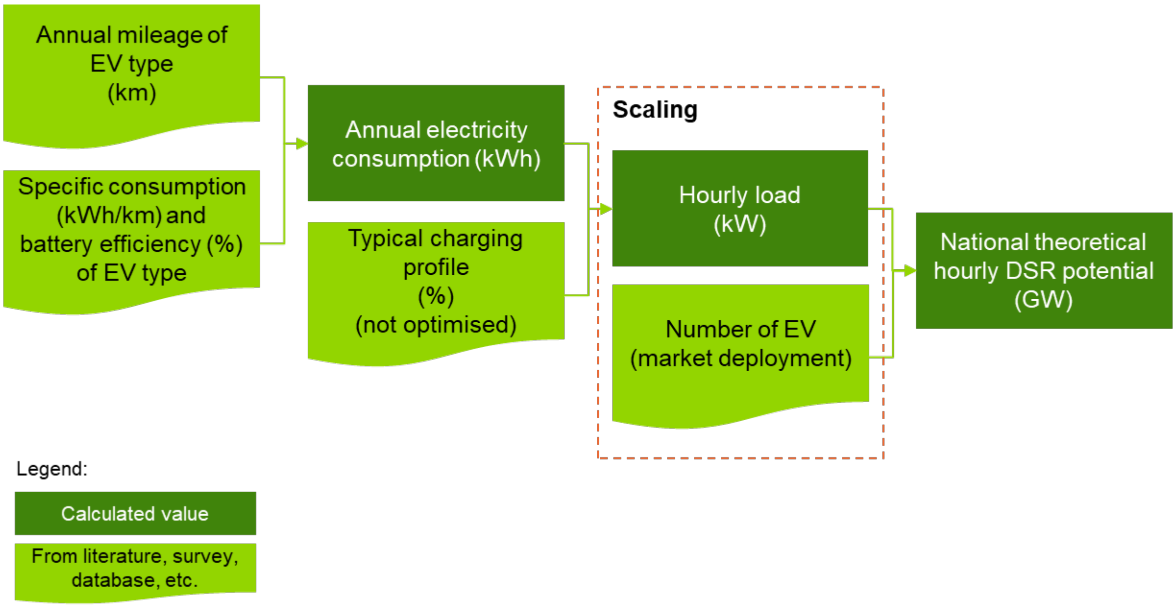

Figure 3-10: Scaling method to calculate the national hourly theoretical DSR potential of specific DSR appliances (example electric vehicle).

3.3.3 Market response analysis (Top-Down/Market-Data)

Use case: The method was developed by E-Cube Strategy Consultants in 2017 to support the Belgian TSO Elia in considering DSR in their RAA.[23] The method has been continuously updated over the years and was also used by Elia in its most recent Adequacy and Flexibility study for Belgium.[24] TenneT's day-ahead bid ladder analysis applies the same method to approximate the DSR volume active in the Dutch DAM.[25]

Functioning of the method: Market response (MR) corresponds to the response of consumers active in the DAM in periods of high prices and can be used as a proxy for current DSR in the market. The market response analysis determines current DSR volume (MW) in the DAM based on historical market data published by a power exchange (in this case EPEX SPOT). The MR volumes in the DAM can be derived from the aggregated demand and supply curves. The MR in the form of a demand decrease due to high prices can be directly analysed by studying the decrease of volume in the aggregated demand curve. However, instead of a demand decrease, MR can also appear as an offer increase in the aggregated supply (offer) curve. To exclude generation bids from the supply curve a price threshold is defined for the aggregated supply curve (> 150 €/MWh high bound, > 500 €/MWh for low bound) as shown in Figure 3-11. The MR volume (high bound) is the total volume of price sensitive bids in the demand curve (bids at a price < 3000 €/MWh) and the supply curve (bids at a price > -500 €/MWh) minus the volume of all price sensitive bids below 150 €/MWh.[26] The MR high bound, i.e. where a threshold of > 150 €/MWh is applied for the sup-

[23] E-Cube (2018)
[24] ELIA (2021)
[25] TenneT (2020)
[26] Maximum (3000 €/MWh) and minimum price (-500 €/MWh) per bid set by the power exchange (EPEX SPOT).

ply curve, represents the base case. To ensure that certainly all generation bids are excluded for the MR analysis, the threshold for the supply curve is set to > 500 €/MWh. In this case the MR volumes correspond to the lower bound (min MR volume) To provide input for RAAs, historic development MR (volume) is extrapolated for future years.

