Driving forces for intelligent electricity distribution system innovation

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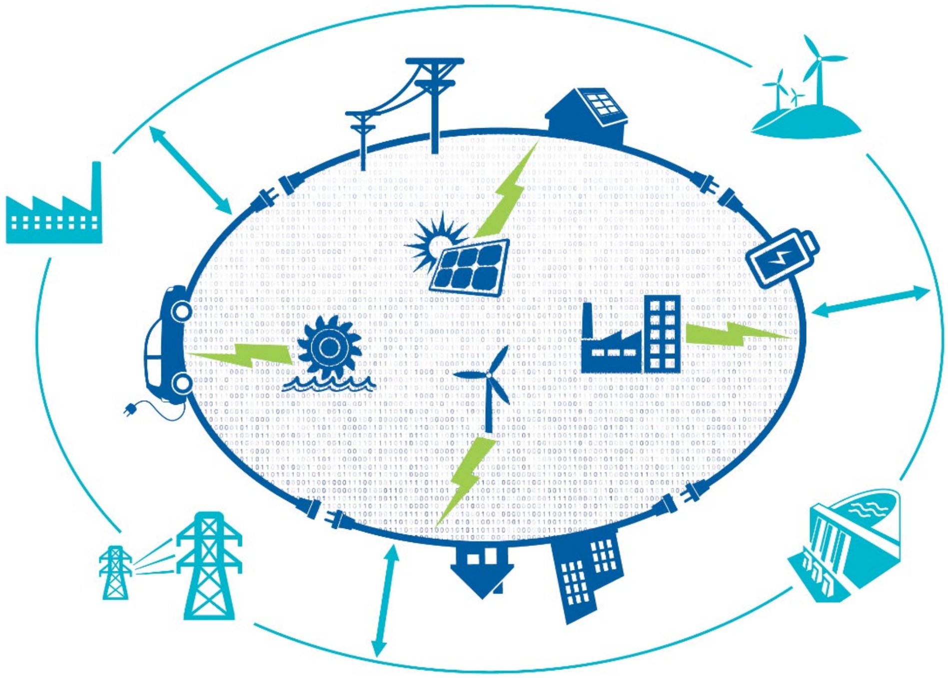

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Centre for intelligent electricity distribution
- to empower the future Smart Grid

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CINELDI - Centre for intelligent electricity distribution

SINTEF and NTNU are the main research partners, with grid operators, technology providers, public authorities and international R&D institutes and universities as partners.

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Summary:

The future electricity grid will be a complex system-of-systems, incorporating various intelligent devices for monitoring and automatic control. The interaction between various technological, regulatory and social factors add complexity which need to be addressed in a holistic and coordinated way to support system innovation. The driving forces for the Norwegian distribution grid system changes and innovations have been identified and structured. Based on the driving forces, a repository of more than 100 mini scenarios has been developed. This report describes the foresight process used in this work, the structure of the driving forces and shows examples of mini scenarios and their impact on the future development of the distribution grid. This new knowledge has already been applied by project partners in their business strategies, for competence development and recruitment for the future.

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1 Introduction

1.1 The research centre CINELDI and Smart Grid scenarios

The Centre for Intelligent Electricity Distribution (CINELDI)[1] is one of the Centres for Environment-friendly Energy Research in Norway (FME). The main objective of FME CINELDI is to enable a cost-efficient realisation of the future flexible and robust electricity distribution grid. This will pave the ground for increased distributed generation from renewable sources, electrification of transport, and more efficient power and energy use.

The CINELDI ecosystem is shown in Figure 1, indicating the main stakeholders, smart grid domains and zones, control architecture and main IT systems. The distribution system covers the HV sub transmission grids, MV and LV distribution grids, as well as microgrids and distributed electricity generation and storage. The system boundaries are indicated by the frame, illustrating that the consumer/prosumer is an integrated part of the system through the smart metering interface. It also illustrates the need for interaction between the transmission system operator (TSO) and the distribution system operator (DSO), providing flexibility services from the distribution grid to the system level.

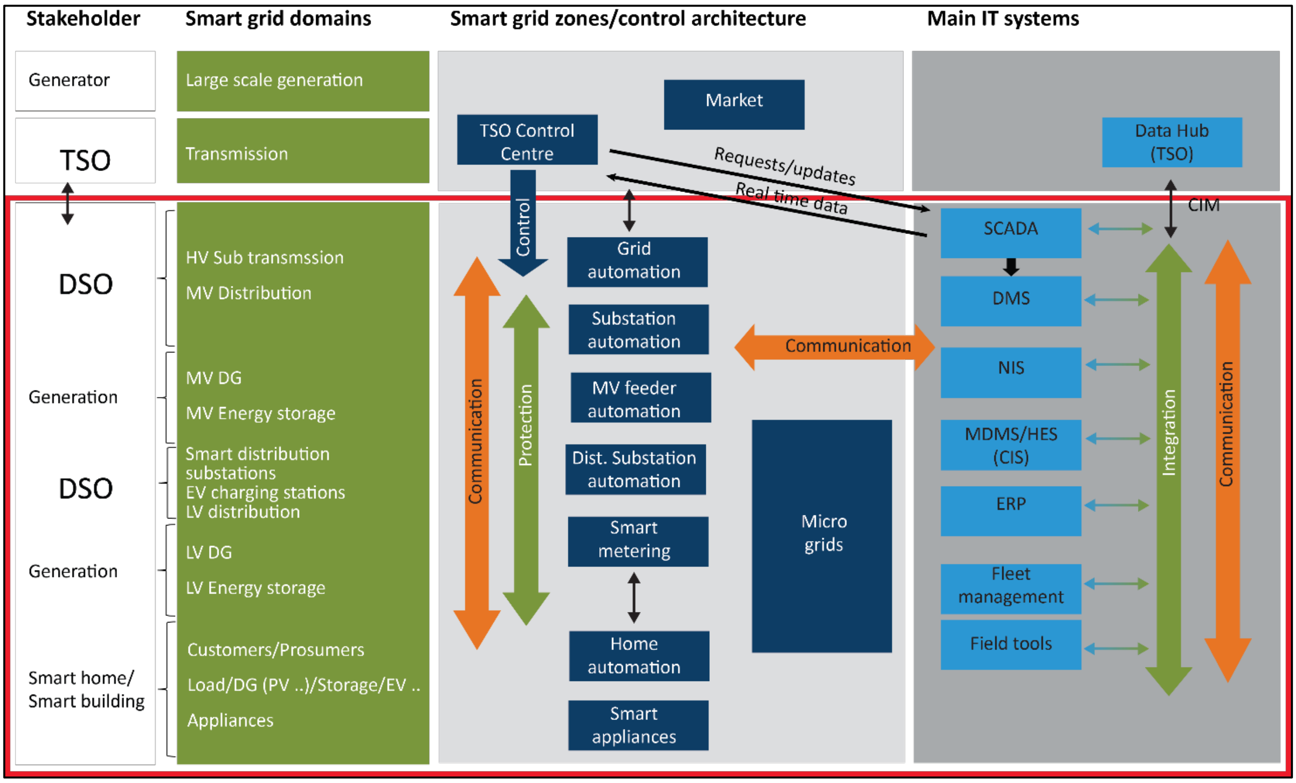

Figure 1: The CINELDI ecosystem.

CINELDI's work on Smart Grid scenarios and transition strategies establishes a common basis for the various research areas, while providing direction for research in the centre. CINELDI seeks to identify drivers, barriers and enablers for system innovation in the electricity distribution grid and to develop a set of plausible scenarios for the future electricity distribution in Norway. The scenarios serve as input to the research in CINELDI, and as a basis for fostering new ideas and innovation. The findings from the research

[1] More information about CINELDI can be found at www.cineldi.no

will further be integrated into a roadmap for a structured transformation towards an intelligent electricity distribution system. The expected impact is twofold:

1) A structured multidisciplinary approach, providing results that are robust to external requirements and opportunities for the future distribution system.

2) A road map and recommendations to be used by the electricity industry to update their local strategies thus enabling the transition to happen.

1.2 The future electricity distribution grid is a Smart Grid

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 extensively utilized [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. Such visions and plans are useful for the power industry, the manufacturers and the ICT industry, so that they can align their own development plans with the roadmap.

The future electricity grid will be a complex system-of-systems [5], incorporating various intelligent devices for monitoring and automation. The interaction between various technological, economical, organisational and human factors add complexity which need to be addressed in a holistic and coordinated way to support system innovation and development. 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 realise the prospective benefits from these new opportunities [6]. Innovation journeys are often highly unpredictable and uncontrollable [7], which is also the case for radical innovations like the Smart Grid.

1.3 Purpose and structure of the report

One of the purposes of this work is to increase the understanding of the requirements for the future distribution grid. Knowledge about the factors driving the development of the grid is important for developing robust strategies for distribution system transition.

