UNIVERSITY OF TWENTE.

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KEY PERFORMANCE INDICATORS FOR SMART GRIDS

Master Thesis on Performance Measurement for Smart Grids

Vattenfall AB - R&D - Power Technology

Author:

W.J. Harder

Supervisors:

R.A.M.G. Joosten — University of Twente
B. Roorda — University of Twente
Y. He — Vattenfall

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Summary

The purpose of this report is to present a method which facilitates the use of Key Performance Indicators in Smart Grids. The aspects that are covered are the related projects and processes as well as the company level perspective. This method is the result of a master thesis assignment on what Smart Grids are and which benefits are associated with them. A wide range of benefits such as more reliable energy distribution and generation as well as cost savings have been found. Some of these benefits would mostly be enjoyed by society in general, whilst the investments to acquire these benefits have to be made by the Distribution System Operators. The author expects that the asymmetric distribution of knowledge on the goals of the projects could be made more symmetrical by using the KPI method. This can be realised by the cooperation of management with project members in deciding which KPIs will be used in the project and setting their target levels. Conversations with several colleagues at Vattenfall Research and Development and with some colleagues at Vattenfall Distribution have greatly contributed to forming these chapters. After setting the framework for this study and stating which methods will be used, a description of the KPIs that have been found is presented. The full list can be found in Appendix I – Existing KPIs. The main sources were European Commission publications, regulatory documents published by regulators in Europe, documents from energy utilities and DSOs. It is worth to specifically mention the use of the EU Discern project for providing a comprehensive source of information.

An approach to quantifying Smart Grids benefits with Key Performance Indicators and how they relate to regulations and incentives is presented. It has been found that many KPIs are directly incentivised by the regulatory agency. However, the current scheme (ending 2019) promotes capital intensive solutions, as it operates on a cost-plus basis. This conclusion is not only valid for Sweden, but for several other countries in Europe. Since Smart Grids bring benefits in many different areas, the recommended KPIs are presented per focus area in the Smart Grid Roadmap, together with a guide on how to implement KPIs and how to use them during and after implementation. This implementation guide is the main deliverable towards Vattenfall. An important aspect of the implementation of KPIs is the cooperation between the different layers of management and the employees. Making sure everyone is working towards the same goals is difficult if the information asymmetry is large, therefore this method aims to make the distribution of information more symmetrical. Chapter 7 also contains the guide which was developed as part of this thesis on how KPIs can be applied in the Vattenfall Smart Grid Roadmap.

Acknowledgements

The moment is finally here, writing these acknowledgements is the last touch on my thesis. I had a very rewarding time in Sweden in general, and at Vattenfall in specific. At the Research and Development department I was surrounded by people who are experts in their respective fields and were always willing to provide support and guide me in the right direction. I would especially like to thank Ying He, who was always willing to provide feedback in a very clear manner whilst still allowing for constructive discussion: exactly how I like it. I might not have always listened when she told me to go home because it was past five o'clock already, but luckily, she did allow me to join the organisational team of the Vattenfall Innovation Competition, also known as The Unicorns, in the after-work hours. This group of people have made my time at Vattenfall even better, being able to organise and join so many workshops and inspirational lectures was truly rewarding and I thank each and every one of the team members.

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Last but not least I thank my parents and sister for their support during my entire studies. Their contribution has come in many ways and I could not have done it without them.

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List of Acronyms

Acronym	Meaning
AC	Alternating Current
ADI	Average Duration of Interruption
AI	Availability Index
AMI	Advanced Metering Infrastructure
AMR	Automated Meter Reading
BA	Business Area
BaU	Business as Usual
CAIDI	Customer Average Interruption Duration Index
CAPEX	Capital Expense
CBA	Cost Benefit Analysis
CBM	Condition Based Maintenance
CEMI	Customers Experiencing Multiple Interruptions
$CEMI_{12}$	Customers Experiencing Multiple Interruptions – twelve or more
DC	Direct Current
DG	Distributed Generation
DLR	Dynamic Line Rating
DR	Demand Response
DSO	Distribution System Operator
EI	Energimarknadsinspektionen
ENS	Energy Not Supplied
EU	European Union
EV	Electric Vehicle
FLIR	Fault Location, Isolation and Restauration
GHG	Greenhouse Gas
GRI G4	Global Reporting Initiative, Sustainability Reporting Guidelines, Fourth Revision
GWh	Gigawatt hour
HV	High Voltage
KPI	Key Performance Indicator
kWh	Kilowatt hour
LF	Load Factor
LTIF	Lost Time Injury Frequency

MTonnes	Million Tonne
MW	Megawatt
MWh	Megawatt hour
NPS	Net Promotor Score
NPV	Net Present Value
OPEX	Operational Expense
PNS	Power Not Supplied
PPV	Present Purchase Value
PV	Photovoltaic
PWA	Prioritised Work Area
R&D	Research and Development
ROCE	Return On Capital Employed
ROI	Return on Investment
RTP	Real Time Pricing
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	Supervisory Control and Data Acquisition
SGR	Smart Grid Roadmap
TSO	Transmission System Operator
VF ENV R&D	Vattenfall Environmental Research & Development
WACC	Weighted Average Cost of Capital

1. Introduction

1.1. Company Description

Vattenfall is in the top 10 of largest energy companies in Europe and the leading energy company in the Nordic countries. This makes it a major player whose decisions affect over 6 million electricity customers, over 3 million electricity network customers and over 2 million gas customers. After unbundling the distribution part from the rest of the company, the power distribution department was placed in a separate company which is fully owned by Vattenfall AB. Unbundling was ordered by the government [1] to improve competition in those parts of the energy industry that are not characterised by a natural monopoly. Since the completion of the unbundling process, Business Area Distribution has been operating as an independent organisation with full decision-making power. It is this part of Vattenfall that Vattenfall R&D Distribution reports to and receives a budget from.

1.2. Operation of a State-Owned Commercial Company

The Swedish state owns 100% of the shares of Vattenfall AB and is the receiver of dividends if the company decides to pay out. As the only shareholder, the government has given Vattenfall a mandate that enables it to operate on a level playing field with privately owned competitors, although the state provides the targets and mission for Vattenfall. In the report by the Swedish government on state-owned business in 2015 [2], the targets were defined and published as stated below. Please note that the revenue for the Distribution System Operator part of Vattenfall is subject to limitations based on incentive regulations.

Table 1 Targets set by the Swedish government for Vattenfall

	Target	Outcome
Return on capital employed	9%	-8.2%
Debt/equity ratio	50-90%	55.4%
Funds from operations /adjusted net debt	22-30%	21.1%
Carbon exposure in the company portfolio by 2020	65 Mt	83.8 Mt
Outpace market growth in renewable capacity by 2020	>Market growth	13.4% (>Market growth of 9.9%)
Improve energy efficiency improvements by reducing annual usage of primary energy	440 GWh improvement	1,066 GWh improvement

These targets have been set by the Swedish government and are therefore the result of the political process. The negative outcome of the return on capital employed is largely caused by necessary depreciations to take the lower than expected energy price into account, as well as losses from the sale of a lignite mine and associated power plants.

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1.3. Vattenfall Research and Development Department

The Vattenfall Research and Development (R&D) department is part of Strategic Development and provides R&D services to the six Business Areas (BA) known as Heat, Customers & Solutions, Wind, Generation, Market and Distribution. The sponsor for this project is BA Distribution through Vattenfall R&D Distribution. In general, R&D Distribution runs projects that aim to improve the Vattenfall-owned distribution grid in Sweden. Some examples could be improving power lines, transformers, breakers, switches, metering at the customer end and automating the operation of the grid.

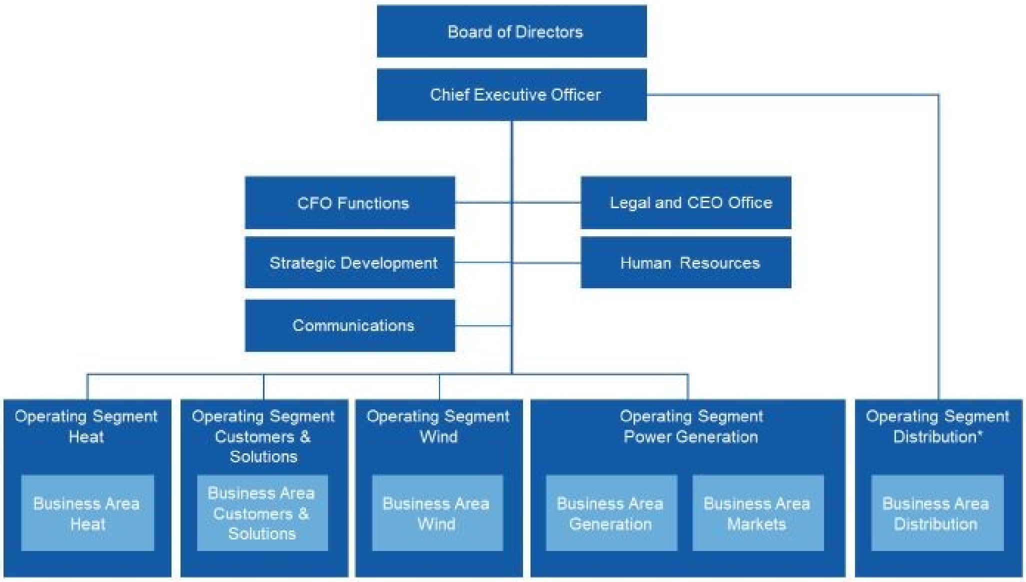

Figure 1 Vattenfall Organisation Chart.

1.4. Key Performance Indicators

A main subject of this thesis is the part of the Balanced Score Card (a strategy management tool) known as Key Performance Indicators. These indicators measure different aspects of performance such as quality, delivery time, capacity and financial figures. When these measure an aspect of performance which is the key to the success of the entity, they become Key Performance Indicators.

A metric is defined as a measurement made over time, which communicates vital information about the quality of a process, activity or resource [3]. In this thesis, a Key Performance Indicator will be an indicator which is a measurement of the performance towards a main objective of the project. Key Performance Indicators have an associated quantified goal per indicator.

1.5. Problem Description

In the energy utility sector, Smart Grid development has started. Grid equipment is being automated, more and more sensors are being installed and self-healing[1] networks are becoming a reality. The benefits of these improvements are manifold, which makes that measuring the total benefit of having a Smart Grid requires analysis on many different levels and aspects.

How to evaluate the performance and how to assess the effects the projects have was unknown and has recently become more relevant after the first Smart Grid projects have started at Vattenfall. To measure the performance of the electrical grid, KPIs are being used by the European Commission, regulators (such as the Energimarknadsinspektionen, the Swedish Energy Markets Inspectorate), other utility companies and Distribution System Operators (DSOs) to evaluate, monitor, follow up and guide the performance of grid projects. Vattenfall Distribution Nordic uses, among other KPIs, the System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI) and Energy Not Supplied (ENS) to follow up on business performance. This is common in the electric utility industry since regulators in several countries (Table 5) require the DSOs to use them as the basis for their performance measurement.

However, at Vattenfall Distribution Nordic the use of KPIs to evaluate the performance and implementation of smart grid technology and functionalities, has not yet reached its full potential. Evaluation of the costs of the project is done before and after the project implementation, but not in every case an analysis on the intended effect and business benefits of Smart Grid technology implementation is done. The management of Vattenfall's DSO has requested that the results of the projects are analysed ex-ante and ex-post to keep track of the progress that has been made, and whether the projects have fulfilled their expectations.

In projects sponsored by the EU, several KPIs and a framework to apply them with Smart Grid projects have been developed, but this framework strives to encompass all aspects of Smart Grids and the author has found these to be too general for Vattenfall Distribution Nordic's needs, since they focus on the distribution aspect of Smart Grids.

We can summarise the problem as follows:

> *"Project managers would like the current method of evaluating, monitoring and following up on Smart Grid projects, to be improved. They consider using KPIs, but a suitable set of KPIs in a clear framework for Smart Grid projects at Vattenfall Distribution Nordic is not available."*

The aim of this study is to solve this problem by performing a KPI application study specifically for Smart Grid projects.

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[1] A self-healing network is a network that is able to identify faults, locate them and reroute energy to isolate the fault whilst restoring connection to other affected areas.

1.6. Research Questions

Vattenfall Distribution Nordic is interested in using KPIs in measuring project proposals, performance and evaluation. The management within this Business Area believes using KPIs would be useful for managing the projects on Smart Grids. This thesis is expected to serve as a basis and input to the application of KPIs for Smart Grid benefit analysis. The main question has thus been posed:

“How can Vattenfall Distribution Use Key Performance Indicators to evaluate proposals, measure performance and evaluate the outcome of Smart Grid projects?”

The question is divided into a number of sub-questions in order to answer it in a structured manner.

Sub-question 1:

“Which Smart Grid related KPIs are used in power industry by different organisations including the European Commission, regulators, utilities and DSOs?”

The literature study provides Vattenfall with a list of KPIs that have been used in relation to Smart Grids and might prove valuable in the future as well. The author expects that this list includes KPIs that are relatively similar and are only different in the formal definition, as well as KPIs that would not be relevant for Vattenfall Distribution. A need to select the KPIs which will be used for Smart Grid projects in Vattenfall Distribution brings us to the next subquestion:

“What are the requirements for KPIs to be useful to evaluate proposals, measure performance and evaluate the outcome of Smart Grid projects.”

The outcome of this question should provide clarity on which KPIs should be selected and developed further. Measuring something has associated costs. An analysis should be made by the users of the KPI framework during its implementation whether the information is worth more than it costs to acquire. The final sub-question deals with the validation of the previous answers.

“In what way should the KPI framework be implemented in order to facilitate usage by Vattenfall Distribution?”

Just providing a list of KPIs might prove insufficient in enabling Vattenfall Distribution to use KPIs for Smart Grid project evaluation, but providing a method for implementation might go a long way in facilitating efficient use of the proposed metrics.

1.7. Scope

The study is performed for Vattenfall Distribution and this has direct implications for the scope, namely that it focuses on the distribution aspect of Smart Grids, having priority over power generation and consumption related aspects. The study builds on several EU-projects that have studied and developed Smart Grid related KPIs. Vattenfall has contributed to many of these projects in one way or another and many of the people involved in them are still around.

The technical aspects of these projects are not relevant for this report; the focus is on the goals the projects have. These goals are specified in terms of what they would like to achieve (such as lowering outage times) and the ambition level in the relevant aspect (how many minutes reduction of outage time).

Vattenfall has a diverse portfolio of Smart Grid projects, which provide a basis to study the sought-after benefits of a Smart Grid in this stage of development. Aspects that have an influence on the realisation of the benefits are presented briefly; the focus of this aspect are the regulations which are used to determine the revenue cap. The calculation of KPI values from measurements for real projects is not included in this study.

2. Current Situation

2.1. KPI Framework Developed by EU-Funded Projects

Several projects that aimed to define a Smart Grid KPI framework have been sponsored by the EU [4, 5]. They have produced metrics that can be applied broadly and cover much more than the aspects that Vattenfall Distribution is interested in, and in some cases lack calculation methods. An example would be “automation and control”: a way to actually quantify automation and control in the context of Smart Grids from a Distribution System Operator aspect has not been found yet. As a result of the lack of quantification methods, these KPIs have only been used sporadically in evaluating Smart Grid projects on the distribution aspect.

2.2. Stakeholders

The Vattenfall R&D Distribution portfolio is the program within the Vattenfall R&D organisation which contains R&D activities with Vattenfall BU Distribution as client. The portfolio has a focus on development and implementation of proven methods and equipment. Several projects are run parallel, from automating grid equipment to using smart meters to be notified of grid failure and setting up micro-grids that are able to run independently of the main grid. The overarching goals of these projects are lowering technical energy losses, improving the reliability of the power grid, and running pilot projects that explore future business opportunities for Vattenfall Distribution.

Vattenfall BU Distribution runs the distribution grids that Vattenfall owns. Their main goals are providing a reliable distribution of electrical energy and doing this with low electrical losses of energy. Since operating an electric grid is a natural monopoly,[2] the profit Vattenfall Distribution AB is allowed to make is set by the state. In recent years, the state has introduced several incentive schemes (based on the reliability, efficiency and effective capacity) that influence the financial reward the company is allowed to have. Smart Grid projects have the potential to improve the metrics which are incentivised by the government.

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[2] Duplicate equipment is considered a waste of resources or more formally, “A necessary condition for a natural monopoly to exist for output Q of some good is that the cost of producing that good is subadditive at Q” [4]. This means that the products are produced most efficiently if there is only one producer per (geographical) market. Authors note: Another, less strict definition of this term would be that it in the specified market, it is always cheaper to produce something with only one company instead of more than one.

Vattenfall BU Distribution customers rely on Vattenfall BU Distribution to provide them with electric energy. These customers can be residential, commercial or industrial. For most of these customers, electric energy is a critical product. Without it, shops and factories would come to a standstill. Many houses are heated electrically as well, from not very efficient methods like electrical radiator panels to the more efficient heat pumps. Several KPIs are directly linked to the quality of power that customers receive and are incentivised by the government. Distribution customers are entitled to compensation in case of interruption of the power supply for more than 12 hours according to state laws [6].

