DRIVING FORCES FOR INTELLIGENT DISTRIBUTION SYSTEM INNOVATION – RESULTS FROM A FORESIGHT PROCESS

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ABSTRACT

The future electricity grid will be a complex system-of-systems, incorporating various intelligent devices for monitoring, control and automation. The interaction between various technological, regulatory and social factors add complexity which need to be addressed in a holistic and coordinated way to support the system innovation. To better understand the complexity, the driving forces for system innovation have been identified and structured, for the Norwegian distribution grid. Based on the driving forces, a repository of 109 mini scenarios has been developed. This paper describes the foresight process, the structure of the driving forces and shows examples of mini scenarios and their impact on the future development of the distribution grid. Further it gives some insight into how the DSOs can prepare for the uncertain future by utilising the knowledge gained from this work.

INTRODUCTION

According to the ETIP SNET Vision 2050, the energy system is fully integrated in 2050, with the electricity system as the backbone, the customer is fully engaged, and digitalisation is all around [1]. Many countries have developed Smart Grid roadmaps (e.g. [2] [3] [4]) which point out the objectives and directions for the Smart Grid development – plans that are also useful for the power industry, the manufacturers and the ICT industry, so that they can align their own development plans with such a roadmap. The future electricity grid will be a complex system-of-systems, incorporating various intelligent devices for monitoring, control and automation. The interaction between various technological, economic, organisational and human factors add complexity which need to be addressed in a holistic and coordinated way to support the system innovation. Major new benefits for the future electricity distribution system arise from the interaction between a range of new technologies as well as interaction with grid customers. System innovation, here defined as a co-evolution of system-level technical, social and regulatory changes, is necessary to realize the prospective benefits from these new opportunities. Innovation journeys are often highly unpredictable and uncontrollable [5] , which is also the case for radical innovations like the Smart Grid. In the Norwegian centre for environment-friendly energy research, Centre for Intelligent Electricity Distribution (CINELDI), the main objective is to provide knowledge and guidelines enabling a cost-efficient realization of the future flexible, intelligent, cyber secure and robust electricity distribution grid. To better understand the complexity of the future Norwegian distribution grid anno 2040, the driving forces for distribution system innovation have been identified and structured. This knowledge will help stakeholders (DSOs, TSOs, grid customers, manufacturers, etc.) to develop robust strategies contributing to the system innovation given different credible futures. Coordinated strategies will contribute to more joint efforts and investments.

THE FORESIGHT PROCESS

A foresight process has been used as methodology in this work. Foresight can be defined as "*...a systematic, participatory, future intelligence-gathering and medium-to-long-term vision-building process aimed at enabling present-day decisions and mobilizing joint actions*"[6] . The foresight process has involved the most prominent technology providers in Norway together with the most innovative grid operators (DSOs/TSO), research institutes, university, authorities and market operators. The participants represent a multidisciplinary background consisting of the main technology domains power engineering, cybernetics, information and communication technology. Experts from the social science domain has also participated as customer behaviour is regarded as an important element in the distribution system transition.

Reference [7] describes a generic foresight process framework. Figure 1 shows the steps of the process. In the **input** step, information about the topic to be studied is gathered. The **analysis** step of the foresight process can be considered a preliminary stage to more in-depth evaluation work. In this step, workshops were held with all stakeholders and driving forces for system innovation were identified. In the **interpretation** step, deeper insights are sought. The driving forces have been structured, and relations are analysed. This has been supplemented by literature review. In the **prospection** step, the actual creation of forward views and alternative futures are carried out. Stakeholder workshops have been arranged, and mini scenarios are developed based on the identified driving forces. The mini scenarios will form the basis for establishing the alternative futures for the distribution grid of 2040. The **outputs** from the foresight process are new insights generated in the interpretation step and forward views created in the prospection step. Based on this, an analysis of the scenarios will be carried out and challenges for the grid and recommendations are identified. In the **strategy** step, output from the foresight process will be handled over for consideration by decision-makers in directing strategic actions for implementation. In CINELDI, this represents developing a roadmap and transition strategy for Smart Grid development in Norway.