This report describes the results of the work on identifying and structuring the driving forces (drivers, barriers and enablers) for the electricity distribution system innovation. The structured driving forces are the basis for developing scenarios/mini scenarios for the future grid. The mini scenarios further illustrate how the driving forces can influence the development of the future distribution grid.

This report is organised as follows:

- Section 2 of the report explains the foresight process.
- Section 3 describes the driving forces for electricity distribution system innovation.
- Section 4 describes the impact of driving forces on the development of the distribution grid
- Section 5 describes the use of the results from this foresight process, both in the research activities in CINELDI and by the CINELDI partners.
- Section 6 concludes the report.

1.4 Terminology

The tables below give an overview of the main terms and abbreviations used in this document.

Table 1: Terms

Term	Definition
Barrier	Stakeholder or factor hindering the development towards system innovation in the distribution grid. E.g. cyber risk, lack of competence.
Driver	Stakeholder or factor driving the development towards system innovation in the distribution grid. E.g. distributed generation, electrification, digitalisation.
Driving force	A collective term for drivers, barriers and enablers.
Enabler	Stakeholder or factor enabling the development towards system innovation in the distribution grid. E.g. big data analytics, market for flexibility.
Grid company	DSO or TSO
Innovation	Development and utilisation of new ideas, utilisation of existing knowledge in new applications, new methods, new tools, new services, etc.
Mini scenario	A plausible event, development or action of significance for the future electricity distribution grid (HV, MV and LV distribution grid).
Prosumer	A prosumer is an end user that is both consuming and producing electricity, for example from PV generation on the roof top, and is thus a source of distributed generation.
Scenario	A description of a future situation and the course of events which allows one to move forward from the original situation to the future situation [8].
System innovation	A co-evolution of technical, social and regulatory change[2]

Table 2: Abbreviations

Abbreviation	Definition
DSO	Distribution system operator - party operating a distribution system
FASIT	FASIT is the Norwegian standard for collecting and reporting fault and interruption data for the total electricity system in Norway. It consists of basic requirements, reporting schemes, guidelines for data collection and a software requirement specification [9].
GDPR	General Data Protection Regulation (EU)
HV	High voltage (HV) -AC voltage. The nominal r.m.s. value is 36 kV < Un ≤ 150 kV
IEC	International Electrotechnical Commission
LV	Low voltage (LV) – AC voltage. The nominal r.m.s. value is Un ≤ 1 kV

[2] A process is initiated to conceptualise and define the term "system innovation" in the context of FME CINELDI. This is a preliminary proposal.

Abbreviation	Definition
MV	Medium voltage (MV) – AC voltage. The nominal r.m.s. value is 1 kV < Un ≤ 36 kV
NEK	Norwegian Electrotechnical Committee
RES	Renewable energy sources
TSO	Transmission system operator - party operating a transmission system
UAV	Unmanned Aerial Vehicle
5G	Fifth generation standard for telecommunication, following 4G, 3G and 2G.

2 The foresight process

The foresight process has been chosen as a framework for developing scenarios and transition strategies in CINELDI. Section 2.1 explains what foresight is, section 2.2 explains the scenario concepts, section 2.3 describes a generic process framework, and section 2.4 explains the work process in CINELDI.

2.1 Foresight: Thinking, debating and shaping the future

Foresight provides a framework for a group of people/stakeholders concerned with common issues allowing joint thinking about the future in a structured way. As such, the foresight process is suitable for a centre like CINELDI that consists of many partners and different types of stakeholders. Foresight provides several tools to support participants to develop visions for the future and pathways towards these visions.

There exist several definitions of *foresight*. The Research Council of Norway refers to the definition from the European Commission's Joint Research Centre (JRC) Institute of Prospective Technological Studies (IPTS), first formulated by the FOREN network [10]:

> *Foresight is a systematic, participatory, future-intelligence-gathering and medium-to-long-term vision-building process aimed at enabling present-day decisions and mobilizing joint actions.*

As the figure below shows, foresight is about thinking the future, debating the future and shaping the future. It invites to consider the future as something stakeholders can create or shape, rather than something already decided [11].

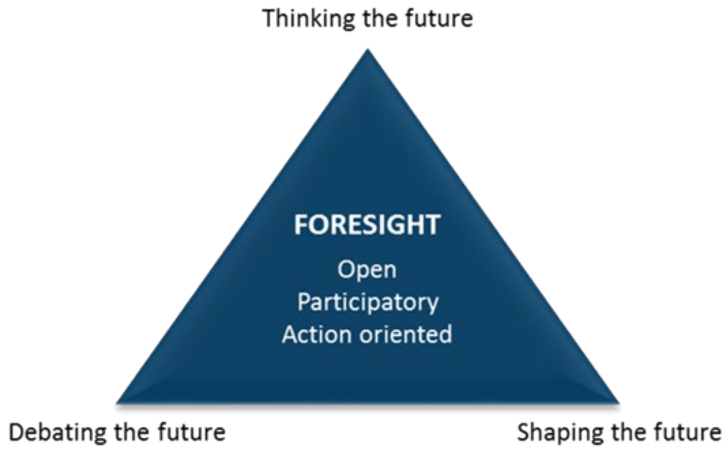

Figure 2: Characteristics of the foresight process (based on [11]).

Some important characteristics of the foresight process are [11]:

- *Openness to alternative futures*: Foresight assumes that the future is not pre-determined. The future can therefore evolve in different directions, which can be shaped to some extent by the actions of various players and the decisions taken today.
- *Participatory*: Foresight processes involve several different groups or actors concerned with the issue at stake. The results of the process are disseminated among a wide audience from which feedback is actively sought.

- *Multidisciplinary*: Foresight provides an approach that captures realities in their totality with all the variables influencing them, based on the principle that the problems faced cannot be correctly understood if reduced to one dimension.
- *Action-oriented*: Foresight is not only about analysing future developments, but also supporting actors to actively shape the future.

2.2 Scenarios

Creating forward views is an important step of the foresight process. A main scenario is a description of a potential future and the progression towards the given future.

In [12], different classes of potential alternative futures are described, as shown in Figure 3. "The futures cone" illustrates the span of potential futures, which expands from the present on the left into alternative futures on the right.

Possible futures, illustrated by the outermost circle of the cone, includes all kinds of futures that can possibly be imagined, those which might happen, no matter how unlikely. They might involve knowledge not yet possessed or might involve transgressions of currently accepted physical laws or principles.

Plausible futures are futures that could happen according to current knowledge of how things work.

Probable futures are those which are considered most likely to happen and can be seen as continuance of current trends.

Preferable futures are concerned with what is wanted. These futures are based on value judgements and are more subjective than the previous three classes.

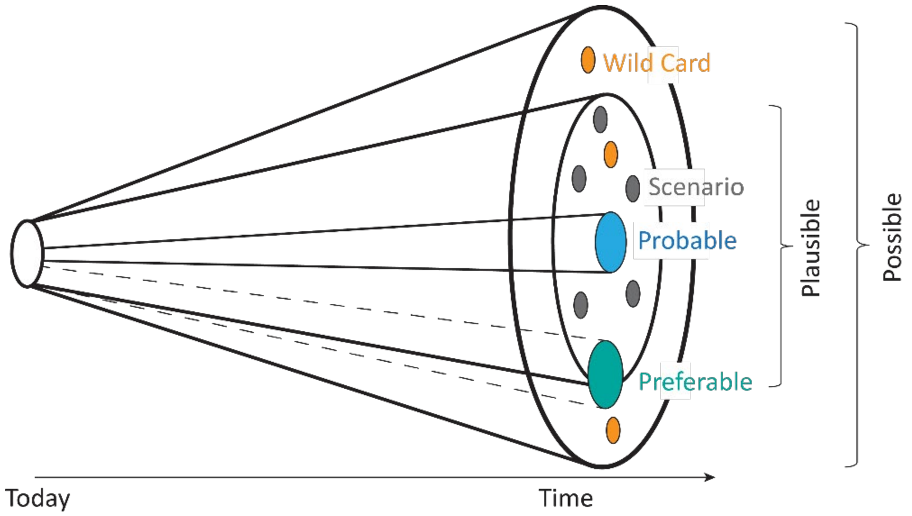

Figure 3: The futures cone (based on [12]).

The scenarios established as part of the foresight process are typically based on current knowledge and expectations, thus, depicted in the plausible region in the figure.

As part of the process of building scenarios, mini scenarios can be established. *A mini scenario is a plausible event, development or action of significance for the future electricity distribution*. Mini scenarios can be combined in different ways yielding different main scenarios. Mini scenarios can therefore be important steps towards the given future in the main scenarios.

2.3 Foresight process framework

A generic foresight process framework is described in [12] and illustrated in Figure 5, showing the steps of the process framework, as well as the implementation of the steps in the work process in CINELDI, which is further described in section 2.4.

In the **input** step, information is gathered about the topic to be studied.