2.3. Incentives

The energy distribution market is regulated in Sweden with over 160 businesses responsible for their specific areas. [6] Revenue is capped, with the cap calculated by adding a percentage to the WACC (Weighted Average Cost of Capital). This has led to a situation in which there was an incentive to choose solutions with a high capital investment, even when solutions with lower costs would have been available. To provide an extra stimulus for distribution companies to perform at the top of their capabilities the following incentives were introduced: [7, 8]

Table 2 Incentive scheme for DSOs in Sweden

Name	Meaning	Description
SAIDI	System Average Interruption Duration Index	Part of incentive scheme by adjusting revenue cap, based on average interruption duration [8]
SAIFI	System Average Interruption Frequency Index	Part of incentive scheme by adjusting revenue cap, based on average interruption frequency [8]
CEMI	Percentage of customers experiencing at least 4 interruptions	Part of incentive scheme by adjusting revenue cap, based on amount of customers experiencing multiple interruptions [8]
Network Losses	Energy lost in the networks	Part of incentive scheme with bonus/malus, depending on network losses [7]
Load Factor	Daily average load divided by daily maximum load	Part of incentive scheme, bonus only, related to average load divided by maximum load [7]

The combination of these incentives makes it rewarding to operate a reliable distribution network that is efficient in the network losses aspect as well as in the use of the assets. Some of the incentives are stronger (e.g. outage related) than others (e.g. efficiency related); internal experts on this matter have indicated that the incentive related to the network losses is currently too low to influence decisions. The financial result of the incentive is not significant given the scale of the investment that would be required to improve the network losses. Therefore, the incentive currently does not have the desired effect of providing extra motivation for grid operators to invest in more efficient grid equipment. However, the strategic goals of reaching a Net Promotor Score (NPS) of +2 relative to Vattenfall's peer competitors [9] and absolute CO2 emissions of less than 21 MTonnes before 2020 is a clear indication that there are other forms of motivation than purely financial ones.

Since the regulator requires data on the incentives mentioned in Table 2, this data already exists within the company. This makes them suitable candidates for KPIs, since these are defined in a strict manner already and data could be obtained from sources within the company.

Quantifying the improvement of these metrics can be coupled to these financial rewards with great accuracy, providing a reliable indication of what an improvement in the metric would be worth. Smart Grids

In the traditional grid, about 8% of the energy from generating facilities is lost along transmission lines, whilst 20% of generation capacity is reserved to meet peak demand (i.e., only in use 5% of the time) [10]. This is not an optimal situation, since this reserve has very low utilisation of its capacity. The implementation of a Smart Grid aims to improve these figures. In general, this is done by adding a stream of information parallel to the stream of energy. This stream of information enables a bi-directional stream of electricity, where a consumer can also become a producer when the market conditions favour this. An actor that is a consumer for the largest part of the time but who will produce energy if the conditions are favourable, for instance high solar panel output and low self-consumption, is called a prosumer. For a consumer to be labelled as a prosumer, there is a need for either some asset that generates electricity (e.g. solar panels, micro wind turbines and micro-hydro generation), or stores energy for later use, for instance stationary batteries, or an EV that is capable of delivering energy as well as consuming it. If a prosumer and consumer are living next to each other, there would be a scenario where the prosumer delivers energy to the consumer with much lower losses than those that would be associated with long-distance transmission of energy.

Another beneficial aspect of smart grids is the improved knowledge on how the grid is doing. Before, the first moment a DSO finds out about an outage is when it receives a call from a customer. The time between the start of the outage and the first call is a direct contributor to SAIDI, which could be avoided if automated detection systems were in place. An example of an improvement that has been made in this field is the automatic “pinging” or automated meters. If a meter does not respond, it is a sign of an outage and the Fault Location, Isolation and Restoration (FLIR) process can be started.

A problem that has arisen with the installations of DER is that these can cause voltage problems. Without knowing what the voltages at the customer sites are, limits have to be put onto DER at prosumer sites to make sure these voltage deviations do not violate quality limits. One way to do this is to install a Smart Transformer, which is able to provide different output voltages to compensate for the generation from the prosumer. Having this intelligent equipment is an aspect of a Smart Grid as it will facilitate the installation of higher capacities of distributed renewable energy resources.

The option to read values from a distance also reduces the need to physically travel from site to site, reducing the number of possibilities for accidents, thereby increasing safety. This counts not only for the measuring of meter data at customer sites, but also of measuring the condition of transformers. This increase in data sources opens up possibilities for condition based maintenance as well.

All aspects of Smart Grids combined will change the way society generates, distributes and consumes power [10].

3. Literature Study

3.1. Smart Grids

The definition of a Smart Grid has been discussed in the past years [10-13]. The sources used in this thesis all describe a method or combination of methods of improvement of the current grid. This can be a limited scope such as putting a focus on the implementation of smart homes, or can include many different aspects. In every case, the grid as we know it today plays an important role. A Smart Grid should not be viewed as a replacement of our current grid but more as an upgrade. Gharavi and Ghafurian state the following requirements of a Smart Grid [13]:

- Allow for the integration of renewable energy resources to address global climate change.
- Allow for active customer participation to enable improved energy conservation.
- Allow for secure communications.
- Allow for better utilisation of existing assets to address long-term sustainability.
- Allow for optimised energy flow to reduce losses and lower the cost of energy.
- Allow for the integration of electric vehicles to reduce dependence on hydrocarbon fuels.
- Allow for the management of distributed generation and energy storage to eliminate or defer system expansion and reduce the overall cost of energy.
- Allow for the integration of communication and control across the energy system to promote interoperability and open systems and to increase safety and operational flexibility.

If all of these requirements are fulfilled, an electrical energy distribution grid has become a Smart Grid. Farhangi [10] expects that the implementation of the Smart Grid will be an organic growth instead of a drastic overhaul. Although many of the functions of a Smart Grid could be developed and implemented parallel to each other, this would require a large capital investment in a short time period [14]. According to Gharavi and Ghafurian [13] the Smart Grid will have the following characteristics when it is fully implemented:

- Self-healing: automatic removal of potentially faulty equipment from service before it fails by operating disconnection switches, and reconfiguration of the system to reroute supplies of energy to sustain power to all customers,
- Flexible: the rapid and safe interconnection of distributed generation and energy storage at any point on the system at any time,
- Predictive: use of machine learning, weather impact projections, and stochastic analysis to provide predictions of the next most likely events so that appropriate actions are taken to reconfigure the system before next worst events can happen,
- Interactive: appropriate information regarding the status of the system is provided not only to the operators, but also to the customers to allow all key participants in the energy system to play an active role in optimal management of contingencies,
- Optimised: knowing the status of every major component in real or near real time and having control equipment to provide optional routeing paths provides the capability for autonomous optimisation of the flow of electricity throughout the system,
- Secure: considering the two-way communication capability of the Smart Grid covering many components between generation and consumption, the need for physical- as well as cyber-security of all critical assets is essential.

These requirements and characteristics give a clear view on what a Smart Grid can be. With these definitions, we can define a Smart Grid Project as follows:

A Smart Grid Project aims to bring the grid closer to a Smart Grid. This can be done by doing exploratory studies, pilot projects, developing prototypes or full-scale implementation.

This definition is a valid description of the Smart Grid projects which are in the Vattenfall Distribution portfolio and which are a subject for this study.

A challenge with investing in Smart Grids is that the value of the improvements usually does not end up with the actor that invested, but with other actors. For instance the improvement in reliability has an estimated present value over 20 years of $30 billion for the U.S. market [15]. A large majority of this value will be for consumers, limiting the incentive utility companies have to invest. Incentive schemes are a useful tool here, for instance the reliability incentive schemes the Swedish State has set up for distribution companies [8].

"The Path of the Smart Grid" by Farhangi [10] provides a comprehensive and in-depth description of Smart Grids and is recommended by the author for those who wish to read more about Smart Grids.

3.2. KPIs in General

Since the start of the industrial revolution, management towards optimisation of processes has been an important aspect of running a profitable business [16, 17]. Several tools have been used in order to improve performance since then, going through a never-ending cycle of improvement. One of the recent developments in this field is the use of KPIs for motivating, monitoring, evaluating and supporting [18-21]. KPIs are used to communicate goals, progress and room for improvement or even indicate where immediate attention is required.

For setting up an effective implementation of KPIs several authors have argued that the KPI framework should be:

1. Acceptable [3, 22],
2. Meaningful to industry [3, 23],
3. Easily understood [22] (simple, understandable and logical [23]),
4. Repeatable [3, 23],
5. Showing a trend over time [3],
6. Suitable – they measure important things [22],
7. Feasible – they are easy [22] and economical to collect [3],
8. Effective – They concentrate on encouraging the right behaviour [22] and are unambiguously defined [3, 23, 24],
9. Aligned – Must link to national goals for the industry [22],
10. Timely [3, 23],
11. Driving appropriate action [3].

These requirements for KPIs are expected to be relevant in the current context of a Swedish energy distribution company as well, given that they are independent of the specific industry and have been compiled from sources from several different industries.

A KPI system is always based on what the priorities, strategic targets and critical processes were when it was set up. There are several possible circumstances that might cause a KPI system to become outdated and should trigger an update [24]:

- The strategic alignment and subordinate objectives are changed,
- A change in the measured processes,
- A change to the application landscape.

In the case of Smart Grid Projects, it is unlikely that the targets for the projects change during the completion of the project. However, the compiled list of recommended KPIs could be in need of an update if new processes, products or services are added or if a project is started which is not measurable by the metrics in the recommended KPI list.

3.3. KPIs in R&D

KPIs have historically mostly been used for process and connected financial metrics. Most KPIs used in the manufacturing industry are focused on processes which are repeated or are continuous [25]. These processes often have historical data available, even if they are just averages over long time periods such as quartiles or even years. This facilitates setting targets, for instance a percentage increase in sales or lower amount or orders delivered with a delay. However, the project based world of R&D is different in this aspect. Instead of process based, the KPIs will need to be project based [26]. In general, a distinction can be made between projects aimed to improve the current system and projects that intend to provide new services and products. For the first category, the project result can be measured by the improvement of the system that is already in place. The second category could have benefits that are outside of the scope of the current recommended KPIs. If this situation is identified, the KPI framework should be updated in order to include the new benefits of the project.

4. Methodology

4.1. Finding KPIs

The goal of the literature study part of this project is to find the KPIs that have been formulated for use with Smart Grids. Several sources were used to compile a comprehensive list:

- FindUT – The academic literature search engine provided by the University of Twente. This engine searches in physical libraries worldwide and a range of online databases, including but not limited to: worldcat.org, IEEE Publications database, Wiley Online Library, ScienceDirect, Springerlink and Directory of Open Access Journals,
- Web of Science,
- Brownzine,
- Google Scholar,
- KPILibrary.com,
- Vattenfall Smart Grid Project Repository,
- EU reports on Smart Grids.

The KPIs that were found in these sources have been summarised in existing KPIs which can be found in

Existing KPIs on page 13. In this table, the names and the sources of these KPIs are presented. Please note that many of these KPIs were relatively similar or didn't make it to the final recommendations for other reasons such as not relevant enough in the scope of this project, too vague to measure or not focused on a result but on a method. An example here would be measuring the number of standardised protocols used, but the number of standardised protocols is not related to a benefit.

Table 3 Number of KPIs per source

Source	Number of KPIs found
Academic literature	46
EU/Utility projects	174
Regulators	12
Other	77

4.2. Study of Smart Grid Workings and Advantages

An understanding of the workings and advantages of a Smart Grid compared to an energy distribution network in general is required to identify the respective advantages. A literature study in combination with interviews with Vattenfall employees in the Research and Development department as well as in the Vattenfall Distribution Business Area leads to a wide perspective on both subjects. The regulations the Swedish government has imposed on the DSOs serves as a basis for analysis on the economic aspects of energy distribution.

4.3. Setting up a Method for Applying KPIs

In order to set up a structured method for the application of KPIs in Smart Grid projects, literature studies on the effectiveness are used by the author in combination with feedback from experts on the matter at Vattenfall Research and Development. After a feedback loop with higher management this method is detailed further and complemented by the selected set of KPIs which are recommended for use in Smart Grid related projects, processes and company level approaches.

4.4. Selecting KPIs for Recommendation

A large number of KPIs have been found in several sources which can be found in the appendix, but some KPIs are more relevant than others. A method is needed to provide a set of metrics that cover the relevant aspects of a Smart Grid. Requirements for the KPIs to be in this set have been created.

The Smart Grid recommended KPI criteria have partly come from Smart Grid experts at Vattenfall Distribution.

Table 4 Requirements for KPIs to be recommended

KPI	Description
Quantifiable	A quantified KPI can have a goal that can be reached and progress can be measured. This rules out qualitative goals such as "improvement" where assessing if the goal has been reached is an arbitrary process. All monetary KPIs must have a non-monetary KPI which has a monetary value assigned to it.
Clear	KPIs need to be well defined to avoid multiple definitions at different departments or management levels. In the past, some KPIs have had different definitions at different levels in the organisation, this needs to be avoided in the future. It would be advisable to present the calculation method (and what is included/excluded) together with the KPI.
Aligned with strategic targets	Communicating how much a specific project can improve strategic targets, Business Area targets or Smart Grid Roadmap targets goes a long way in securing funding.
Known purpose	Knowing why something is measured avoids measuring just for the sake of measuring. The general method for making sure there is a known purpose, is to link each KPI to at least one main goal.

When the department of Power Technology at Vattenfall R&D was presented with a preliminary list of KPIs that were candidates for the recommended status, some points of attention were identified. The common opinion was that the KPIs need to be strictly defined, this could be done after the goals of the project are known. At that stage, strictly defining the KPIs contributes to aligning all actors by making sure everyone knows exactly what is required for success. For KPIs that are only used within a project, the latter option could be considered. For company-wide KPIs, a uniform and well-defined description and calculation method should be provided. This makes sure that there is a defined method of calculating the KPI, ensuring comparability to other areas and within the same project.

5. Existing KPIs

KPIs are widely discussed in academic literature and this has resulted in several publications, projects and other sources on KPIs that can potentially be used. The full list of KPIs can be found in Appendix I – Existing KPIs. These KPIs have been used in this project as input to select which are recommended by the author to be used in Smart Grids to measure the benefits for the distribution aspect. Many entries in the database compiled as part of this project are relatively similar and are only separated by a matter of definition.

5.1. KPIs Used by Regulators for DSOs

Regulatory instances have introduced artificial competition into the monopoly markets by using incentive schemes. Throughout Europe, these schemes are quite similar. Usually they have a measurement on the number of outages, the duration of outages and the number of customers affected. Some also use incentives on energy losses and the effective capacity versus the theoretic maximum capacity. An overview of which National Regulatory Authorities (NRAs) use which KPIs is given below. The sources are mentioned per country or state.

Table 5 KPIs used by Regulators per Country

	Sweden [6-8]	Germany [27]	Netherlands [28-30]	UK [27]	Spain[29, 31]	Italy [30]	California [27]	Illinois [27]
SAIDI	X	X	X		X	X	X	X
CAIDI			X					
ADI					X			
SAIFI	X	X	X	X	X		X	X
MAIFI							X	
CEMI$_{12}$	X						X	
ENS		X			X			
LF	X						X	
Grid losses	X			X	X			
Availability index					X			
Customer satisfaction				X				
Availability index					X			
Average duration of interruption					X			
Number of customers exceeding reliability targets								X

These measurements are used to provide incentives for DSOs to improve their operations. The exact way this is done in Sweden is discussed in the next chapter.

6. Monetising Smart Grid KPIs

The value of a project at Vattenfall Distribution generally comes from one of three categories:

- Incentives
  - The distribution business is government regulated.
  - Improvement of the performance on the criteria set by the state results in a higher revenue cap.
- Revenue
  - This can be either higher revenues or new revenue sources.
- Cost savings
  - Either lowering of CAPEX of OPEX.

This does not necessarily have to be realised directly within the R&D project but could also be the potential effect of full-scale implementation in the distribution business. Usually an R&D project is not profitable but an investment to enable future implementation.

Another aspect is that an R&D project can result in the knowledge that the proposed solution is not suitable for large scale implementation. The value of this knowledge depends on the value of a failed implementation and the perceived change for this to happen. In such a case, the value of the project is the avoided losses that would be made if the pilot project would have been skipped and the project would directly have been implemented at full scale. In the energy distribution business where reliability and continuity of supply are of key importance, directly going to full-scale brings high risks since a small failure can affect large areas.

6.1. Revenue Cap

These metrics are used to modify the revenue cap adjustment for distribution companies in Sweden. The base revenue cap depends on the depreciation time, the number of years that provide capital costs after the depreciation time, the weighted average cost of capital (WACC) and the present purchase value. The calculation method is described in the following way [6]:

$$Capital\ cost = Depreciation + Return = \begin{cases} (\frac{1}{LT} + \frac{LT+1-age}{LT} * WACC) * PPV & if\ age \leq LT \\ (\frac{1}{age} + \frac{1}{age} * WACC) * PPV & if\ LT < age \leq (LT+\alpha) \\ 0 & if\ age > (LT+\alpha) \end{cases}$$

Variable	Meaning
LT	Depreciation time in years.
α	Constant for providing some capital costs α more years after the LT. α is 2 years for meters and IT, else 10 years.
WACC	Weighted average cost of capital and was initially proposed to be 4.53% (this value may differ between regulatory periods), but there are however ongoing legal processes.
PPV	Present purchase value.

For a thorough description of the calculation methods, see “Kvalitetsreglering av intäktsram för elnätsföretag” (Quality Control of the revenue cap for electrical distribution companies) by the EI [32].

