D4.2 CHARACTERISATION OF FLEXIBILITY RESOURCES

VERSION 1.0

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Co-creating with partners that help to understand the needs of relevant stakeholders, we team up with intermediaries to provide an innovation eco-system supporting consortia for research, innovation, technical development, piloting and demonstration activities. These co-operations pave the way towards implementation in real-life environments and market introduction.

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EXECUTIVE SUMMARY

The overall focus of ANM is to control active and reactive power to maintain voltage limits throughout the network as well as avoiding overload situations thereby allowing for a larger share of renewable generation. Voltage and overload control can be performed by different means using flexibility resources to alter and/or limit the flow of active and/or reactive power.

This report, D4.2, provides a characterisation of selected flexibility resources that are relevant for an ANM solution. It includes for example information on what type of entity is the counterparty to the DSO, the type of service(s) it provides, and costs that occur when utilising it.

Heat pumps can for example provide active power flexibility, shift active power consumption to another time, see the table below. This is useful when avoiding overload situation in the grid. The owner of a heat pump can be a private household or a company, and its flexibility service can be managed by either the owner or an aggregator acting on behalf of the owner. The one managing the flexibility service will be the counterparty to the DSO. The availability depends on outdoor temperature and the insulation of the house in which it is located, the accepted deviations from a certain indoor temperature and whether there is any rebound of power to take into consideration. Costs are not quantified but listed and may be quantified in future deliverables.

Table 1: Extract from Table 4, Flexibility characterisation

Resource	Counterparty	Provides	Availability / reliability	Utilization cost	DSM/DR
Heat pumps	Private / Aggregator / Company	Active power, Shifting power in time	• Depending on the outdoor temperature and insulation value for the building • Only impact on indoor climate as defined in the agreement • Consider rebound of power	• Low impact on total energy use • Cost of inconvenience for the owner need to be considered	DSM/DR

Furthermore, the report elaborates on possibilities for how the DSO can acquire flexibility. For example, whether flexibility is traded on a case-by-case basis or on longer-term contracts. This part, described in chapter 4, represents Milestone 4 of the ANM4L project.

Demand side management and demand response are described, and available options under each market solution is investigated. For demand side management, focus is on contracts enabling the DSO to access and activate the resource upon demand. While for demand response, focus is on different ways to organise an auction-based solution enabling the DSO to procure flexibility upon demand for a specific hour. For the latter it is discussed whether a local flexibility market is able to uphold such a solution, for example considering liquidity concerns. Moreover, it is discussed what may be an optimal solution for each type of resource. For the

purpose of this discussion the flexibility resources are divided into large- or small-scale generation and large- or small-scale load.

The report is not exhaustive, meaning it does not cover all thinkable resources that can provide flexibility in an ANM solution. Instead, it covers a selection of resources that are relevant from the perspective of the project demo cases as well as some additional examples.

The overall objective of Work package 4 (WP4) “Business models for ANM in local and regional energy systems” is to create decision support for investments and operation, through development of business case methods and models. This deliverable is part of Work package 4 (WP4).

TABLE OF CONTENTS

INTRODUCTION TO ANM4L

The ANM4L (Active network management for all) project, anm4l.eu, will develop solutions to enable integration of renewables with the agility required from developments in demand and production.

> *Alternatives to traditional network expansion are needed to ensure sustainable development of the power grids. New technologies, methods, and markets are emerging to provide increased flexibility in consumption, generation, and power transfer capacity.*

ANM4L aims at demonstrating innovative active network management (ANM) solutions to increase integration of renewable energy sources (RES) in electricity distribution systems.

ANM solutions will consider management of active and reactive power to avoid overload situations, maintain voltages within limits, minimize the need of RES curtailment, and enable further RES uptake even above the theoretical design limit of the electricity network.

Core research and development activities include development of:

- Active network management methods for local energy systems.
- Business models to provide decision support for market players.
- An integrated toolbox to support the planning and operation of the distribution system.

The toolbox, methods and business models for ANM will be demonstrated in Sweden and Hungary. The project will also prepare solutions and recommendations for replication in other local and regional energy systems.

The ANM4L project is an international cooperation with a consortium consisting of partners in Sweden, Germany and Hungary:

- RISE Research Institutes of Sweden (coordinator)
- Municipality of Borgholm
- Lumenaza GmbH
- Lund University
- RWTH Aachen University
- E.ON Energidistribution AB
- E.ON Észak-dunántúli Áramhálózati Zrt.
- E.ON Group Innovation GmbH

DOCUMENT INFORMATION

This deliverable is part of Work package 4 (WP4): *Business models for ANM in local and regional energy systems.*

The main objective of WP4 is to create decision support for investments and operation, through development of business case methods and models.

This document provides information on characterisation of flexibility resources, Deliverable D4.2, and Market models for flexibility providers developed, milestone 4.

1 INTRODUCTION

The focus of ANM is to control active and reactive power to maintain voltage limits throughout the network as well as avoiding overload situations.

Voltage and overload control can be performed by different means using flexibility resources to alter and/or limit the flow of active and/or reactive power.