The **analysis** step is the first part of the foresight process and can be considered as a preliminary stage to more in-depth work. The question asked here is: *what seems to be happening?*

In the **interpretation** step, a deeper structure and insights are sought for and the question is: *what is really happening?*

The **prospection** step is the actual creation of forward views and alternative futures and the question is: *What might happen?*

The **outputs** from the foresight process are new insights generated in the interpretation step and forward views created in the prospection step.

In the **strategy** step, output from the foresight process will be handed over for consideration by decision-makers in making decisions and directing strategic actions for implementation. The questions are: *What needs to be done?* and *How can it be done?*

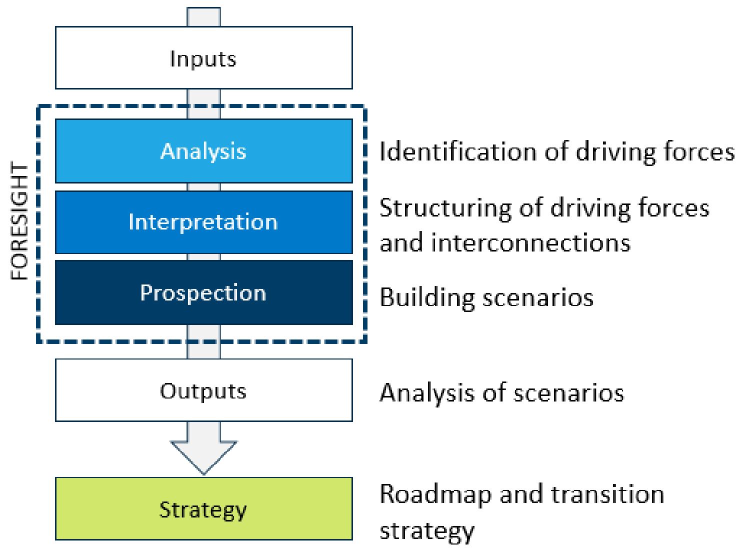

Figure 4: A generic foresight process framework (based on [12]) and the implementation of the steps in CINELDI.

2.4 Work process in CINELDI

The participants in the foresight process involves the most prominent technology providers in Norway together with the most innovative grid operators (DSOs), the Norwegian Transmission System Operator (TSO), research institutes, a university, energy authorities and market operators. The participants represent a multidisciplinary background consisting of the main technology domains:

- Power engineering
- Cybernetics
- Information and communication technology (ICT).

Experts from the social science domain have also participated, as customer behaviour is regarded as instrumental to facilitate the transition.

In the analysis step, two workshops on identifying drivers, barriers and enablers have been held. The first workshop focused on stakeholders, and the second workshop focused on factors that can be drivers, barriers and enablers. This is supplemented by reviewing other scenario studies ([13], [14], [15], [16]) and other countries' Smart Grid visions / road maps ([2], [3], [4], [17], [18], [19], [19], [20], [21]), to gather supplementary information about the driving forces and seeking to include all relevant driving forces. The work is also inspired by reports from IEA [22], IRENA [23], WEC [24], ETIP-SNET [1] and others.

In the interpretation step of the foresight process, the results from the workshops have been processed together with information from the review of previous studies and road maps to form input to the list of driving forces for intelligent electricity distribution system innovation. Some of the identified driving forces were overlapping, and were thus aggregated, and some driving forces were added during this process.

The further processing and structuring of the driving forces has mainly been carried out by the research partners in CINELDI. The proposed structure has been discussed in several steps, among the CINELDI researchers and in stakeholder meetings where all partners were invited to give feedback on the structuring of the driving forces.

The inputs to the work on driving forces are illustrated in Figure 6.

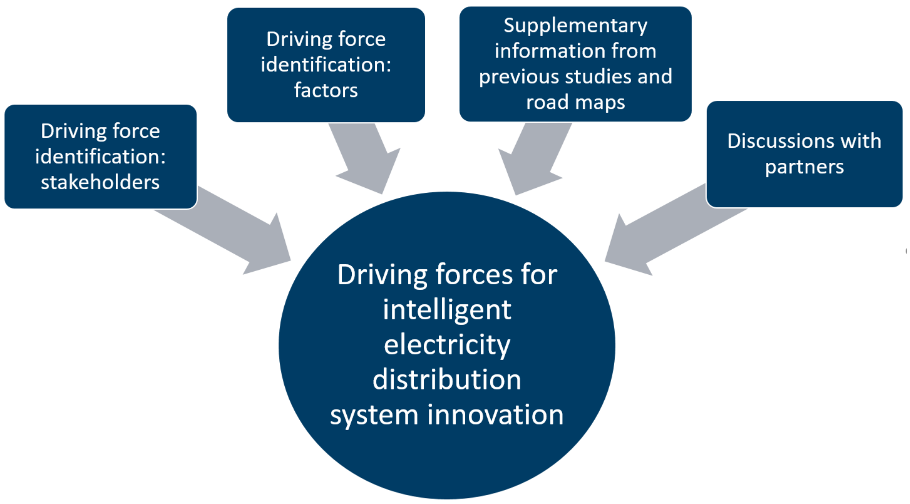

Figure 5: Processing of results from workshops, literature review and partner discussions.

In the prospection step, workshops have been arranged, and mini scenarios are developed based on the identified driving forces. The mini scenarios illustrate possible directions for the driving forces and form the basis for establishing the alternative futures (main scenarios) for the distribution grid of 2040.
Based on the new insights and forward views, an analysis of the scenarios will be carried out and challenges for the grid and recommendations will be identified.

In the strategy step, a road map and transition strategy for smart grid development in Norway will be developed in joint efforts among the stakeholders.

This report presents the results from the **analysis** and **interpretation** step of the foresight process, together with some initial results from the **prospection** step.

3 Driving forces for intelligent electricity distribution system innovation

The driving forces will pose some challenges or opportunities on the grid. This may lead to a measure, an investment and/or an innovation (in the grid management, in the regulation, at the customer etc.), as illustrated in Figure 7 below.

Figure 6: Driving forces leading to measures, investments or innovations.

The following section describes the proposed structure of the driving forces.

3.1 Structure of the driving forces

The driving forces have been sorted into three levels; megatrends, external driving forces and grid related driving forces. The levels are defined as follows:

Megatrends:	Overall, global trends.
External driving forces:	Driving forces outside the grid companies' direct control.
Grid related driving forces:	Driving forces which are internal parts of the grid management and customer relationships.

Megatrends are assumed to influence on both the external and indirectly also the grid related driving forces. This is illustrated with the right arrow in Figure 8. The external driving forces and the grid related driving forces are assumed to have mutual influence on each other, illustrated by the double arrow in Figure 8.

Figure 7: Relation between levels of driving forces.

Under each of the levels, several groups of driving forces are sorted as shown in Figure 9.

The megatrends considered relevant for the development of the distribution grid are:

- Climate change
- Digitalisation
- Globalisation and urbanisation
- Population growth.

These trends together influence all the groups of external and grid related driving forces shown in the figure below and are exemplified at the end of this section. The megatrends are further described in section 3.2.

The following groups of driving forces are considered external:

- Political goals
- Regulation and standardisation
- Societal trends and values
- Technology development
- External threats
- Business models and stakeholders.

Under each of these groups there are several driving forces, as described in section 3.3. The borderline between external and grid related (internal) driving forces has been discussed in CINELDI. Regulations and standardisation, technology development and business models are groups of driving forces that the grid companies to some extent can influence by e.g. lobbying and responding to public consultation processes. However, the inclusion of the distinction "internal parts of the grid management" for grid related driving forces, explains the placing of these groups as external driving forces, as they are not directly controlled by grid companies.

The grid related driving forces are sorted on a more detailed level than the external driving forces and are described in section 3.4. The uppermost dashed rectangle in Figure 9 contains topics related to the grid customers, i.e., distributed generation and load (consumption of electricity). 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 the constraints that the DSOs must comply with, i.e., the grid performance in terms of security of supply, economy, safety, and cybersecurity.