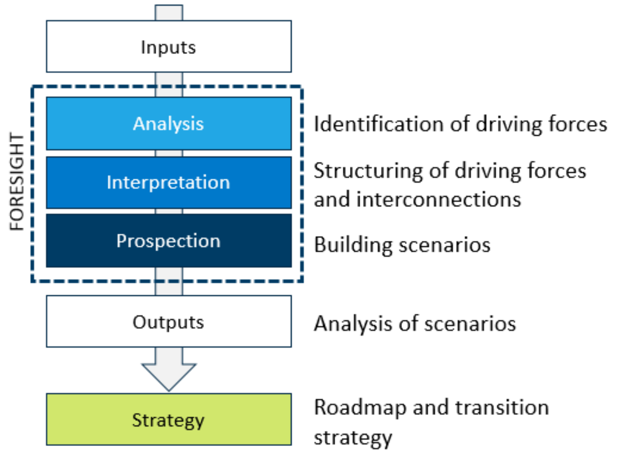

Figure 1 A generic foresight process framework (based on [7]) and implementation of the steps in this work.

DRIVING FORCES

The term driving force used in this work include:

- Drivers, barriers and enablers for the electricity distribution system innovation
- Factors and stakeholders and their motives and interests.

The structure of the driving forces described in the following has been discussed in several steps, including all stakeholders.

Structure of driving forces

The driving forces were sorted into three levels:
Megatrends: Overall, global trends.
External driving forces: Driving forces outside the grid companies' area of operation.
Grid related driving forces: Driving forces which are part of the grid management and driving forces which the grid companies and grid customers can influence.

The external and grid related driving forces were sorted in groups representing different topics. Figure 2 shows the proposed structure of the driving forces. The blue boxes in the figure represents groups of driving forces. The **megatrends** considered relevant for the development of the distribution grid are: *Climate change, Digitalisation, Globalisation* and *Urbanisation and Population growth.* These trends together influence on all the groups of external driving forces shown in the figure below. The following groups of driving forces are considered **external**: *Politics, Regulation and standardisation, Societal trends and values, Technology development, External threats* and *Business models and stakeholders.* The **grid related driving forces** are described on a more detailed level than the external driving forces. The uppermost dashed rectangle contains topics related to grid customers: *Generation* and *Loads.* The dashed rectangle in the middle contains topics related to management of the grid: *Flexibility, Microgrids, Grid development* and *Grid operation*. The lower dashed rectangle contains topics related to grid performance: *Security of supply, Economy, Safety* and *Cyber security.*

Example of interconnected driving forces

The driving force *prosumer* and its connection with other driving forces will be discussed in the following, to illustrate the connection between the driving forces. A prosumer is an end user that both uses and produces energy, for example from PV generation on the roof top, and is thus a source of distributed generation. This sorts under the driving force group *Generation*. The underlying megatrend is *Climate change*. Climate change influences on the *Politics* and *Regulation and standardisation*, to promote more production from renewable sources. Climate change also influences on the *Societal trends and values* as environmental awareness is more widespread, and people want to contribute. Another driving force caused by climate change is *Technology development*, in this example through development of PV panels, where the manufacturing costs have been dramatically reduced. This opens for new *Business models and stakeholders*, e.g. for investing in PV panels for private households. All these driving forces affect the increased amount of distributed generation in the grid.