1.1 Scope of work

This deliverable is part of Work package 4 (WP4): *Business models for ANM in local and regional energy systems.* The overall objective of WP4 is to create decision support for investments and operation, through development of business case methods and models.

This deliverable provides a characterisation of flexibility resources for the ANM solutions, focusing on the Swedish and Hungarian demo cases. In contrast to most other deliverables in the ANM4L project, this task focusses on the flexibility supply side. Chapter 3 provides a characterisation of selected flexibility resources for ANM solutions. Including information on what type of entity is the counterparty to the DSO, costs that occur when utilising it, the type of service(s) it provides, its availability, response time and duration.

Further, this deliverable encompasses the project milestone MS4. This milestone elaborates on possibilities for how the DSO can procure flexibility services from flexibility providers and is presented in Chapter 4. For example, whether the flexibility is traded on a case-by-case basis or on longer-term contracts, and to what extent flexibility providers actively engage in any day-to-day trading.

1.2 Notations, abbreviations and acronyms

The table below provides an overview of the notations, abbreviations and acronyms used in this report.

Table 2: List of notations, abbreviations, and acronyms

ANM	Active Network Management
ANM4L	Active Network Management for all (project name)
BESS	Battery Energy Storage Systems
BRP	Balance responsible party
DG	Distributed Generation
DLR	Dynamic Line Rating
DR	Demand Response
DSM	Demand Side Management
ERA-Net SES	ERA-Net Smart Energy Systems
MC	Marginal Cost
NLTC	No-load Tap Changer
OLTC	On-load Tap Changer
PV	Photovoltaic
RES	Renewable Energy Source
STATCOM	Static Compensator
SVC	Static Var Compensator
WTG	Wind Turbine Generator

2 DEFINITIONS

The definitions below are used throughout the ANM project:

ANM (Active Network Management): is the exploitation of flexible network assets for the purpose of providing secure means of increasing grid utilisation.

ANM solution: is the concept of a control system, integrated with ICT and the power system, with the ability to manage generation, load and electrical tolerances for DSO-driven purposes.

Flexible resource: resources in the power system (load, production, and other controllable equipment) with the ability of being controlled to support grid needs.

Power transfer capacity: the ability of the grid (cables, lines, transformers, etc.) to transfer electricity between generation and demand.[1]

Demand Side Management (DSM): the control of flexible resources performed directly by the DSO for operational network security purposes.

Demand Response (DR): the control of flexible resources performed via market procurement (e.g., direct from supplier or via aggregators), not directly controlled by the DSO itself as it would cause market distortions.

[1] The power transfer capacity has physical limitations (thermal and stability) and limitations based on standards (power quality) and protection settings.

3 FLEXIBILITY RESOURCES

In this chapter we present resources that can provide flexibility in an ANM solution. The purpose is to allow for a larger share of renewable generation without investments in grid reinforcement due to capacity and voltage problems. The focus of the ANM4L Project and this report is on the Swedish and Hungarian demonstrations that will be performed later in the project.

Most flexibility resources covered in this report are listed in the deliverable *D1.3 Report on framework of the project and transferable best practices* [1] where they are described in more detail.

For each flexible resource, the following is defined:

- who is the counterparty to the DSO,
- the estimated cost of using the resource,
- what type of service it provides, and
- its availability, response time and possible duration of flexibility.

The counterparty, if not the owner of a resource, can be an aggregator. An aggregator is a company or organisation that aggregates resources and provides flexibility to the DSO.

For a manually activation of a flexibility resource any response time below a few minutes is negligible compared to the time it takes for an operator to take a decision. Therefore, all flexibility resources with a response time below a few minutes can be considered equal from a response time perspective.

For an automatically activation and control of a flexibility resource the response time may need to be in the range of seconds, depending on the control algorithm. In report D3.1 [2], delivered by this project and dealing with control algorithms used in this project, the sampling interval was set to 10 seconds for some examples. If the flexibility resource is connected via power electronic converters the response time is fast, normally in the range of milliseconds. Other flexibility resources might have a longer response time and can also have a maximum ramp rate that needs to be considered for the control algorithm. This needs to be investigated and verified for each specific flexibility resource that will be included in an ANM solution.

An overview of the characterisation for the flexibility resources is presented in Table 4 in Chapter 5.

3.1 Generation control

3.1.1 Active power curtailment

The active power, due to the low X/R-ratio in the distribution grid, leads to a voltage rise at the point of connection of the DG. There can also be overload of lines/cables due to the active power. To avoid a voltage rise or to avoid overload the active power from the DGs can be curtailed. The response time is in the range of milliseconds or seconds depending on the type of turbine.

Without storage, this energy is not possible to shift to another time of consumption and therefore it means spilling a part of the available energy from sources as wind parks and PV plants. Active power curtailment should be used first after the DG has depleted its capability to reduce the voltage by reactive power consumption or by other means in the grid.

The counterparty of the DSO when it comes to the DG is the owner of the power source or an aggregator.

