D4.1 VALUE OF FLEXIBILITY FOR UTILITIES

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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.

Beyond that, ERA-Net SES provides a Knowledge Community, involving key demo projects and experts from all over Europe, to facilitate learning between projects and programs from the local level up to the European level.

LIST OF ACRONYMS

ANM	Active network management
ANM4L	Active network management for all
BAU	Business-as-usual
CBA	Cost-benefit analysis
DSO	Distribution system operator
EUR	Euro
ICT	Information and communications technology
IRR	Internal rate of return
MW	Megawatt
NPV	Net present value
O&M	Operations and maintenance
TSO	Transmission system operator
WACC	Weighted average cost of capital
WP	Work package

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 Solutions GmbH

EXECUTIVE SUMMARY

This report is the first of 5 reports from work package 4 of the ANM4L project. The report provides a methodological framework for estimating the value of an ANM solution using a cost-benefit analysis (CBA) approach. The method discussed in this report is applicable when the value of the ANM solution stems from a reduced need for traditional network reinforcements.

The CBA methodology is explained using an illustrative example which is entirely fictitious and does not represent any specific real-world case. This report is intended to be applicable to a wide range of ANM solutions, and therefore does not discuss any particular types of ANM solutions or costs thereof.

In addition to describing the methodological framework, the following key points are highlighted in this report:

- The value of an ANM solution differs depending on the perspective taken in the analysis. Specifically, a financial value can be estimated from a DSO perspective, or an economic value can be estimated from a broader societal perspective. While a CBA approach is applicable in both cases, some of the principles and input data differ. It is possible for an ANM solution to have a high value from one perspective but no value at all from the other. Both types of value are of interest when considering the appropriateness of an ANM solution in a given case.

- The financial value for a DSO of an ANM solution is to a large extent determined by the regulatory model that govern the DSOs tariffs or revenues. It is therefore necessary to include a realistic representation of the applicable regulatory model when performing the analysis. The CBA methodology described in this report can also be used to evaluate a regulatory model, analyzing if the regulatory model incentivizes efficient investments.

- The CBA methods described in this report can be used to estimate a maximum long-run average price that the DSO is willing to pay for flexibility services. However, this long-run willingness to pay may not be the same as the short-run willingness to pay once the DSO relies on the ANM solution. This discrepancy creates a need for the DSO to ensure access to flexibility services at a reasonable price, for example using long-run contractual arrangements.

1. INTRODUCTION

1.1. Purpose and scope

This report constitutes the deliverable for task 4.1 of the ANM4L project. Task 4.1 focuses on the value of ANM for DSOs and is the first of five interlinked tasks in work package 4 (WP4). The overall objective of WP4 is to create decision support for investments and operation, through development of business case methods and models.

Task 4.1 is the first step in a series of tasks that will be conducted throughout the ANM4L project. Therefore, the content of this report should be viewed as an initial analysis that lays the groundwork for further work in subsequent tasks.

This report mainly focuses on the value of ANM from a long-term planning perspective, focusing on the case where the value of the ANM solution stems from a reduced need for investments in physical network reinforcements. Estimating the value of the ANM solution in this context is therefore a matter of comparing the costs and benefits associated with the ANM solution to the costs and benefits that would arise under an alternative scenario without ANM. This report describes a cost-benefit analysis (CBA) methodology that can be used for making such a comparison. The methodology is described using a simplified illustrative example. The example does not represent any particular location or DSO.

The methodology discussed in this report aims at being applicable to a wide range of ANM solutions. Therefore, the type of ANM solution is not specified and the report does not elaborate on the costs or benefits associated with any particular kind of ANM. In the next WP4 task (task 4.2), various types of flexibility resources will be characterized, including an analysis of the associated costs.

Since DSOs are generally operated as regulated monopolies, it is necessary to account for the regulatory model when estimating financial implications of an investment from a DSO perspective. Therefore, WP4 includes a task (task 4.3) focusing on a detailed analysis of regulatory implications.

1.2. Outline of report

The next section, section 2, provides some background information regarding unbundling requirements and financial regulations that govern European DSOs, as well as a short discussion regarding the emerging expanded role of DSOs when ANM solutions become available at the distribution level.

Sections 3-5 describe the CBA methodology, where section 3 outlines the high-level structure of the analysis, section 4 provides a discussion of general CBA principles, and section 5 provides a methodology for the analysis through use of a simplified example.

Finally, section 6 briefly discusses how the long-term values obtained using a CBA method relate to the short-run valuation of flexibility services.

2. BACKGROUND

2.1. The European electricity market context

The regulatory frameworks and overall market designs of Europe's electricity markets have in recent decades slowly converged. Significant differences between European countries still remain, but it is nevertheless possible to identify electricity market features that are common across most EU member states. This is partly a result of several EU regulations and directives, not least the Third Energy Package of 2009 [1], with recent updates as part of the 2019 Clean Energy Package [2]. For example, the Third Energy Package established minimum requirements for EU Member States regarding unbundling (see section 2.1.1 below), while the Clean Energy Package provides common rules regarding, for example, consumer rights.

2.1.1. Unbundling requirements

The European electricity market structure is based on an unbundled principle, whereby activities related to transmission and distribution are separated from activities related to generation and supply (where supply refers to the sale of electricity to end-users). For transmission and distribution activities, the natural monopoly aspect of electricity grid infrastructure means that competition is neither likely to arise spontaneously nor likely to be economically efficient. Therefore, these activities are conducted within companies that are awarded explicit concessions to operate said monopolies under the regulatory constraints stipulated by national regulators.

However, activities related to generation and supply can be conducted in a liberalized and competitive market. To promote a level playing-field whereby market participants are given access to the grid infrastructure on equal terms, unbundling regulations have been implemented aiming to ensure the independence of companies engaged in transmission and distribution from generation or supply interests.