Limitations: The method is not able to distinguish between DSR in the form of load shedding and load shifting and to identify MR of individual DSR resources and their activation details. Therefore, market response analysis also includes a survey (qualitative questionnaire) to get insights from market participants regarding activation details of DSR resources (number of weekly[27] activation and maximum activation duration). DSR resources that are "out-of-market" or respond to price signals below the defined threshold are not captured. Future potential can only be determined by extrapolating historic development

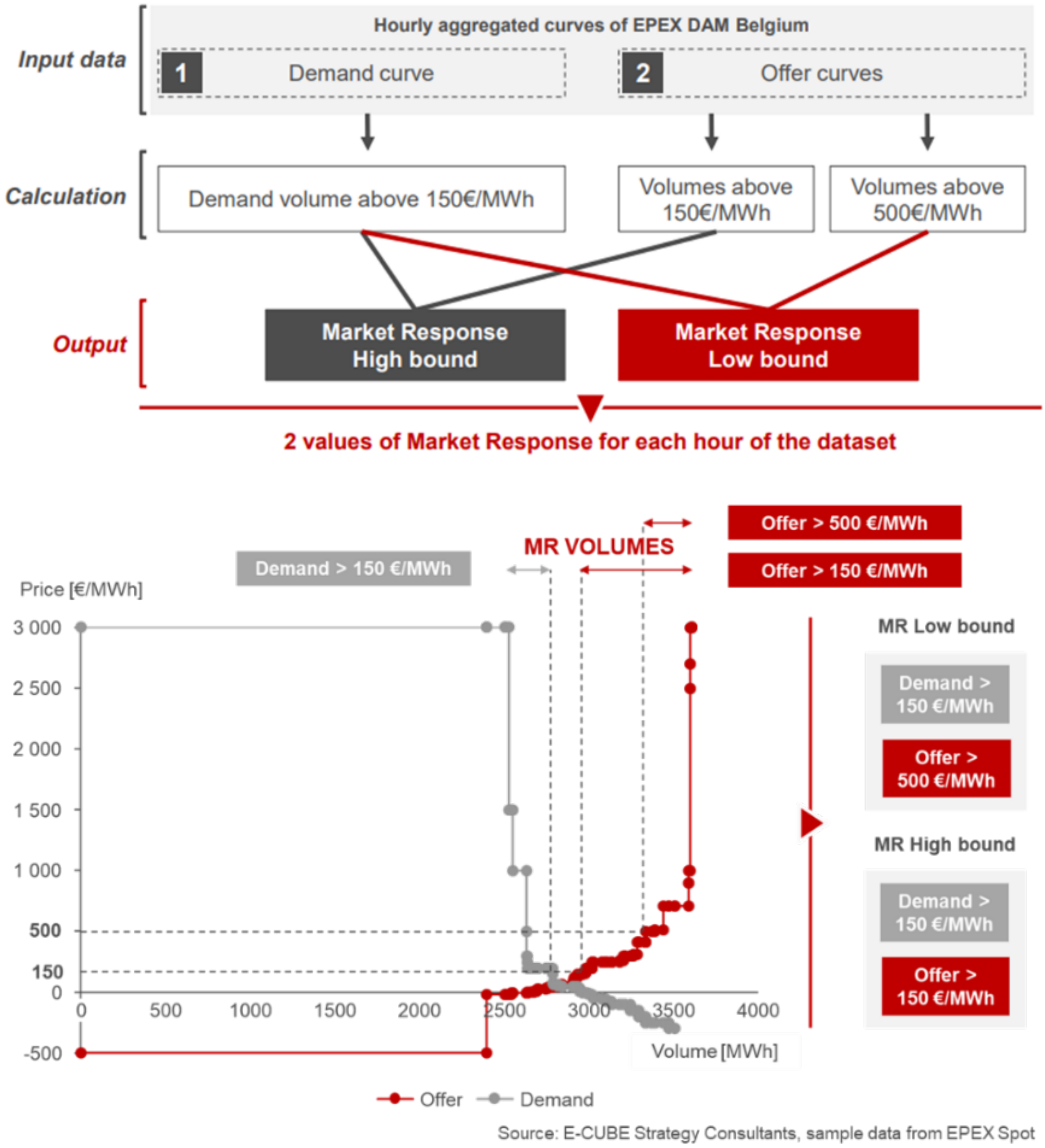

***Figure 3-11: Market response analysis to determine current DSR active in the DA market.*[28]**

[27] The UCED model that Elia uses within its RAA (Antares) separates the 8760 h of a year into weekly intervals with hourly resolution. Therefore, the number of activations peer week is an important input parameter.
[28] E-Cube (2018)