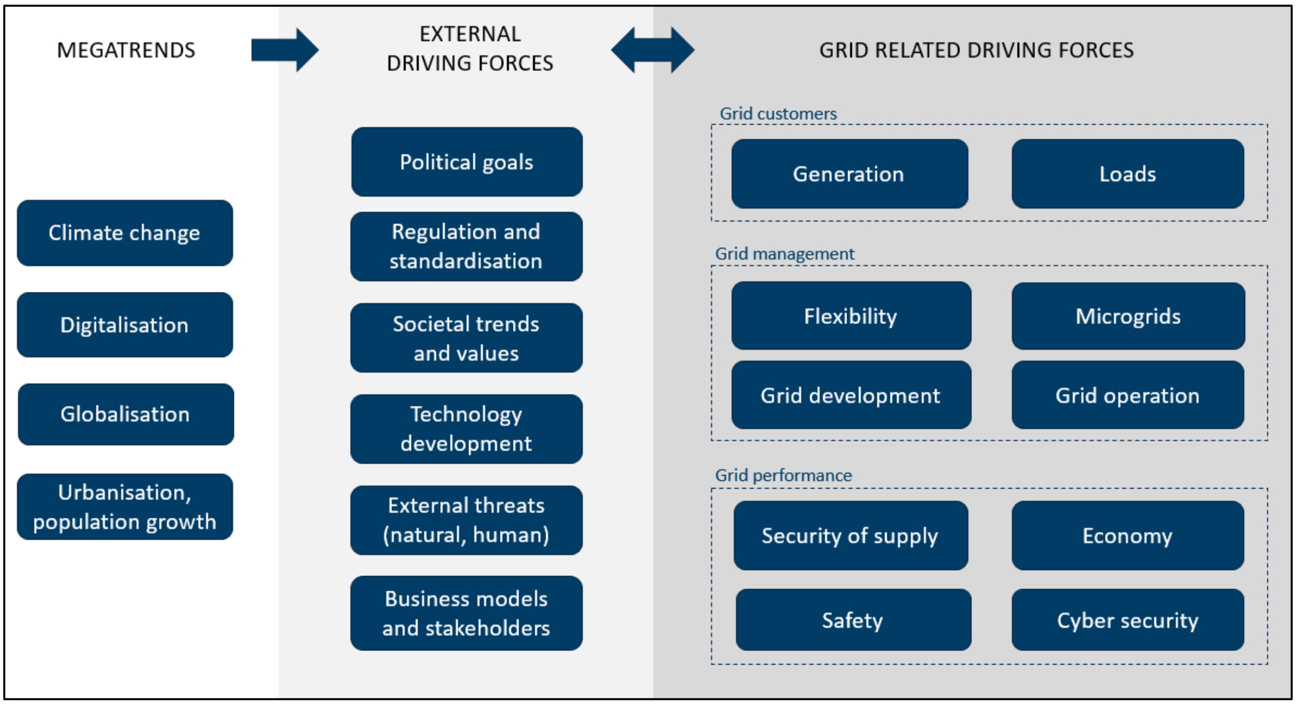

Figure 8: Overview of the groups of driving forces.

The driving forces in each of the groups are described in the following, and an example of interconnected driving forces is shown in section 3.5. A complete list of the driving forces is given in appendix A.

3.2 Megatrends

The megatrends are overall, global trends that indirectly influence the grid operation and management through other external and grid related driving forces.

3.2.1 Climate change

Climate change is an underlying driving force for all the external driving forces. It influences politics through agreements on CO_2 reductions. It influences regulation and standardisation through requirements to e.g. electrification and energy efficiency, and societal trends and values through consumer awareness and behaviour. Further, climate change leads to development of more climate friendly technologies and new business models, whilst it also influences external threats through more extreme weather.

3.2.2 Digitalisation

Digitalisation is the core of the transformation towards the future Smart Grid and influences all the external driving forces.

Digitalisation describes the growing application of ICT across the economy, including energy systems, and can be thought of as the increasing interaction and convergence between the digital and physical worlds. The trend toward greater digitalisation is enabled by advances in three areas: increasing volumes of **data** thanks to the declining costs of sensors and data storage, rapid progress in advanced **analytics** and computing capabilities, and greater **connectivity** with faster and cheaper data transmission [22].

3.2.3 Globalisation

In a globalised world, information and knowledge are exchanged almost immediately. Societal trends and values are spread across borders, and the development of new technologies and business models have the potential to reach a global market. Globalisation also influences on external threats, e.g. through easier spread of epidemics due to travelling.

3.2.4 Urbanisation, population growth

Population growth, migration and settlement pattern are some of the most important drivers for the development of economic growth and energy use. Population growth will increase the demand for energy, whereas urbanisation results in decreased energy demand, e.g. for heating purposes (in Norway) because of smaller living areas per housing. Compact cities where public transport, walking and biking are real alternatives, reduce the need for electricity for transportation. Urbanisation and compact living open up possibilities for new business models, i.e. establishing local marketplaces / microgrids for electricity generation and trading [25].

3.3 External driving forces

The external driving forces are considered outside the grid companies' direct control. As explained above, it might to some extent be possible to influence the external driving forces, illustrated by the double arrow in Figure 9.

3.3.1 Political goals

Political goals on different levels will indirectly influence the development of the grid.

- International political goals, policies and agreements will set guidelines or requirements to the national political goals. (e.g. Paris Agreement, UN's Sustainable Development Goals, etc.)
- National political goals and policies for e.g. energy and climate goals, electrification, and building technologies will influence the electricity generation and demand (e.g. Report to the Storting [25], BREEAM-NOR certificate, etc.)
- Local policies (e.g. public support for electrification of transport, local development plans) also influence the electricity demand and distributed generation.
- Interest organisations, non-governmental organisations (NGOs) may influence on e.g. the amount of distributed generation through lobbying, and by contributing to the public debate through media influence etc.

3.3.2 Regulation and standardisation

Political goals are underlying driving forces for the regulation and standardisation. The following driving forces related to regulation and standardisation are identified:

- Authority regulation and frameworks for grid management and grid customers: this include development of the DSO role, economic incentives both for grid companies and grid customers, data and privacy protection requirements etc. (e.g. The Norwegian Water Resources and Energy Directorates regulation regarding grid companies economic revenues (revenue cap) and compliance monitoring, Data Protection Authority, GDPR, etc.)
- Public support schemes, e.g. RES support schemes / green certificates, research and innovation funding.
- Standardisation related to grid management and grid components, digitalisation, internet of things (IoT), e.g. IEC, NEK, FASIT.

3.3.3 Societal trends and values

Societal trends and values will indirectly influence the development of the grid, both at the customers (producers and consumers) side and at the grid company side.

- Level of prosperity, economic growth: in prosperous times, people and companies are more willing to invest in new technologies. This will influence both on technology development and on the deployment of new technologies.
- Competence and growing education level in the population will influence the adaptation of new technologies on the grid customer side and on the recruitment of competent personnel in the industry.
- Media influence, e.g. from social media, may influence on values and behaviour of customers.
- Evolution of consumer values and behaviour is closely related to the points above. Environmental awareness, technology optimism, individualism, openness to change are examples of values that will affect the development and the customer role in the future distribution grid.

3.3.4 Technology development

Technology development leads to more efficient and improved technologies, as well as reduced costs. Development of technologies for the combined power and ICT system is thus an important driver for system innovation in the distribution grid. The following technologies are identified as important for the development of the grid:

- Power electronics, for automation of the grid operation
- Sensors, IoT, UAVs and mobile robots for better collection of data for grid monitoring
- Machine learning and increased computational power for processing and analysing large amount of data

- Communication infrastructure (5G) for data transmission
- Batteries and other energy storages for flexibility solutions in the distribution grid
- Improved PV and wind power technologies for more distributed generation
- Development of ICT tools for more efficient grid operation, development and decision support
- Smart home technologies and consumer electronics for customers to control the electricity consumption
- New and disruptive products and technologies.

3.3.5 External threats

Due to the society's increasing dependency of electricity, the electricity system infrastructure is becoming more and more critical and external threats need to be considered in operation and planning of the distribution grid and in emergency preparedness. The following threats are identified:

- Natural threats: Extreme weather (wind, snow, ice, landslides, flooding, etc.) is expected to increase both in frequency and magnitude, and the "normal" weather is expected to be more extreme. Natural disasters (solar flare, earthquake, etc.) may also cause incidents that will influence the development of the grid.
- Physical attacks, terror, and sabotage on grid infrastructures
- Cyber-attacks, hacking: with the increased digitalisation, the potential entries for cyber-attacks are increasing, and the consequences may be more severe.
- Unintended incidents and human errors may be more severe in the combined ICT and power system due to the increased complexity.
- Epidemics may put out the workforce
- "Black swans" (HILP) are events that have a low probability but have a potentially high impact. These threats need to be handled by emergency preparedness and resilience.

3.3.6 Business models and stakeholders

To realise the flexibility potential in the grid, new technologies and active customers are not enough; there must also be business models for new solutions, and a marketplace for trading flexibility. The following driving forces related to business models and new stakeholders are identified:

- Business models for solar cells (e.g. renting the roof instead of investments)
- Business models for energy storage (e.g. offering battery as back-up during events as concerts, festivals and soccer games, offering battery as a source for increased peak load in cabin areas during holidays, battery for improving power quality, etc.)
- Business models for demand response (e.g. aggregators business models)
- Market solutions for flexibility where grid operators can buy flexibility offered by both producers and consumers in a well-functioning market, with given availability, durability and accessibility of the flexible resources.

3.4 Grid related driving forces

Grid related driving forces are driving forces which are considered part of the grid management and customer relationship.

3.4.1 Generation

Electricity producers in the MV and LV grid will influence planning and operation of the distribution grid and give opportunities for flexibility solutions and microgrids. The following driving forces related to generation are identified:

- Increased amount of distributed generation in MV and LV grid (producers, prosumers)
- Increased share of intermittent electricity generation from renewable sources as PV, wind and run-of-river power station.