For the PV plant the cost for curtailing is the loss of sold production. If the exact cost is unknown, this can be proxied as the spot price multiplied by the curtailed energy. There is no extra cost, such as mechanical wear and tear, for curtailing a PV plant.

For the WTG one cost for curtailing is the loss of sold production. As for the PV, if the exact cost is unknown this can be proxied as the spot price multiplied by the curtailed energy. Another cost for curtailing WTG stems from the mechanical wear and tear. There is one cost for curtailing, turning the blades, and an additional cost for shutting the WTG down.

3.1.2 Reactive power generation and consumption

Reactive power is used to control the voltage magnitude. Due to the low X/R-ratio in the distribution grid both active and reactive power influences the voltage magnitude.

DG with power electronic converters have reactive power capability integrated into the converter's control features and can therefore control the reactive power and contribute to the voltage control without any additional reactive power equipment. They can both generate and consume reactive power and the capability is limited by internal voltage, temperature, and current constraints. Therefore, the amount of reactive power the converters can provide decreases as the active power generation increases. The response time is due to power electronic converters fast, in the range of milliseconds and reactive power can normally be provided as long as the power plant is connected to the grid.

DGs without capabilities or limited capabilities to provide reactive power normally have other reactive power equipment such as capacitor banks installed in the power plant to fulfil the grid code requirements.

The counterparty of the DSO when it comes to the DG is the owner of the power source or an aggregator.

For PV plants and WTGs that can control the reactive power the cost for reactive compensation is the potential reduction of active power, i.e., loss of sold production. If the exact cost is unknown, this can be proxied as the spot price multiplied by the curtailed energy. There is no extra cost, such as mechanical wear and tear, for reactive power control.

Price of electricity produced in a wind park is not necessarily equal to the spot price however for simplicity we use the spot price as a proxy.

3.2 Flexible consumers

The voltage can also be adjusted in the distribution grid by controlling the load in the grid. Not all types of loads can be used for this control method, typically it should be loads with limited impact on the comfort for the users, suitable types include loads with slow dynamics typically with thermal storage such as ventilation, heating/cooling. Charging of electrical vehicles can also be considered.

Load control can be used both for preventing overload and to maintain bus voltages. To be able to regulate the voltage both up and down and to prevent overload the loads need to be controlled in both ways, both a reduction and an increase of the active power consumption is desirable. It is not necessary that each individual load can be controlled in both ways, however the portfolio must be able to respond efficiently to both needs.

During the demo case in Sweden that is planned in this project there are plans to include heat pumps and electrical vehicles as controllable loads. These are both described below but there are of course other loads that could be used. Most loads that can be shifted in time have a similar cost as heat pumps and electrical vehicles.

Other loads that could be relevant to act as a flexibility resource are electrolysers (for hydrogen production), desalination plants (there is one on Öland), electric energy storage (hydro pumping, compressed air, flywheels, hydrogen, batteries, supercapacitors etc), etc.

Shifting power consumption in time is rarely expected to lead to increased (or decreased) electricity costs. Rebound of power should however be considered if the load is turned off/reduced and needs to be turned on. The load might need more power after than before it was turned off/reduced.

3.2.1 Charging infrastructure of electrical vehicles (EV)

It is here assumed that the EVs cannot push energy back to the grid, i.e., V2G. In a future scenario this may be possible and relevant to explore.

EVs are loads that potentially can be controlled for utilization as a flexible resource. The owner can be the DSO, a company, or a private individual. To avoid too many contracts for the DSO, EVs are preferably controlled by an aggregator. The response time should be below one minute but probably faster depending on the type of charging equipment and the communication protocol and the system architecture of the charging equipment.

If the user of the EV is always charging the vehicle with the highest possible power this resource can only be used for reduction of active power consumption.

One cost for utilizing EVs as a flexible resource is the difference for the hourly spot price when charging, meaning that the cost can be both positive and negative. Further, there is a cost of inconvenience for providing the resource as a flexibility resource, as the EV may not be fully charged when needed. This cost needs to be considered when paying for utilizing the resource. No other costs exist, because it is automated and always active there are no extra mechanical wear and tear, no loss of income nor any additional technical cost.

3.2.2 Heat pumps (Residential)

Heat pumps are also loads that potentially can be controlled for utilization as flexible resources and can be controlled by the owner. The owner can be the DSO, a company, or a private individual. To avoid too many contracts for the DSO heat pumps are preferably controlled by an aggregator. The response time should be below one minute but probably faster depending on the communication protocol and the system architecture for the control of the heat pumps.

If a heat pump is turned off it normally consumes more power upon reactivation compared to before it was turned off, there is a rebound of power which is important to take into consideration.

There is a cost of inconvenience for providing the heat pump as a flexibility resource, because the in-door temperature can both become higher and lower than desired. This cost needs to be considered when paying for utilizing the resource.

Other costs for utilizing heat pumps as a flexible resource are here estimated to be zero because the energy is only shifted in time, there are no extra mechanical wear and tear for using it since it is automated and always active, no loss of income nor any additional cost. The only cost is the difference for the hourly spot price when heating, it means that the cost can be both positive and negative.