The EU regulatory requirements regarding unbundling are different for TSOs and DSOs. For TSOs, the requirements are relatively strict with full ownership unbundling being the preferred approach. For DSOs, the EU requirements are less far-reaching, in the sense that it does not require unbundling in terms of ownership, i.e. the DSO may be part of a larger vertically integrated undertaking. For larger DSOs (more than 100 000 connected customers), unbundling is required in terms of legal form, organization, and decision making. For smaller DSOs, the EU directives only require unbundling of accounts for the distribution activities. However, some European countries have chosen to implement stricter unbundling requirements also for smaller DSOs.

2.1.2. Zonal trading

Trading of electricity between generators and suppliers take place both bilaterally and on auction-based marketplaces, with the former being more common in countries such as Germany and the UK while the latter dominates in, for example, the Nordics and Italy [3]. Irrespective of whether trading takes place bilaterally or on an auction-based marketplace, the trading is based on a zonal model where it is assumed that electricity can be delivered without any network constrains as long as buyer and seller are in the same bidding zone.

For example, Sweden is subdivided into four bidding zones. If two market participants are located within the same bidding zone, then it is assumed that sufficient network capacity will be available to handle the resulting power flows. If network limitations nevertheless arise within a zone, then the TSO is responsible for managing the situation using, for example, countertrading. The TSOs are also responsible for determining the cross-zonal capacities that should be made available to the market for transfers across zonal borders.

2.1.3. Financial regulation of DSOs

As noted above, because of the monopoly status of DSOs, their revenues and/or tariffs need to be regulated. Regulation is needed to ensure controlled pricing, efficient investment and non-discriminatory access and tariffs. The objectives of these regulations are therefore to ensure reasonable prices and availability for all customers, whilst also ensuring long-term supply quality, encompassing supply security, safety and infrastructure health.

Many different methods exist for how such a regulation can be carried out. The most commonly used regulatory approach in Europe is to use a revenue cap [4]. This means that the regulator specifies a cap for the total revenues that the DSO is allowed to collect from its customers but allows the DSO some flexibility in how the tariffs should be specified. The calculation of the revenue cap is typically based on a specification of a regulatory asset base, consisting of the assets that the DSO should be allowed a regulated financial return on. The valuation of the asset base is in some countries made based on the actual historical cost of the investments, and in other countries based on an estimated re-investment cost.

Instead of a revenue cap approach, some European countries use other regulatory models, such as where the regulator directly specify the tariffs. Furthermore, even though many European countries use some form of revenue cap, there are still significant differences between countries in terms of how the revenue cap is calculated. A relatively detailed comparison between different European countries is provided in [4], and a theoretical discussion of pros and cons of various approaches can be found in [5]. Task 4.3 of the ANM4L project plans to analyze financial regulations and their consequences for ANM in more detail.

2.2. ANM and flexibility in distribution networks

Traditionally, most distribution networks are planned and operated in a relatively passive way, in the sense that the physical network infrastructure is dimensioned to handle power flows that can be reasonably expected. This has been necessary, since DSOs generally do not have the ability to control power flows in real time. The development of high bandwidth communication solutions is changing the way grids can be operated allowing for more accurate prognosis data and remote control of grid infrastructures. Thus, the potential for active management is increasing.

An increased penetration of distributed generation, as well as new loads from e.g. electric vehicles, create new power flow patterns in distribution networks. With the traditional approach to network planning, this could necessitate costly investments in physical network reinforcements. However, alternative solutions, where DSOs take a more active role in monitoring and controlling distribution networks, are increasingly being suggested (see, for example, [6]). Within the ANM4L project, the term active network management (ANM) is used to capture these types of alternative solutions. The ANM4L project uses the following definition of ANM:

ANM is the exploitation of flexible network assets for the purpose of providing secure means of increasing grid utilization.

There are many different potential types of flexible network assets, such as demand response, distributed generation and battery energy storage systems. There are also different types of network issues for which ANM can be useful, such as for controlling voltage or avoiding overloading.

In many cases, the DSO does not own the flexible asset that could be used for an ANM solution. In such cases the DSO may need to compensate the owner for allowing the DSO to control the asset, especially if such action could lead to increased costs, lost revenues or some other inconvenience for the asset owner. For this reason, several research projects and commercial initiatives around Europe are developing and implementing flexibility markets where DSOs can procure flexibility services from assets in their networks. Examples include the PicloFlex marketplace in the UK [7], the NODES market concept [8] and the CoordiNet project [9].

The proposed flexibility markets differ substantially in terms of market design and functionality. For example, some include continuous short-term trading for activation of the flexibility assets, whereas others rely on long-term agreements. Furthermore, some have a narrow DSO focus whereas others attempt to create marketplaces where the flexibility can be made accessible also to other participants, such as TSOs.

3. COST-BENEFIT ANALYSIS IN AN ANM SETTING

The central question regarding the value of ANM for long-term planning is "Should an ANM solution be invested in?". The answer to this question depends on what other options are available to the DSO. Estimating the value of ANM for long-term planning is therefore a matter of comparing the costs and benefits that are expected to arise if the ANM solution is used, to the costs and benefits that are expected under an alternative approach without ANM.

The cost-benefit analysis (CBA) approach is an often-used framework for conducting structured comparisons between investment options. In this report, we discuss how a cost-benefit analysis can be performed in an ANM setting. Although the CBA framework discussed in this report is general and could be applied in a wide range of situations, it is nevertheless useful to present the framework using a more specific example. The main setup for this example is presented here, with additional details provided later, in section 5. This example is entirely fictional and is not based on any actual DSO or location.

The example used in this report focuses on a case where a DSO operates a network in an area where the amount of distributed generation is large relative to the local network capacity. Therefore, the DSO finds it challenging to accept new generation connections in the area. To enable new connections without jeopardizing security of supply, the DSO needs to consider options for how to increase the capacity of the network.

The traditional method for such capacity expansions would be to invest in higher-capacity physical network infrastructure. This could, for example, involve installing higher-capacity transformers or upgrading distribution lines. However, for the discussions in this report, it is assumed that an alternative to traditional infrastructure reinforcements is available in the form of an ANM solution. Such ANM solutions could, for example, involve procurement of flexibility services from local flexibility assets such as flexible load, energy storage or generation resources.