6.2. Incentives

Two schemes have been designed and implemented by the Swedish regulator (Energimarknadsinspektionen) to provide financial incentives, one for continuity of supply [8] and one for the efficient utilisation of the grid [7]. Since the distribution of energy is officially recognised as a natural monopoly in Sweden, the Swedish government provides these schemes to compensate for the absence of free market competition. The first scheme, a revenue cap adjustment that depends on the continuity of supply is described in this section and structured as follows:

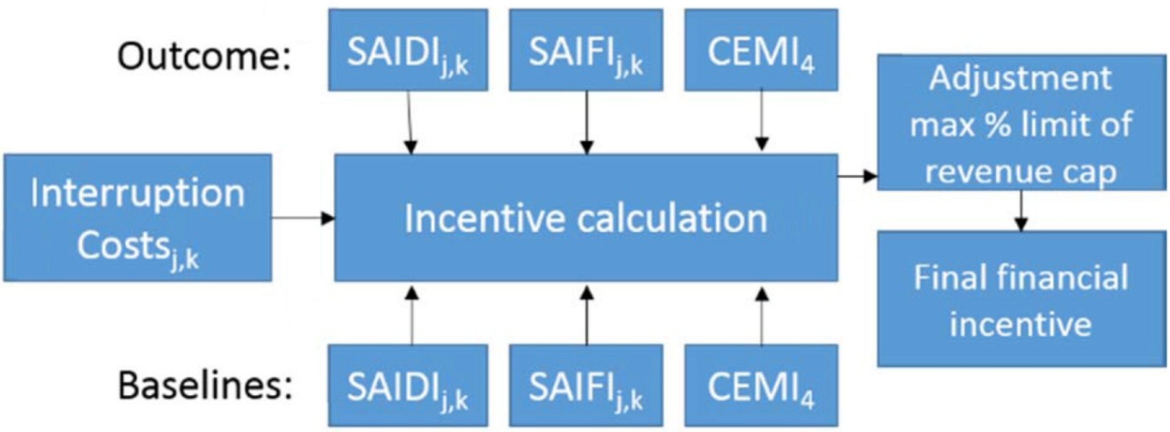

Figure 2 Schematic description of the incentive calculation [8]

The calculation methods and several constants for the input of the financial incentive are described per box in the following section. These values and calculation methods are likely to change in the next legislative period, which could provide a challenge for accurate estimation of the NPV that arises in the years after the current legislative period.

Interruption Costs

The costs associated with an interruption are significantly different for different customer groups. Therefore, they are estimated separately for different groups [30]. The values for the regulatory period from 2016-2019 are presented below.

Table 6 Cost parameters of quality incentive for regulatory period provided by the EI 2016-2019 [32]

Customer category	Non-notified interruption		Notified interruption	
	SEK/kWh	SEK/kW	SEK/kWh	SEK/kW
Industry	71	23	70	22
Trade and Services	148	62	135	41
Agriculture	44	8	26	3
Government controlled businesses	39	5	24	4
Household	2	1	2	0
Boundary Points	66	24	61	18

As can be seen in the table, trade and services are associated with much higher costs per outage and outage duration than the other categories. This could lead to distribution companies prioritising this category of customers when deciding where to put the focus in grid improvement. The values here are one of the inputs for the calculation of the adjustment of the revenue cap.

The interruption costs are then calculated according to the following equations.

Equation 1 Impact per affected customer on the revenue cap in SEK for local networks [i]

$$Impact = \left(\frac{kWh_{cat}/\ number\ of\ customers_{cat}}{8760}\right) * K_{P,cat,j} + \left(\frac{\frac{kWh_{cat}}{number}\ of\ customers_{cat}}{8760}\right) * K_{E,cat,j} * Duration$$

Equation 2 Impact per affected customer on the revenue cap in SEK for regional networks

$$Impact = \left(\frac{kWh_{cust}}{8760}\right) * K_{P,cat,j} + \left(\frac{kWh_{cust}}{8760}\right) * K_{E,cat,j} * Duration$$

Variable	Meaning
Impact	impact on the revenue cap from the interruption [SEK]
$\mathbf{kWh_{cat}}$	total yearly energy usage in the customer category [kWh]
$\mathbf{Number\ of\ customers_{cat}}$	total number of customers in the customer category
j	interruption type: notified or not
$\mathbf{K_{P,cat,j}}$	the cost parameter is given in SEK/kW per category (cf. Table 6)
$\mathbf{K_{E,cat,j}}$	the cost parameter is given in SEK/kWh per category (cf. Table 6)

Duration	duration of the interruption [h]
$\mathbf{kWh_{cust}}$	energy usage of the customer experiencing the interruption

SAIDI

This metric is the System Average Interruption Duration Index which represents the average time a customer of the DSO experiences an interruption of the power supply. The outcome of the year for which the revenue cap is calculated is compared to the baseline value.

SAIFI

This metric is the System Average Interruption Frequency Index which represents the average number of interruptions of the power supply a customer of the DSO experiences. The outcome of the year for which the revenue cap is calculated is compared to the baseline value.

$CEMI_4$

This metric is defined as the number of customers who experience more than 4 interruptions. Having this metric makes sure customers in sparsely populated areas are provided with a high-quality network, even if there is only a limited number of customers and paying compensation would be cheaper since their influence on SAIDI and SAIFI is limited since they only represent a non-significant part of the customer base.

Compensation Scheme

In case of an outage lasting longer than twelve hours, customers receive compensation from the DSO. The amount of compensation is calculated in the following manner:

Table 7 Consequences of outages longer than 12 hours

Outage length	Customer compensation [SEK]	Minimum customer compensation [SEK]
100 msec – 3 min	Data collected by EI, no consequences for direct compensation scheme	
3 min – 12 hours	Input to the revenue cap regulation	
12 – 24 hours	12.5% of individual customer network tariff	2% of yearly set base amount
24 – 48 hours	37.5% of individual customer network tariff and possible consequences from breaking the law (24-hour functional requirement)	4% of yearly set base amount
Following 24 hour periods	+ 25% of individual customer network tariff and possible consequences from breaking the law (24-hour functional requirement)	+2% of yearly set base amount
Maximum	300% of individual customer network tariff and possible consequences from breaking the law (24-hour functional requirement)	-

If a widespread outage is not resolved for a duration of more than 24 hours, this would have significant financial consequences for the DSO as well as potential loss of (part of) the monopoly market assigned to the DSO. This makes sure that the reliability is not only improved because that is what a distribution company would strive for, but also financially incentivised. Knowing these costs, we can calculate how much money it would save to improve the reliability of the grid. Among other advantages (avoiding the costs of the fault repair for instance), lowering the costs of the customer compensation could justify investments in the grid.

Network Losses

Lowering losses in the network is beneficial for society. Costs of generation go down and the effective capacity increases, which lowers the costs of energy as a whole. To compensate the DSOs for costs to improve on this aspects, the EI has put this incentive in place which makes sure that half of these benefits are awarded to the DSO and the other half are enjoyed by the customer in the form of a lower bill for equal consumption [6].

$$K_n = (Nf_{norm} - Nf_{turn-out}) * E_{turn-out} * P_n * 0.5$$

Equation 3 Calculation of Network Losses Incentive

Variable	Meaning
K_n	The value of the incentive for network losses, an addition or reduction of the revenue cap. [kSEK – thousands of Swedish kronor
Nf_{norm}	The historical share of network losses for each DSO (2010-2013) as a percentage of the total amount of energy distributed. [%]
$Nf_{turn-out}$	The share of network losses for each DSO during the regulatory period (2016-2019) as a percentage of the total amount of energy distributed. [%]
$E_{turn-out}$	The amount of distributed energy during the regulatory period (2016-2019). [MWh]
P_n	Price per megawatt hour for network losses calculated as an average price during the regulatory period (2016-2019). All DSOs' costs for network losses are considered in the calculation. [kSEK/MWh]
0.5	The factor 0.5 in Equation 3 splits the incentive so that an improvement regarding network losses rewards the DSO with half of the additional value of the reduction. The other half of the additional value benefits the customers due to a lower revenue cap. On the contrary, if the share of network losses increases, half of the reduction of the revenue cap is transferred to the customers from the grid company's revenue cap.

Load Factor (LF)

The load factor is negatively correlated with the network losses, since the losses that occur when the grid is utilised at a constant level are lower than if this level is not constant, given that the total amount of energy distributed remains equal. This is caused by the quadratically increasing losses with the linear increase of current. A more significant aspect of the load factor is however that having a low load factor leads to a higher effective capacity of the grid, since the amount of energy that can potentially be distributed is higher if there is a lower need for peak capacity. The Load Factor is incentivised as follows [6].

$$K_b = \begin{matrix} |Lf_{turn-out} * B_{diff} * E_{turn-out}| & if\ B_{diff} < 0 \\ 0 & if\ B_{diff} \geq 0 \end{matrix}$$

Equation 4 Load Factor Incentive

$$Lf_{day} = P_{average} \ / \ P_{max}$$

Equation 5 Calculation of the Load Factor

Variable	Meaning
K_b	The value of the incentive for the cost of feeding grid and average load factor. [kSEK]
$Lf_{turn-out}$	Average of all daily load factors.
B_{diff}	Saving per megawatt hour for the cost that DSOs pay to the feeding grid, i.e. the feeding grid charge, for the withdrawal and costs for the input of electricity. [kSEK/MWh]
$E_{turn-out}$	Distributed energy during the regulatory period (2016-2019). [MWh]
Lf_{day}	The load factor for a given day
$P_{average}$	The average load during a day. This is calculated as the sum of load in the interconnection points between DSOs during a day divided by 24 hours
P_{max}	The maximum load during a day. This is calculated as the sum of the load in all interconnection points at the hour of the day when the highest load sum occurs. This calculation presumes that the load measurement is made on an hourly basis.

Calculation of Financial Outcome

Using the interruption costs, we can now calculate the financial outcome of the incentive scheme for continuity of supply. This outcome might be adjusted later on the basis of $CEMI_4$.

$$Q_y = \sum_{k=1}^{5}\sum_{j=1}^{2}\left(\left(SAIDI_{b,j,k} - SAIDI_{o,j,k}\right)K_{E,j,k} + \left(SAIFI_{b,jk} - SAIFI_{o,jk}\right)K_{P,j,k}\right)P_{av}$$

Equation 6 Quality adjustment

Where:

Variable	Meaning
y	the year
k	the five different customer groups (1-5)
j	the two categories of interruptions (notified and unnotified)
b	The norm level
o	the outcome during the period of regulation
Q_y	Value of the incentive, still to be adjusted by $CEMI_4$
SAIDI	System average interruption duration index in minutes
SAIFI	System Average Interruption Frequency Index in number of outages
K_E	Cost parameter in SEK/kWh
K_p	Cost parameter in SEK/kW
P_{av}	Average yearly power usage

6.3. Revenue Increase

There are no incentive schemes for the increase of revenue from non-distribution services, since this part is not regulated. There is no limit on the number of extra services the grid company offers. In the future, it is possible that money is made by providing services linked to smart meters, for instance remotely setting the temperature you want or letting your house know you are almost home and the oven should be preheated. A bit more in the line of the DSOs expertise would be price predictions and real-time pricing, so customers are able to use energy in an economically optimal fashion. This would also enable the DSO to have a better load factor and to lower losses in the grid since the grid losses are inversely correlated with the load factor.

Increasing the revenue from non-regulated activities would be valuable for the organisation as it would directly lead to a higher profit. If a Smart Grid project would lead to increased revenue at equal or lower costs, this would be an economically interesting case of full-scale implementation.

Selling Information

Providing customers with price forecasts in several grades of accuracy, potentially with price guarantees for short periods of time could be a new revenue stream. The customers buy some security by knowing the energy prices for the coming hours, enabling the optimal scheduling of energy consuming devices. In practice this would be similar to selling futures on energy, where Vattenfall would (in contrast to the long-term futures Vattenfall has had in the past) take the risk of price deviations in exchange for a small fee. Given the knowledge and expertise has in BA Markets, this could be estimated much more accurately than most other (potential) competitors could.

Scheduling Customers Energy Consumption

Instead of providing electricity, heating and cooling there is potential for ‘comfort’. Providing customers with the equipment that they can set the boundary values on (max temperature, min temperature) these devices make sure these values are respected whilst scheduling the energy consumption in such a way that this is the cheapest for the customer on an RTP plan. This service could be combined with advice on how to reduce energy consumption by analysing the customer’s electricity consumption and identifying options for improvement. This could be a new revenue stream in an emerging market.

6.4. Cost Savings

Several projects at Vattenfall Distribution strive to lower OPEX and/or CAPEX. It could be argued that the current way of calculating the revenue cap provides an anti-incentive to lowering the CAPEX, since this would also lead to a lower revenue cap. It would be of interest for future studies to explore ways to mitigate this effect. Options to do this could include a larger influence of quality metrics on the revenue cap. The OPEX side of the costs has several aspects that could be improved by Smart Grid solutions, those that the author finds most relevant are presented below:

Automation

Measuring the energy consumption at the customer end was historically done by visually inspecting the meter and inputting the measurement into the billing system. Nowadays, 100% of the meters in Sweden are digital and can be read remotely. This has drastically reduced the costs of meter reading.

Similar opportunities are available for the grid at a higher level, for instance distribution meters and outage detection. Having an automated monitoring system which detects outages is much faster than not being aware of an outage until a customer complaint is received. Automatic outage detection makes it possible to respond faster, but being able to remotely reroute power past failed components reduces the impact of an outage. Being aware of power flows opens up more opportunities for power system optimisation, e.g. peak shaving, lowering transport distance and increasing the resilience of the system [33].

Going even further with the implementation of Smart Grids enables demand-response systems which in turn open up possibilities to shift energy usage in time to periods where demand is usually lower. Having a peak which is closer to the average consumption means that the effective capacity of the grid is increased without having to build new network infrastructure. Even the energy losses associated with energy distribution would be reduced, since grid equipment is less efficient when working closer to its maximum capacity [34].

In the asset management field, there is an opportunity for optimisation of maintenance and replacement. Having an automated asset health monitoring system opens up opportunities to optimise maintenance and replacement schedules and reduces the amount of costly physical or visual inspections required.

Deferred Investments

With the expected increase in electrical energy consumption due to electrification of previously non-electrically powered devices, a need arises for increased distribution capacity as well. With the current methods, this would mean investing in new grid infrastructure or upgrading existing infrastructure, which comes with a significant price tag. Increasing the effective capacity of the grid by lowering the load factor could have the same effect, increasing the effective distribution capacity, but with lower costs. This lowering of the load factor could, for instance, be realised by using demand response schemes. Additionally Smart Grids are expected to facilitate the integration of distributed generation, also lowering the need of distribution network reinforcements [35]. The actual value would be the savings by not having to pay for the Weighted Average Cost of Capital (WACC) of the asset during the deferral period.

Reduced Technical Losses

Smart Grids can lower the technical losses by shortening the distance energy has to travel before being consumed by implementing distributed energy sources and with lowering the load factor (losses in a transmission line and transformer are approximately proportional to the square of the current). Energy that is not lost is energy that does not need to be bought, thereby lowering the marginal costs of energy distribution [35].

Reduced Call Centre Cost

With improvements in Smart Meters, it would be possible to send customers text messages to inform them of an outage, together with information on the expected time needed to get back online. This has the potential to reduce the number of customers that call to give a notification and ask questions about the outage [35]. An extra, however difficult to quantify, benefit could be that customers would appreciate the proactive provision of information.

6.5. General Method for Monetising KPIs

One of the goals in using KPIs is to have an expectation of what the value of the project would be. After the goals of the project have been identified and KPIs have been assigned to each goal, an estimation can be made on the value of improving these KPIs using the methods proposed earlier in this section. This information in combination with the expected costs for the project can give a quantified economic value of the project.

7. Recommended KPIs and their Usage

The overarching goal of this study was to recommend a set of KPIs that can be used to measure the performance of Smart Grid Projects. With the methods described in this report, many KPIs have been found and some have been found to satisfy the criteria to be recommended for use. Since Smart Grid Projects can have a multitude of goals, not every KPI is suitable for every project.

7.1. Recommended KPIs

The KPIs which are recommended by the author for use in Smart Grids can be found in Appendix II – Recommended KPIs. They have been selected based on their quantifiability, ambiguity, alignment with strategic targets and if they have a known purpose. Six different categories are available: metering, asset management, quality of supply and distributed generation, sustainable communities, flexibility and network balance and digitalisation. These categories can be found on three different levels: project, process and company. The distinction between a project and a process is mainly that a process is continuous and in general does not change. A project strives to bring change within a certain time period.

7.2. Usage of KPIs

To obtain optimal advantage from the KPI framework, the author recommends to use three separate stages: planning, realisation and evaluation. The next sections provide guidance in each phase.

Planning

Setting targets should be done in the proposal phase of a project. This way, it is clear what is being strived for from the start, for the project members as well as for the project sponsor. Each of the goals defined by management or other project sponsors for the projects should be covered by a KPI with a target level. Setting targets could be a reason for the project members to ask additional questions to management, since management has more information than the project members. It is expected to work both ways, since the project members are generally more knowledgeable about the specific techniques used in the project, and which opportunities and limitations this brings. The knowledge asymmetry that is present before this is done will not vanish, but it should lead to improving the understanding of the other actors. This in turn makes decisions further down in the project easier, since the parties have a better understanding of the drivers and motivation of the other actors in the project.

The calculation methods should be stated (e.g. defined input data and formulas to be used), including any circumstances that include or exclude data for use in the calculation of resulting values. After these targets have been set, it is recommended by the author to do a Cost Benefit Analysis (CBA) of these KPIs, using Net Present Value (NPV) calculations in combination with incentive expectations and/or expectations on non-incentivised benefits. The advantage of the incentivised benefits is that they are defined and there is little uncertainty of their value if the improvement of the metric is realised. The largest difference with the usual way of using KPIs is the setting of targets and using absolute values instead of percentages. Percentages can be used for KPIs and provide a reference to the baseline, but sometimes this can be misleading, for instance consider the following example:

A target is set for introducing standards at a top level in the project. This is measured by the increased use of standards. However, in one of the subprojects standards have been fully implemented already. This results in a 0% increase in standard use, because the situation was optimal already which does not look good for the sub-project. A “solution” might be to split standards and/or introduce new standards where it might not be beneficial but it does give the sub-project a better overall KPI score.