3.3.4 Surveys (Bottom-Up/Market-Data)

Use case: Questionnaire-based surveys or interviews with current (and potential future) market participants, i.e. aggregators, balancing responsible parties and grid connected parties, can be used to get insights in the type, volume, techno-economic characteristics and perceived barriers of DSR resources. Expectations of (potential) market participants regarding future developments can help to approximate future developments.[29] [30] [31] [32]

Functioning of the method: Figure 3-12 shows an example of a market questionnaire developed by TenneT.[33] The questionnaire aimed to quantify – inter alia from market participants with DSR and storage resources in their portfolio – current flexible resources that are active in the different organised markets in the Netherlands. The questionnaire included a breakdown between implicit and explicit DSR and requested the flexible capacity (bandwidth in MW) that was operational, the technology type and the market segment in which the resource is active. In addition, information was gathered on whether flexible capacity is significantly influenced by day/night or weather patterns. For practical reasons, TenneT did not seek information about other technical characteristics that are necessary as input for a RAA, such as the temporal availability of capacity, rebound effect, duration of activation or notification time. However, this is intended in future applications of the method.

Limitations: As multiple market participants have been approached, care was taken to avoid double counting of reported flexibility volumes. Low response rates and resulting limited coverage of the market represented a major issue and therefore limited the insights into available DSR capacity. Scaling DSR potentials to a national level based on a small sample size can lead to an over- or underestimation depending on the nature of the sample.

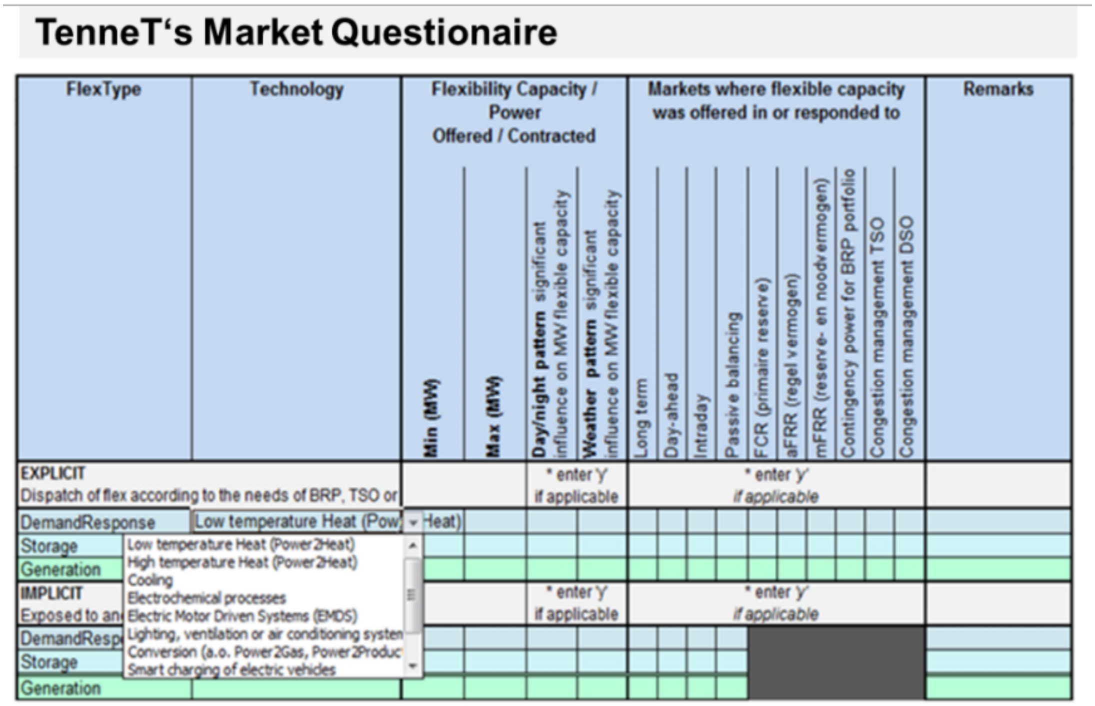

Figure 3-12: Example of a market questionnaire.