3.4.2 Loads

Electrification goals, technology development and societal trends and values will make the loads less predictable and more variable, both in terms of power and in terms of location. The following driving forces related to loads are identified:

- Increased electrification of transport and industry (e.g. offshore oil and gas) / new loads (e.g. data centres) lead to a higher demand for electricity
- More power intensive loads and energy efficient appliances leads to increased peak power demand.

3.4.3 Flexibility

A commonly used definition of flexibility is given by EURELECTRIC [26]: "On an individual level *flexibility* is the modification of generation injection and/or consumption patterns in reaction to an external signal (price signal or activation) in order to provide a service within the energy system. The parameters used to characterise flexibility include the amount of power modulation, the duration, the rate of change, the response time, the location etc."

The availability of the different flexible resources (load, generation and storage) will influence the operation and development of the grid and may improve the security of supply (power capacity, reliability and quality) and the economy (in terms of deferred investments). The following driving forces are identified:

- Energy storage as a flexible resource (batteries, hydrogen, thermal storage etc.): in addition to the factors above, the availability of energy storage in the grid or at customers also influences on potential microgrid operation.
- Flexible generation units for utilisation in the grid
- Dispatchable loads as a flexible resource in the grid.

3.4.4 Microgrids

Increased amounts of distributed generation in the grid combined with storage open possibilities for microgrid operation.

CIGRÉ C6.22 Working Group, Microgrid Evolution Roadmap [27] has the following definition of microgrids: *Microgrids are electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded.*

- Microgrids will have influence on how the grid is operated and may give new possibilities and challenges for development of the grid. It will influence the security of supply and may have impact on the economy for the grid companies, if customers are using microgrid as off-grid solutions.

3.4.5 Grid operation

There are many factors related to grid operation that may trigger or hinder system innovation in the distribution grid.

- Automated operation will improve reliability of supply due to shorter interruption duration and faster restoration. Personnel safety may be improved due to fewer personnel doing manual actions but may also increase due to errors in the automation software, e.g. leading to power supply to areas that should be de-energised. With more automation, the interdependency between power and ICT will increase, resulting in an increased complex cyber-physical power system. The cybersecurity issues may arise and must be handled.
- Real-time monitoring and control, through increased utilisation of sensors and communication, opens new possibilities for more automated grid operation, development and asset management.
- Workforce / human in the loop: even with comprehensive automation, there will be humans in the loop, who may fail. With more complex systems, the human factors may become more prominent.
- Customer service (reputation, information flow) may be a trigger for improved reliability of supply, information systems, and potential for new services.

3.4.6 Grid development

The changes related to distributed generation and more power intensive loads will influence the grid development approach. The following driving forces are identified:

- Ageing grids: A large part of the equipment in the Norwegian distribution grid has reached its lifetime, and huge investments are needed [28].
- Available no-grid solutions: alternative solutions, e.g. investment in new technologies and flexibility solutions may be an alternative to grid reinforcement.
- Access to and quality of data for grid management is crucial for realising the potential in new grid management solutions (flexibility, microgrids, automated operation etc.)
- Changes in grid systems and topologies, e.g. underground cables vs. overhead lines, meshed vs. radial operation, AC/DC, low voltage grid as IT/TN.

3.4.7 Security of electricity supply

The security of electricity supply in Norway is high today, and in the transition to the future smart grid, it must be ensured. The following driving forces related to security of electricity supply are identified:

- Energy availability (the ability of the power system to supply the energy demand [29]) will be influenced by the increased amount of distributed generation.
- Power capacity (the ability of the power system to supply the instantaneous load [29]) may be challenged by electrification and the increased amount of power intensive loads.
- Reliability of supply (the ability of the power system to supply electric energy to end-users, related to frequency and duration of interruptions [29]) may be a trigger e.g. for more automated and flexible solutions.
- Power quality (the quality of the supply voltage according to given criteria [30]) will be influenced by e.g. increased amount of distributed generation and power intensive loads.
- Emergency preparedness (planned and prepared measures that enable handling unwanted events and crises in order to minimize the consequences [31]) may be influenced by the digitalisation and automation leading to changes in the responsibilities for the workforce. The workforce is more needed for the emergency situations and less in the day-to-day operation of the grid.

3.4.8 Safety

Personnel safety is the highest priority and must be ensured in all grid operations.

- Personnel safety may be a trigger for automated solutions, e.g. faster restoration in case of faults.

3.4.9 Economy

The economic framework for the grid companies will set requirements to the operation and management of the grid. The following driving forces are identified:

- Grid tariffs, energy pricing: price models may influence on the demand patterns, and the investments of the grid companies.
- Cost of energy not supplied (CENS, interruption costs) is a driver for faster restoration of supply and an incentive for socio-economic optimised solutions.
- Economic restraints at DSOs and revenue caps are closely related to the regulations, and will influence on how the grid companies are managed, the willingness and possibilities to invest etc.

3.4.10 Cybersecurity

When increasing ICT support and automation in the distribution grid, cybersecurity issues may arise. A realisation of the future smart grid requires the cybersecurity to be ensured.

- ICT competence and organisational aspects: Multidisciplinary competence and knowledge about interdependencies between the systems is important when integrating ICT and power systems.
- Privacy protection must be ensured by the grid companies and may be a barrier for utilisation of the data. Remote access and control may ease the operation but may also be a vulnerability with regards to cyber-attacks.

3.5 Example: prosumers

To illustrate the connection between the driving forces, the driving force *Distributed generation (prosumer)* and its connections with other driving forces are shown in Figure 10 and Figure 11.

Figure 10 shows the underlying driving forces for the prosumer. The underlying megatrend is *Climate change*. Climate change influences the *Political goals*, and *Regulation and standardisation*, to promote more production from renewable sources. Climate change also influences 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.

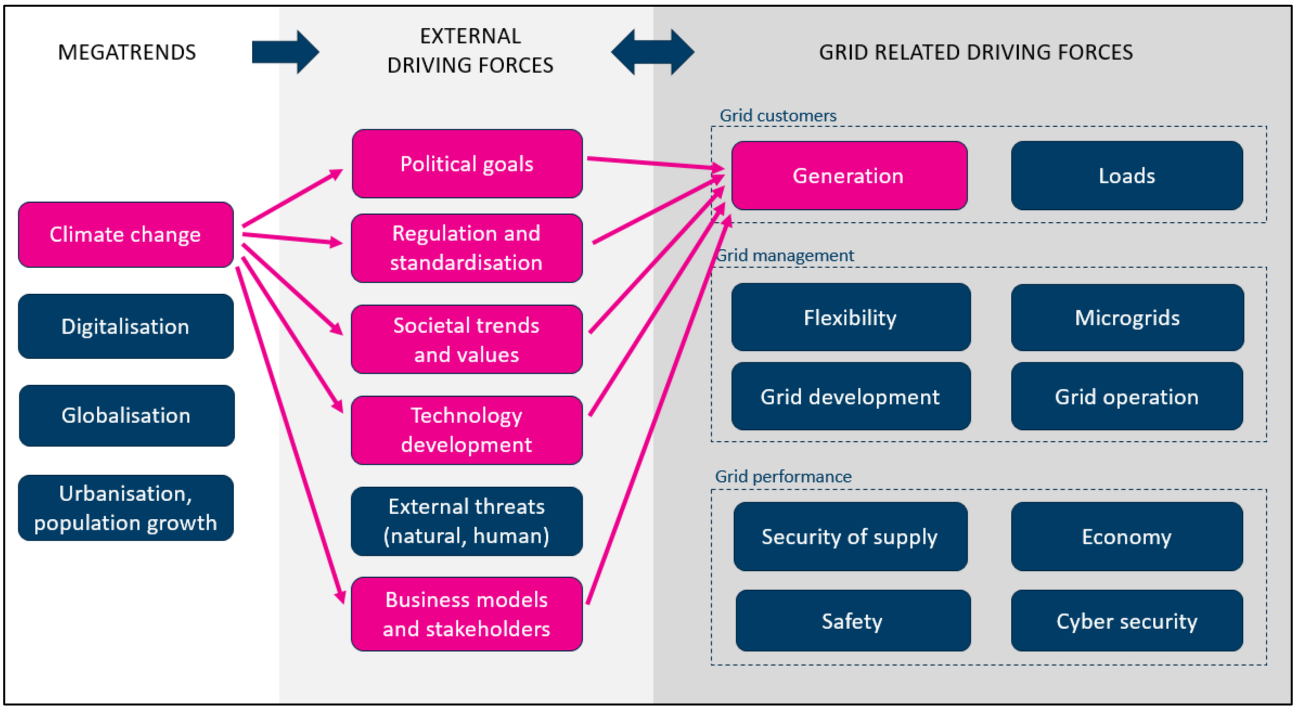

Figure 9: Example: prosumer and the underlying driving forces.