This is of course a situation that should be avoided. An option to mitigate this risk could be to measure the implementation of standards at project end, but this might give the subproject with already standardised methods an unfair advantage. Setting targets for each subproject would be an option to do this. Since implementing standards would not be a goal for the subproject that already scores well on this metric, this won’t influence the measurement either.

In the first three steps, project management and sponsors should be asked to provide feedback and sign off on the results of these steps. The following diagram visualises the proposed KPI process:

Figure 3 KPI setup process.

Realisation

During the realisation phase the KPIs can be used to keep the goal in sight. Decisions can be supported by the goals which have been set for the KPIs. The requirements for equipment can potentially (partially) be derived from the KPIs, or at the least the KPIs give an indication of what could be good enough. If there is no equipment available that falls within the budget then either the KPI expectation or the budget should be updated. This is a change compared to the way KPIs have been used in the past, where there would be an indication of what is perceived as a success, but without set goals.

In this phase, it could also happen that newly obtained knowledge or an update in estimations (for instance market factors which cause a drop in price for equipment) leads to a change in expectations, either positive or negative. The expectations on which levels can be reached with the KPIs should then be updated to reflect the newly acquired information. These changes should also be communicated to other projects since it might be relevant for the estimations and future decisions as well.

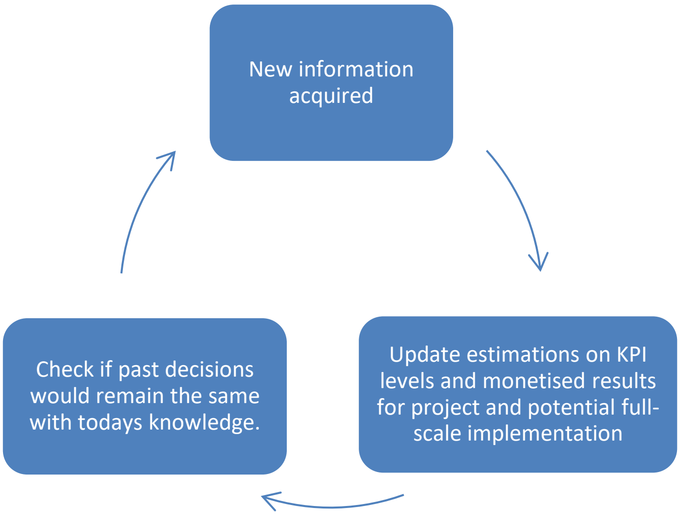

Figure 4 KPI update cycle.

Evaluation

During an evaluation meeting, the project manager discusses the results of the projects with the team. The basis for discussion are the resulting values of the KPIs. Has the project fallen short of the goals, reached them or even surpassed them? What were the causes for this? What does this mean for a potential full-scale implementation? Any KPI specific learnings, including updated estimations should be added to the KPI framework so future projects can benefit from this information.

In this way KPIs directly give an indication of the successfulness of a project during the evaluation phase. It is clear what the goals were and if they have been reached, which can be used as input for discussion where any discrepancies between expectations and reality might have come from. Evaluation of the return on investment for the project sponsor could also be done, although putting a price on knowledge acquired and experience gained is a difficult task.

The realised KPI levels have a great influence on the path towards full-scale implementation since they can be used by management as estimates for the benefits of full-scale implementation.

Figure 5 KPIs in project evaluation.

7.3. KPIs in the Smart Grid Roadmap

The current goals in the Smart Grid Roadmap can be perceived as KPIs. Some already have target values, but others are presented in a qualitative manner. Adding quantitative targets to these provides goals which Smart Grid Projects can strive for and provides clarity in communication with internal and external actors. After an estimation has been made of how the current portfolio of Smart Grid Projects perform in reaching these targets, it should be clear how realistic the targets are.

During the realisation of the projects, there will be deviations from the initial expectations. Since these are measured during project realisation, a more up to date Smart Grid Roadmap is feasible compared to a situation where project performance evaluation is only done after completion of the project or is omitted at all. Having accurate information in a timely fashion is relevant in a business area where the developments are likely to speed up in the coming years, to avoid lagging behind compared to competitors and new market entrants.

Quantification of how much each project brings Vattenfall Distribution closer to the goals set in the Smart Grid Roadmap go a long way in facilitating fact-based decisions on pilot projects and full-scale implementation.

Depending on the scalability of the project, it might be useful to include estimations on what the effect on the SGR KPIs would be in case of full-scale implementation. However, if this full-scale implementation is not planned for, this estimation could be omitted in the expected values for the SGR KPIs.

8. Conclusion

In literature as well as in business, an abundance of Key Performance Indicators (KPIs) for measuring a wide range of aspects exists. Those that the author found to be relevant are presented in Appendix I – Existing KPIs. KPIs are well established as tools for setting targets, measuring performance and evaluating results, especially in the manufacturing industry as has been found in KPIs in General [3-5, 21, 36-46]. In the area of energy distribution, Smart Grid KPIs are increasingly seen as a reliable tool to support planning and evaluation, which has resulted in several publications [4, 5, 36, 37] by EU sponsored research and development projects.

Many of the KPIs from these projects have a broad perspective measuring the benefits for society in the EU as a whole. This causes difficulties in applying them directly from a Distribution System Operator’s point of view. In order to evaluate projects and roadmaps properly, there is a need for KPIs focused on the benefits that will be enjoyed by the distribution company. This also means that KPIs focused on methods (number of customers with Advanced Metering Infrastructure, AMI) should be avoided; instead measuring the benefit which arises from this AMI should be used. Setting targets supports setting priorities during the start of the project, forcing the updating of expectations and allowing for evaluating on clear goals. This helps to reduce the knowledge asymmetry between the different actors. These goals help in keeping focus during the project, prioritising on what benefits the metrics and leaving behind things which do not have a significant effect on the goals of the project.

The benefits of Smart Grids can be monetised using three general approaches. A quantification of the reduction in costs (6.4), the increase in revenue (6.3) and the available incentives in regulatory schemes (6.2). Given the current regulations for Distribution System Operators, an increase in revenue is not expected. The incentives provided by the regulator to reward increasing the reliability of the power grid are successful in influencing the decision-making process, but the current incentives for lowering power losses and increasing the load factor have not been found to influence decision making.

Keeping the KPIs limited to the types of benefits the project aims to achieve provides focus and limits the required effort in working with KPIs (7.2). It is possible for a KPI to have sub-KPIs, but these should be assigned per project and be in line with the project characteristics. An example would be measuring the increase in effective distribution capacity by adding the increased capacity from using Dynamic Line Rating to the increased effective capacity from lowering the Load Factor, if these benefits are both targets of the same project.

To evaluate how the overall progress is towards implementation of the Smart Grid or more specifically, how progress is towards achieving the targets set in the Smart Grid Roadmap, the expected KPI values of running and planned projects in the SGR should be added to see whether they are expected to reach the target (7.3). Discrepancies found during this process between the target and the expectations could be a trigger to re-evaluate the current project portfolio.

Setting up KPIs for a project has synergies with doing the Net Present Value (NPV) calculations and writing the project plan, since all of them have to do with estimating the costs and benefits (7.2). These activities can contribute to making the knowledge distribution less asymmetrical by having the different actors formalise and align their expectations. Project proposals have always included the benefits; KPIs might just take it one step further and add targets to these benefits. The same goes for project evaluation: in order to evaluate a project, the result of the project should be known. Therefore, using the KPIs as a tool in project management will contribute to activities which are traditionally done such as measuring project results.

Having a common KPI framework facilitates sharing knowledge in the following manner: if one project has made calculations on how much improvement of SAIDI is worth in a certain area, it is likely that a large part of this analysis can be reused by other projects. To make this system viable, it should be updated as soon as new insights are acquired either during project planning, realisation or evaluation.

The management or members of projects that have started already could decide whether they want to set targets for their expected benefits, even though they have completed the setting up phase already. Late would be better than never and many of the benefits, such as having a clear goal and an indication of how much it will bring to the overarching targets of the SGR, can still be enjoyed.

To facilitate the use of KPIs in Smart Grid related projects, a set of proposed KPIs is presented by the author for the company, project and process level (12). The company and project KPIs are most relevant for Smart Grid projects and the Smart Grid Roadmap (SGR). The definitions of these KPIs will be linked to the benefits for the distribution company, together with the required data, calculations and methods.

9. Discussion and Future Work

The findings of this study should be validated by doing a case study in a project from the planning phase until the evaluation. This way, the actual effect of using KPIs in a Smart Grid project as well as how accurate the predictions were, can be studied. For the Smart Grid Roadmap KPIs this could be realised by asking the SGR projects to report their expected benefits for the

BA Distribution Strategic Objectives. Some strategic objectives are in need of quantified targets. The KPIs that have been presented in this report provide a basis for setting up this measurement system. However, for the financial aspect there are some unknowns after the regulatory period for the incentives ends. This limits the reliability of long-term estimations of benefits related to these incentives. Constants in the incentives might be changed, incentives might be removed completely and new incentives might be added.

Currently, some prosumers can use the grid as a virtual energy buffer since their energy production is simply deducted from their consumption. Given the costs this brings to generators and distributors, it is possible that this will have a price for the prosumer in the future, drastically changing the economic viability of distributed generation. When this happens, it might have a significant effect on the revenue model of DSOs.

The rapidly changing energy market also imposes a time limit on the validity of this study. Rapid advancements in technology make for an uncertain future, which limits the reliability of the expectations of what the grid needs in the future. However, a Smart Grid will most likely be a requirement for these changes to happen at all.

Studies on each of the potential benefits of Smart Grids for Vattenfall BA Distribution, preferably in combination with projects that strive to realise these benefits would lead to more reliable expectations on the ROI of full-scale implementation.

Another suggestion for future work would be to do a case study by implementing the KPIs in one or several Smart Grid projects.

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11. Appendix I – Existing KPIs

11.1. KPIs from Academic Literature

Using databases search engines provided by the university in combination with public search engines, the following Smart Grid related KPIs have been found in scholarly literature:

KPIs from Measuring the "Smartness" of the Electricity Grid [47]
Amount of production generated by local, distributed generation (MW/MW)
Amount of voltage variations in the grid [RMS]
CAIDI represents the average outage duration that a customer experiences [Minutes]
Distributed Generation and Storage
Efficiency of generation facilities [energy output (MWh) / energy input (MWh)]
Energy losses in transmission and distribution [MWh/year]
Fraction of consumers contributing in DSM [%]
Fraction of time prosumer is net producer and consumer [h/h]
Fraction of transmission-level synchrophasor measurement points shared multilaterally (%)
Infrastructure
MAIFI represents the total number of customer interruptions per customer lasting less than five minutes for a particular electric
Minimal demand from grid (maximal own production) versus maximal demand from the grid (own production is zero) [MW/MW]
Number (or percentage) of grid elements (substations, switches, …) that can be remotely monitored and controlled in real-time
Number of additional energy services offered to the consumer
Number of advanced meters installed
Number of charging points that are provided to charge the vehicles
Number of customers served by ESCO's
Number of kWh that the consumer saves in comparison to the consumption before the energy service
Number of lines operated under dynamic line ratings
Number of tariff plans available to end consumers
Percentage of consumer load capacity participating in DSM [MW/MW]
Percentage of kilometres of transmission circuits operated under dynamic line ratings [km]
Percentage of storage and DG that can be modified vs. total storage and DG [MW/MW]
Percentage of substations applying automation technologies
Percentage of the charging capacity of the vehicles that can be controlled (versus the charging capacity of the vehicles or the total power capacity of the grid) [MW/MW]
Percentage of the stored energy in vehicles that can be controlled (versus the available energy in the vehicles or the total energy consumption in the grid) [MWh/MWh]
Percentage of total demand served by advanced meters
Performance (bandwidth, response speed, availability, adaptability, …) of the communication channels towards grid elements
Potential for direct electrical energy storage relative to daily demand for electrical energy [MWhel/MWhel]
Potential for time shift (before start-up and during operation) [h]
Range of frequencies [Hz] contracted and range of voltages [V] contracted
SAIDI represents the average number of minutes customers are interrupted each year [Minutes]

SAIFI represents the total number of customer interruptions per customer for a particular electric supply system [Interruptions]
Standards in telecommunication
The average percentage of smart grid investment that can be recovered through rates or subsidies
The capacity of microgrids [MW]
The compliance of electric power industries with European and international telecommunication standards and protocols.
The flexibility that aggregators can offer to other market players [MWh]
The fraction of customers served by RTP tariffs
The fraction of load served by RTP tariffs
The number of applications supported by these various measurement technologies
The number of customers offering flexibility to aggregators
The number of microgrids in operation.
The percentage of customer complaints related to power quality problems (excluding outages)
The percentage of grid operators with standard distributed resource interconnection policies
The percentage of smart grid investment covered by external financing
The percentage of substations possessing advanced measurement technology
The time that aggregators can offer a certain flexibility [h]
The total grid capacity of microgrids to the capacity of the entire grid [MW/MW]
The total number and percentage shares of on-road light-duty vehicles, comprising PHEVs
The weighted average maturity level of interoperability realised among electricity system stakeholders
Time of a certain voltage variation [h]
Time shift allowed for heating/cooling [h]
To what extent are storage and DG able to provide ancillary services as a percentage of the total offered ancillary services
Total electrical energy locally (decentralised) produced versus total electrical energy consumed [MWh/MWh]
Total load capacity in each consumer category that is actually or potentially modified by behaviours of smart appliances [MW]
Total SCADA points shared per substation (ratio)
Total yearly retail sales volume for purchases of smart appliances [€]
Yearly average and average peak capacity factor for a typical kilometre of transmission line (%-km per km)
Yearly average and average peak distribution transformer capacity factor (%)
Yearly average and peak generation capacity factor (%)
Yearly average transmission transfer capacity expansion due to the use of dynamic (versus fixed) line ratings [MW-km]

KPIs from Assessing the Effect of Public Subsidies on Firm R&D Investment [48]
External funding

Key performance indicators: A useful tool to assess Smart Grid goals [42]
Reduction in Overall Demand
Reduction in Peak Demand

Reduction in Technical Losses
Reduction in High Power Customer Consumption
Improvement in Control System Efficiency
Improvement in Total Renewable Generation
Improvement in Renewable Mini-Generation
Improvement in Renewable Micro-Generation
Improvement in Zonal Quality
Improvement in Waveform Quality
Lower LV failure detection time
Lower MV failure detection time

Reliability and Economic Assessment of Generating Systems Containing Wind Energy Sources [49]
Energy Not Supplied

Incentivising Continuity of Supply in Sweden [8]
SAIDI
SAIFI
CEMI

11.2. KPIs from EU projects

The EU has funded many projects that stimulate the implementation of a Smart Grid in its member states. Some of these projects have proposed frameworks for KPIs to be used with Smart Grids whilst others have used them to report their goals and/or results. The KPIs found in the documents published by these projects are listed below.

KPIs from UPGRID [4]
Demand flexibility
Generation flexibility
Hosting Capacity of Electric Vehicles
Fulfilment of voltage limits
Average time for LV faults
Average time needed for fault location in MV
Quality of Supply Improvement in LV
Quality of Supply Improvement in MV
Energy losses
Monitoring information categories
Available information categories
Characterised information categories
Availability of intelligent network components
Success index in meter reading
Success index in event reading

Success index in advanced functionalities
Success index in meter connectivity
Consumers being metered automatically
Improved lifetime of transformers
Participant recruitment
Active participation
Load curve valley filling
Use of equipment standards
Use of protocol standards
Reduction in greenhouse gas emissions
Active Demand for increased network flexibility
Enabling maximum energy efficiency in new or refurbished urban using smart distribution grids
Integration of DER at low voltage
Integration of DER at medium voltage / high voltage
Integration of storage in network management
Integration of infrastructure to host Electrical Vehicles
Monitoring and control of LV networks
Automation and control of MV networks
Network management methodologies for network operation
Smart metering data utilisation
Novel planning approaches for distribution networks
Novel approaches to asset management
New approaches for market design

Vattenfall Smart Grid Project Smart Grids2010
Meter Measuring Costs

KPIs from DISCERN [4]
Asset Lifetime
Reduction in CO2 Emissions
Production Curtailment
Increased Hosting Capacity EV
Hosting Capacity EV
Shiftable Demand Through DR
Reduction of Accidents and Risk
Time to Fault Awareness
Time to Fault Localisation
Time to Fault Isolation
Increased Distribution Capacity
Success in Meter Reading
Success in Event Reading
Customers with AMI
Generation Response

Fulfilment voltage limits
Reduced RES Curtailment
Amount of load capacity participating in DR
Curtailment DER
Improvement voltage quality (monitoring)
Reduction in time required for fault awareness, localisation and isolation
Peak load reduction
The amount of flexible generation
Load curtailed after a disturbance
Increase transportation capacity of grid
Hosting Capacity DER
Curtailment DER
Improvement SAIDI/ASIDI (no of customers not needed)
Improvement SAIFI
Improvement voltage quality (monitoring)
Reduction in time required for fault awareness, localisation and isolation
Amount of load capacity participating in DR
Peak load reduction
The amount of flexible generation
Load curtailed after a disturbance
Increase transportation capacity of grid
% of market recovered after outage
Reduction of technician actuation
Percentage reduction in complaints of customers because of outages
No of switching operations after each fault/outage event 16 Number of events when thermal limits are exceeded
Availability of network components (ICT)
Percentage reduction in energy losses
Amount non-technical losses identified
Reduction Technical losses
Percentage cost reduction in comparison with conventional grid reinforcement strategies for DG integration
Share of electrical energy produced by DER
Cost per customer invoice
Reduced delays for new connections
Number of sensors/data to achieve the functionality
Percentage of Consumers being metered automatically
Voltage variation in Distribution grid
Better support of network planning
Increased hosting capacity
Improvement SAIDI
Improvement ASIDI
Improvement voltage quality
Amount of load capacity participating in Demand Response
Percentage reduction in complaints of customers
Amount of technical losses identified (LV)