[29] TenneT (2020)
[30] Gruber , A-M (2017)
[31] ADEME (2017)
[32] Wohlfarth, K., Klobasa, M., Gutknecht, R (2020)
[33] TenneT (2020)

4 Suitability of identified methods to serve needs of RAAs

In the following chapter, we evaluate the suitability of the most promising methods used within existing DSR potential assessments to serve RAAs. We first specify evaluation criteria and apply them to the scaling method, decomposition method, market response analysis and survey. Afterwards, we point out strengths and weaknesses of these methods based on the results of the evaluation.

4.1 Applied evaluation criteria

The suitability of the scaling method, decomposition method, MR analysis and surveys are evaluated with a set of evaluation criteria. The evaluation criteria ensure that all aspects relevant for RAAs are covered. Therefore, the minimum requirements identified in our analysis framework (see section 2.3) are considered when defining the evaluation criteria. In addition, feedback from our expert workshop, SG2 meeting and online survey is considered.

Nine different evaluation criteria, presented in Figure 13, have been determined, which are clustered into three categories:

- **Coverage:** 1) Is the method able to determine future DSR potentials? 2) Does it allow to distinguish between different DSR types? 3) Is it able to cover multiple technologies, appliances and sectors?
- **Accurate representation of the DSR potentials in the RAA modelling framework:** 4) Does the method provide insights into technical characteristics of DSR types? 5) Does the method provide insights into costs of DSR types? 6) Does it provide insights into the price-elasticity of end-users? 7) Is the method able to accurately identify DSR potentials?
- **Applicability:** 8) Is the method transferable to other countries/applicable to the whole Penta region? 9) Is the method easy to use, and can it be implemented with moderate efforts (e.g., due to readily available data)?

The identified methods are semi-quantitatively evaluated against these criteria based on a three-point scale; from 1, the criterion is not met, to 2, the criterion is partly met, to 3, the criterion is met.

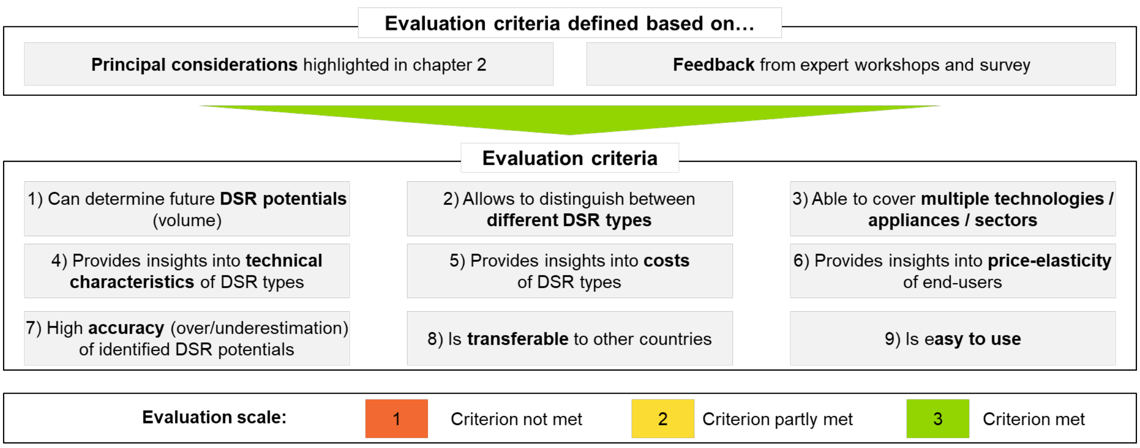

Figure 13: Evaluation criteria for the DSR potential assessment methods.

4.2 Strengths and weaknesses of evaluated methods

The results of the semi-quantitative assessment are shown in Figure 14. The evaluation results indicate that each of the methods displays strengths and weaknesses in different areas. In the following the strengths and weaknesses of the four assessed methods are discussed along the applied evaluation criteria.