3.3 Equipment in the grid

Equipment in the grid can help to maintain voltage limits throughout the network as well as avoiding overload situations. They will be activated when needed to avoid an unwanted situation in the grid and, if possible, activated before the loads and production resources in the grid are affected.

3.3.1 Transformer tap changer

There are both no-load tap changers (NLTC) and on-load tap changer (OLTC) in the grid. NLTC requires the power to be cut before operated and might therefore not be relevant for an ANM solution. The OLTC can be managed during operation and are normally operated by an automatic voltage control relay that decides the position of the tap changer. If the OLTC tap changer is of online type it can be operated remotely from the control room. The OLTC is always available where it is installed in the grid but the possibility to use it to depends on the rating and the actual position of the tap changer. The response time and the time for the tap changer to change position is in the range of minutes.

Tap changers are owned and controlled by the DSO and the cost for operating them stems from the mechanical wear and tear.

The cost for using NLTC is higher than for OLTC due to manual on-site operation of the equipment and cut of power but the equipment is excluded in this context.

3.3.2 Line Voltage Regulator (LVR)

A Line Voltage Regulator (LVR), also known as Series Voltage Regulator, can be used in a distribution system to have control over the voltage for an individual feeder without affecting other feeders in the grid. The LVR is always available where it is installed in the grid but the possibility to use it to depends on the rating and the actual position. The response time is in the range of minutes.

Line Voltage Regulators are owned and controlled by the DSO and the cost for operating them stems from the mechanical wear and tear.

3.3.3 Reactive power compensation equipment

The reactive power can be controlled by shunt capacitors and reactors, STATCOMs, SVCs and similar equipment. Shunt capacitors and reactors provide static passive compensation, and they are either permanently connected or possible to switch. STATCOM and SVC (Static Var Compensator) devices provide active compensation, have fast switching capability and can both absorb and provide reactive power. The response time is the range of milliseconds.

Equipment for reactive power compensation is normally used and owned by the DSO. There can also be reactive power equipment installed in a power plant to fulfil grid code requirements.

The cost for operating them stems from the mechanical wear and tear. Switching of shunt capacitors/reactors can also cause stress on other electrical equipment in the grid.

3.4 Flexibility enabler

There is equipment, such as information communication technology and measurement system, that do not provide flexibility, but that enable flexibility to maintain voltage limits throughout the network as well as avoiding overload situations. The monitoring system for dynamic line rating (DLR) is part of the Swedish demo and therefore included in this report.

3.4.1 Dynamic Line Rating (DLR)

Dynamic line rating (DLR) is a method to maximize the ampacity of the powerline/cable depending on the environmental conditions, without compromising safety. The benefit is that more power can be transferred compared to if a static nominal rating of the powerline/cable would have been used. DLR is always active and therefore available to be utilised for the powerline/cable it is installed, but the output is dependent on external factors such as outdoor temperature and wind.

The equipment is owned by the DSO and the output defines the maximum transfer capacity.

The utilization cost for DLR is zero because of three reasons. First, the DSO owns the equipment. Second, there is no mechanical wear and deterioration for using it since it is automated and always active. Third, there is no loss of income nor any additional cost.

4 FINANCIAL MODELS

While the project focuses on developing solutions enabling integration of renewables with the agility required from developments in demand and production, it is by necessity also discussing the basis of a local flexibility market. The market is needed to make the solutions available to the DSO and sets the rules for how flexibility is traded. In this chapter several options are discussed. Regardless of market solution, the goal is to optimize the usage of flexibility and thereby maximising the integration of renewables.

For the demonstrators of the ANM4L project, flexible resources will be directly controlled by the DSO. Task 4.2/MS4 elaborates on possibilities for how the DSO can procure flexibility services from flexibility providers from a theoretical perspective in the future.

The first section of this chapter briefly reminds the reader of the definitions of demand side management (DSM) and demand response (DR) used by the ANM4L project. The second section discusses some of the fundamental market requirements to take into consideration when deciding which financial model to apply. The third section elaborates on Chapter 4.1 and describes DR and DSM in relation to the market and presents options available under DR and DSM respectively, and finally the fourth section discusses the pros and cons of different options for different types of flexibility resources.

4.1 Energy demand management

There are different flexibility solutions related to customers in the grid, demand side management (DSM) and demand response (DR). Both provides the DSO with the ability to increase or decrease e.g. household power consumption, thus making residents direct contributors and part of the solution by adding grid supporting flexibility. [1]

The differentiation between DSM and DR are agreed within the ANM4L project. In this deliverable the description and definition of these expressions are expanded, and the market arrangement for both involve any flexible resource.

4.1.1 Demand Side Management (DSM)

In the case of DSM (direct DSO activation), a contractual bi-lateral agreement between DSO and customer, or other relevant counterparty, can allow the DSO to instantly access and activate a flexibility resource upon demand.

4.1.2 Demand Response (DR)

In case of the market-based approach DR, flexibility requests and offers are matched in a market enabling the DSO to procure flexibility upon demand for a specific hour.