In Figure 11, the driving forces which are influenced by the prosumer and increased distributed generation, are shown. 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 *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 of the distributed generation.

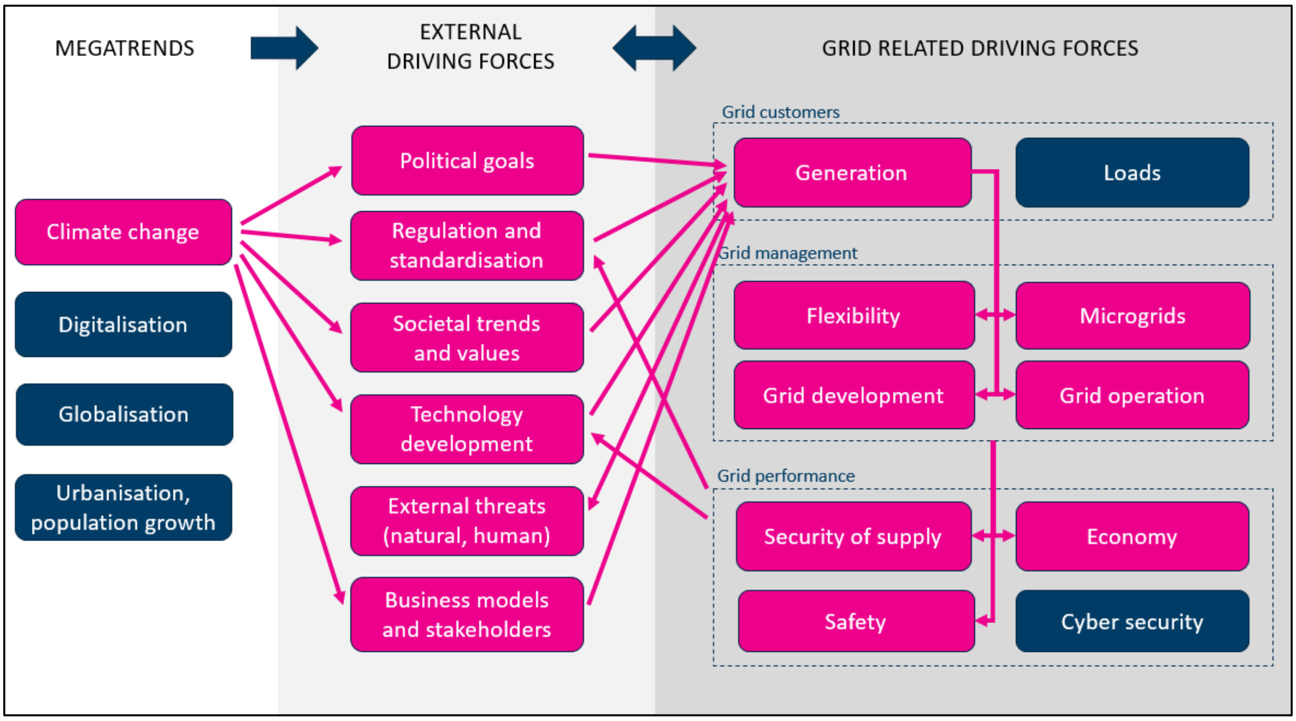

Figure 10: Example: prosumer and connections to other driving forces.

The example illustrates how the driving forces are interconnected, and that there is a variety of factors within different domains influencing each other. This emphasizes 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.

4 Impact of driving forces on the distribution grid development

The driving forces identified and structured as described in the previous section give the foundation for developing scenarios. The prospection step (*What might happen?*) in the foresight process framework shown in Figure 5, consists of the establishment of scenarios. The first step is to develop mini scenarios. *A mini scenario is a probable event, development or action of significance for the future electricity distribution system*.

4.1 Driving forces as basis for developing mini scenarios

As a part of the process of developing mini scenarios two workshops were carried out in CINELDI, one with stakeholders (CINELDI partners) and the other with a smaller group of researchers.

The identified driving forces, described in section 3 and summarised in appendix A, were used as a basis for developing the mini scenarios. In both workshops, the groups were given a list of driving forces and were encouraged to develop one or more mini scenarios inspired by the given driving forces. A mini scenario consists of a title reflecting the essence of the mini scenario and a body text of 3-4 sentences describing what happens, why it happens and what will be the consequences for the distribution grid. In total, more than 100 mini scenarios were established. Examples of impact analyses for some of the mini scenarios are given in the next section.

An example of a mini scenario is shown below:

Battery in every home: *Technology development leads to inexpensive and more efficient batteries. All end users install batteries at home, which reduces power variations. The grid companies experience less voltage quality issues and can postpone expensive investments in grid infrastructure.*

4.2 Examples of impact analyses of driving forces on the development of the distribution grid

The driving forces' impact on the distribution grid depends on the development of the driving forces. To illustrate possible impacts, five mini scenarios are described, and their impact on the grid performance in terms of security of supply, economy, cybersecurity and safety is discussed. The selected mini scenarios represent grid internal driving forces with a variety of impact on the grid performance. It can be noticed that the representative mini scenario only points out *one* plausible development of the driving force, and that the impact assessment relates to the specific mini scenario, and not the driving force in general.

The selected driving forces and their representative mini scenario are presented in a table containing the following information:

- Driving force
- Mini scenario title
- Mini scenario description
- Impact on the grid performance:
  - Security of supply
  - Economy
  - Cybersecurity
  - Safety
- Relevance of the mini scenario for other driving forces.

The impact on the grid performance is presented 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 or neutral and can be 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

The mini scenarios are intended to illustrate one plausible direction of a specific driving force. However, as shown in section 3.1, as the driving forces are closely connected, several of the mini scenarios can relate to more than one driving force. This is shown in the last part of the table.

The following driving forces are exemplified:

- ICT competence and organisational aspects (Table 4)
- Energy storage as a flexible resource (Table 5)
- Automated operation (Table 6)
- Real-time monitoring and control (Table 7)
- Microgrids (Table 8).

Table 3 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 cybersecurity.

Table 3: Representative mini scenario for the driving force *ICT competence and organisational aspects*.

Driving force: ICT competence and organisational aspects **Driving force group: Cybersecurity**	
Mini scenario title: "Specialised competence"	
Recruitment in the DSOs is focused on specialised expertise, meaning that personnel are either working with electric power or ICT. These 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 coordinated.	
Impact on grid performance	
Security of supply	Unidentified interdependencies between ICT and power system may lead to higher frequency and longer duration of interruptions.
Economy	Increase in OPEX (interruption costs) and CAPEX (bad investments).
Cybersecurity	Cybersecurity has a high attention among ICT personnel but may be threatened by lack of competence among electric power personnel.
Safety	-
Relevance for other driving forces (Group / driving force)	
Societal trends and values / Competence and education Grid operation / Interoperability Security of supply / Emergency preparedness	

Table 4 shows a mini scenario example for the driving force *energy storage as a flexible resource*. 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 4: Representative mini scenario for the driving force *Energy storage as a flexible resource*.

Driving force: Energy storage as a flexible resource **Driving force group: Flexibility**	
Mini scenario title: "From peak power to stable loads"	
Electrification of transport (EVs, ferries etc.) causes power challenges to the grid due to simultaneous fast charging. The ferry companies make large investments in onshore 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	
Security of supply	Batteries are utilised to increase the security of supply
Economy	Decreased CAPEX (deferred grid investments), decreased OPEX (reduced costs of electrical losses and reduced interruption costs)
Cybersecurity	-
Safety	It may be challenging to know if the grid is energized or not when batteries can feed the grid. This must be solved to ensure personnel safety.
Relevance for other driving forces (Group / driving force)	
Business models and stakeholders / Business models for flexibility Loads / Electrification of transport and industry Loads / Power intensive and energy efficient appliances increasing peak loads Technology development / Batteries and other energy storages	

Table 5 shows a mini scenario example for the driving force *automated operation*. The mini scenario pictures a development with robotics and artificial intelligence used to automate some of the operation and maintenance tasks in the grid. The mini scenario has a positive impact on security of supply, economy and safety.

Table 5: Mini scenario for the driving force *Automated operation*.

Driving force: Automated operation **Driving force group: Grid operation**	
Mini scenario title: "Robotics and artificial intelligence"	
Robots and artificial intelligence monitor the grid and controls the emergency preparedness. Robots take over the contractor work and can carry out preventive maintenance such as vegetation management. The technology development can e.g. lead to cost savings through shorter duration of fault localisation and faster service restoration.	
Impact on grid performance	
Security of supply	Shorter interruption durations and fewer interruptions
Economy	Decreased OPEX (faster fault handling)
Cybersecurity	
Safety	Improved personnel safety through faster fault handling and avoidance of manual work.
Relevance for other driving forces (Group / driving force)	
Technology development / Sensors, IoT, Unmanned Aerial Vehicles, robots, Phasor Measurement Units Technology development / Artificial Intelligence (AI), big data analytics, machine learning, use of data, increasing computational power Grid operation / Real-time monitoring and control Security of supply / Reliability of supply and voltage quality requirements Security of supply / Emergency preparedness Safety / Personnel safety Economy / Cost of energy not supplied	

Table 6 shows a mini scenario example for the driving force *real-time monitoring and control*. The mini scenario concerns overload of data for the grid operator resulting in wrong decisions during fault handling, and has a negative impact on security of supply, economy and safety. An operator fault may also be a risk to the cybersecurity, even if this specific mini scenario does not imply that directly.