		Scaling method	Decomposition method	Market response analysis	Surveys
Coverage	Can determine future DSR potentials (volume)	3	2	1	2
	Allows to distuingish between different DSR types	3	2	1	3
	Able to cover multiple technologies / appliances / sectors	2	3	1	2
Accurate representation	Provides insights into technical characteristics of DSR types	2	1	1	3
	Provides insights into costs of DSR types	1	1	2	3
	Provides insights into price-elasticity	1	1	3	2
	High accuracy (over/underestimation) of identified DSR potentials	2	2	2	2
Applicability	Is tranferable to other countries	2	3	3	2
	Easy to use	2	2	3	1

1 Criterion not met; 2 Criterion partly met; 3 Criterion met

Figure 14: Evaluation of the selected DSR potential assessment methods.

The scaling method performs well in the category 'coverage' as the method can be used to determine future DSR potentials by assuming a certain deployment rate for the respective DSR type over time and can be applied to all kinds of existing and entirely new DSR options in different sectors. In the category 'accurate representation in RAA modelling framework' the scaling method performs less well. Without supplementary methods, the scaling method can only be used to determine the flexible capacity for a DSR option., i.e. the theoretical DSR volume. The method provides only limited insights into technical characteristics which determine the flexibility constraints of a DSR resource. Without additional methods, no insights into costs of DSR options and price-elasticity of end-users can be derived. The accuracy of the method in terms of over/underestimation of DSR potentials is limited in that sense that the scaling method provides accurate results only for homogenous DSR options like heat-pumps or electric vehicles when scaling DSR potentials from the specifically analysed unit to the national potential. In terms of 'applicability' the scaling method performs not as good as the decomposition method and especially the market response analysis. Mainly because the method requires granular and precise data on a certain DSR option, which is often not readily available. Required data must be developed for each individual DSR option that shall be included in the potential assessment which limits the number of DSR types that can be included in the assessment. This limits the method's applicability considerably.

The decomposition method performs relatively well in the category 'coverage', especially as the method can be used for various sectors and technologies. One disadvantage is that – in contrast to the scaling method – DSR potentials for currently not existing DSR options cannot be assessed, simply because aggregated production and electricity consumption data and representative utilisation patterns do not exist yet. The same is true for niche industries and processes which are not explicitly covered in statistics for entire sectors or branches. In the category ‘accurate representation in RAA modelling framework’ the decomposition method performs poorly, due to the same reasons as the scaling method. Compared to the scaling method, the decomposition method provides less insights into technical characteristics due to the applied top-down approach based on aggregated data. The heterogeneity of individual processes cannot be captured by the method due to the usage of aggregated and representative data which limits the accuracy of the method. The decomposition method performs well in the category ‘applicability’. The method is easily transferable to other countries as the required aggregated data, especially for major industries and processes are typically available in national statistics.

The market response analysis performs weakly in the category ‘coverage’. Future potentials can only be determined by extrapolating historic development. Consequently, the method is not able to consider new DSR options that currently do not exist or are not yet reflected in the market that is analysed. The market response analysis can only assess DSR that is currently operating in the DAM, which means potentials that are technically available but cannot participate due to regulatory barriers are overlooked. The method cannot distinguish between individual DSR resources because bids in the DAM are anonymised. DSR resources that are “out-of-market” or respond to price signals below the defined threshold are not captured. This needs to be kept in mind when interpretating the results. In the category ‘accurate’ representation in RAA modelling framework’ the method performs poorly as it provides no insights into the technical characteristics of DSR resources. In contrast, the method provides valuable insights into the price-elasticity of DSR operating in the DAM. The market response analysis outperforms all other methods in the category ‘applicability. The method is very easy to use in terms of data availability because required data is readily available for download from power exchanges’ websites (e.g. EPEX SPOT). As DAM functioning is similar across the Penta-region the method is very transferable to other countries.