This can be done by aggregators handling the bidding and end-customer activation to ensure adequate pricing, efficient allocation, and access to flexibility. This is a more complex approach with numerous interactions and limited number of market participants for liquid transactions. [1]

4.2 Asymmetric information and willingness to participate

The purpose of the financial model is to financially connect the DSO and the flexibility provider. However, some fundamental market requirements[2] must be fulfilled for the market to function efficiently. Two relevant topics will be described in this section: Asymmetric information and marginal cost versus price.

First, at least initially, there is asymmetric information where the DSO has access to relevant information that the seller does not. This is due to the role of the DSO as network owner and the traditional role of consumers that now turn sellers. The seller does not have access to the same detailed information nor have knowhow needed to interpret information. This may for example cause issues when the seller must rely on the DSO to gain knowledge on their sold quantity of flexibility.

Furthermore, the level of available information and knowhow is likely to vary among different types of sellers of flexibility. A company owning a wind park is likely to be better informed and to have more resources to invest in knowledge compared to the average household. However, the household (as well as companies) may be able to use the services of an aggregator. Such an agent may be able to bridge the information-gap.

Second, the price must be right. For the seller to be willing to participate on the market, the price must be equal to or higher than the marginal cost and at the same time it must meet the willingness to buy of the DSO. The definition of marginal cost is the cost of supplying one extra unit and is bound to differ between resources.

The price of flexibility will be determined by the market, through negotiations between actors (in the DSM and potentially the DR solution) or auctions (in the DR solution). This report does not discuss specific mechanisms, but instead focus on the willingness to pay and buy of the parties, the providers of flexibility and the DSO.

Upon deciding on the most efficient solution to a congestion problem the DSO must perform a two-step analysis. First, at some point in time, the DSO has decided how to tackle the problems they are trying to solve using flexibility resources. This decision process is described in delivery 4.1 of the ANM4L project *Value of Flexibility for Utilities* [3] and consist of a CBA analysis comparing ANM solutions to reinforcement of the grid. Second, assuming the DSO decided to go with the ANM solution and exploit available sources of flexibility in the grid, the DSO must have a strategy upon deciding when and which resources to activate and/or request. There are multiple factors that determine whether a resource is suitable to help solve a

[2] All criteria for perfect competition will not be described in detail, however they include: a homogenous product, that all agents are price takers and that market shares do not influence price, perfect information, and free entry and exit.

situation or not, both locational and technical aspects are pivotal and therefore ahead of cost, see Figure 1. The remaining subset of resources are then prioritised based on cost/price. One may think there are no costs associated with utilizing equipment in the grid as these are owned by the DSO, however this is not the case. The costs consist of for example mechanical wear and tear and it is important that these costs are taken into consideration.

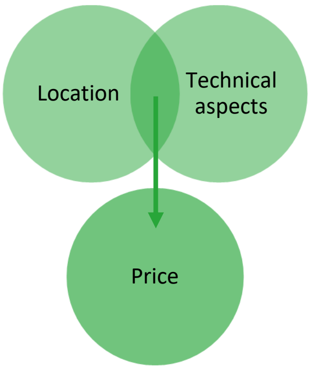

Figure 1: Order of events

4.3 Options under DSM and DR

The Council of European Energy Regulators (CEER) highlights four alternative ways for the DSO to access flexibility [4]:

- a rules-based approach,
- through connection agreements,
- by using network tariffs, and
- through market-based procurement.

The ANM4L project focuses on the latter, which under the assumption of perfect competition and sufficient market liquidity will offer efficient solutions. Both DSM and DR are available as the market-based approach include bilateral negotiations, organized marketplaces, aggregators etc. [4].

Under both DSM and DR, aggregators are likely to play an extremely important role in organizing trade and enabling flexibility exchange. They are however not discussed in detail in this report.

4.3.1 Options under DSM

A DSM solution leaves limited control to the flexibility provider (seller) and the DSO can, given a number of constraints depending on the resource, access the flexibility on demand. Here, three remuneration options are investigated: A flat rate contract, a flex rate contract, and a combination of both.

- The flat rate contract is independent of usage, the DSO reimburses the seller with a fixed amount and can, given a number of constraints such as indoor temperature if the flexibility resource is a heat pump, access the flexibility and activate the resource when need occurs.

- The flex rate contract is fully dependent on usage. The seller receives a remuneration of a predefined amount (can for example be a fixed amount or dependent on the spot price) times the used kWh.
- The combination consists of a flat base reimbursement and an additional kWh rate.

The main difference between these options is the risk allocation. With a flat rate the DSO takes on all risk because the cost is constant regardless of need. With a flex rate, the seller takes on all risk because the cost for the DSO fully correlates with need and usage, and the seller cannot be certain to recover costs of any investments made. With a combined rate the risk is shared between the DSO and the seller. How the risk is allocated under the combined rate depends on the distribution between the fixed and flex part of the contract. The larger the share of the fixed rate the more risk is allocated to the DSO and vice versa.