Potential for reduction in technical losses (LV)
Amount of non-technical losses identified
% cost reduction in IT in comparison with conv. Strategies for AMR data concentration & communication
Number of sensors to achieve the functionality
Change in voltage variation on medium voltage level
Change in voltage variation on low voltage level
Information reduction for central control systems
Reduction of network congestions

KPIs from ADVANCED [36]
Asset OPEX
Asset CAPEX
Average Production Cost/kWh

KPIs from GRID+ [37]
Hosting capacity RES
Hosting capacity DER
Reduced DER Curtailment
Increased RES
Increased DER
Increased RES & DER hosting capacity
Reduced energy curtailment of RES and DER
Power Quality and Quality of Supply
Increased flexibility from energy players
Extended asset lifetime
Improved competitiveness of the electricity market
Increased hosting capacity for Electric Vehicles and other new loads
Increased Network Capacity
Increased system flexibility
Network Capacity
Variation of the amount of network capacity per euro of cost
Variation of network capacity
System Flexibility
System Flexibility at Affordable Cost

KPIs from IDE4L [41]
Improved competitiveness of the electricity market
Current Monitoring Data Volume
Current Monitoring Granularity
Powers Monitoring Data Volume
Powers Monitoring Granularity
Voltage Monitoring Data Volume
Voltage Monitoring Granularity

Real-time LV Network State Estimation
Real-time MV Network State Estimation
Voltage stability of the electricity system
TSO´s visibility of distribution network
Evaluation of IEC 61850-90-5 library
LV load/generation forecaster
MV load/generation forecaster
LV state forecaster
MV state forecaster
Network Description Update
Protection Configuration Update
Control Centre Tertiary Power Control - Technical and Economic Parameters
Control Center Tertiary Power Control - Operational Parameters
Control Center Tertiary Power Control - Technical Safety Parameters
LV Network Power Control - Technical and Economic Parameters
LV Network Power Control - Operational Parameters
LV Network Power Control - Technical Safety Parameters
MV Network Power Control - Technical and Economic Parameters
MV Network Power Control - Operational Parameters
MV Network Power Control - Technical Safety Parameters
Breaker energised operations
Interconnection Switch
Flicker mitigation MV/LV active grid
Expansion Planning Scenario Evaluation
Target network Planning
Reduction of technical network losses
Percentage utilisation of electricity network components
RES curtailment
Demand Response
Day Ahead Dynamic Tariff

KPIs from Definition of an Assessment Framework for Projects of Common Interest in the Field of Smart Grids [35]
Reduction of greenhouse gas emissions
Environmental impact of electricity grid infrastructure
Installed capacity of distributed energy resources in distribution networks
Allowable maximum injection of power without congestion risks in transmission networks
Energy not withdrawn from renewable sources due to congestion or security risks
Methods adopted to calculate charges and tariffs, as well as their structure, for generators, consumers and those that do both
Operational flexibility for dynamic balancing of electricity in the network
Ratio of reliably available generation capacity and peak demand
Share of electricity generated from renewable sources
Stability of the electricity system
Duration and frequency of interruptions per customer, including climate-related disruptions

Voltage quality performance
Level of losses in transmission and in distribution networks
Ratio between minimum and maximum electricity demand within a defined time period
Demand side participation in electricity markets and in energy efficiency measures
Percentage utilisation (i.e. average loading) of electricity network components
Availability of network components (related to planned and unplanned maintenance) and its impact on network performances
Actual availability of network capacity with respect to its standard value
Ratio between interconnection capacity of a Member State and its electricity demand
Exploitation of interconnection capacities
Congestion rents across interconnections

11.3. KPIs from other sources

This group of KPIs have been found in sources that are not peer-reviewed academic literature or EU-projects. Many are sourced from kpilibrary.com or globalreporting.org. The sources in this section are in no way scrutinised for correctness or verified in any other way. However, it did contain KPIs which were not included in the other categories, especially different ways to estimate costs in Smart Grids and environmental KPIs. Providing KPIs that measure environmental impact will support projects which strive to improve on this aspect and might motivate all projects to look into their own environmental impact. The Global Reporting Initiative (GRI) provides a wide range of general standard disclosures, of which the environmental category has been listed below.

KPIs from kpilibrary.com
Average cost per power connection
Power purchased on spot market
Energy transmission and distribution losses %
Average corrective maintenance time per power connection
NOx emission rate per megawatthour of generation
Average retail price of electricity
% of electricity generated with non-hydroelectric renewable power
Number of problems per 1000 power connections
Average revenue per power connection
Average preventive maintenance time per power connection
SO2 emission rate per megawatthour of generation
% of power purchased on spot-market
% of power purchased in long-term supply contracts
% of electricity generated with hydroelectric power
% of customers participating in green power market
% of unaccounted electricity delivery
% of electricity imported
% of electricity exported
% of electricity billed
Annual infrastructure renewal and replacement rate as % of base assets

Connection density per km network
Profit per power distribution km
Average total costs per power distribution km
Average fixed costs per power distribution km
Average variable costs per power distribution km
Average employee costs per power distribution km
Average non-employee costs per power distribution km
Average direct costs per power distribution km
Average corrective maintenance costs per power distribution km
Average preventive maintenance costs per power distribution km
Average maintenance costs per power distribution km
Average corrective maintenance time per power distribution km
Average preventive maintenance time per power distribution km
Average maintenance time per power distribution km
Power distribution km per power connection
Average maintenance time per connection
Average fixed costs per power connection
Average variable costs per power connection
Average employee costs per power connection
Average non-employee costs per power connection
Average direct costs per power connection
Average corrective maintenance costs per power connection
Average preventive maintenance costs per power connection
Average maintenance costs per power connection
Costs of fuel for electricity generation
Average power consumption per connection

KPIs from Global Reporting Initiative G4 [50]
Materials used (renewable or non-renewable)
Amount of recycled materials used
Energy consumption within organisation
Energy consumption outside of organisation
Energy intensity
Reduction of energy consumption
Reductions in energy requirements of products and services
Total water withdrawal
Water sources significantly affected by withdrawal of water
Percentage and total volume of water recycled and reused
Operational sites owned, leased, managed in or adjacent to, protected areas and areas of high biodiversity value outside protected areas
Habitats protected of restored
Total number of IUCN red list species and national conservation list species with habitats in areas affected by operations, by level of extinction risk
Direct greenhouse gas (GHG) emissions
Energy indirect greenhouse gas (GHG) emissions

Other indirect greenhouse gas (GHG) emissions
Greenhouse gas (GHG) emissions intensity
Reduction of greenhouse gas emissions
Emissions of ozone-depleting substances
NOx, SOx, and other significant air emissions
Total water discharge by quality and destination
Total weight of waste by tape and disposal method
Total number and volume of significant spills
Weight of transported, imported, exported, or treated waste deemed hazardous under the terms of the Basel Convention Annex I, II, III and VIII, and percentage of transported waste shipped internationally
Identity, size, protected status, and biodiversity value of water bodies and related habitats significantly affected by the organisation's discharges of water and runoff
Extent of impact mitigation of environmental impacts of products and services
Percentage of products sold and their packaging materials that are reclaimed by category
Monetary value of significant fines and total number of non-monetary sanctions for non-compliance with environmental laws and regulations
Significant environmental impacts of transporting products and other goods and materials for the organisation's operations, and transporting members of the workforce
Total environmental protection expenditures and investments by type

12. Appendix II – Recommended KPIs

12.1. Project level KPIs

The project KPIs are selected for measuring the performance of projects in energy distribution. All Smart Grid related aspects of energy distribution projects should be measurable by one of these KPIs.

Metering KPIs

The KPIs presented in this section are relevant for projects that have to do with metering.

Name	Reason for recommendation	What is measured
Asset OPEX	Direct measurement of operational costs. Automation of grid equipment could lower operational costs by having less frequent manual operations. Aligns with strategic goal of an ROCE of ≥ 9% and PWA Asset Management.	OPEX of asset
Automated Remote Event reading	Reliable event reading is a prerequisite for fast restoration of service, therefore aligns with Improved Network Quality and Metering (mostly roll-out new functionality)	Percentage of events successfully read through AMI (<1 min), alternatively number of events failed to read through AMI (<1 min)

Name	Reason for recommendation	What is measured
Automation and control	Automation and control bring cost reduction and safety increase. Aligns with the strategic target of LTIF and PWAs Asset Management; increased automation and control enables analytics, Network Balance with Steering; accurate information on loads is required for dynamic rating and Metering; LV monitoring relies on automation and control. Does not require a system to be fully autonomous, can also be remotely operated or using other methods to reduce intervention time.	Reduction in human intervention on MV or LV networks. A suggestion would be to calculate the reduction of costs of manual control. Improvements in performance should be covered by different KPIs, such as SAIDI.
Average cost per power connection	Cost per connection is a measurement that might enable comparison between different proposals. Calculating this per connection will give an indication of costs of a large-scale implementation.	Average cost of project per associated power connection
CAIDI	Customer Average Interruption Duration Index. The average outage duration for any given customer with an interruption.	SAIDI/SAIFI, both as defined by EI.
CEMI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	CEMI, as defined by the EI.
Consumers being metered automatically	AMR adds to the quality of life for customers and cost reduction for VF. Mostly relevant for the German grid since this has already been implemented in Sweden. Serves as a platform on which other functionalities can be built.	Number of consumers being metered automatically
Demand flexibility	An attribute of Smart Grid, aligns with prioritised area Tariffs, Demand Response and Network Balance with Steering. Beneficial for enabling a higher number of renewables.	The amount of load that can be shifted temporally. Needs specification dependent on the method used to provide an incentive (RTP, remote operation of customer assets or other options).
Distributed Generation	A key aspect of Smart Grid, providing higher resilience and reliability to the grid. Aligned with strategic target of Commissioned Renewable Capacity and PWAs Metering and Environment & Energy Efficiency	Amount of power produced by distributed generation in MWh

Name	Reason for recommendation	What is measured
Forecasting reliability of demand/generation	This will enable close to optimal use of renewable energy and setting optimising the pricing strategy. Is an enabler for PWAs Network Balance with Steering and Environment & Energy Efficiency, since more accurate forecasting leads to more optimal running of generation facilities.	SD of predicted capacity VS actual capacity. Needs specification of how far in advance. Option to set this time period per project, but needs clear communication of calculation method.
Fulfilment of voltage limits	Aligns with Improved Network Quality. Useful for measuring quality improvement of automation of assets.	Deviation of voltage from ideal voltage.
Generation flexibility	Attribute of Smart Grid, aligns with prioritised area Tariffs & Demand Response. Especially relevant for projects with storage solutions.	The amount of generation that can be shifted temporally.
Hosting Capacity of Electric Vehicles	Aligns with Environment & Energy Efficiency. Might also lead to increased revenue due to connections with upgraded load limit.	kWh used for charging EVs per time period. The reason for not measuring in kW is that unused charging stations would lead to an unwanted increase to the measure.
Hosting capacity RES	Aligned with strategic target of Renewable Energy and PWAs Network Balance with Steering and Environment & Energy Efficiency	Hosting Capacity of Renewable Energy Sources in MW
Increased Distribution Capacity	With the electrification of society an increased distribution capacity is required to keep a stable and reliable grid. Somewhat related to the strategic target of Commissioned Renewable Capacity and PWAs Network Balance with Steering and Asset Management. One of the ways to achieve this is by using dynamic ratings.	Amount of capacity added
Load Factor	Incentivised by EI. Improvements in load factor lead to lower losses, which makes it relevant for PWAs Environment & Energy Efficiency and Tariffs & Demand response. However, in some cases it would be closer to ideal to accept a lower Load Factor, for instance to have a higher utilisation of non-controllable energy sources.	Load Factor, as defined by the EI.
Meter Measuring Costs	Reductions in meter measuring costs will help to reach an ROCE of ≥ 9%. Especially relevant for German grid.	Average metering measurement costs per year.

Name	Reason for recommendation	What is measured
Outage compensation fee	Depending on the duration of the outage and the type of customer, a compensation fee is paid to the customer. Having to pay fewer fees is a direct financial reward for having a more reliable grid.	Compensation fee in case of outage
Peak Shaving Valley Filling	Incentivised by EI. Also adds to Environment & Energy Efficiency and can be a result of improvements in Tariffs & Demand Response and Network Balance with Steering	Reduction of required peak distribution capacity and/or load factor as defined by EI.
Power Not Supplied	The amount of power that normally would be delivered, but now is not because of an outage. Incentivised by the EI for sub-transmission network operators.	Power not supplied because of a grid failure as defined by EI.
Price Volatility	The volatility of the final price for consumers. Aligns with PWAs Network Balance with Steering and Tariffs & Demand Response.	Volatility of price per type of price (use sub-KPIs)
Production Curtailment	Production curtailment can be avoided by increasing distribution capacity, either by building new infrastructure or making more efficient use of existing infrastructure. However, under specific circumstances accepting some curtailment can be the optimal solution. Linked to strategic target of commissioned renewable capacity and PWA Network Balance with Steering and Environment & Energy Efficiency	Production curtailed in MWh
Reduction in greenhouse gas emissions	A strategic target as well as a PWA. Could be relevant for projects involving EVs.	Emission of CO_2, NO_x, SF_6 and other greenhouse gasses.
SAIDI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIDI, as defined by the EI.
SAIFI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIFI, as defined by the EI.
Success index in advanced functionalities	Aligns with PWA metering. Needs specification on what the advanced functionalities are for accurate measurements. Still in the recommended list since these advanced functionalities are a PWA.	Needs definition of advanced functionalities.

Name	Reason for recommendation	What is measured
Success index in meter reading	Less hassle with the measuring of customer meters might add to the strategic target customer loyalty. Also aligns with PWA Metering and Improved Network Quality.	Percentage of meters successfully read through AMI, alternatively the number of meters which failed to be read through AMI. Another option would be percentage of quickly detected (<1 min) outages, depending on project goal.

Asset Management KPIs

The KPIs presented in this section are relevant for projects that have to do with asset management.

Name	Reason for recommendation	What is measured
Asset CAPEX	Direct measurement of capital expenditure. Keeping track of the initial investment for Smart Grid projects helps with project management but also makes it comparable with BaU solutions. Aligns with the strategic goal of an ROCE of ≥ 9% and PWA Asset Management.	CAPEX of asset
Asset Lifetime	Elongation of economic lifetime of an asset will avoid high costs in the short term. Automated, more accurate and frequent measurements can keep the risks in this extra lifetime at an acceptable level. This could be the result of condition-based maintenance. This aligns with PWA Improved Network Quality and Asset management. Extending asset lifetime can be valued by the costs that would be required for a BaU solution. It should be noted however that the average profitability/year decreases sharply after 50 years due to the regulations in place.	Expected economic lifetime of the asset. Also, an option for operational lifetime. Given the cap on economic lifetime, the operational lifetime can be longer.
Asset OPEX	Direct measurement of operational costs. Automation of grid equipment could lower operational costs by having less frequent manual operations. Aligns with the strategic goal of an ROCE of ≥ 9% and PWA Asset Management.	OPEX of asset

Name	Reason for recommendation	What is measured
Automated Remote Event reading	Reliable event reading is a prerequisite for fast restoration of service, therefore aligns with Improved Network Quality and Metering (mostly roll-out new functionality)	Percentage of events successfully read through AMI (<1 min), alternatively number of events failed to read through AMI (<1 min)
Automation and control	Automation and control bring cost reduction and safety increase. Aligns with the strategic target of LTIF and PWAs Asset Management; increased automation and control enables analytics, Network Balance with Steering; accurate information on loads is required for dynamic rating and Metering; LV monitoring relies on automation and control. Does not require a system to be fully autonomous, can also be remotely operated or using other methods to reduce intervention time.	Reduction in human intervention on MV or LV networks. A suggestion would be to calculate the reduction of costs of manual control. Improvements in performance should be covered by different KPIs, such as SAIDI.
Average cost per power connection	Cost per connection is a measurement that might enable comparison between different proposals. Calculating this per connection will give an indication of costs of a large-scale implementation.	Average cost of project per associated power connection
Average time for fault restoration	Aligns with Improved network quality. Time to fault detection adds to SAIDI. Possible alignment with strategic target of +2 NPS.	Average time needed to restore nominal operation. It would be recommended to define sub-KPIs such as time to fault detection and time between fault detection and restoration of service.
Average variable costs per power distribution km	Automation on average needs a one-time capital investment in equipment with lower variable costs after (high CAPEX, low OPEX). By measuring the improvement in the variable costs per km, an estimation can be made for the effect in a possible large-scale implementation. Aligns with PWA Asset Management	Average variable costs per power distribution km in SEK
CAIDI	Customer Average Interruption Duration Index. The average outage duration for any given customer with an interruption.	SAIDI/SAIFI, both as defined by EI.
CEMI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	CEMI, as defined by the EI.