Surveys perform well in the category ‘coverage’ because an appropriately designed survey can cover multiple technologies and sectors. Information for individual DSR types and expectations regarding future developments can explicitly be requested from respondents. However, care should be taken when interpreting results for future DSR potentials derived from surveys. Respondents may lack experience with new technologies and have potentially inconsistent views of the future. In the category ‘accurate representation in RAA modelling framework’ surveys outperform the other methods. Surveys can be used to request both technical and economic characteristics for specific DSR types that can be used to determine the load shedding and load shifting potentials. Therefore, surveys are suitable to supplement the other assessed methods which all have in common that they can’t determine technical and economic parameters of individual DSR types if they are used isolated. A shortcoming of surveys is that respondents may have a tendency to answer strategically or to underestimate the flexibilization potential of e.g. processes due to a lack of awareness and education around how much DSR could be made available. Thereby, potential may be underestimated, and cost overestimated. In addition, surveys which are completed by non-experts without supervision may lead to lower accuracy and thereby lower reliability of the results. To cope with this issue, survey participants need to be educated on DSR potential assessments, or interviews need to be performed as a complement which makes surveys more burdensome to implement. Low response rates and resulting limited coverage can limit the accuracy of surveys when determining DSR potentials and associated techno-economic parameters. Scaling DSR potentials to a national level based on a small sample sizes can lead to an over- or underestimation depending on the nature of the sample, potentially limiting the accuracy of the method. In the category ‘applicability’, surveys are therefore outperformed by all other methods. Well-designed surveys require considerable effort and are resource intensive for respondents and those implementing the surveys alike.

5 Conclusions and outlook

The desk research and expert workshops identified the scaling method, decomposition method, market response analysis and surveys as most relevant and promising methods for DSR resource assessments that aim to provide input for RAAs. Nevertheless, our semi-quantitative assessment of the four methods has highlighted that all of them exhibit strengths and weaknesses in different areas. None of the methods can provide all DSR related inputs required by RAAs that aim to be compliant with the ERAA methodology specified by ACER.

The limitation of the assessed methods is the reason why in most existing DSR potential assessments - irrespective of whether their objective is to serve RAAs or not – typically a combination of methods is applied. Surveys and literature analysis are often used to complement other methods to determine the load shedding and load shifting potentials based on techno-economic characteristics of individual DSR types. The analysis also highlighted that the appropriate combination of methods is DSR-type specific, meaning that e. g. assessing DSR potentials in industry requires other methods (e.g. a combination of survey and market analysis) than assessing DSR potentials in the transport sector (e.g. scaling methods combined with literature review).

DSR potential assessments for RAAs in the Penta-region needs to be robust, able to cover various technologies and time horizons and should be implementable with reasonable efforts. This requires the involvement of the right stakeholders in the design and implementation of DSR potential assessments, an appropriate DSR type specific combination of methods as well as a careful elaboration on which steps of the DSR potential assessment need to be implemented frequently and which ones, e.g. more extensive surveys, can be conducted less frequently while providing valuable insights.

The way in which available DSR capacity in the DAM is determined in the RAA (exogenously defined vs endogenously within the EVA) determines what type of DSR potential needs to be assessed. When the available DSR capacity is defined exogenously, the ‘achievable’ DSR potential is to be assessed as an input for the RAA modelling framework. Whereas, when the economic viability of resources is determined endogenously in the RAA within the EVA, rather the ‘technical’ potential of DSR, together with techno-economic parameters for individual DSR types, is needed as input. Non-economic implementation barriers need to be considered in the EVA as well. Depending on the DSR potential type that needs to be assessed, a different set of methods is required.

Furthermore, data availability, recency and quality are of major importance for DSR potential assessments, irrespective of the applied method or combination of methods. Literature suggests, that even within a particular method for DSR potential estimation substantial deviations in the results may be found, depending on the input data.[34]

As a next step, recommendations and guidelines for DSR potential assessments that aim to serve RAAs in the Penta-region will be developed building on the findings of the present report and considering the specific characteristic of the Penta-region. The results will be documented in a separate report that follows the report at hand.

[34] A literature review and comparison of DSR potentials for industrial processes results based on the decomposition method using different input data may be found in Steurer, M. (2017)