Table 3: Risk allocation

	Flat rate	Flex rate	Combined rate
Risk allocation	DSO	Seller	Shared

There are pros and cons with all solutions. On the downside, contracts are costly to establish and maintain from an administrative perspective. Therefore, it would be convenient with an independent aggregator to facilitate the relationship between the potentially many sellers and the DSO. On the upside, contracts do not require any trading platform to match bids.

The ANM operational tool should aim to optimize and activate the most cost-efficient combination of flexibility resources and must therefore take cost per kWh for each resource into consideration. The cost should be stated in the contract, hence there is no need for a trading platform.

4.3.2 Options under DR

In contrast to the DSM solution, the DR solution leaves more control to the flexibility provider and is dependent on usage. Instead of a long-term contract, the terms of trade are defined on a case-by-case basis where flexibility providers place bids that the DSO can chose to accept or not accept depending on its willingness to pay and other available offers.

The bid holds information on how much flexibility the provider has to offer, at what cost, and when. An owner of a wind park may for example not always accept being curtailed and the resource may therefore not always be available. However, since the flexibility provider price their resource themselves, their willingness to sell is reflected in the bid.

The design of auctions and price mechanisms are not covered in this report, however, as these are local markets, liquidity is likely to become an issue, and is therefore discussed next.

Liquidity is important for a market to function effectively. An illiquid market will likely result in insufficient amounts of flexibility and/or excessively high prices for flexibility. While liquidity is not directly observable and there is no generally accepted measure, it can be described as how easy or difficult it is to trade in a market. The trading volume is often used as a proxy. If the market is liquid, it is easy to trade, and otherwise it is difficult to trade. It is a function of many parameters, but high numbers of participants and transactions are positive. [5]

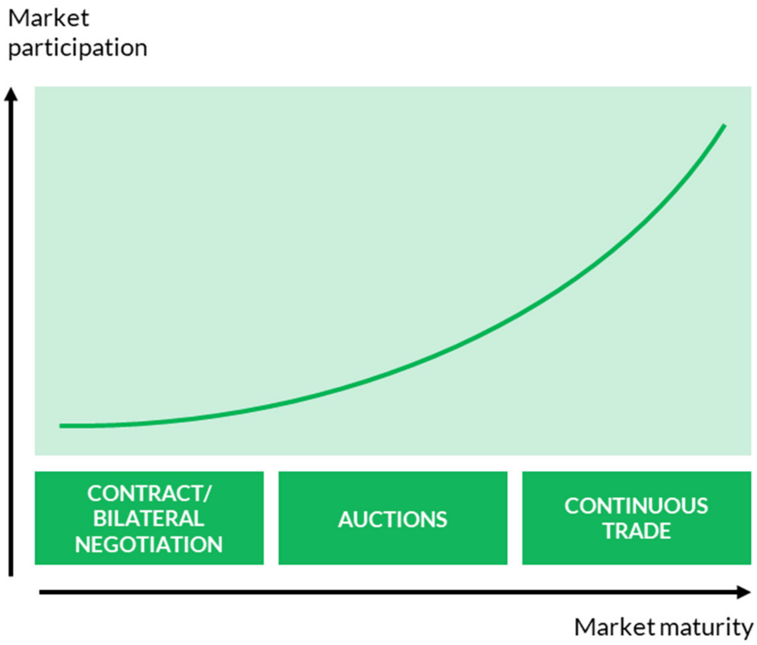

Figure 2: Market participation, maturity, and type of market organisation

While bilateral negotiations or contract-based solutions are inconvenient as many potential flexibility providers will result in an administrative burden for the DSO, they may be the most suitable way to go about organizing this market while the number of potential flexibility providers are few and the market is immature. The main reason is that the liquidity is likely to be too low to be able to support auction-based clearing mechanisms. While the administrative burden per contract is high, there is no need for advanced market platforms or the like.

As the market matures and more participants get involved, it can transfer into auction-based trade. There are different type of setups and coordination mechanisms to consider. To mitigate a potentially low liquidity, discrete auctions are suitable because these gather participants at the same time. As the market matures further and becomes more liquid the frequency of auctions can increase until it eventually makes sense to cross over into continuous trade, see Figure 3. However, some markets do not reach a level of liquidity that allows for continuous trade.