The purpose of the CBA method discussed in this report is to estimate the value of such an ANM solution by comparing it to the traditional reinforcements that otherwise would have been needed.

Although the discussions in this report focus on a case with excess generation in a local network, the same general principles would apply for the reverse case with load demand exceeding the network capacity. The methods discussed here could therefore be applied in either of these situations.

3.1. Specification of scenarios

CBA is often used in either one of the following two settings: either for determining whether a particular investment should be made or not, or for comparing a set of investment options against each other. Either way, it is important to precisely define both the investment options of interest and appropriate counterfactual scenarios that the investment options are to be compared against.

For the ANM setting, either of these two options can be pursued. With the first approach, an investment option that includes an ANM solution is directly compared to a traditional reinforcement option without ANM, implicitly assuming that business-as-usual (doing no major investment at all) is not a viable option. Alternatively, a business-as-usual scenario can be defined, and the two investment approaches can be evaluated compared to the business-as-usual scenario. In the following, we focus on the second approach since this provides greater transparency regarding the costs and benefits that are attributable to the two investment options and allows for greater flexibility in expanding the analysis to cover additional investment alternatives.

Therefore, to perform the CBA analysis discussed in this report, (at least) the following three scenarios need to be specified:

- A business-as-usual scenario where investments are kept at a minimum (*the BAU case*).
- A scenario where investments are made in traditional network reinforcements (*the reinforcement case*).
- A scenario where an ANM solution is implemented (*the ANM case*).

3.2. CBA from whose perspective?

Cost-benefit analyses differ depending on the perspective taken in the analysis. Following the terminology in [10], two main types of CBA can be identified:

- **Financial CBA**: This type of CBA compares costs and benefits from the perspective of a single entity (such as a DSO), analyzing if the benefits enjoyed by the entity outweighs the costs incurred by the entity.
- **Economic CBA**: This type of CBA compares costs and benefits from a broader societal perspective, analyzing if the benefits enjoyed by society as a whole exceeds the costs incurred by society as a whole.

In our ANM setting, a financial CBA can be carried out from a DSO perspective, aiming to answer the question "Would it be beneficial for the DSO to invest in an ANM solution?". An economic CBA takes a broader societal perspective, aiming at answering "Would it be beneficial for society as a whole if the DSO invested in an ANM solution?".

Since DSOs are regulated monopolies, the financial CBA from a DSO perspective is influenced by the regulatory model that govern DSO revenues and profits. Therefore, the financial CBA needs to take the regulatory model into account.

In this report, both of these approaches (economic CBA and financial CBA) are considered and compared. This is especially interesting from a regulatory perspective, since it can help shed light on how a particular regulatory model brings the outcome of the financial CBA closer to or further away from the outcome of the economic CBA. Figure 1 provides an overview of how the three cases and the two CBA approaches relate to each other.

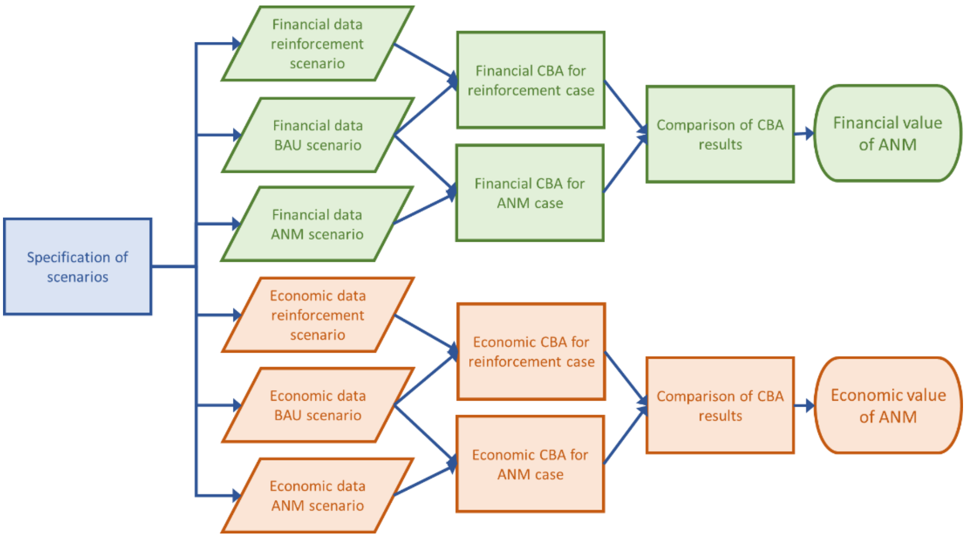

Figure 1 Overview of CBA methodology described in this report

4. GENERAL PRINCIPLES OF COST-BENEFIT ANALYSIS

The basic idea behind cost-benefit analysis (CBA) is simple and intuitive: by assessing costs and benefits of various investment options in a structured way, the option with the highest net benefits can be identified. However, even if the basic idea is simple, performing CBA in practice can be very challenging. For example, CBA often involves making forecasts of costs and benefits far into the future, placing monetary values on non-traded goods or services, comparing costs and benefits that arise at different points in time, accounting for risk and uncertainty, and so on. This section briefly discusses some general considerations regarding CBA and how they relate to the ANM setting considered in this report.

4.1. Which items to include?

CBAs are based on an incremental approach. This means that costs and benefits of a particular investment case are valued relative to some without-the-project counterfactual case [10]. In this report, the business-as-usual case is used as a common counterfactual, against which both the traditional reinforcement case and the AMN case is evaluated. Therefore, only costs and benefits that differ between at least two of these cases need to be included in the analysis.

The list of factors that potentially could be affected by an investment can often be made very long, especially for an economic CBA. In theory, a CBA should include all such items. In practice, it is often impossible or prohibitively time-consuming to analyze all possible costs and benefits. Therefore, only those factors that are likely to be large enough to significantly alter the conclusions of the analysis should be included [11].

4.2. All values expressed in monetary terms

To enable a quantitative comparison between all relevant costs and benefits, they must all be measured in the same unit. This typically means that monetary values need to be provided for all costs and benefits that are included in the CBA analysis.