Increased distributed generation opens possibilities for utilisation of *Flexibility* and *Microgrids*. It also calls for new planning methods for *Grid development* and new aspects to be included in *Grid operation*. The distributed generation influences on *Security of supply*, e.g. in terms of possibilities for islanding during faults and interruptions, and regarding voltage quality issues related to e.g. voltage increase. Increased distributed generation also influences *Economy*, as this will decrease the need for electricity from the grid, and *Safety* challenges regarding controlling all small-scale generation during faults and interruptions. All these internal driving forces and challenges again influence the *Technology development* and the need for changes in *Regulation and standardisation*, as well as *External threats* through possible new channels for hackers to get into the control system. The example illustrates how the driving forces are interconnected, and that there is a variety of factors within different fields influencing on each other. This emphasizes

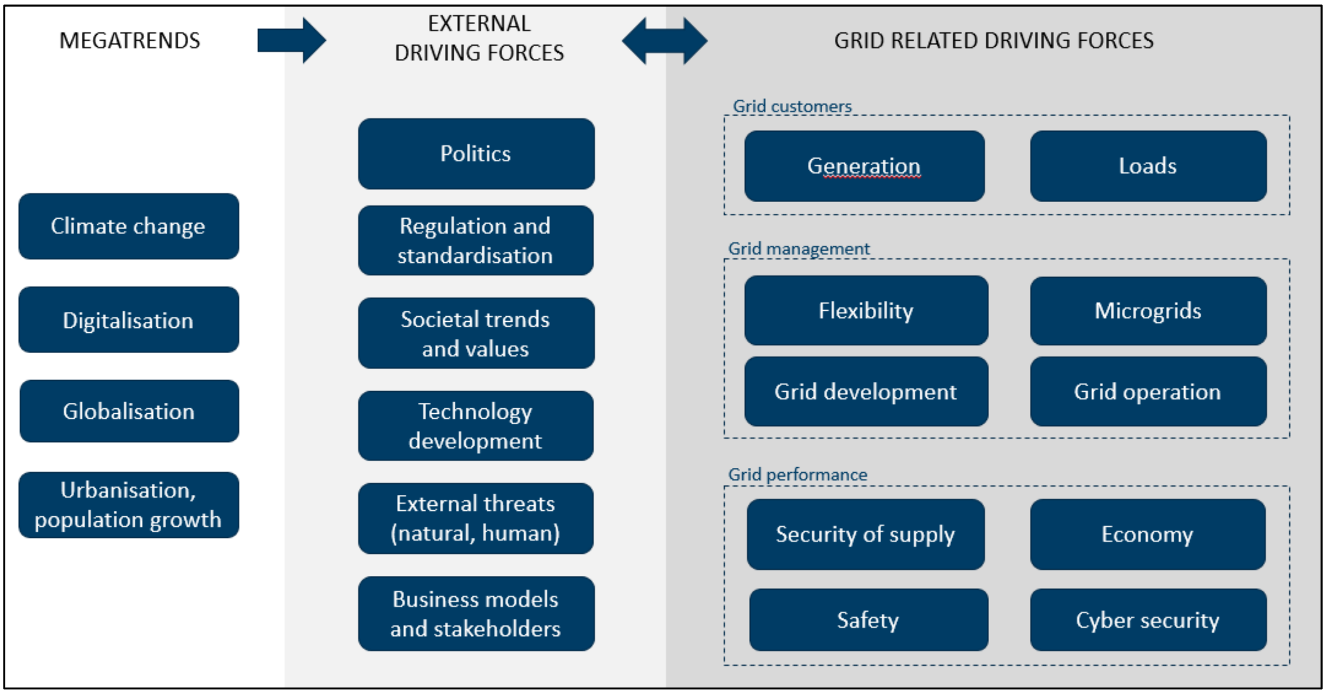

Figure 2 Overview of the groups of driving forces

the need for system innovation in the distribution grid (in addition to innovation in products, methods, services etc.) for the grid operations to improve and to handle the upcoming challenges in a robust way.

Importance and uncertainty

To proceed to the prospection step (developing scenarios) in the foresight methodology, the driving forces were evaluated in terms of importance and uncertainty. The categories were identified as follows:

Importance: How important is the driving force for the system innovation in the distribution grid and the development towards 2030/2040?

Uncertainty: How uncertain is the development / direction of the driving force?