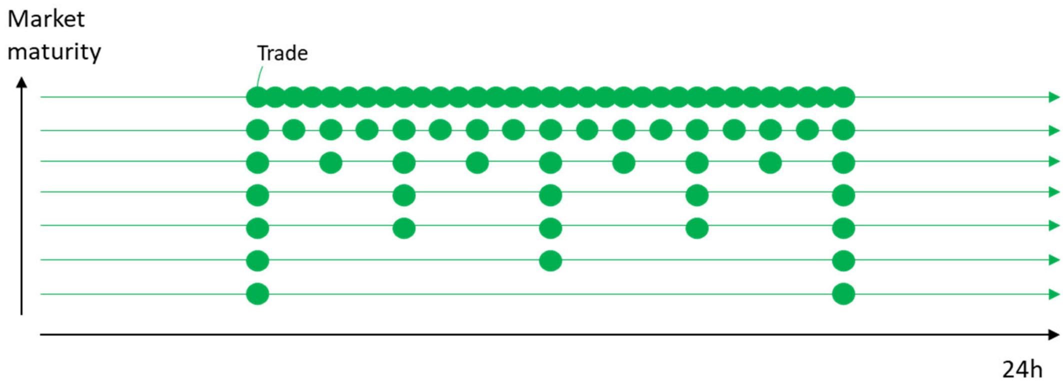

Figure 3: Market maturity and frequency of auctions

From the perspective of the DSO, continuous trade is likely an ideal market solution under the provision that it is able to provide an effective market clearing. This is assumed due to the constant availability of flexibility resources. The more realistic and, in this setting, also effective market solution may however be one based on discrete auctions. The reason is that a local market may have troubles gathering enough participants and thus liquidity to be able to support continuous trade. For reference, the Swedish intraday market is based on continuous trade and sometimes face efficiency problems due to low liquidity.

4.4 Pros and cons of DSM and DR for different resources

As explained in Chapter 4.1, a DSM solution allows the DSO to directly control the flexibility asset for operational network security purposes while a DR solution is only available after a case-by-case trade agreement is in place. A typical DSM asset may for example be a single heat pump while a typical DR asset may be multiple EV chargers managed by an aggregator. Note that DSM and/or DR are applicable to all flexibility resources. In this section potential pros and cons of the different solutions are discussed for broad groups of flexibility resources. Further research is needed within this field. *Equipment in the grid* is not covered in this section as these are inhouse services and therefore not applicable for DSM or DR.

4.4.1 Large scale generation

Large generating units such as wind parks may be better suited for a DR solution rather than a DSM solution. One reason is potential issues regarding the balance responsibility. This example is simplified and based on current Swedish regulation. Before the hour of delivery, the expected production from the unit is estimated and traded on the electricity markets aiming for balance during the delivery hour meaning that the sold volume equals the produced volume. The BRP (which may or may not be the owner of the generating unit) reports the production plan to the TSO 45 minutes prior to the start of the delivery hour.[6] If production is curtailed during the delivery hour the reported and actual production will differ. The balance settlement is calculated per bidding area [6] which may be larger than the area captured by the local market and the curtailment may therefore have resulted in an unintended imbalance and subsequent charge to the BRP.

While it is difficult to achieve perfect balance due to many other reasons than potential curtailment, it is problematic if a BRP would find itself in imbalance and subsequently subject to a charge due to a unit in its portfolio being curtailed by a third party. Especially since the curtailment likely solved a local network issue.

Applying a DR solution to large generating units would regain the control to the owner of the resource and the BRP. It may be possible to, in real time, adjust for the curtailment thereby avoiding imbalance.

This potential issue will be further investigated in task 4.3 in the ANM4L project.

4.4.2 Small scale generation

Small generating units such as residential PVs may be suitable for either a DSM or DR solution. It is likely to depend on either the interest of the owners of the resource or on how they choose to engage their flexibility resource on the market.

The owners may be interested in participating on the flexibility market themselves. The best solution is then given by their individual preferences. However, they may not be interested in active participation. If that is the case and they do not engage with an aggregator, the DSM solution is likely more suitable than the DR solution, minimising the effort. If they do engage with an aggregator, the DR solution may be more suitable than the DSM solution given that it is more dynamic, and the aggregator has resources to actively participate with large volumes on the market.

4.4.3 Large scale loads

Large scale loads are found at for example property owners using large amounts of electricity on functions such as heating and cooling. Similarly to owners of large scale generation, it is likely that owners of large scale loads are unwilling to hand over control to the DSO. Heating costs for Swedish apartment buildings is on average 30 percent of total operating costs and 20 percent of total costs, meaning that it is a significant cost item.[7] While this makes it attractive to offer flexibility to the DSO, it is also high risk and the provider must be able to trust that for example indoor temperatures are within acceptable intervals.

With sufficient control equipment, sensitive parameters will be automatically controlled for, and the DSO and the property owner will be able to act according to these parameters. This can for example allow for a DSM solution with a dynamic price mechanism as one of the steering parameters. However, if it is not possible to incorporate relevant parameters a DR solution may be better suited.

4.4.4 Small scale loads

When utilising a load as a flexibility resource its contribution is often to advance or delay power use. It may therefore be suitable for a DSM solution as the total consumption over time is unaffected, and the owner of the flexibility resource owner is unlikely to notice that the flexibility resource is being utilised unless informed. Unlike the large scale load owner the small scale load owner is usually only responsible for its own personal convenience. The main cost to take into consideration is any adverse effects on the convenience for the owner/relevant stakeholders, such as residents in a house with a heat pump being utilised as a flexibility resource, and this is easily captured and regulated by a long-term contract.

5 OVERVIEW OF CHARACTERISATION

This chapter provides an overview of the flexibility resources described in this report under chapter 3. All flexibility resources have a low enough response time, below minutes that are considered to be needed for the ANM4L project.