However, this *does not* mean that CBAs need to be limited to costs and benefits where money actually changes hands. Especially for economic CBA, all types of relevant costs and benefits should be included, irrespectively of whether anyone actually pays for them or not. Examples of non-traded items that can be included in an economic CBA are the cost of environmental damage, the value of additional leisure time, the value of good health, or the cost of noise exposure. In an ANM context, non-traded items could include, for example, security of supply or the visual impact of overhead lines.

Obviously, it can be very challenging to find good and objective valuation estimates for non-traded items. Some CBA guidelines (such as [12]) therefore suggest that difficult-to-quantify items should be left out of the quantitative CBA analysis and instead analyzed qualitatively. However, when time comes for choosing between the investment options, the decision-maker will need to weigh the value of the qualitatively assessed items against the ones that has been quantified. In doing so, the decision-maker implicitly makes a quantification of the value, but in a much less transparent way. Therefore, it is often suggested [13] that CBAs should attempt to quantify costs and benefits in monetary terms as far as possible.

4.3. Time and discounting

Irrespective of the type of CBA, it is often necessary to make comparisons between costs and benefits that arise at different points in time. There are two slightly different – but closely related – methods commonly used for this purpose: the net present value (NPV) method and the internal rate of return (IRR) method.

With the NPV method, all future costs and benefits are discounted to a present value using a pre-determined discount rate. This can be expressed as:

$$NPV = \sum_{t=1}^{T} \frac{b_t - c_t}{(1+r)^t}$$

where the net present value is calculated based on T time periods (often years), b_t and c_t represent the monetized expected benefits and costs for time-period t, and r is the discount rate. The time horizon T is typically chosen based on the expected lifetime of the investment, and the calculation can be adapted to include end-of-life residual values. While the discount rate could vary over time, it is common practice to assume a fixed discount rate [10].

The choice of an appropriate discount rate, r, is a key decision that can greatly influence the outcome of an NPV calculation. Further, it may be difficult to find objective exact values for the discount rate, necessitating some amount of judgement.

For financial CBAs, the discount rate should reflect the opportunity cost of capital, taking the riskiness of the investment into account. It should therefore represent the return on investment that the firm could get if it invested in an alternative project with a similar risk profile. In practice, it is common to use the firm's weighted average cost of capital (WACC) for this purpose, although this may need to be adjusted to capture the risk profile of the investment.

For an economic CBA, a social discount rate should be used. The theoretical underpinnings for what such a discount rate should reflect is a somewhat controversial topic with ethical questions at its core [14]. Common approaches include the social rate of time preference method and the social opportunity cost of capital method [15].

The IRR method is similar to the NPV method, but instead of specifying a discount rate, one calculates which discount rate that would yield a zero NPV. In other words, the IRR for the project solves the following equation:

$$0 = \sum_{t=1}^{T} \frac{b_t - c_t}{(1 + IRR)^t}$$

Therefore, the IRR can be calculated without first determining a discount rate, which may seem like an advantage for the IRR method. However, the calculated IRR needs to be compared to something, which brings one back to the same discount rate. The IRR method and the NPV method are therefore essentially two different perspectives on the same calculation.

When calculating the NPV or IRR for projects spanning multiple years, it is important to keep inflation in mind. This can be done either by consistently using monetary amounts that reflect the price level at a chosen reference year, irrespectively of when the cost or benefit actually occurs (real valuation). Alternatively, costs and benefits can be valued at a price that reflects the expected price level during the year when they occur (nominal valuation). If the real valuation approach is chosen, then the discount rate must be adjusted accordingly, subtracting an amount equal to the expected yearly inflation rate compared to a nominal discount rate.

To make the calculations in the following illustrative example as simple as possible, real valuation is applied and the assumed discount rates are therefore real discount rates.

4.4. Risk and uncertainty

Performing CBA in practice typically involves estimating values for many different parameters, many of which will be highly uncertain. For a CBA to provide a fair picture of expected net benefits, it is necessary to somehow capture and represent this uncertainty.

A common approach for capturing uncertainty regarding parameter estimates is to simulate net benefits using a Monte Carlo approach, with probability distributions for input parameters rather than point estimates. This can provide a quantification of how uncertain the results of the CBA are, provided that reasonable probability distributions for the input parameters are available. Alternatively, if it is difficult to motivate a particular probability distribution for some key parameters, a sensitivity analysis may be preferable, analyzing the sensitivity of the CBA results to changes in some key parameter values.

4.5. How should the results of an economic CBA be interpreted?

While the purpose of a financial CBA is relatively clear – it shows if an investment would financially benefit the relevant entity or not – the purpose of an economic CBA is somewhat less obvious. The idea is that an economic CBA should indicate if a proposed investment would be beneficial for society as a whole. However, from a social fairness perspective, the appropriateness of using economic CBA can be questioned.

Economic CBA is commonly used for evaluating, for example, public investment projects. The idea behind this is that, if the total value for those who benefit from the investment exceeds the total costs, then the investment should be made. While this might sound obvious, it is not clear that such an approach actually leads to appropriate and fair policy decisions. This issue has been a topic of academic debate for almost a century [16].

One of the main points of contention concerns the distributional effects of the investments in question. CBA typically sums up total costs and benefits, disregarding who benefits from the investment and who pays for it. Therefore, even if the total benefits to society outweighs the total costs, there will most likely be individual members of society for whom the costs outweigh the benefits. A simple example is when an infrastructure project provides large benefits to a small region of a country but is paid for by taxpayers across the whole country. In such a case, a CBA may show that the benefits of the project outweigh the costs, while most members of society would be left worse off from the investment.

The traditional argument for nevertheless following a CBA approach when determining the appropriateness of public investments involves some patience: if CBA methods are consistently applied, then most individuals would likely be better off in the long run. However, this requires that investments are distributed somewhat evenly across the population, which may contradict a strict prioritization of investment options purely based on CBA results.