High importance / low uncertainty driving forces represent factors for which current planning must be prepared. High importance / high uncertainty driving forces are the potential shapers of different futures for which the long-term planning should prepare [8] .

Electrification of transport (under the driving force group *Loads)* is an example of a driving force assessed to have high importance and low uncertainty. Electrification of transport may pose challenges to the grid in terms of increased peak loads, variability and uncertainty, high demand in rural areas etc. These challenges will lead to measures, investments and/or innovations, in order to fully integrate electrification of transport in the grid. The importance is therefore high. The uncertainty of this driving force is assessed to be low, as electrification is high on the political agenda, and is already taking place to a large extent in Norway.

Energy storage (under the driving force group *Flexibility*) is an example of a driving force assessed to have high importance and high uncertainty. Utilisation of energy storage may provide opportunities for the grid in terms of peak load shaving, voltage regulation, possibilities for microgrid etc. It is therefore assessed to have high importance. However, the uncertainty of the development is also assessed to be high, mainly because utilisation of energy storage by the DSOs require changes to the regulations.

IMPACT OF DRIVING FORCES ON THE DISTRIBUTION GRID DEVELOPMENT

Establishing mini scenarios

Creating forward views is an important step of the foresight process. As a first step of the process of describing the alternative futures, mini scenarios were established. A mini scenario is *a probable event, development or action of significance for the future distribution system*. The driving forces described above provide the foundation for developing mini scenarios. In total, 109 mini scenarios were developed in stakeholder workshops. Examples are shown in the following.

Impact on the grid

The impact of the driving forces on the distribution grid depends on the development of the driving forces. To illustrate possible impacts, three mini scenarios representing driving forces with high importance are described, and their impact on the grid performance is discussed. The impact on the different topics of grid performance is shown with a description and a colour code as shown below.

Red	The mini scenario has a negative impact on the grid performance
Yellow	The impact on the grid performance is uncertain and can be both positive and / or negative
Green	The mini scenario has a positive impact on the grid performance
White	The mini scenario has no direct impact on the grid performance

Table 1 shows a mini scenario example for the driving force *energy storage*. The mini scenario is about utilisation of batteries in the grid. It has a positive effect on security of supply and economy, and an uncertain impact on safety, as batteries in the grid may be a challenge to personnel safety during fault situations.

Table 1 Mini scenario for the driving force "Energy storage"

Driving force: Energy storage	
Driving force group: Flexibility	
Title: "From peak power to stable loads"	
Electrification of transport causes power challenges to the grid due to simultaneous fast charging. The ferry companies make large investments in on-shore battery packages with extra capacity. This results in stable load from the grid side, and possibilities for the ferry companies to provide flexibility / grid support in high load periods and fault situations.	
Impact on grid performance topics	
Security of supply	Batteries are utilised to increase the security of supply.
Economy	Decreased CAPEX (defer investments)
Cyber security	-
Safety	It may be challenging to know if the grid is energised or not when batteries can feed the grid. This must be solved to ensure personnel safety.

Table 2 shows a mini scenario example for the driving force *ICT competence and organisational aspects*. The mini scenario concerns specialised competence in the organisation and has a negative impact on security of supply and economy, and an uncertain impact on cyber security.

Table 2 Mini scenario for the driving force "ICT competence and organizational aspects"

Driving force: ICT competence and organisational aspects	
Driving force group: Cyber security	
Title: "Specialised competence"	
Recruitment in the DSOs is focused on specialised competence, meaning that personnel are either working with electric power or ICT. The disciplines are organised in different departments, and the understanding of the interdependencies between the two disciplines is lacking. The departments develop solutions that are separately good, but not interoperable. This results in longer duration of interruptions due to systems that are not able to work together.	
Impact on grid performance topics	
Security of supply	Problems with interoperability may lead to longer durations of interruptions.
Economy	Increased OPEX (interruption costs) and CAPEX (bad investments)
Cyber security	Cyber security has a high attention among ICT personnel but may be threatened by lack of competence among electric power personnel.
Safety	-

Table 3 shows a mini scenario example for the driving force *Microgrid.* The mini scenario is about neighbourhoods organizing themselves as microgrids and some are disconnected from the grid. The impact of this mini scenario is uncertain.