Name	Reason for recommendation	What is measured
Energy losses	Directly linked to strategic target Absolute CO2 emissions and with Prioritised Work Area (PWA) Environment & Energy Efficiency.	Energy lost in transmission, distribution and storage. If the project is focused on a specific part, a sub KPI should be defined. This will lower calculation costs and makes sure to focus on the result of the project.
Energy Not Supplied	The amount of energy that normally would be delivered, but now is not because of an outage. Incentivised by the EI for sub-transmission network operators.	Energy not supplied from fault occurrence until reconnection as defined by EI.
Environmental impact	Many different types of environmental impact are defined in the GRI G4.	As defined in the Global Reporting Initiative, fourth revision [50].
Fulfilment of voltage limits	Aligns with Improved Network Quality. Useful for measuring quality improvement of automation of assets.	Deviation of voltage from ideal voltage.
Hosting Capacity of Electric Vehicles	Aligns with Environment & Energy Efficiency. Might also lead to increased revenue due to connections with upgraded load limit.	kWh used for charging EVs per time period. The reason for not measuring in kW is that unused charging stations would lead to an unwanted increase in the measure.
Hosting capacity RES	Aligned with strategic target of Renewable Energy and PWAs Network Balance with Steering and Environment & Energy Efficiency	Hosting Capacity of Renewable Energy Sources in MW
Increased Distribution Capacity	With the electrification of society an increased distribution capacity is required to keep a stable and reliable grid. Somewhat related to the strategic target of Commissioned Renewable Capacity and PWAs Network Balance with Steering and Asset Management. One of the ways to achieve this is by using dynamic ratings.	Amount of capacity added
Load Factor	Incentivised by EI. Improvements in load factor lead to lower losses, which makes it relevant for PWAs Environment & Energy Efficiency and Tariffs & Demand response. However, in some cases it would be closer to ideal to accept a lower Load Factor, for instance to have a higher utilisation of non-controllable energy sources.	Load Factor, as defined by the EI.

Name	Reason for recommendation	What is measured
Outage compensation fee	Depending on the duration of the outage and the type of customer, a compensation fee is paid to the customer. Having to pay fewer fees is a direct financial reward for having a more reliable grid.	Compensation fee in case of outage
Peak Shaving Valley Filling	Incentivised by EI. Also adds to Environment & Energy Efficiency and can be a result of improvements in Tariffs & Demand Response and Network Balance with Steering	Reduction of required peak distribution capacity and/or load factor as defined by EI.
Power Not Supplied	The amount of power that normally would be delivered, but now is not because of an outage. Incentivised by the EI for sub-transmission network operators.	Power not supplied because of a grid failure as defined by EI.
Production Curtailment	Production curtailment can be avoided by increasing distribution capacity, either by building new infrastructure or making more efficient use of existing infrastructure. However, under specific circumstances accepting some curtailment can be the optimal solution. Linked to strategic target of commissioned renewable capacity and PWA Network Balance with Steering and Environment & Energy Efficiency	Production curtailed in MWh
Reduction in greenhouse gas emissions	A strategic target as well as a PWA. Could be relevant for projects involving EVs.	Emission of CO2, NOx, SF6 and other greenhouse gasses.
Reduction of Accidents and Risk	Direct link to strategic target Safety. Several Smart Grid aspects (remote reading, automation etc.) lower human interaction or travel, thereby increasing safety.	LTIF
SAIDI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIDI, as defined by the EI.
SAIFI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIFI, as defined by the EI.

Name	Reason for recommendation	What is measured
Use of equipment standards	Lower costs and more choice in the future by using standards. Facilitates interoperability of different assets and avoids vendor lock-in. Can increase lifetime (longer support), speed up engineering process and lead to quicker setting up of requirements. Lowers the chance of miscommunicating. Improves data quality and traceability.	Percentage of equipment that uses standards for communication or other interfaces.
Use of protocol standards	Lower costs and more choice in the future by using standards. Facilitates interoperability of different assets and avoids vendor lock-in. Can increase lifetime (longer support), speed up engineering process and lead to quicker setting up of requirements. Lowers the chance of miscommunicating. Improves data quality and traceability.	Percentage of equipment that uses standard protocols. Leads to cheaper and more flexible systems.

Quality of Supply & Distributed Generation

The KPIs presented in this section are relevant for projects that have to do with the quality of supply & distributed generation.

Name	Reason for recommendation	What is measured
Automated Remote Event reading	Reliable event reading is a prerequisite for fast restoration of service, therefore aligns with Improved Network Quality and Metering (mostly roll-out new functionality)	Percentage of events successfully read through AMI (<1 min), alternatively number of events failed to read through AMI (<1 min)
Automation and control	Automation and control bring cost reduction and safety increase. Aligns with the strategic target of LTIF and PWAs: Asset Management; increased automation and control enables analytics, Network Balance with Steering; accurate information on loads is required for dynamic rating and Metering; LV monitoring relies on automation and control. Does not require a system to be fully autonomous, can also be remotely operated or using other methods to reduce intervention time.	Reduction in human intervention on MV or LV networks. A suggestion would be to calculate the reduction of costs of manual control. Improvements in performance should be covered by different KPIs, such as SAIDI.

Name	Reason for recommendation	What is measured
Average time for fault restoration	Aligns with Improved network quality. Time to fault detection adds to SAIDI. Possible alignment with the strategic target of +2 NPS.	Average time needed to restore nominal operation. It would be recommended to define sub-KPIs such as time to fault detection and time between fault detection and restoration of service.
CAIDI	Customer Average Interruption Duration Index. The average outage duration for any given customer with an interruption.	SAIDI/SAIFI, both as defined by EI.
CEMI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	CEMI, as defined by the EI.
Demand flexibility	An attribute of Smart Grid, aligns with prioritised area Tariffs, Demand Response and Network Balance with Steering. Beneficial for enabling a higher number of renewables.	The amount of load that can be shifted temporally. Needs specification dependent on the method used to provide an incentive (RTP, remote operation of customer assets or other options).
Distributed Generation	A key aspect of Smart Grid, providing higher resilience and reliability to the grid. Aligned with strategic target of Commissioned Renewable Capacity and PWAs Metering and Environment & Energy Efficiency	Amount of power produced by distributed generation in MWh
Energy Not Supplied	The amount of energy that normally would be delivered, but now is not because of an outage. Incentivised by the EI for sub-transmission network operators.	Energy not supplied from fault occurrence until reconnection as defined by EI.
Environmental impact	Many different types of environmental impact are defined in the GRI G4. Another source would be the VF ENV R&D project overview (confidential).	As defined in the sources
Forecasting reliability of demand/generation	This will enable closer to optimal use of renewable energy and setting optimising the pricing strategy. Is an enabler for PWAs Network Balance with Steering and Environment & Energy Efficiency, since more accurate forecasting leads to closer to optimal operation of generation facilities.	SD of predicted capacity VS actual capacity. Needs specification of how far in advance. Option to set this time period per project, but needs clear communication of calculation method.
Fulfilment of voltage limits	Aligns with Improved Network Quality. Useful for measuring quality improvement of automation of assets.	Deviation of voltage from ideal voltage.

Name	Reason for recommendation	What is measured
Generation flexibility	An attribute of Smart Grid, aligns with prioritised area Tariffs & Demand Response. Especially relevant for projects with storage solutions.	The amount of generation that can be shifted temporally.
Hosting capacity RES	Aligned with strategic target of Renewable Energy and PWAs Network Balance with Steering and Environment & Energy Efficiency	Hosting Capacity of Renewable Energy Sources in MW
Increased Distribution Capacity	With the electrification of society an increased distribution capacity is required to keep a stable and reliable grid. Somewhat related to the strategic target of Commissioned Renewable Capacity and PWAs Network Balance with Steering and Asset Management. One of the ways to achieve this is by using dynamic ratings.	Amount of capacity added
Load Factor	Incentivised by EI. Improvements in load factor lead to lower losses, which makes it relevant for PWAs Environment & Energy Efficiency and Tariffs & Demand response. However, in some cases it would be more ideal to accept a lower Load Factor, for instance to have a higher utilisation of non-controllable energy sources.	Load Factor, as defined by the EI.
Outage compensation fee	Depending on the duration of the outage and the type of customer, a compensation fee is paid to the customer. Having to pay fewer fees is a direct financial reward for having a more reliable grid.	Compensation fee in case of outage
Peak Shaving Valley Filling	Incentivised by EI. Also adds to Environment & Energy Efficiency and can be a result of improvements in Tariffs & Demand Response and Network Balance with Steering	Reduction of required peak distribution capacity and/or load factor as defined by EI.
Power Not Supplied	The amount of power that normally would be delivered, but now is not because of an outage. Incentivised by the EI for sub-transmission network operators.	Power not supplied because of a grid failure as defined by EI.

Name	Reason for recommendation	What is measured
Production Curtailment	Production curtailment can be avoided by increasing distribution capacity, either by building new infrastructure or making more efficient use of existing infrastructure. However, under specific circumstances accepting some curtailment can be the optimal solution. Linked to strategic target of commissioned renewable capacity and PWA Network Balance with Steering and Environment & Energy Efficiency	Production curtailed in MWh
Reduction in greenhouse gas emissions	A strategic target as well as a PWA. Could be relevant for projects involving EVs.	Emission of CO2, NOx, SF6 and other greenhouse gasses.
Reduction of Accidents and Risk	Direct link to strategic target Safety. Several Smart Grid aspects (remote reading, automation etc.) lower human interaction or travel, thereby increasing safety.	LTIF
SAIDI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIDI, as defined by the EI.
SAIFI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIFI, as defined by the EI.

Sustainable Communities

The KPIs presented in this section are relevant for projects that have to do with sustainable communities.

Name	Reason for recommendation	What is measured
Automation and control	Automation and control bring cost reduction and safety increase. Aligns with the strategic target of LTIF and PWAs Asset Management; increased automation and control enables analytics, Network Balance with Steering; accurate information on loads is required for dynamic rating and Metering; LV monitoring relies on automation and control. Does not require a system to be fully autonomous, can also be remotely operated or using other methods to reduce intervention time.	Reduction in human intervention on MV or LV networks. A suggestion would be to calculate the reduction of costs of manual control. Improvements in performance should be covered by different KPIs, such as SAIDI.

Name	Reason for recommendation	What is measured
Average Production Cost/MWh	Several aspects of Smart Grids enable consumers to shift their consumption to times with lower prices. This simultaneously means that Vattenfall can make better use of their low marginal cost production facilities but will make lower profits on the high marginal cost production facilities. More relevant to the generation business than to the distribution business.	The average cost of producing 1MWh.
Average retail price of electricity	Relevant for Demand Response projects, although subject to market conditions. Aligns with PWAs Network Balance with Steering, Tariffs & Demand Response and Metering. Useful for communication with customers as well.	Average price for energy sold to consumers in the project.
Average time for fault restoration	Aligns with Improved network quality. Time to fault detection adds to SAIDI. Possible alignment with strategic target of +2 NPS.	Average time needed to restore nominal operation. It would be recommended to define sub-KPIs such as time to fault detection and time between fault detection and restoration of service.
Demand flexibility	An attribute of Smart Grid, aligns with prioritised area Tariffs, Demand Response and Network Balance with Steering. Beneficial for enabling a higher number of renewables.	The amount of load that can be shifted temporally. Needs specification dependent on the method used to provide an incentive (RTP, remote operation of customer assets or other options).
Distributed Generation	A key aspect of Smart Grid, providing higher resilience and reliability to the grid. Aligned with strategic target of Commissioned Renewable Capacity and PWAs Metering and Environment & Energy Efficiency	Amount of power produced by distributed generation in MWh
Energy losses	Directly linked to strategic target Absolute CO2 emissions and with Prioritised Work Area (PWA) Environment & Energy Efficiency.	Energy lost in transmission, distribution and storage. If the project is focused on a specific part, a sub KPI should be defined. This will lower calculation costs and makes sure to focus on the result of the project.
Environmental impact	Many different types of environmental impact are defined in the GRI G4. Another source would be the VF ENV R&D project overview (confidential).	As defined in the sources

Name	Reason for recommendation	What is measured
Forecasting reliability of demand/generation	This will enable closer to optimal use of renewable energy and setting optimising the pricing strategy. Is an enabler for PWAs Network Balance with Steering and Environment & Energy Efficiency, since more accurate forecasting leads to more optimal running of generation facilities.	SD of predicted capacity VS actual capacity. Needs specification of how far in advance. Option to set this time period per project, but needs clear communication of calculation method.
Generation flexibility	An attribute of Smart Grid, aligns with prioritised area Tariffs & Demand Response. Especially relevant for projects with storage solutions.	The amount of generation that can be shifted temporally.
Hosting Capacity of Electric Vehicles	Aligns with Environment & Energy Efficiency. Might also lead to increased revenue due to connections with upgraded load limit.	kWh used for charging EVs per time period. The reason for not measuring in kW is that unused charging stations would lead to an unwanted increase in the measure.
Hosting capacity RES	Aligned with strategic target of Renewable Energy and PWAs Network Balance with Steering and Environment & Energy Efficiency	Hosting Capacity of Renewable Energy Sources in MW
Participant recruitment	If participants are essential, setting goals and following up on recruitment is essential for project success.	The number of customers committing to being a participant in the project.
Peak Shaving Valley Filling	Incentivised by EI. Also adds to Environment & Energy Efficiency and can be a result of improvements in Tariffs & Demand Response and Network Balance with Steering	Reduction of required peak distribution capacity and/or load factor as defined by EI.
Production Curtailment	Production curtailment can be avoided by increasing distribution capacity, either by building new infrastructure or making more efficient use of existing infrastructure. However, under specific circumstances accepting some curtailment can be the optimal solution. Linked to strategic target of commissioned renewable capacity and PWA Network Balance with Steering and Environment & Energy Efficiency	Production curtailed in MWh
Reduction in greenhouse gas emissions	A strategic target as well as a PWA. Could be relevant for projects involving EVs.	Emission of CO2, NOx, SF6 and other greenhouse gases.

Name	Reason for recommendation	What is measured
Reduction of Accidents and Risk	Direct link to strategic target Safety. Several Smart Grid aspects (remote reading, automation etc.) lower human interaction or travel, thereby increasing safety.	LTIF

Flexibility and Network Balance

The KPIs presented in this section are relevant for projects that have to do with flexibility and network balance.

Name	Reason for recommendation	What is measured
Automated Remote Event reading	Reliable event reading is a prerequisite for fast restoration of service, therefore aligns with Improved Network Quality and Metering (mostly roll-out new functionality)	Percentage of events successfully read through AMI (<1 min), alternatively number of events failed to read through AMI (<1 min)
Automation and control	Automation and control bring cost reduction and safety increase. Aligns with strategic target of LTIF and PWAs Asset Management; increased automation and control enables analytics, Network Balance with Steering; accurate information on loads is required for dynamic rating and Metering; LV monitoring relies on automation and control. Does not require a system to be fully autonomous, can also be remotely operated or using other methods to reduce intervention time.	Reduction in human intervention on MV or LV networks. A suggestion would be to calculate the reduction of costs of manual control. Improvements in performance should be covered by different KPIs, such as SAIDI.
Average Production Cost/MWh	Several aspects of Smart Grids enable consumers to shift their consumption to times with lower prices. This simultaneously means that Vattenfall can make better use of their low marginal cost production facilities but will make lower profits on the high marginal cost production facilities. More relevant to the generation business than to the distribution business.	The average cost of producing 1MWh.
Consumers being metered automatically	AMR adds to the quality of life for customers and cost reduction for VF. Mostly relevant for the German grid since this has already been implemented in Sweden. Serves as a platform on which other functionalities can be built.	Number of consumers being metered automatically

Name	Reason for recommendation	What is measured
Demand flexibility	An attribute of Smart Grid, aligns with prioritised area Tariffs, Demand Response and Network Balance with Steering. Beneficial for enabling a higher number of renewables.	The amount of load that can be shifted temporally. Needs specification dependent on the method used to provide an incentive (RTP, remote operation of customer assets or other options).
Distributed Generation	A key aspect of Smart Grid, providing higher resilience and reliability to the grid. Aligned with strategic target of Commissioned Renewable Capacity and PWAs Metering and Environment & Energy Efficiency	Amount of power produced by distributed generation in MWh
Forecasting reliability of demand/generation	This will enable closer to optimal use of renewable energy and setting optimising the pricing strategy. Is an enabler for PWAs Network Balance with Steering and Environment & Energy Efficiency, since more accurate forecasting leads to the more optimal operation of generation facilities.	SD of predicted capacity VS actual capacity. Needs specification of how far in advance. Option to set this time period per project, but needs clear communication of calculation method.
Fulfilment of voltage limits	Aligns with Improved Network Quality. Useful for measuring quality improvement of automation of assets.	Deviation of voltage from ideal voltage.
Generation flexibility	An attribute of Smart Grid, aligns with prioritised area Tariffs & Demand Response. Especially relevant for projects with storage solutions.	The amount of generation that can be shifted temporally.
Hosting Capacity of Electric Vehicles	Aligns with Environment & Energy Efficiency. Might also lead to increased revenue due to connections with upgraded load limit.	kWh used for charging EVs per time period. The reason for not measuring in kW is that unused charging stations would lead to an unwanted increase in the measure.
Hosting capacity RES	Aligned with strategic target of Renewable Energy and PWAs Network Balance with Steering and Environment & Energy Efficiency	Hosting Capacity of Renewable Energy Sources in MW
Increased Distribution Capacity	With the electrification of society an increased distribution capacity is required to keep a stable and reliable grid. Somewhat related to the strategic target of Commissioned Renewable Capacity and PWAs Network Balance with Steering and Asset Management. One of the ways to achieve this is by using dynamic ratings.	Amount of capacity added

Name	Reason for recommendation	What is measured
Load Factor	Incentivised by EI. Improvements in load factor lead to lower losses, which makes it relevant for PWAs Environment & Energy Efficiency and Tariffs & Demand response. However, in some cases it would be more ideal to accept a lower Load Factor, for instance to have a higher utilisation of non-controllable energy sources.	Load Factor, as defined by the EI.
Peak Shaving Valley Filling	Incentivised by EI. Also adds to Environment & Energy Efficiency and can be a result of improvements in Tariffs & Demand Response and Network Balance with Steering	Reduction of required peak distribution capacity and/or load factor as defined by EI.
Price Volatility	The volatility of the final price for consumers. Aligns with PWAs Network Balance with Steering and Tariffs & Demand Response.	Volatility of price per type of price (use sub-KPIs)
Production Curtailment	Production curtailment can be avoided by increasing distribution capacity, either by building new infrastructure or making more efficient use of existing infrastructure. However, under specific circumstances accepting some curtailment can be the optimal solution. Linked to strategic target of commissioned renewable capacity and PWA Network Balance with Steering and Environment & Energy Efficiency	Production curtailed in MWh

Digitalisation

The KPIs presented in this section are relevant for projects that have to do with digitalisation.