What does this mean for the methodological approach described in this report? The reason for making a comparison between the outcome of a financial CBA and an economic CBA, is to enable an analysis of whether the regulatory regime incentivizes the DSO to make “the right” investments, where the economic CBA is meant to indicate if the investment is “right” or not. However, economic CBA cannot alone be interpreted as providing the final answer to whether an investment is “right” for society. Providing such an answer would require complementing the economic CBA analysis with a judgement that captures society’s preferences regarding, for example, fairness. This limitation of the CBA approach needs to be kept in mind when applying the method described in this report.

5. ILLUSTRATIVE EXAMPLE

In the following, the CBA analysis framework is explained using an illustrative example case. This example case is entirely fictional and is not intended to represent any specific location or DSO. The monetary values used for different cost and benefit components are not based on any actual cost or benefit assessments. The example is also relatively simple; a real application of the CBA framework would likely include a more detailed breakdown of the various costs and benefits.

First, it is assumed that a clearly defined network area has been identified, wherein a large amount of variable renewable generation is installed. For the sake of illustration, it is assumed that there is a lot of wind power in this particular area. The amount of installed wind power has reached a level such that, on windy days, the resulting power flows are approaching the limit of what the local network is dimensioned for.

The DSO has received requests for connecting an additional 30 MW of wind power generation in the area. It is assumed that the DSO is not expecting any further requests after these 30 MW have been installed. Therefore, the problem at hand is to enable the connection of these new wind power connections, after which no further changes are anticipated.

5.1. Description of cases

5.1.1. The BAU case

The BAU case in this illustrative example is a case where the existing network capacity is maintained but not expanded. It is here assumed that this means that the DSO has to decline the requests for new generation connections. Since DSOs are typically required to connect new customers upon request (within a reasonable time-period and at a regulated cost), the BAU case may not be a legally viable option for the DSO in the long run. Nevertheless, the BAU case is used as the counterfactual against which the reinforcement case and the ANM case is compared.

5.1.2. The reinforcement case

In the reinforcement case, the DSO makes an upgrade in the physical network infrastructure. For the sake of illustration, it is here assumed that this reinforcement involves constructing a new medium-voltage overhead line. This investment is expected to require 5 years of permitting and planning, followed by 2 years for construction and testing, which means that it would take 7 years before the capacity of the network has been expanded and the new generation connections can be allowed.

5.1.3. The ANM case

In the ANM case, the DSO implements an ANM solution that enables increased use of the existing network infrastructure. In this illustration, an ANM solution is envisioned where the DSO is given access to control the load and/or generation of a set of flexible resources within the local network area such that the DSO can manage flows on the network. Because of this capability, the DSO is able to connect new customers to the network without making any physical reinforcements. Compared to the reinforcement case, the ANM solution would be faster to implement. It is assumed to require 2 years for planning and development followed by 1 year for implementation and testing, meaning that new connection can be allowed after 3 years.

5.2. Costs and benefits in illustrative example

This section discusses some costs and benefits that are used to illustrate the CBA framework for the illustrative example. These costs and benefits are here discussed both from a narrow DSO perspective (for the financial CBAs) and from a broader societal perspective (for the economic CBAs).

5.2.1. Investment costs

The investment cost for the new overhead line is the largest cost component for the reinforcement case. These costs include the cost for purchasing the equipment, any costs associated with the construction, installation and testing, as well as the cost incurred during the planning phase.

In addition to the costs directly associated with purchasing and installing the new equipment, the construction of a new overhead line also involves a range of other related costs. The DSO needs to compensate landowners for utilizing their land. Obtaining all necessary permits and approvals is likely to require substantial efforts from DSO personnel, consultancy costs, etc.

For the illustrative example it is assumed that the total investment costs for the reinforcement is 25 million EUR. It is assumed that 5 million of these arise during the planning phase (1 million per year), and 20 million during the 2-year construction phase. The expected useful life of the investment is 50 years, which is assumed to coincide with the regulatory depreciation period. The amount included in the regulatory asset base (before depreciations) is assumed to be the same as the actual investment cost, i.e. 25 million EUR.

The investment costs for the ANM case concerns the development and implementation of ICT infrastructure and systems, but also implementation costs associated with recruiting flexibility providers and personnel training. As noted above, it is assumed that the ANM solution can be implemented faster than the physical reinforcement. It is also assumed that the initial investment cost is lower: 1 million EUR per year during the 2-year planning phase, followed by 2 million EUR for the 1-year implementation and testing phase, for a total cost of 4 million EUR.

The ICT infrastructure and systems are here assumed to have a useful life of 10 years, which again is assumed to coincide with the regulatory depreciation period. A reinvestment is therefore needed every 10 years, at a cost of 2 million EUR. It is assumed that only the implementation costs are eligible for inclusion in the regulatory asset base, meaning that 2 million EUR are included in the asset base (before depreciations) for the ANM ICT infrastructure.

For simplicity, it is here assumed that the societal investment costs (for the economic CBAs) are the same as the financial costs incurred by the DSO for the investments. However, this may not always be the case.

5.2.2. Value of new connections

The main benefit created by the increased capacity of the network (both for the ANM case and for the reinforcement case) is the value that is created by the possibility to connect 30 MW of new wind power generation in the area. For simplicity, it is assumed that both the ANM case and the reinforcement case would be sufficient to enable this.

The new connections would result in additional tariff revenues for the DSO. Specifically, the yearly network tariff payments from the new connections are here assumed be 0.5

million EUR. However, in this illustrative example it is assumed that DSO revenues are determined by a regulated revenue cap, which means that the investment's impact on total tariff revenues need to be considered, not just the tariff revenues from the new connections. This is discussed further in section 5.3.

From an economic CBA perspective, the tariff payments are of less relevance since they do not reflect the underlying economic value created by the new connections. The economic value that is enabled by the new connections is the net economic value created by the wind power investments, i.e. the difference between the value of the energy generated and the costs associated with the investments (including both financial values as well as any externalities). Estimating this value would therefore require an estimate of the expected revenues that the wind power would bring in, the costs for investments and operations, any externalities etc.