Table 3 Mini scenario for the driving force "Microgrid"

Driving force: Microgrid	
Driving force group: Microgrid	
Title: "Microgrids for all"	
Many neighbourhoods are organised as microgrids. With heat pumps and distributed generation, the power and energy demand in the connection point is reduced. Several microgrids choose to go off-line, and the number of customers connected to the distribution grid is decreasing.	
Impact on grid performance topics	
Security of supply	End-users may experience decreasing security of supply due to off-grid solutions
Economy	Uncertain revenue for the grid company
Cyber security	Local solutions (+), but more automation (-)
Safety	Must be handled by the local community itself

Some of the mini scenarios above have a quite uncertain impact on the grid performance, depending on the development of other interconnected driving forces. The research in CINELDI aims to provide new knowledge to reduce some of these uncertainties.

HOW CAN THE DSOS PREPARE FOR THE UNCERTAIN FUTURE?

To receive more insight into how DSOs prepare for the uncertain future and how they may utilise the results from this foresight process, a survey was conducted to all partners in CINELDI. A total of nine (out of thirteen)

DSOs answered the survey.

Some of the DSOs have already taken results from this foresight process in use in their strategic process. The DSOs participate in research and development (R&D) projects to build new knowledge and gain insight into possible future scenarios, as a basis for increased understanding and to prepare for the future. Only a few DSOs have dedicated staff working on future scenarios and strategic plans in the day to day work. All DSOs answered that they are lacking resources for working with future scenarios and to plan for the uncertain future. Some of the DSOs report that there is a gap between the strategy and how the strategy is operationalized. To prepare for the uncertain future the DSOs focus on the following:

- Recruitment and competence building, for instance in data science
- Build new knowledge through new demonstration/ pilot projects
- Prepare for better utilisation of existing and new data
- Utilise the new knowledge to improve the work processes in grid management and operation.

One example of utilising the new knowledge to improve the work processes in grid operation is related to the automation of the fault and interruption handling process described in one of the 109 mini scenarios: "*The Cost of Energy Not Supplied increases significantly because the society is becoming increasingly dependent on a reliable grid. This leads to increased profitability for investments in the grid, also for self-healing solutions*." The self-healing solutions will lead to improved work processes in the control centre, which will contribute to a more efficient operation and reduce the interruption duration and costs, as described in [9].

CONCLUSION

This paper describes driving forces for intelligent electricity distribution system innovation in Norway. System innovation is here defined as a co-evolution of system-level technical, social and regulatory changes. The identified driving forces have been structured and further provided the foundation for developing mini scenarios. In total, 109 mini scenarios were developed in stakeholder workshops and possible impacts for the development of the future distribution grid have been illustrated. The driving forces are closely interconnected, and there is a variety of factors within different fields influencing on each other, which emphasizes the need for distribution system innovation.

A small survey was performed among DSOs to gain insight into how they prepare for the uncertain future and how they may utilise the results from the foresight process. The survey has indicated that there is a need for better utilisation of the knowledge about the future to improve the decision-making processes in the DSOs.

This work is performed in a foresight process through a systematic and participatory process involving the various stakeholders: technology providers, grid operators (DSOs/TSO), research institutes, university, authorities and market operators in Norway, representing a multidisciplinary group of experts. The foresight methodology has so far shown to give promising results and new knowledge that the stakeholders can relate to and integrate in their decision-making processes.

FURTHER WORK

The driving forces and mini scenarios will form the basis for establishing a set of credible futures/main scenarios for the distribution grid in Norway of 2040. Based on the scenarios and the research in CINELDI, a road map and transition strategy for Smart Grid development in Norway will be developed in joint efforts among the stakeholders.

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