Name	Reason for recommendation	What is measured
Asset CAPEX	Direct measurement of capital expenditure. Keeping track of the initial investment for Smart Grid projects helps with project management but also makes it comparable with BaU solutions. Aligns with the strategic goal of an ROCE of ≥ 9% and PWA Asset Management.	CAPEX of asset

Name	Reason for recommendation	What is measured
Asset Lifetime	Elongation of economic lifetime of an asset will avoid high costs in the short term. Automated, more accurate and frequent measurements can keep the risks in this extra lifetime at an acceptable level. This could be the result of condition-based maintenance. This aligns with PWA Improved Network Quality and Asset management. Extending asset lifetime can be valued by the costs that would be required for a BaU solution. It should be noted however that the average profitability/year decreases sharply after 50 years due to the regulations in place.	Expected economic lifetime of the asset. Also, an option for operational lifetime. Given the cap on economic lifetime, the operational lifetime can be longer.
Asset OPEX	Direct measurement of operational costs. Automation of grid equipment could lower operational costs by having less frequent manual operations. Aligns with the strategic goal of an ROCE of ≥ 9% and PWA Asset Management.	OPEX of asset
Automated Remote Event reading	Reliable event reading is a prerequisite for fast restoration of service, therefore aligns with Improved Network Quality and Metering (mostly roll-out new functionality)	Percentage of events successfully read through AMI (<1 min), alternatively number of events failed to read through AMI (<1 min)
Automation and control	Automation and control bring cost reduction and safety increase. Aligns with the strategic target of LTIF and PWAs Asset Management; increased automation and control enables analytics, Network Balance with Steering; accurate information on loads is required for dynamic rating and Metering; LV monitoring relies on automation and control. Does not require a system to be fully autonomous, can also be remotely operated or using other methods to reduce intervention time.	Reduction in human intervention on MV or LV networks. A suggestion would be to calculate the reduction of costs of manual control. Improvements in performance should be covered by different KPIs, such as SAIDI.
Average cost per power connection	Cost per connection is a measurement that might enable comparison between different proposals. Calculating this per connection will give an indication of costs of a large-scale implementation.	Average cost of project per associated power connection

Name	Reason for recommendation	What is measured
Average time for fault restoration	Aligns with Improved network quality. Time to fault detection adds to SAIDI. Possible alignment with the strategic target of +2 NPS.	Average time needed to restore nominal operation. It would be recommended to define sub-KPIs such as time to fault detection and time between fault detection and restoration of service.
Average variable costs per power distribution km	Automation on average needs a one-time capital investment in equipment with lower variable costs after (high CAPEX, low OPEX). By measuring the improvement in the variable costs per km, an estimation can be made for the effect of a possible large-scale implementation. Aligns with PWA Asset Management	Average variable costs per power distribution km in SEK
CAIDI	Customer Average Interruption Duration Index. The average outage duration for any given customer with an interruption.	SAIDI/SAIFI, both as defined by EI.
CEMI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	CEMI, as defined by the EI.
Consumers being metered automatically	AMR adds to the quality of life for customers and cost reduction for VF. Mostly relevant for the German grid since this has already been implemented in Sweden. Serves as a platform on which other functionalities can be built.	Number of consumers being metered automatically
Demand flexibility	An attribute of Smart Grid, aligns with prioritised area Tariffs, Demand Response and Network Balance with Steering. Beneficial for enabling a higher number of renewables.	The amount of load that can be shifted temporally. Needs specification dependent on the method used to provide an incentive (RTP, remote operation of customer assets or other options).
Distributed Generation	A key aspect of Smart Grid, providing higher resilience and reliability to the grid. Aligned with strategic target of Commissioned Renewable Capacity and PWAs Metering and Environment & Energy Efficiency	Amount of power produced by distributed generation in MWh
Energy Not Supplied	The amount of energy that normally would be delivered, but now is not because of an outage. Incentivised by the EI for sub-transmission network operators.	Energy not supplied from fault occurrence until reconnection as defined by EI.

Name	Reason for recommendation	What is measured
Forecasting reliability of demand/generation	This will enable close to optimal use of renewable energy and setting optimising the pricing strategy. Is an enabler for PWAs Network Balance with Steering and Environment & Energy Efficiency, since more accurate forecasting leads to more optimal running of generation facilities.	SD of predicted capacity VS actual capacity. Needs specification of how far in advance. Option to set this time period per project, but needs clear communication of calculation method.
Fulfilment of voltage limits	Aligns with Improved Network Quality. Useful for measuring quality improvement of automation of assets.	Deviation of voltage from ideal voltage.
Generation flexibility	An attribute of Smart Grid, aligns with prioritised area Tariffs & Demand Response. Especially relevant for projects with storage solutions.	The amount of generation that can be shifted temporally.
Outage compensation fee	Depending on the duration of the outage and the type of customer, a compensation fee is paid to the customer. Having to pay fewer fees is a direct financial reward for having a more reliable grid.	Compensation fee in case of outage
Peak Shaving Valley Filling	Incentivised by EI. Also adds to Environment & Energy Efficiency and can be a result of improvements in Tariffs & Demand Response and Network Balance with Steering	Reduction of required peak distribution capacity and/or load factor as defined by EI.
Power Not Supplied	The amount of power that normally would be delivered, but now is not because of an outage. Incentivised by the EI for sub-transmission network operators.	Power not supplied because of a grid failure as defined by EI.
Production Curtailment	Production curtailment can be avoided by increasing distribution capacity, either by building new infrastructure or making more efficient use of existing infrastructure. However, under specific circumstances accepting some curtailment can be the optimal solution. Linked to strategic target of commissioned renewable capacity and PWA Network Balance with Steering and Environment & Energy Efficiency	Production curtailed in MWh
Reduction of Accidents and Risk	Direct link to strategic target Safety. Several Smart Grid aspects (remote reading, automation etc.) lower human interaction or travel, thereby increasing safety.	LTIF

Name	Reason for recommendation	What is measured
SAIDI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIDI, as defined by the EI.
SAIFI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIFI, as defined by the EI.
Use of equipment standards	Lower costs and more choice in the future by using standards. Facilitates interoperability of different assets and avoids vendor lock-in. Can increase lifetime (longer support), speed up engineering process and lead to quicker setting up of requirements. Lowers the chance of miscommunicating. Improves data quality and traceability.	Percentage of equipment that uses standards for communication or other interfaces.
Use of protocol standards	Lower costs and more choice in the future by using standards. Facilitates interoperability of different assets and avoids vendor lock-in. Can increase lifetime (longer support), speed up engineering process and lead to quicker setting up of requirements. Lowers the chance of miscommunicating. Improves data quality and traceability.	Percentage of equipment that uses standard protocols. Leads to cheaper and more flexible systems.

12.2. Process level KPIs

The process KPIs are selected for measuring the performance of continuous processes in distribution. All Smart Grid related aspects of distribution processes should be measurable by one of these KPIs.

Metering KPIs

The KPIs presented in this section are relevant for processes that have to do with metering.

Name	Reason for recommendation	What is measured
Asset OPEX	Direct measurement of operational costs. Automation of grid equipment could lower operational costs by having less frequent manual operations. Aligns with the strategic goal of an ROCE of ≥ 9% and PWA Asset Management.	OPEX of asset

Name	Reason for recommendation	What is measured
Average cost per power connection	Cost per connection is a measurement that might enable comparison between different proposals. Calculating this per connection will give an indication of costs of a large-scale implementation.	Average cost of project per associated power connection
Average time for fault restoration	Aligns with Improved network quality. Time to fault detection adds to SAIDI. Possible alignment with a strategic target of +2 NPS. A major advantage of Smart Grids.	Average time needed to restore nominal operation. It would be recommended to define sub-KPIs such as time to fault detection and time between fault detection and restoration of service.
Average variable costs per power distribution km	Automation on average needs a one-time capital investment in equipment with lower variable costs after (high CAPEX, low OPEX). By measuring the improvement in the variable costs per km, an estimation can be made for the effect of a possible large-scale implementation. Aligns with PWA Asset Management	Average variable costs per power distribution km in SEK
CEMI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	CEMI, as defined by the EI.
Demand flexibility	The amount of load that can be shifted temporally. Needs specification dependent on the method used to provide an incentive (RTP, remote operation of customer assets or other options).	The amount of load that can be shifted temporally.
Distributed Generation	A key aspect of Smart Grid, providing higher resilience and reliability to the grid. Aligned with strategic target of Commissioned Renewable Capacity and PWAs Metering and Environment & Energy Efficiency	Amount of power produced by distributed generation in MWh
Energy losses	Directly linked to strategic target Absolute CO2 emissions and with Prioritised Work Area (PWA) Environment & Energy Efficiency.	Energy lost in transmission, distribution and storage. If the project is focused on a specific part, a sub KPI should be defined. This will lower calculation costs and makes sure to focus on the result of the project.
Energy Not Supplied	The amount of energy that normally would be delivered, but now is not because of an outage. Incentivised by the EI for sub-transmission network operators.	Energy not supplied from fault occurrence until reconnection as defined by EI.

Name	Reason for recommendation	What is measured
Forecasting reliability of demand/generation	This will enable close to the optimal use of renewable energy and setting optimising the pricing strategy. Is an enabler for PWAs Network Balance with Steering and Environment & Energy Efficiency, since more accurate forecasting leads to the more optimal running of generation facilities.	SD of predicted capacity VS actual capacity. Needs specification of how far in advance. Option to set this time period per project, but needs clear communication of calculation method.
Fulfilment of voltage limits	Aligns with Improved Network Quality. Useful for measuring quality improvement of automation of assets.	Deviation of voltage from ideal voltage.
Generation flexibility	An attribute of Smart Grid, aligns with prioritised area Tariffs & Demand Response. Especially relevant for projects with storage solutions.	The amount of generation that can be shifted temporally.
Load Factor	Incentivised by EI. Improvements in load factor lead to lower losses, which makes it relevant for PWAs Environment & Energy Efficiency and Tariffs & Demand response. However, in some cases it would be more ideal to accept a lower Load Factor, for instance to have a higher utilisation of non-controllable energy sources.	Load Factor, as defined by the EI.
Meter Measuring Costs	Reductions in meter measuring costs will help to reach an ROCE of ≥ 9%. Especially relevant for German grid.	Average metering measurement costs per year.
Outage compensation fee	Depending on the duration of the outage and the type of customer, a compensation fee is paid to the customer. Having to pay fewer fees is a direct financial reward for having a more reliable grid.	Compensation fee in case of outage
Peak Shaving Valley Filling	Incentivised by EI. Also adds to Environment & Energy Efficiency and can be a result of improvements in Tariffs & Demand Response and Network Balance with Steering	Reduction of required peak distribution capacity and/or load factor as defined by EI.
Power Not Supplied	The amount of power that normally would be delivered, but now is not because of an outage. Incentivised by the EI for sub-transmission network operators.	Power not supplied because of a grid failure as defined by EI.
Price Volatility	The volatility of the final price for consumers. Aligns with PWAs Network Balance with Steering and Tariffs & Demand Response.	Volatility of price per type of price (use sub-KPIs)

Name	Reason for recommendation	What is measured
Reduction of Accidents and Risk	Direct link to strategic target Safety. Several Smart Grid aspects (remote reading, automation etc.) lower human interaction or travel, thereby increasing safety.	LTIF
SAIDI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIDI, as defined by the EI.
SAIFI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIFI, as defined by the EI.
Success index in advanced functionalities	Aligns with PWA metering. Needs specification on what the advanced functionalities are to measure a goal instead of a method.	Needs definition of advanced functionalities.
Success index in event reading	Reliable event reading is a prerequisite for fast restoration of service, therefore aligns with Improved Network Quality and Metering (mostly roll-out new functionality)	Percentage of events successfully read through AMI (<1 min), alternatively number of events failed to read through AMI (<1 min)
Success index in meter reading	Less hassle with the measuring of customer meters might add to the strategic target customer loyalty. Also aligns with PWA Metering and Improved Network Quality.	Percentage of meters successfully read through AMI, alternatively the number of meters which failed to read through AMI. Another option would be percentage of quickly detected (<1 min) outages, depending on project goal.

Asset Management KPIs

The KPIs presented in this section are relevant for processes that have to do with asset management.

Name	Reason for recommendation	What is measured
Asset OPEX	Direct measurement of operational costs. Automation of grid equipment could lower operational costs by having less frequent manual operations. Aligns with the strategic goal of an ROCE of ≥ 9% and PWA Asset Management.	OPEX of asset
Average cost per power connection	Cost per connection is a measurement that might enable comparison between different proposals. Calculating this per connection will give an indication of costs of a large-scale implementation.	Average cost of project per associated power connection
Average time for fault restoration	Aligns with Improved network quality. Time to fault detection adds to SAIDI. Possible alignment with strategic target of +2 NPS. Major advantage of Smart Grids.	Average time needed to restore nominal operation. It would be recommended to define sub-KPIs such as time to fault detection and time between fault detection and restoration of service.
Average variable costs per power distribution km	Automation on average needs a one-time capital investment in equipment with lower variable costs after (high CAPEX, low OPEX). By measuring the improvement in the variable costs per km, an estimation can be made for the effect of a possible large-scale implementation. Aligns with PWA Asset Management	Average variable costs per power distribution km in SEK
CEMI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	CEMI, as defined by the EI.
Energy losses	Directly linked to strategic target Absolute CO_2 emissions and with Prioritised Work Area (PWA) Environment & Energy Efficiency.	Energy lost in transmission, distribution and storage. If the project is focused on a specific part, a sub KPI should be defined. This will lower calculation costs and makes sure to focus on the result of the project.

Name	Reason for recommendation	What is measured
Forecasting reliability of demand/generation	This will enable closer to optimal use of renewable energy and setting optimising the pricing strategy. Is an enabler for PWAs Network Balance with Steering and Environment & Energy Efficiency, since more accurate forecasting leads to the more optimal running of generation facilities.	SD of predicted capacity VS actual capacity. Needs specification of how far in advance. Option to set this time period per project, but needs clear communication of calculation method.
Fulfilment of voltage limits	Aligns with Improved Network Quality. Useful for measuring quality improvement of automation of assets.	Deviation of voltage from ideal voltage.
Hosting Capacity of Electric Vehicles	Aligns with Environment & Energy Efficiency. Might also lead to increased revenue due to connections with upgraded load limit.	kWh used for charging EVs per time period. The reason for not measuring in kW is that unused charging stations would lead to an unwanted increase to the measure.
Meter Measuring Costs	Reductions in meter measuring costs will help to reach an ROCE of ≥ 9%. Especially relevant for German grid.	Average metering measurement costs per year.
Peak Shaving Valley Filling	Incentivised by EI. Also adds to Environment & Energy Efficiency and can be a result of improvements in Tariffs & Demand Response and Network Balance with Steering	Reduction of required peak distribution capacity and/or load factor as defined by EI.
Power Not Supplied	The amount of power that normally would be delivered, but now is not because of an outage. Incentivised by the EI for sub-transmission network operators.	Power not supplied because of a grid failure as defined by EI.
Production Curtailment	Production curtailment can be avoided by increasing distribution capacity, either by building new infrastructure or making more efficient use of existing infrastructure. However, under specific circumstances accepting some curtailment can be the optimal solution. Linked to strategic target of commissioned renewable capacity and PWA Network Balance with Steering and Environment & Energy Efficiency	Production curtailed in MWh
Reduction in greenhouse gas emissions	A strategic target as well as a PWA. Could be relevant for projects involving EVs.	Emission of CO_2, NO_x and other greenhouse gasses.

Name	Reason for recommendation	What is measured
Reduction of Accidents and Risk	Direct link to strategic target Safety. Several Smart Grid aspects (remote reading, automation etc.) lower human interaction or travel, thereby increasing safety.	LTIF
SAIDI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIDI, as defined by the EI.
SAIFI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIFI, as defined by the EI.

Quality of Supply & Distributed Generation

The KPIs presented in this section are relevant for processes that have to do with the quality of supply and distributed generation.

Name	Reason for recommendation	What is measured
Asset OPEX	Direct measurement of operational costs. Automation of grid equipment could lower operational costs by having less frequent manual operations. Aligns with the strategic goal of an ROCE of ≥ 9% and PWA Asset Management.	OPEX of asset
Average time for fault restoration	Aligns with Improved network quality. Time to fault detection adds to SAIDI. Possible alignment with a strategic target of +2 NPS. A major advantage of Smart Grids.	Average time needed to restore nominal operation. It would be recommended to define sub-KPIs such as time to fault detection and time between fault detection and restoration of service.
Average variable costs per power distribution km	Automation on average needs a one-time capital investment in equipment with lower variable costs after (high CAPEX, low OPEX). By measuring the improvement in the variable costs per km, an estimation can be made for the effect of a possible large-scale implementation. Aligns with PWA Asset Management	Average variable costs per power distribution km in SEK
CEMI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	CEMI, as defined by the EI.