Given that investors are willing to invest in wind power in the area, it is reasonable to assume that the economic value created exceeds the tariff payments from the new connections. For this example, the economic value created by the investments is assumed to be 1.5 million EUR per year.

5.2.3. Energy losses

Both the ANM case and the reinforcement case could potentially have an impact on the amount of energy losses that occur in the DSO network, compared to the BAU case. The ANM case involves operating the existing infrastructure closer to its physical limitations. Therefore, it is assumed that the amount of energy losses in the DSO network in the ANM case is higher than in the BAU case.

For the reinforcement case, there are two opposing effects. On the one hand, the additional power flows from the new wind power installations create additional losses in the DSO network compared to the BAU case. On the other hand, the reinforced infrastructure could result in lower losses. For this example, we assume that these two effects cancel out and that the total amount of energy losses in the DSO network are the same under the BAU and the reinforcement cases.

The DSO is responsible for procuring energy to cover the losses that occur in its network. Assuming that externalities in electricity generation are priced appropriately, the financial cost to the DSO (for the financial CBA) and the societal costs (for the economic CBA) attributable to the energy losses are the same. In this example, the additional energy losses in the ANM case compared to the BAU case is assumed to cost 0.1 million EUR per year.

5.2.4. Operational costs

The ANM case and the reinforcement case affect operations and maintenance costs (excluding energy losses) in very different ways. For the reinforcement case, the new overhead line requires some maintenance in the form of, for example, tree clearing. For this example, it is assumed that the reinforcement case therefore leads to an increase in O&M costs of 0.1 million EUR per year, compared to the BAU case.

The operational costs for the ANM case are more complex to represent. The ANM solution requires time from DSO personnel to, for example, monitor the ANM operations and handle the interaction with flexibility providers. Further, the ANM case could involve recurring payments for, for example, software licenses and other IT-related costs. In this example it is assumed that the ANM case would increase DSO costs for this kind of operational items by 0.2 million EUR per year.

The ANM case in this example involves local flexibility providers that sell flexibility services to the DSO. There are two different types of flexibility provision costs of relevance for this example: the cost incurred by flexibility providers for providing the flexibility and the payment that the DSO makes to the flexibility providers for their services. The former is likely to be lower than the later, assuming that the flexibility providers want to earn a profit for providing the services. The cost incurred by flexibility providers include monetary cost as well as their valuation of perceived inconvenience (for example due to variations in indoor temperature or due to a longer duration for electric vehicle charging).

In this example, the flexibility providers' incurred costs for delivering the necessary flexibility services are assumed to total 0.4 million EUR per year, for which the DSO pays 0.5 million EUR per year.

5.2.5. Other externalities

The costs and benefits discussed so far are related to some payment to or from the DSO. However, some costs and benefits have no clear connection to any traded good or service. This type of item may not be relevant for a financial CBA, but they are for economic CBAs. For the illustrative example, the visual impact of the new overhead line in the reinforcement case is used to illustrate a non-traded externality that is included in the economic CBA but not in the financial CBA.

Thus we assume that people living nearby the new overhead line perceive that the overhead line has a negative impact on the beauty of the landscape. Collectively, they would be willing pay 0.2 million EUR per year to not have their landscape affected by the new infrastructure. Even though it is not possible for these local residents to pay that amount and thereby make the overhead line invisible, this negative externality of the new infrastructure should still be included in the economic CBA. This externality is assumed to be present during both the construction phase and when the infrastructure is in place.

5.3. Net present value calculations

Based on the cost and benefit assumptions outlined above, this section calculates net present values (NPV) for the different CBAs and compare the results.

According to the assumptions discussed above, the expected life of the infrastructure associated with the ANM solution (10 years) is shorter than the expected life of the network reinforcement infrastructure (50 years). To provide a fair comparison between the two options, the NPV is here calculated over the same time-period for both cases. The time-period is determined by the longer reinforcement case, with assumed reinvestments every 10 years for the ANM case. The timelines for the NPV calculations are illustrated in Figure 2 below.

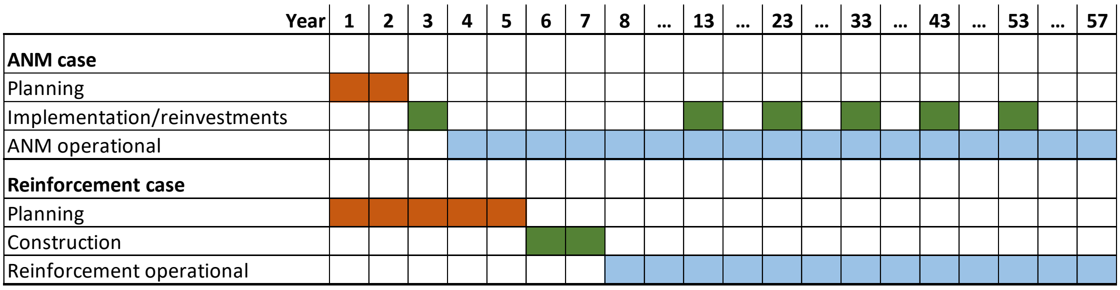

Figure 2 Timeline for NPV calculations

As discussed in section 4.3, the choice of discount rate is a key input for any NPV calculation. For this example, a 5% real discount rate is used both for the financial and economic CBAs. For simplicity, it is also assumed that regulated rate of return used for calculating the revenue cap is 5%.

5.3.1. Representation of the revenue cap

It is here assumed that the DSO is subject to a revenue cap, and that the revenue cap is binding (i.e. the DSO makes full use of the revenue cap). The method used here for calculating the revenue cap is highly simplified and is not meant to mimic the actual revenue cap model of any particular jurisdiction.

The revenue cap is used for calculating the additional tariff revenues that the DSO may collect as a consequence of the investment, compared to the BAU case. There is no need to calculate the total revenue cap amount for the DSO, just the difference in the revenue cap compared to the BAU case.

The revenue cap is here made up of 3 components: operational costs, capital depreciation and return on capital. In this example, it is assumed that all operational costs (O&M costs and energy losses) enters the revenue cap without any modifications, both for the ANM case and the reinforcement case.