Table 4: Flexibility characterisation

Resource	Owner	Provides	Availability / reliability	Utilization cost	DSM/DR
Wind Park (Large scale generation)	Company	Active power	• Depends on the wind conditions • Can only increase the active power if already running in curtailed mode	• Reduction of revenue for owner • Cost of mechanical wear and tear, for curtailment and for shutdown	DR
Wind Park (Large scale generation)	Company	Reactive power	• Always available if connected to the grid	• Potential reduction of revenue for owner due to reduced production of active power	DR
PV (Large scale generation)	Company	Active power	• Depends on the solar radiation • Can only increase the active power if already running in curtailed mode	• Reduction of revenue for owner • Potential mechanical wear and tear of the inverter	DR
PV (Large scale generation)	Company	Reactive power	• Always available if connected to the grid	• Potential reduction of revenue for owner due to reduced production of active power	DR
PV (Small scale generation)	Private / Aggregator/ Company	Active power	• Depends on the solar radiation • Can only increase the active power if already running in curtailed mode	• Reduction of revenue for owner	DSM/DR
PV (Small scale generation)	Private / Aggregator/ Company	Reactive power	• Control equipment for reactive power must be installed • Always available if connected to the grid	• Potential reduction of revenue for owner due to reduced production of active power	DSM/DR
Heat pumps (Residential load)	Private / Aggregator / Company	Active power, Shifting power in time	• Depending on the outdoor temperature and insulation value for the building • Only impact on indoor climate as defined in the agreement • Consider rebound of power	• Low impact on total energy use • Cost of inconvenience for the owner need to be considered	DSM/DR
EV charger (Load)	Private / Aggregator / Company	Active power, Shifting power in time	• Depending on the use of the cars and if connected to the charger • Can only increase the power consumption if battery is not already fully charged	• No impact on the total energy use • Cost of inconvenience for the owner need to be considered	DSM/DR
Tap changer	DSO	Voltage control	• Depending on the rating and current position of tap changer	• Mechanical wear and tear	-
DLR	DSO	Enables flexibility through increased capacity	• DLR is always available but its output depends on external factors such as temperature and wind	• No direct cost to supply flexibility	-
Reactive power compensation equipment (Capacitor bank, STATCOM, etc)	DSO	Reactive power	• Depending on the rating and current level of activation	• Mechanical wear and tear	-

6 SUMMARY AND DISCUSSION

In this report, different flexibility resources relevant for the Swedish and Hungarian demo cases of the ANM4L project, are characterised. They are divided into four different categories:

- Generation
- Load
- Equipment in the grid
- Flexibility enabler

As part of the characterization process, costs for utilising the different resources are identified. These are listed in Table 4 in the previous chapter and described in Chapter 3. While different cost types are identified, the task of quantifying each cost for each resource is challenging. However, although it is difficult to exactly quantify each cost, it is possible to argue that some may be negligible while others may be major.

Costs that, on the one hand, may be negligible under certain circumstances include shift of power consumption in time, and in some cases cost of inconvenience.

For small scale loads in Sweden shifting power consumption in time is expected to rarely lead to increased (or decreased) electricity costs. For these consumers, the most common electricity rate is a fixed monthly rate, meaning that the cost of consuming electricity is the same at all times during one month. There are three exceptions to when shifting power consumption to another time may lead to changed electricity costs.

- The first is if consumption is shifted from one month to another. The rates are likely to differ between months and if the rate of the second month is higher, the electricity costs will be higher compared to if consumption was left unchanged, however, if the rate of the second month is lower the electricity costs will instead be lower compared to if consumption was left unchanged.
- The second is if there are any rebound of power. There may be a rebound of power if a load is turned off or reduced and later turned back on or returned to normal operation. The load might need more power after than before it was utilised as a flexibility resource.
- The third is if it is more energy (and therefore also cost) efficient to maintain electricity consumption compared to temporarily increasing or decreasing consumption.

As described in chapter 4, the use of some flexibility resources may affect the comfort of consumers in their home and daily lives. The cost of inconvenience is likely to depend on how much consumers are affected, and in some cases it may be insignificant. For example, it is assumed that the cost of inconvenience for utilising a heat pump as a flexibility resource is limited as long as limits concerning indoor temperature etc. are respected, however not that if temperatures vary significantly or outside agreed limitations the cost is expected to be substantial. Much research has been done on consumer willingness to participate in flexibility markets and the importance of different aspects such as (in)convenience, remuneration/savings vs. environmental motivations, see for example Ref. [8] and [9].

Costs that, on the other hand, may be major are reduction of revenue for owners due to curtailment of renewable energy sources, and potentially also penalties for not delivering as promised. The latter can for example refer to power purchase agreements or unmet production plans. In addition, there are other factors such as environmental aspects to consider when contemplating curtailment of renewable energy sources.

Curtailing renewable energy sources means spilling available renewable power and, unless storage is available, it is not possible to shift consumption of spilled power to another time. Therefore, curtailment should always be the last option.

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