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Appendix

Table A-1: Tabular overview of analysed literature

Author	Year	Title	Country scope[35]	Methods	Sectors	Timeframe
ADEME, E-CUBE Strategy Consultants, CEREN	2017	L'effacement de consommation electrique en France	FR	Load-shift modelling decomposition, literature review, survey	Industry, Commerce and Trade, Other	up to 20 years
Alstone et al.	2017	2025 California Demand Response Potential Study, Charting California's Demand Response Future: Final Report on Phase 2 Results	US (CA)	Load-shift modelling decomposition, scaling	Industry, Residential, Commerce and Trade, Mobility	up to 20 years
Berger et al.	2011	Demand Response Potential of the Austrian industrial and commerce sector	AT	Survey, literature review, decomposition	Industry, Residential, Other	Status-quo
Birrer et al.	2014	Load Shift Potential Analysis Using Various Demand Response Tariff Models on Swiss Service Sector Buildings	CH	Load-shift modelling, decomposition	Industry, Commerce and Trade, Other	Status-quo
Bundesnetzagentur	2019	Monitoringbericht 2018	DE	Survey	Industry	Status-quo
Cadmus	2018	Demand Response Elasticities Analysis	US	Elasticity analysis	Industry, Residential, Commerce and Trade	Status-quo
CE Delft	2016	Markt en Flexibiliteit- Hoofdrapport	NL	Barrier analysis, case study	Industry, Residential, Mobility	up to 20 years
CEPA	2018	Study on the Estimation of the Value of Lost Load of Electricty Supply in Europe	EU	VoLL	Industry, Other	N/A
Connect Energy Economics	2015	Leitstudie Strommarkt 2015	DE	Barrier analysis	N/A	N/A
de Bruyn et al.	2017	LoadShift: Lastverschiebung in Haushalt, Industrie, Gewerbe und kommunaler Infrastruktur Potenzialanalyse für Smart Grids	AT	Literature review, barrier analysis	Industry, Residential, Commerce and Trade, Mobility, Other	Status-quo
DNV GL	2020	De mogelijke bijdrage van industriële vraagrespons aan leveringszekerheid	NL	Survey, Market response and bid analysis	Industry	up to 20 years
Dranka, Ferriera	2019	Review and assessment of the different categories of demand response potentials	-	Literature review	-	-
E-Cube	2018	Market Response 2018	BL	Market response and bid analysis	-	Status-quo
Eid et al.	2016	Time-based pricing and electricity demand response: Existing barriers and next steps	EU	Barrier	N/A	Status-quo

[35] Country scope does not imply a national/regional scope of a potential assessment. It can also refer to a corresponding area to the analysis.

Author	Year	Title	Country scope[35]	Methods	Sectors	Timeframe
Elberg et al.	2018	Kurzstudie: Flexibilitätspotenzial von Haushalten zur netzdienlichen Reduktion von Nachfragespitzen	DE	Load-shift modelling, decomposition	Residential	up to 20 years
Elia	2021	Adequacy and Flexibility Study for Belgium	BL	Market response and bid analysis, load-shift modelling	N/A	up to 20 years
Elia	2020	Adequacy and flexibility study for Belgium 2020 - 2030	BL	Market response and bid analysis, load-shift modelling	N/A	up to 20 years
Elia, Febeliec, EnergyVille	2013	Demand Response Survey - Summary Results	BL	Survey	Industry	Status-quo
European Commission	2015	Identification of Appropriate Generation and System Adequacy Standards for the Internal Electricity Market	EU	VoLL	N/A	N/A
Feta et al.	2018	Technical demand response potentials of the integrated steelmaking site of Tata Steel in IJmuiden	NL	Load-shift modelling, Case Study	Industry	Status-quo
Gheuens	2020	Barriers to residential demand response in Belgium and the Netherlands	BL, NL	Barrier analysis, literature review, interview	Residential	Status-quo
Gils	2014	Assessment of the theoretical demand response potential in Europe	EU	Load-shift modelling, decomposition, literature review	Industry, Residential, Commerce and Trade	Status-quo
Gruber	2017	Zeitlich und regional aufgelöstes industrielles Lastflexibilisierungspotenzial als Beitrag zur Integration Erneuerbarer Energien	DE	Literature review, survey, decomposition	Industry, Commerce and Trade	Status-quo
Guidehouse, FFE, IER	2020	Energiewende in der Industrie - Flexibilitätssteckbriefe	DE	Literature review, survey, statistical	Industry, Residential, Commerce and Trade, Other	Status-quo
Heitkoetter; Schyska et al.	2020	Assessment of the regionalised demand response potential in Germany using an open source tool and dataset	DE	Load-shift modelling, decomposition, scaling, literature review	Industry, Residential, Commerce and Trade, Mobility, Other	up to 20 years
Klobasa et al.	2013	Lastmanagement als Beitrag zur Deckung des Spitzenlastbedarfs in Süddeutschland	DE (BY, BW)	Survey	Industry	Status-quo
Klobasa et al.	2021	Demand response in the service sector – Theoretical, technical and practical potentials	DE	Survey, barriers, literature review	Industry	Status-quo
Ladwig	2018	Demand Side Management in Deutschland zur Systemintegration erneuerbarer Energien	DE	Decomposition, scaling, load-shift modelling	Industry, Residential, Mobility	More than 20 years