Both capital depreciation and return on capital are calculated based on a regulatory asset base. It is assumed that the network reinforcement contributes to the asset base at a valuation of 25 million EUR (i.e. a valuation that equals the actual investment cost, including both planning and construction costs). For the ANM case, the ICT infrastructure is valued at 2 million EUR in the asset base. Therefore, the costs associated with the initial planning for the ANM case are not included in the valuation when determining the asset base. This is the main difference between how the ANM and reinforcement cases are treated by the regulatory model in this example.

For the capital depreciation, linear depreciation is applied from the first year of operation until the end of the expected life of the asset (which here is assumed to be the same as the regulatory depreciation period of the asset). For the reinforcement case, this means that 0.5 million EUR (25/50) enters the revenue cap every year during the operational phase. For the ANM case, capital depreciations are 0.2 million per year (2/10) during the operational phase.

The regulatory rate of return is here assumed to be the same as the DSO's required rate of return, i.e. 5%. The return on capital is therefore 5% of the asset base, where the asset base in a given year during the operational phase is obtained by subtracting the depreciations made in previous years from the initial asset base amount.

To summarize, the change in revenue cap for operational year $i \in \{1, \dots, T\}$ is given by:

$$\Delta \text{ revenue cap} = \text{OPEX} + \frac{\text{A}}{T} + 0.05 * \left(A - (i-1) * \frac{A}{T}\right)$$

where T is the depreciation period in years, and A is the valuation of the investment in the asset base. The yearly depreciation amount is therefore A/T and the asset base in year i is given by $\left(A - (i-1) * \frac{A}{T}\right)$.

5.3.2. Financial CBA

This section presents the results from the financial CBAs. Table 1 provides summary information for the reinforcement case. The three rightmost columns summarize the cost and benefits that make up the input data for the NPV calculation, and the column highlighted in blue shows the resulting net present value for each category. Negative values reflect costs and positive values reflect benefits. For example, the investment costs (1 million per year during the planning phase and 10 million per year during the construction phase) correspond to an NPV of 18.9 million EUR.

Table 1 Financial CBA summary for reinforcement case

Financial CBA summary Reinforcement case	NPV	**Planning phase** Years 1-5	**Construction phase** Years 6-7	**Operational phase** Years 8-57
Investment costs	-18.9	-1 per year	-10 per year	
Energy losses	0.0			No net impcat
O&M costs	-1.3			-0.1 per year
Tariff revenues	19.1			Differs by year
Total net benefit	-1.1			

All values in million EUR

The tariff payments made by the newly connected customers are assumed to be 0.5 million EUR per year. However, this amount is not what determines the total impact that the investment has on DSO revenues. Instead, the investment influences the calculation of a revenue cap, which in turn governs the DSO's revenues. Therefore, the amount listed for "Tariff revenues" in Table 1 is not based on the payments made by the newly connected customers, but rather based on the increase in the revenue cap. See section 5.3.1 above for details concerning the calculation of this amount.

In this example, the increase in total tariff revenues turn out to be greater than the payments made by the newly connected customers (0.5 million EUR per year during the operational phase of the reinforcement case corresponds to an NPV of about 6.5 million EUR). This is however highly dependent on the specifics of the case and the details of the regulatory model.

The total net benefit when combining all NPVs in this example is negative 1.1 million EUR. In other words, the financial return for the DSO on this investment does not quite reach the 5% required return on investment. Instead, the IRR for the investment becomes about 4.5%.

Since the regulated rate of return and the discount rate used for the NPV calculation (i.e. the DSO's required rate of return) are both equal to 5%, and since all cost components are included in the revenue cap calculation, one might expect that the NPV should be 0 by construction. The reason why the NPV instead becomes slightly negative is that the investment costs are spread out over the planning and construction phases but are not included in the asset base (and hence does not create any revenues for the DSO) until the project is completed and operational. Had the full investment cost occurred in year 7, then the NPV would have been exactly 0 in this example.

Table 2 provides the same information as Table 1, but for the ANM case. Despite the much lower investment costs, the total net benefit for the DSO is in this example even more negative (-1.9 million EUR) and the IRR is close to zero. In this example, this is primarily driven by the difference in how the regulatory model accounts for planning costs in the ANM case versus the reinforcement case. In the reinforcement case, the planning-related investment costs are included in the asset base, while this in not true for the ANM case. Of course, this does not need to be the case in practice. The point here is to illustrate that a seemingly small difference in the regulatory model can affect the relative ranking of the investment options.

Table 2 Financial CBA summary for ANM case

Financial CBA summary ANM case	NPV	**Planning phase** Years 1-2	**Implementation** Year 3	**Operational phase** Years 4-57
Investment costs	-6.1	-1 per year	-2	-2 every 10 years
Energy losses	-1.6			-0.1 per year
O&M costs	-11.2			-0.7 per year
Tariff revenues	17.0			Differs by year
Total net benefit	-1.9			

All values in million EUR

Since both the reinforcement case and the ANM case show negative total net benefits, the profit-maximizing choice for the DSO in this example would be the BAU case. If this is not a viable option, then the reinforcement case would be the lower cost alternative for the DSO in this example. This result is to a large extent driven by the assumed regulatory model.

5.3.3. Economic CBA

This section presents the economic CBA results. Since economic CBAs are performed from a societal perspective, the underlying value of the new connections is included instead of the tariff revenues. This means that the regulatory model does not enter the economic CBA calculations. Further, the visual impact of the new overhead line is included as an example of a non-traded externality.

Table 3 shows a summary of the economic CBA for the reinforcement case, showing that the net present value is negative (the IRR is just below 4%). However, as seen in Table 4, the ANM case has a large positive net present value (corresponding to an IRR of about

15%). Therefore, the ANM solution has a much higher economic value than the traditional network reinforcement.