Name	Reason for recommendation	What is measured
Demand flexibility	The amount of load that can be shifted temporally. Needs specification dependent on the method used to provide an incentive (RTP, remote operation of customer assets or other options).	The amount of load that can be shifted temporally.
Distributed Generation	A key aspect of Smart Grid, providing higher resilience and reliability to the grid. Aligned with strategic target of Commissioned Renewable Capacity and PWAs Metering and Environment & Energy Efficiency	Amount of power produced by distributed generation in MWh
Energy losses	Directly linked to strategic target Absolute CO2 emissions and with Prioritised Work Area (PWA) Environment & Energy Efficiency.	Energy lost in transmission, distribution and storage. If the project is focused on a specific part, a sub KPI should be defined. This will lower calculation costs and makes sure to focus on the result of the project.
Energy Not Supplied	The amount of energy that normally would be delivered, but now is not because of an outage. Incentivised by the EI for sub-transmission network operators.	Energy not supplied from fault occurrence until reconnection as defined by EI.
Forecasting reliability of demand/generation	This will enable closer to optimal use of renewable energy and setting optimising the pricing strategy. Is an enabler for PWAs Network Balance with Steering and Environment & Energy Efficiency, since more accurate forecasting leads to the more optimal running of generation facilities.	SD of predicted capacity VS actual capacity. Needs specification of how far in advance. Option to set this time period per project, but needs clear communication of calculation method.
Fulfilment of voltage limits	Aligns with Improved Network Quality. Useful for measuring quality improvement of automation of assets.	Deviation of voltage from ideal voltage.
Generation flexibility	Attribute of Smart Grid, aligns with prioritised area Tariffs & Demand Response. Especially relevant for projects with storage solutions.	The amount of generation that can be shifted temporally.
Load Factor	Incentivised by EI. Improvements in load factor lead to lower losses, which makes it relevant for PWAs Environment & Energy Efficiency and Tariffs & Demand response. However, in some cases it would be more ideal to accept a lower Load Factor, for instance to have a higher utilisation of non-controllable energy sources.	Load Factor, as defined by the EI.

Name	Reason for recommendation	What is measured
Outage compensation fee	Depending on the duration of the outage and the type of customer, a compensation fee is paid to the customer. Having to pay fewer fees is a direct financial reward for having a more reliable grid.	Compensation fee in case of outage
Peak Shaving Valley Filling	Incentivised by EI. Also adds to Environment & Energy Efficiency and can be a result of improvements in Tariffs & Demand Response and Network Balance with Steering	Reduction of required peak distribution capacity and/or load factor as defined by EI.
Price Volatility	The volatility of the final price for consumers. Aligns with PWAs Network Balance with Steering and Tariffs & Demand Response.	Volatility of price per type of price (use sub-KPIs)
Production Curtailment	Production curtailment can be avoided by increasing distribution capacity, either by building new infrastructure or making more efficient use of existing infrastructure. However, under specific circumstances accepting some curtailment can be the optimal solution. Linked to strategic target of commissioned renewable capacity and PWA Network Balance with Steering and Environment & Energy Efficiency	Production curtailed in MWh
Reduction in greenhouse gas emissions	A strategic target as well as a PWA. Could be relevant for projects involving EVs.	Emission of CO_2, NO_x and other greenhouse gasses.
Reduction of Accidents and Risk	Direct link to strategic target Safety. Several Smart Grid aspects (remote reading, automation etc.) lower human interaction or travel, thereby increasing safety.	LTIF
SAIDI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIDI, as defined by the EI.
SAIFI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIFI, as defined by the EI.

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Sustainable Communities

The KPIs presented in this section are relevant for processes that have to do with sustainable communities.

Name	Reason for recommendation	What is measured
Asset OPEX	Direct measurement of operational costs. Automation of grid equipment could lower operational costs by having less frequent manual operations. Aligns with the strategic goal of an ROCE of ≥ 9% and PWA Asset Management.	OPEX of asset
Average cost per power connection	Cost per connection is a measurement that might enable comparison between different proposals. Calculating this per connection will give an indication of costs of a large-scale implementation.	Average cost of project per associated power connection
Average time for fault restoration	Aligns with Improved network quality. Time to fault detection adds to SAIDI. Possible alignment with the strategic target of +2 NPS. A major advantage of Smart Grids.	Average time needed to re-store nominal operation. It would be recommended to define sub-KPIs such as time to fault detection and time between fault detection and restoration of service.
Average variable costs per power distribution km	Automation on average needs a one-time capital investment in equipment with lower variable costs after (high CAPEX, low OPEX). By measuring the improvement in the variable costs per km, an estimation can be made for the effect of a possible large-scale imple-mentation. Aligns with PWA Asset Management	Average variable costs per power distribution km in SEK
CEMI	Directly linked to incentive scheme by EI. Relevant for strategic target Cus-tomer engagement and for PWA Im-proved Network Quality	CEMI, as defined by the EI.
Demand flexibility	The amount of load that can be shifted temporally. Needs specification de-pendent on the method used to provide an incentive (RTP, remote operation of customer assets or other options).	The amount of load that can be shifted temporally.
Distributed Genera-tion	A key aspect of a Smart Grid, providing higher resilience and reliability to the grid. Aligned with strategic target of Commissioned Renewable Capacity and PWAs Metering and Environment & Energy Efficiency	Amount of power produced by distributed generation in MWh

Name	Reason for recommendation	What is measured
Energy losses	Directly linked to strategic target Absolute CO2 emissions and with Prioritised Work Area (PWA) Environment & Energy Efficiency.	Energy lost in transmission, distribution and storage. If the project is focused on a specific part, a sub KPI should be defined. This will lower calculation costs and makes sure to focus on the result of the project.
Energy Not Supplied	The amount of energy that normally would be delivered, but now is not because of an outage. Incentivised by the EI for sub-transmission network operators.	Energy not supplied from fault occurrence until reconnection as defined by EI.
Forecasting reliability of demand/generation	This will enable closer to optimal use of renewable energy and setting optimising the pricing strategy. Is an enabler for PWAs Network Balance with Steering and Environment & Energy Efficiency, since more accurate forecasting leads to a more optimal operation of generation facilities.	SD of predicted capacity VS actual capacity. Needs specification of how far in advance. Option to set this time period per project, but needs clear communication of calculation method.
Generation flexibility	An attribute of Smart Grid, aligns with prioritised area Tariffs & Demand Response. Especially relevant for projects with storage solutions.	The amount of generation that can be shifted temporally.
Hosting Capacity of Electric Vehicles	Aligns with Environment & Energy Efficiency. Might also lead to increased revenue due to connections with upgraded load limit.	kWh used for charging EVs per time period. The reason for not measuring in kW is that unused charging stations would lead to an unwanted increase in the measure.
Load Factor	Incentivised by EI. Improvements in load factor lead to lower losses, which makes it relevant for PWAs Environment & Energy Efficiency and Tariffs & Demand response. However, in some cases it would be more ideal to accept a lower Load Factor, for instance to have a higher utilisation of non-controllable energy sources.	Load Factor, as defined by the EI.
Outage compensation fee	Depending on the duration of the outage and the type of customer, a compensation fee is paid to the customer. Having to pay fewer fees is a direct financial reward for having a more reliable grid.	Compensation fee in case of outage

Name	Reason for recommendation	What is measured
Peak Shaving Valley Filling	Incentivised by EI. Also adds to Environment & Energy Efficiency and can be a result of improvements in Tariffs & Demand Response and Network Balance with Steering	Reduction of required peak distribution capacity and/or load factor as defined by EI.
Price Volatility	The volatility of the final price for consumers. Aligns with PWAs Network Balance with Steering and Tariffs & Demand Response.	Volatility of price per type of price (use sub-KPIs)
Production Curtailment	Production curtailment can be avoided by increasing distribution capacity, either by building new infrastructure or making more efficient use of existing infrastructure. However, under specific circumstances accepting some curtailment can be the optimal solution. Linked to strategic target of commissioned renewable capacity and PWA Network Balance with Steering and Environment & Energy Efficiency	Production curtailed in MWh
Reduction in greenhouse gas emissions	A strategic target as well as a PWA. Could be relevant for projects involving EVs.	Emission of CO_2, NO_x and other greenhouse gasses.
Reduction of Accidents and Risk	Direct link to strategic target Safety. Several Smart Grid aspects (remote reading, automation etc.) lower human interaction or travel, thereby increasing safety.	LTIF
SAIDI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIDI, as defined by the EI.
SAIFI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIFI, as defined by the EI.

Flexibility and Network Balance

The KPIs presented in this section are relevant for processes that have to do with flexibility and network balance.

Name	Reason for recommendation	What is measured
Demand flexibility	The amount of load that can be shifted temporally. Needs specification dependent on the method used to provide an incentive (RTP, remote operation of customer assets or other options).	The amount of load that can be shifted temporally.

Distributed Generation	A key aspect of Smart Grid, providing higher resilience and reliability to the grid. Aligned with strategic target of Commissioned Renewable Capacity and PWAs Metering and Environment & Energy Efficiency	Amount of power produced by distributed generation in MWh
Energy losses	Directly linked to strategic target Absolute CO2 emissions and with Prioritised Work Area (PWA) Environment & Energy Efficiency.	Energy lost in transmission, distribution and storage. If the project is focused on a specific part, a sub KPI should be defined. This will lower calculation costs and makes sure to focus on the result of the project.
Forecasting reliability of demand/generation	This will enable closer to optimal use of renewable energy and setting optimising the pricing strategy. Is an enabler for PWAs Network Balance with Steering and Environment & Energy Efficiency, since more accurate forecasting leads to more optimal running of generation facilities.	SD of predicted capacity VS actual capacity. Needs specification of how far in advance. Option to set this time period per project, but needs clear communication of calculation method.
Generation flexibility	Attribute of Smart Grid, aligns with prioritised area Tariffs & Demand Response. Especially relevant for projects with storage solutions.	The amount of generation that can be shifted temporally.
Hosting Capacity of Electric Vehicles	Aligns with Environment & Energy Efficiency. Might also lead to increased revenue due to connections with upgraded load limit.	kWh used for charging EVs per time period. The reason for not measuring in kW is that unused charging stations would lead to an unwanted increase in the measure.
Load Factor	Incentivised by EI. Improvements in load factor lead to lower losses, which makes it relevant for PWAs Environment & Energy Efficiency and Tariffs & Demand response. However, in some cases it would be more ideal to accept a lower Load Factor, for instance to have a higher utilisation of non-controllable energy sources.	Load Factor, as defined by the EI.
Peak Shaving Valley Filling	Incentivised by EI. Also adds to Environment & Energy Efficiency and can be a result of improvements in Tariffs & Demand Response and Network Balance with Steering	Reduction of required peak distribution capacity and/or load factor as defined by EI.
Price Volatility	The volatility of the final price for consumers. Aligns with PWAs Network Balance with Steering and Tariffs & Demand Response.	Volatility of price per type of price (use sub-KPIs)
Production Curtailment	Production curtailment can be avoided by increasing distribution capacity, either by building new infrastructure or	Production curtailed in MWh

	making more efficient use of existing infrastructure. However, under specific circumstances accepting some curtailment can be the optimal solution. Linked to strategic target of commissioned renewable capacity and PWA Network Balance with Steering and Environment & Energy Efficiency	

Digitalisation

The KPIs presented in this section are relevant for processes that have to do with digitalisation.

Asset OPEX	**Direct measurement of operational costs. Automation of grid equipment could lower operational costs by having less frequent manual operations. Aligns with the strategic goal of an ROCE of ≥ 9% and PWA Asset Management.**	**OPEX of asset**
Average cost per power connection	Cost per connection is a measurement that might enable comparison between different proposals. Calculating this per connection will give an indication of costs of a large-scale implementation.	Average cost of project per associated power connection
Average time for fault restoration	Aligns with Improved network quality. Time to fault detection adds to SAIDI. Possible alignment with the strategic target of +2 NPS. A major advantage of Smart Grids.	Average time needed to restore nominal operation. It would be recommended to define sub-KPIs such as time to fault detection and time between fault detection and restoration of service.
CEMI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	CEMI, as defined by the EI.
Demand flexibility	The amount of load that can be shifted temporally. Needs specification dependent on the method used to provide an incentive (RTP, remote operation of customer assets or other options).	The amount of load that can be shifted temporally.
Distributed Generation	A key aspect of Smart Grid, providing higher resilience and reliability to the grid. Aligned with strategic target of Commissioned Renewable Capacity and PWAs Metering and Environment & Energy Efficiency	Amount of power produced by distributed generation in MWh

Energy losses	Directly linked to strategic target Absolute CO2 emissions and with Prioritised Work Area (PWA) Environment & Energy Efficiency.	Energy lost in transmission, distribution and storage. If the project is focused on a specific part, a sub KPI should be defined. This will lower calculation costs and makes sure to focus on the result of the project.
Energy Not Supplied	The amount of energy that normally would be delivered, but now is not because of an outage. Incentivised by the EI for sub-transmission network operators.	Energy not supplied from fault occurrence until reconnection as defined by EI.
Forecasting reliability of demand/generation	This will enable close to optimal use of renewable energy and setting optimising the pricing strategy. Is an enabler for PWAs Network Balance with Steering and Environment & Energy Efficiency, since more accurate forecasting leads to a more optimal operation of generation facilities.	SD of predicted capacity VS actual capacity. Needs specification of how far in advance. Option to set this time period per project, but needs clear communication of calculation method.
Fulfilment of voltage limits	Aligns with Improved Network Quality. Useful for measuring quality improvement of automation of assets.	Deviation of voltage from ideal voltage.
Generation flexibility	An attribute of Smart Grid, aligns with prioritised area Tariffs & Demand Response. Especially relevant for projects with storage solutions.	The amount of generation that can be shifted temporally.
Load Factor	Incentivised by EI. Improvements in load factor lead to lower losses, which makes it relevant for PWAs Environment & Energy Efficiency and Tariffs & Demand response. However, in some cases it would be more ideal to accept a lower Load Factor, for instance to have a higher utilisation of non-controllable energy sources.	Load Factor, as defined by the EI.
Meter Measuring Costs	Reductions in meter measuring costs will help to reach an ROCE of ≥ 9%. Especially relevant for German grid.	Average metering measurement costs per year.
Reduction of Accidents and Risk	Direct link to strategic target Safety. Several Smart Grid aspects (remote reading, automation etc.) lower human interaction or travel, thereby increasing safety.	LTIF
Success index in advanced functionalities	Aligns with PWA metering. Needs specification on what the advanced functionalities are to measure a goal instead of a method.	Needs definition of advanced functionalities.

Success index in event reading	Reliable event reading is a prerequisite for fast restoration of service, therefore aligns with Improved Network Quality and Metering (mostly roll-out new functionality)	Percentage of events successfully read through AMI (<1 min), alternatively number of events failed to read through AMI (<1 min)
Success index in meter reading	Less hassle with the measuring of customer meters might add to the strategic target customer loyalty. Also aligns with PWA Metering and Improved Network Quality.	Percentage of meters successfully read through AMI, alternatively the number of meters which failed to read through AMI. Another option would be percentage of quickly detected (<1 min) outages, depending on project goal.

12.3. Company level KPIs

These KPIs have been selected to be used at a higher level than project or process. They align with the strategic goals of Vattenfall BU Distribution and with the Prioritised Work Areas (PWAs). With these KPIs, an analysis could be done on a level higher than a project or a process. An example could be the targets in the Smart Grid Roadmap.

Name	Reason for recommendation	What is measured
Asset CAPEX	Direct measurement of capital expenditure. Keeping track of the initial investment for Smart Grid projects helps with project management but also makes it comparable with BaU solutions. Aligns with the strategic goal of an ROCE of ≥ 9% and PWA Asset Management.	CAPEX of asset
Asset OPEX	Direct measurement of operational costs. Automation of grid equipment could lower operational costs by having less frequent manual operations. Aligns with the strategic goal of an ROCE of ≥ 9% and PWA Asset Management.	OPEX of asset
CEMI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	CEMI, as defined by the EI.
Hosting capacity RES	Aligned with the strategic target of Renewable Energy and PWAs Network Balance with Steering and Environment & Energy Efficiency.	Hosting Capacity of Renewable Energy Sources in MW

Name	Reason for recommendation	What is measured
Increased Distribution Capacity	With the electrification of society an increased distribution capacity is required to keep a stable and reliable grid. Somewhat related to the strategic target of Commissioned Renewable Capacity and PWAs Network Balance with Steering and Asset Management. One of the ways to achieve this is by using dynamic ratings.	The amount of capacity added.
Load Factor	Incentivised by EI. Improvements in load factor lead to lower losses, which makes it relevant for PWAs Environment & Energy Efficiency and Tariffs & Demand response. However, in some cases it would be more ideal to accept a lower Load Factor, for instance to have a higher utilisation of non-controllable energy sources.	Load Factor, as defined by the EI.
Outage compensation fee	Depending on the duration of the outage and the type of customer, a compensation fee is paid to the customer. Having to pay fewer fees is a direct financial reward for having a more reliable grid.	Compensation fee in case of an outage, as defined by EI.
Peak Shaving Valley Filling	Incentivised by EI. Also adds to Environment & Energy Efficiency and can be a result of improvements in Tariffs & Demand Response and Network Balance with Steering. New functionality added through the Metering PWA can play a large role to improve this KPI.	Reduction of required peak distribution capacity and/or load factor as defined by EI.
Production Curtailment	Production curtailment can be avoided by increasing distribution capacity, either by building new infrastructure or making more efficient use of existing infrastructure. However, under specific circumstances accepting some curtailment can be the optimal solution. Linked to strategic target of commissioned renewable capacity and PWA Network Balance with Steering and Environment & Energy Efficiency	Production curtailed in MWh
Reduction in greenhouse gas emissions	A strategic target as well as a PWA. Could be relevant for projects involving EVs.	Emission of CO2, NOx and other greenhouse gasses.

Name	Reason for recommendation	What is measured
Reduction of Accidents and Risk	Direct link to strategic target Safety. Several Smart Grid aspects (remote reading, automation etc.) lower human interaction or travel, thereby increasing safety.	LTIF
SAIDI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIDI, as defined by the EI.
SAIFI	Directly linked to incentive scheme by EI. Relevant for strategic target Customer engagement and for PWA Improved Network Quality	SAIFI, as defined by the EI.

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