Author	Year	Title	Country scope[35]	Methods	Sectors	Timeframe
Langrock et al.	2015	Potentiale regelbaren Lasten in einem Energieversorgungssystem mit wachsendem Anteil erneuerbarer Energien	DE	Literature review, survey	Commerce and Trade	Status-quo
Misconel et al.	2021	Assessing the value of demand response in a decarbonized energy system – A large-scale model application	EU	Load-shift modelling, literature	Industry, Residential, Commerce and Trade, Mobility	More than 20 years
Müller, Most	2018	Demand Response Potential: Available when Needed?	DE	Decomposition, load-shift modelling	Industry, Residential	More than 20 years
Navigant	2019	Nova Scotia Energy Efficiency and Demand Response Potential Study for 2021-2045	US (Nova Scotia)	load-shift modelling, decomposition, scaling	Residential, Commerce and Trade, Mobility	More than 20 years
Nitsch et al.	2012	Langfristszenarien und Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global	DE	load-shift modelling, scaling, literature review	Industry, Residential, Commerce and Trade, Mobility	More than 20 years
PentaSGIIII	2017	Expert Group 2 on Demand Side Response: Final document	EU	Barrier analysis	N/A	Status-quo
r2b energy consulting	2019	Definition und Monitoring der Versorgungssicherheit an den europäischen Strommärkten	EU	Load-shift modelling, literature review, barrier analysis	Industry, Residential, Mobility	up to 20 years
r2b energy consulting	2014	Endbericht Leitstudie Strommarkt - Arbeitspaket Funktionsfähigkeit EOM & Impact-Analyse Kapazitätsmechanismen	DE	Barrier analysis	N/A	up to 20 years
Reiter et al.	2017	Empirical study on DSM potentials and survey of mobility patterns in European countries	EU	Survey	Commerce and Trade	Status-Quo
Schyska et al.	2016	The Demand Side Management Potential to Balance a Highly Renewable European Power System	EU	Load-shift modelling	Industry, Residential, Commerce and Trade, Mobility	More than 20 years
Smart Energy Demand Coalition (SEDC)	2017	Explicit Demand Response in Europe - Mapping the Markets 2017	EU	Barrier analysis	N/A	Status-Quo
Steurer, Martin	2017	Analyse von Demand Side Integration im Hinblick auf eine effiziente und umweltfreundliche Energieversorgung	DE	Load-shift modelling, literature review	Industry, Residential, Commerce and Trade	Status Quo
Strobel et al.	2020	Quantifying the Demand Response Potential of Inherent Energy Storages in Production Systems	-	Load-shift modelling, Case Study	Industry	Status Quo
TenneT	2010	TenneT Flexibility Monitor	NL	Market response and bid analysis, Survey	Industry, Residential, Commerce and Trade, Mobility, Other	Status Quo

Author	Year	Title	Country scope[35]	Methods	Sectors	Timeframe
TenneT	2021	Unlocking Industrial Demand Side Response	UK, FR, BL, NL, DK, ES	Literature, Interview, barrier analysis	Industry, Residential	Status Quo
TenneT	2019	Monitoring Leveringszekerheid 2019 (2018-2034)	NL	Market response and bid analysis	Industry	Up to 20 years
Torriti et al.	2013	Demand response from the non-domestic sector: Early UK experiences and future opportunities	UK	Market response and bid analysis, barrier	Commerce and Trade	Status Quo
Umweltbundesamt	2015	Strommarktdesign der Zukunft	-	Barrier analysis	N/A	N/A
Verrier	2018	The economic potential of Demand Response in liberalised electricity markets – A quantitative assessment for the French power system	FR	Load-shift modelling, literature	Industry, Residential, Commerce and Trade	Status Quo
von Roon & Conrad	2013	Demand Response potential of electrical heat pumps and electric storage heaters	DE (south)	load-shift modelling, scaling	Residential	Status Quo
von Roon et al.	2018	Flexibilitätsoptionen in der Grundstoffindustrie	DE	load-shift modelling, scaling	Industry	Status Quo
Vossebein et al.	2019	Studie «Potential Demand Side Management in der Schweiz»	CH	Surveys, decomposition, market response and bid analysis, barrier analysis	Industry, Residential, Mobility, Other	Status Quo