Table 3 Economic CBA summary for reinforcement case

Economic CBA summary Reinforcement case	NPV	Planning phase Years 1-5	Construction phase Years 6-7	Operational phase Years 8-57
Investment costs	-18.9	-1 per year	-10 per year	
Value of connections	19.5			1.5 per year
Energy losses	0.0			No net impcat
O&M costs	-1.3			-0.1 per year
Visual impact	-2.9		-0.2 per year	-0.2 per year
Total net benefit	-3.6			

All values in million EUR

Table 4 Economic CBA summary for ANM case

Economic CBA summary ANM case	NPV	Planning phase Years 1-2	Implementation Year 3	Operational phase Years 4-57
Investment costs	-6.1	-1 per year	-2	-2 every 10 years
Value of connections	24.1			1.5 per year
Energy losses	-1.6			-0.1 per year
O&M costs	-9.6			-0.6 per year
Visual impact	0.0			no impact
Total net benefit	6.7			

All values in million EUR

5.3.4. Discussion

In this illustrative example, the economic CBA shows that the ANM case has a much higher value than the reinforcement case from a societal perspective. If the BAU case is not a viable option, then the economic value created by the ANM solution is over 10 million EUR compared to the reinforcement case (a net benefit of 6.7 million EUR instead of a net cost of 3.6 million EUR).

However, even though the AMN case has a higher economic value, the financial CBA shows that the ANM case is not the most financially attractive for the DSO. According to the financial CBA, neither of the cases meet the DSO's required return on investment, but the reinforcement case gets closer. Therefore, the ANM case does not create a financial value for the DSO in this example. The financial CBA also shows how important the details of the regulatory model is for the outcome. A change in the regulatory model alters the amount of additional tariff revenues the DSO is allowed to collect in the different cases and can therefore significantly change the attractiveness of the ANM case from a financial perspective.

This illustration shows that the "value of ANM" from a planning perspective can look very different depending on whether the analysis is made from a financial DSO perspective or from a broader economic perspective. It is possible for the ANM case to have a high value from one perspective, while not being valuable at all from the other.

The analysis presented in this example could easily be extended to include additional investment options, for example where an ANM solution is combined with minor reinforcements, or where the ANM solution is used for postponing a network reinforcement rather than replacing it. The latter could be especially valuable from a financial DSO perspective if the reinforcement replaces an existing asset, which has not been fully depreciated.

Finally, as noted in section 4.4, if this was an actual application of the CBA framework on a real case, it would be necessary to complement the analysis with sensitivity analysis and/or Monte Carlo simulations to capture the large amount of uncertainty that would likely be associated with several of the estimated costs and benefits. For example, some investment option may be better suited for accommodating future unforeseen developments, such as further load or generation growth in the area.

6. VALUE OF ANM FROM A SHORT-TERM PERSPECTIVE

The discussions so far in this report have been focusing on the value of ANM from a long-term planning perspective. While this is the appropriate perspective when determining whether an ANM solution should be invested in or not, it is also interesting to consider how this relates to the short-term perspective and the value of flexibility services in short run.

When discussing the short-term value of a flexibility service, it is important to differentiate between the following three items:

1. The cost incurred by the flexibility provider for delivering the flexibility service.
2. The payment that the DSO makes to the flexibility provider for providing the flexibility service.
3. The amount that the DSO is at most willing to pay for the flexibility service.

For the ANM solution to be valuable to both the DSO and the flexibility provider, the payment that the DSO makes (item 2) should be higher than the cost for delivering the service (item 1) and lower than the DSO's willingness-to-pay (item 3). The long-run value of ANM from a planning perspective is related to the latter, as discussed below.

6.1. From long-run to short-run valuation

The financial CBA method described in this report could be used to estimate the maximum amount that the DSO can pay for flexibility services before the ANM solution becomes less financially attractive then a network reinforcement. This can yield an annual average cost of flexibility services that the DSO would find financially acceptable in the long run. Based on an assessment of the amount and frequency of flexibility activations that are likely to be needed, this amount can be further broken down to an average long-run willingness-to-pay for flexibility activations. Such a value can serve as a benchmark for what the DSO at most would be willing to pay for flexibility services, i.e. item number 3 above.

From a regulatory perspective, the regulator has to decide to what extent payments for flexibility services should be included when calculating the revenue cap. For this purpose, an economic CBA could be used for estimating if the use of an ANM solution is motivated from a societal perspective, and hence whether the costs associated with procuring flexibility services can be viewed as being prudently incurred.

6.2. Maximum willingness-to-pay and the holdup problem

When using a long-run CBA approach to estimate the DSO's willingness-to-pay for flexibility services, a long-run average willingness-to-pay is obtained. However, once the DSO has decided to implement an ANM solution, and therefore rely on it for day-to-day grid operations, the short-run willingness-to-pay for a particular flexibility activation is potentially much higher.

This can be viewed as a version of the *hold-up problem*, a suboptimality that may arise when contracting is incomplete [17]. Once the DSO has decided to rely on a flexibility provider for flexibility services, that flexibility provider may be in a very strong negotiating position in the short run. In the long run, the DSO may have other reasonable options (such as a network reinforcement), but in the short run the DSO relies on the flexibility provider for maintaining safe and reliable grid operations, and may therefore be willing to pay a very large amount for the flexibility services.

If the DSO recognizes that this situation may arise, it will likely hesitate to enter into such an agreement with a flexibility provider in the first place. Potential solutions to this issue could involve the DSO and the flexibility provider entering into (relatively detailed) long-term contracts that require the flexibility provider to provide certain services at a certain price. Another possible solution would be to ensure that sufficiently many flexibility providers are available in any given situation, and then rely on competition between the flexibility providers to keep flexibility service prices from soaring.

6.3. Other sources of value

In addition to providing a substitute to traditional network reinforcements, ANM solutions could potentially create value to the DSO in other ways. Such alternative sources of value could motivate an ANM solution in their own right or could provide some additional values on top of the value created by replacing the need for traditional reinforcements.

One type of value arises if the DSO has a contract with the overlaying network owner (such as a TSO) where the DSO needs to pay a penalty fee if the DSO's total load exceeds a certain amount. When this is the case, the DSO could use the ability to activate flexibility resources to manage the peak load of the DSO as a whole.

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