Table 6: Mini scenario for the driving force *Real-time monitoring and control*.

Driving force: Real-time monitoring and control **Driving force group: Grid operation**	
Mini scenario title: "Information overload"	
Technology development results in cheaper sensor devices and the investments are increasing. This results in many measurement devices in the grid, leading to a massive increase in the amount of data for monitoring the system. Software for data processing and decision support have not been prioritised. The grid operator is not able to analyse all the data fast enough and is making wrong actions during fault handling. This leads to longer interruption durations and the OPEX increases.	
Impact on grid performance topics	
Security of supply	Interruption duration may increase due to longer duration of the fault location, isolation and restoration process.
Economy	Increased OPEX (interruption costs).
Cybersecurity	If important information is neglected, cybersecurity may be threatened.
Safety	Personnel safety may be put at risk.
Relevance for other driving forces (Group / driving force)	
Grid operation / Automated operation Grid operation / Workforce/human in loop Security of supply / Emergency preparedness Cybersecurity / ICT competence and organisational aspects	

Table 7 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 7: A mini scenario for the driving force Microgrid.

Driving force: Microgrid **Driving force group: Microgrids**	
Mini scenario title: More offline microgrids	
Many neighbourhoods are organised as microgrids. With 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	
Security of supply	End-users may experience decreasing security of supply due to off-grid solutions
Economy	Uncertain revenue for the grid company
Cybersecurity	Local solutions (+), but more automation (-)
Safety	Must be handled by the local community itself
Relevance for other driving forces (Group / driving force)	
Regulation and standardisation / Regulation and framework for grid management and grid customers Regulation and standardisation / Public support schemes Societal trends and values / Evolution of consumer values and behaviour Technology development / Batteries and other storages Generation / Distributed generation in MV and LV grid Loads / Change in demand (energy, power, power quality)	

Table 8 sums up the assessment of the impact on the grid performance for the selected mini scenarios. Some mini scenarios have a quite clear negative or positive impact on the grid performance, whereas other have a more uncertain impact. The research in CINELDI aims to provide new knowledge to reduce some of these uncertainties.

Table 8: Summary of the mini scenarios and their impact on the grid performance.

Driving force	Mini scenario title	Impact on grid performance			
		Security of supply	Economy	Cybersecurity	Safety
ICT competence and organisational aspects	Specialised expertise				
Energy storage as a flexible resource	From peak power to stable loads				
Automated operation	Robotics and artificial intelligence				
Real-time monitoring and control	Information overload				
Microgrids	More offline microgrids				

5 Use of results from the foresight process

The results from the foresight process have been utilized both in research activities in CINELDI and by user partners in CINELDI. This chapter gives some examples of how the results have been used so far and expectations for further use.

5.1 Examples of use in research activities in CINELDI

5.1.1 Use of driving forces for identification of needs and gaps in the future distribution system development

In one of the research activities in CINELDI, the aim has been to identify needs and gaps in the future distribution planning and asset management. The most prominent driving forces affecting the future planning and asset management were identified, and the driving forces were then evaluated in terms of their impact on different planning methodology aspects. This resulted in a table combining the particular driving forces and the different aspects of grid development, to gain insight into needs and gaps within planning methodology. Table 9 shows an extract of the mapping of the consequences.

Table 9: Mapping of driving forces on planning methodology aspects.

	Planning methodology aspect		
Driving force	**Load and generation estimation and forecasting**	**New network solutions (e.g. flexibility and microgrids as alternatives to investments)**	**…**
Distributed generation (DG)	Need for better methods for forecasting of generation, including uncertainty.	Need for methods to evaluate no-network solutions as alternatives to grid reinforcement	
Power intensive loads	Behaviour and uncertainty of new loads need to be included in the forecasting	Need for methods to evaluate no-network solutions as alternatives to grid reinforcement	
……			

In the table, the two driving forces distributed generation and power intensive loads are analysed in terms of how they influence on the planning methodology aspects; *load and generation estimation and forecasting* and *new network solutions*. As stated in the table, the driving force distributed generation will for instance lead to a need for better methods for generation forecasting of, including uncertainty.

5.1.2 Use of mini scenarios as check list for developed methodology

The repository of mini scenarios (examples of mini scenarios are given in Section 4.2) can be used as a checklist when developing new methodologies, models and tools to see that different plausible future scenarios are taken into account to ensure robust results for the future distribution system.

One example is that the repository of mini scenarios was used in a feasibility study of a method for identification and modelling of cybersecurity risks in the context of smart power grid [32]. The mini scenarios were used to check if all cybersecurity risks identified in the mini scenarios were included in the final risk model. In this specific case, the repository of mini scenarios didn't give any further modification of the risk model but was a useful basis for quality assurance of the model.

5.1.3 Use of mini scenarios for inspiration and direction of development of use cases

Use case methodology has been chosen as a common method for the multi-disciplinary research in CINELDI. The research groups working with Smart Grid operation have used the repository of mini scenarios as inspiration for the direction of development for use cases. More sensors in the grid and smart meters at every end-user from 1.1.2019 provides a lot of information about the grid state. One of the use cases that were developed is about utilisation of these data to improve the fault localisation in the LV-grid. In this use case, machine-learning techniques have been used to improve the fault localisation time based on the new information sources, as described in more detail in [33].

5.1.4 Evaluation of the impact for the DSO of the mini scenarios dealing with flexible resources

One of the research topics in CINELDI is to investigate the opportunities and challenges for utilising flexible resources in the distribution grid. The mini scenarios dealing with flexible resources have been selected from the repository and analysed according to the following questions:

- Which type(s) of flexible resource is included?
- Which actor initiates the event or development in the mini scenario?
- What expected consequence will the mini scenario have for the DSO? (It either requires a measure from the DSO, is neutral or gives new opportunities for the DSO).

The evaluation resulted in a nearly equal number of mini scenarios requiring a measure from the DSO as the number of mini scenarios giving new possibilities for the DSO. Only a few mini scenarios have a neutral impact, meaning business as usual.

The evaluation gives useful insight into challenges and possibilities for the grid related to the different flexible resources. This will be used as basis for the direction of further research activities within flexible resources in CINELDI.

5.2 Use of driving forces by CINELDI-partners – results from a survey

A survey was conducted among CNELDI-partners to retrieve insight into how the results from the foresight process have been used already and how the partners plan to use the results in the future.

5.2.1 Respondents of the survey

The survey was sent to all partners in CINELDI (29 in total) and had a response rate of 48 %. Figure 12 show what type of company the 14 respondents represent. The majority (nine) of the answers are from grid companies, in this case they are all DSOs.

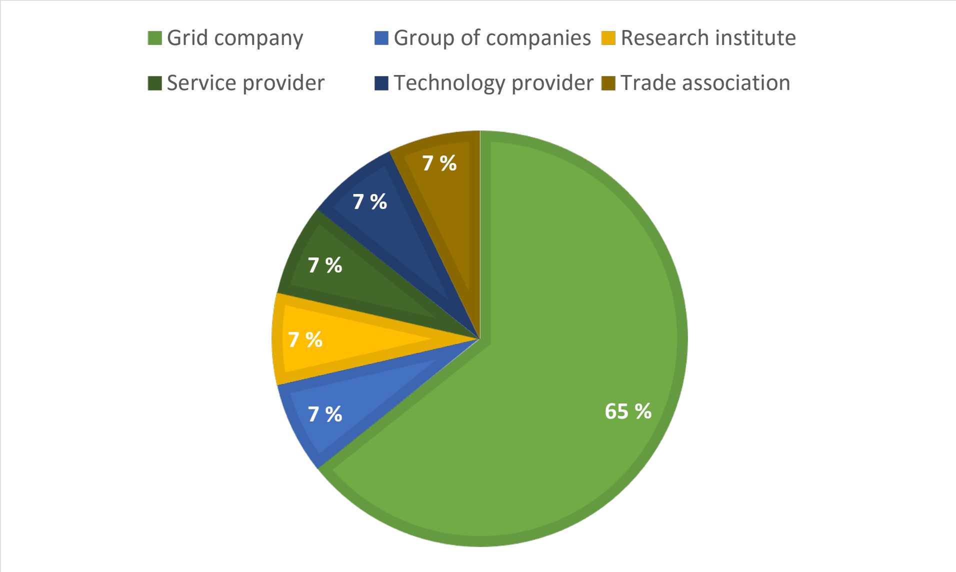

Figure 11: Distribution of the type of company the 14 respondents represent.

5.2.2 The results from the foresight process are already in use by some companies

The companies were asked if they have taken the results from the foresight process in use already. As shown in Figure 13, 29 % have taken the results in use already (in 2018), for instance in their strategic process.

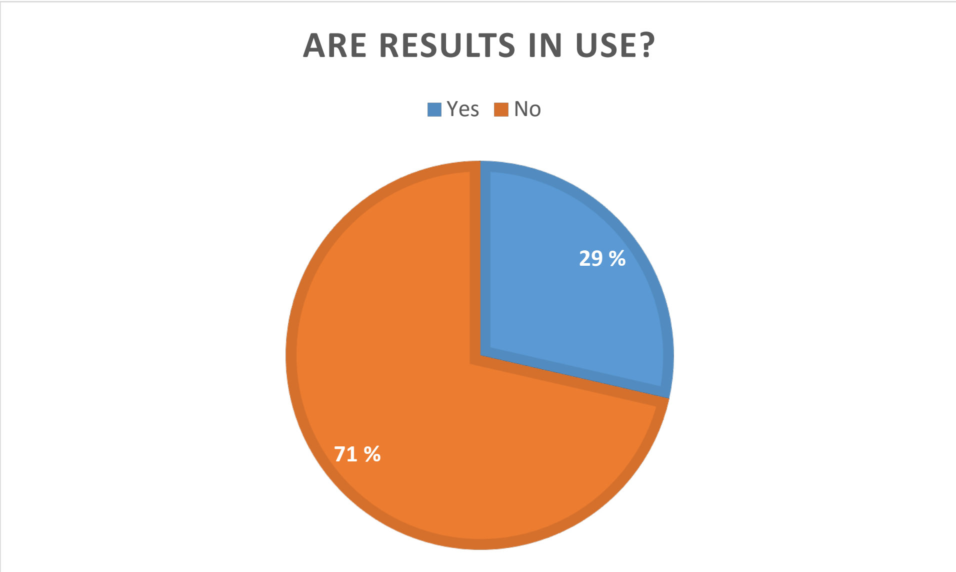

Figure 12: Four of the fourteen answers have taken the results from the foresight process in use already in 2018.

5.2.3 Plans for future use of the results from the foresight process at CINELDI-partners

The companies were in the survey asked how they expect to use the foresight results in the future, by answering how likely it is that they will use the results for the suggested range of application, as shown in

Figure 14. In general, at least 50 % of the respondents answer very likely or somewhat likely that they will use the results from the foresight process for all the suggested applications in Figure 14. In addition, at least 50 % of the respondents answer that they are very likely to use the results from the foresight process as basis for developing research and development strategy, for which expertise they will focus on in the human resource development, for developing demonstration and pilot cases and for developing the overall company strategy, as shown in the upper four bars in Figure 14.

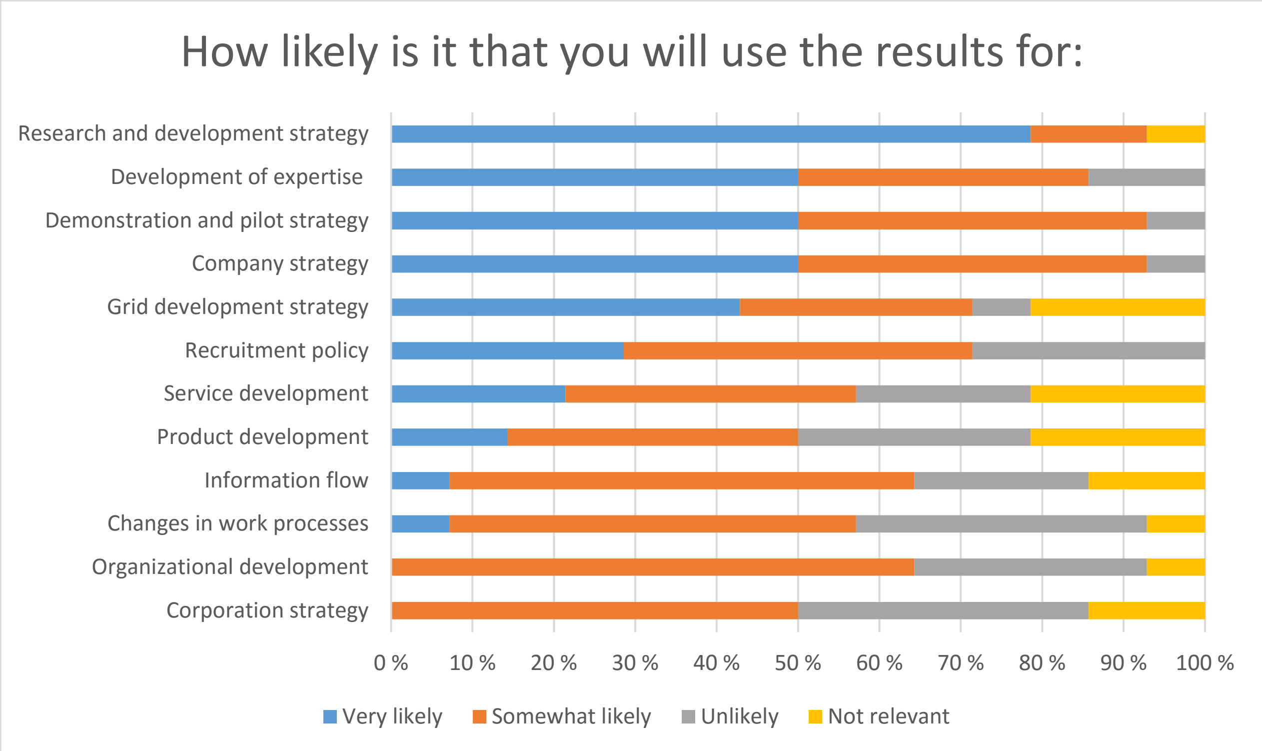

Figure 13: What the companies answer that they expect to use the results of this foresight process for in the future.

5.2.4 How can the grid companies prepare for an uncertain future?

A total of nine (out of thirteen) DSOs within CINELDI answered the survey. Based on their answers, some examples on how they use the results from the foresight process to prepare for an uncertain future were found.

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 operationalised. 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.

6 Conclusion and further work

This report 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 described and have further provided the foundation for developing mini scenarios. In total, more than 100 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 each other, which emphasises the need for distribution system innovation.

This work has been 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.

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 grid management.

The driving forces and mini scenarios form the basis for the development of main scenarios for the future distribution grid in Norway of 2040. A first set of proposals for main scenarios is under development. The work on driving forces and scenarios will be revisited later in the project, based on results from the research in CINELDI.

Based on the scenarios and the research, 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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Appendix A – List of driving forces

Table A1 shows an overview of the external driving forces, and Table A2 shows an overview of the grid related driving forces.

Table A1: External driving forces.

Topic	Driving force
Political goals	International political goals, policies and agreements
	National political goals and policies
	Local policies
	Interest organisations
Regulation	Authority regulation and frameworks for grid management and grid customers
	Public support schemes
	Standardisation
Societal trends and values	Level of prosperity, economic growth
	Competence and growing education level
	Media influence
	Evolution of consumer values and behaviour
Technology development	Power electronics
	Sensors, IoT, UAVs, mobile robots
	Machine learning and increased computational power
	Communication infrastructure (5G)
	Batteries and other energy storages
	Improved PV and wind power technologies
	Development of ICT tools
	Smart homes technologies and consumer electronics
	New and disruptive products and technologies
External threats (human, natural)	Natural threats
	Physical attacks, terror, sabotage
	Cyber attacks, hacking
	Unintended incidents, human errors
	Epidemics
	"Black swans"
Business models and stakeholders	Business models for solar cells
	Business models for energy storage (battery, hydrogen)
	Business models for demand response
	Market solutions for flexibility

Table A2: Grid related driving forces.

Topic	Driving force
Generation	Increased amount of distributed generation in MV and LV grid
	Increased share of intermittent electricity generation from renewables
Loads	Increased electrification of transport and industry / new loads
	More power intensive loads and energy efficient appliances
Flexibility	Energy storage as a flexible resource
	Flexible generation units
	Dispatchable loads as a flexible resource
Microgrids	Microgrid
Grid operation	Automated operation
	Real-time condition monitoring and control
	Workforce / human in the loop
	Customer service
Grid development	Ageing grid
	Available no-grid solutions
	Access to and quality of data
	Changes in grid systems and topologies
Security of supply	Energy availability
	Power capacity
	Reliability of supply
	Power quality
	Emergency preparedness
Safety	Personnel safety
Economy	Grid tariffs, energy pricing
	Cost of energy not supplied (CENS, interruption costs)
	Economic restraints at DSOs / revenue caps
Cybersecurity	ICT competence and organisational aspects
	Privacy protection
	Remote access and control

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