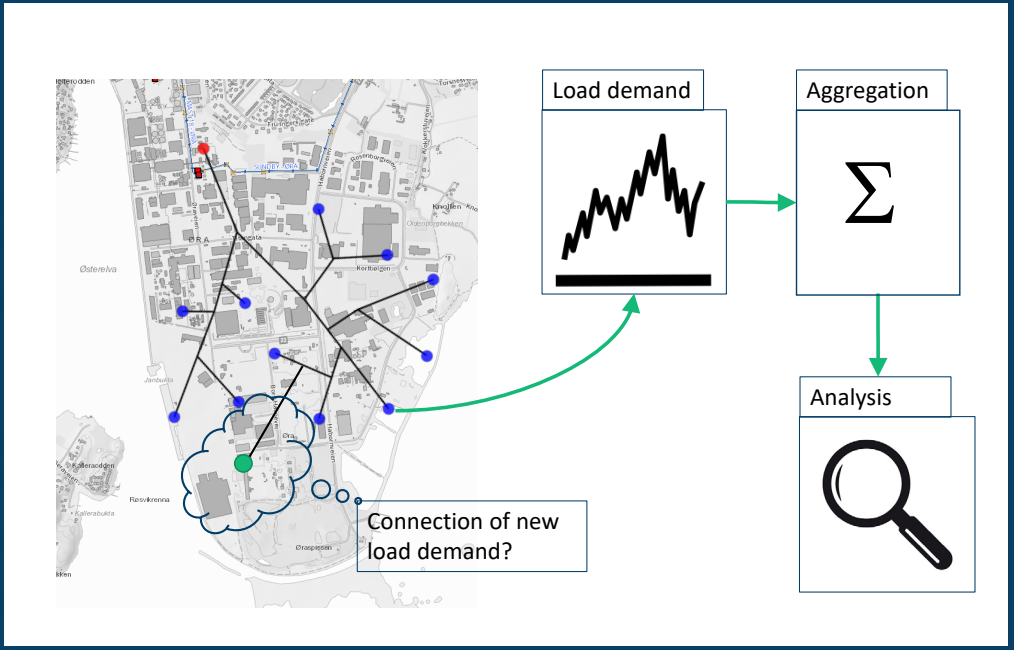

CINELDI
Centre for intelligent electricity distribution
- to empower the future Smart Grid
Norwegian Centre for
Environment-friendly
Energy Research
Selected CINELDI results 2022
for external use

CINELDI result: Code platform "Flexible Load Analysis" (WP1 / WP Pilot / WP5)

Challenge and objective:

- Load modelling is an important part of distribution grid planning to account for uncertainties and risks associated with load demand. A code platform is needed to analyse smart meter data and test the implications of different load modelling approaches.



Work performed:

- A code base was developed through a summer internship at SINTEF Energy Research, and continued work in 2021/2022.
- One example of a stochastic load modelling method (PhD work by Erling Tønne) is implemented.
- Load and grid data for the Øra Industrial area is used for testing in collaboration with Norgesnett in the pilot "Probabilistic planning methodology".

Significant results:

- A modular and flexible code platform implemented in Python for pre-processing and managing historic load demand data in a grid area, apply load modelling method(s), analysing the need for flexibility and run "what-if" analyses.

Impact for distribution system innovation:

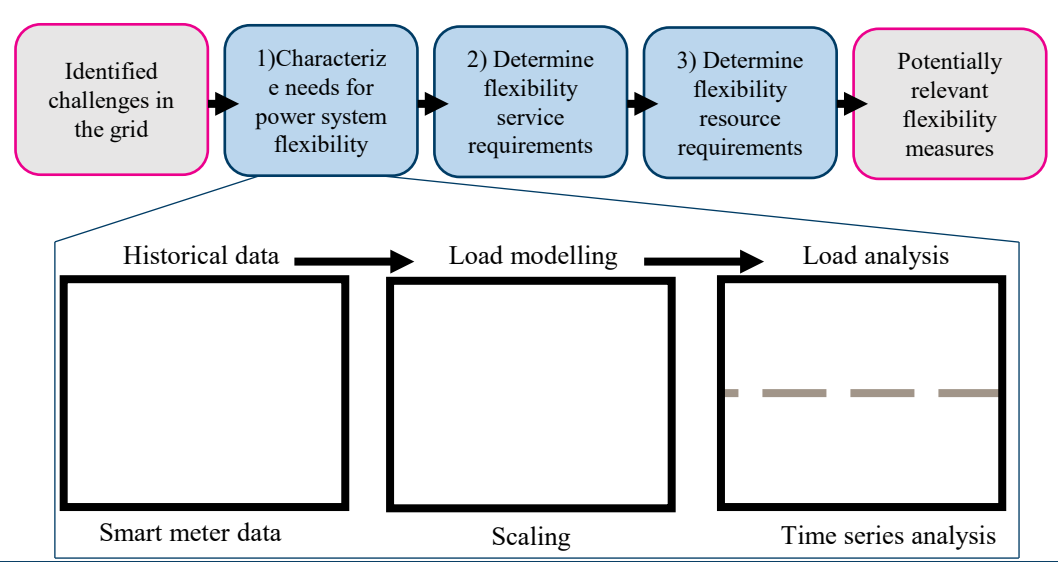
- Testbed for incorporating new load modelling approaches in distribution grid planning.
- Starting point for analysing, e.g., i) risks due to load uncertainty and ii) needs for flexibility in a grid area.

Reference in CINELDI:

- D. Bjerkehagen, S. Sandell , E. Haugen, I. B. Sperstad: "Flexible Load Analysis" (software), 2022. https://github.com/SINTEF-Power-system-asset-management/flexible_load_analysis

CINELDI result: Load Analysis for Evaluating Flexibility Needs in the Planning of an Industrial Distribution Grid (WP1 / WP Pilot)

Challenge and objective:
An increasing load demand in distribution grids drives the need for flexibility. However, traditional load modelling methods do not provide information about when and how much flexibility is needed. In this result, we used grid and load data from a Norwegian DSO to quantify the flexibility need in the grid.



Work performed:
- Grid and load data from a Norwegian DSO was collected and anonymized.
- Research code developed at SINTEF was used for analysing the data.

Significant results:
- The analysis results were presented at the SEST conference in September 2022, and published as a conference paper.
- The dataset was submitted to the journal Data in Brief.

Impact for distribution system innovation:
- The work represents an example of how to use AMS data for grid planning.
- The data set can be used by others who wish to study Norwegian industrial distribution grids.

References in CINELDI:
- S. Sandell, D. Bjerkehagen, I. B. Sperstad: "Load analysis for evaluating flexibility needs in the planning of an industrial distribution grid", 2022, DOI: 10.1109/SEST53650.2022.9898467
- S. Sandell, D. Bjerkehagen, B. Birkeland, I. B. Sperstad: "Dataset for a Norwegian medium and low voltage power distribution system with industrial loads". TechRxiv. Preprint. DOI: 10.36227/techrxiv.21334041.v1

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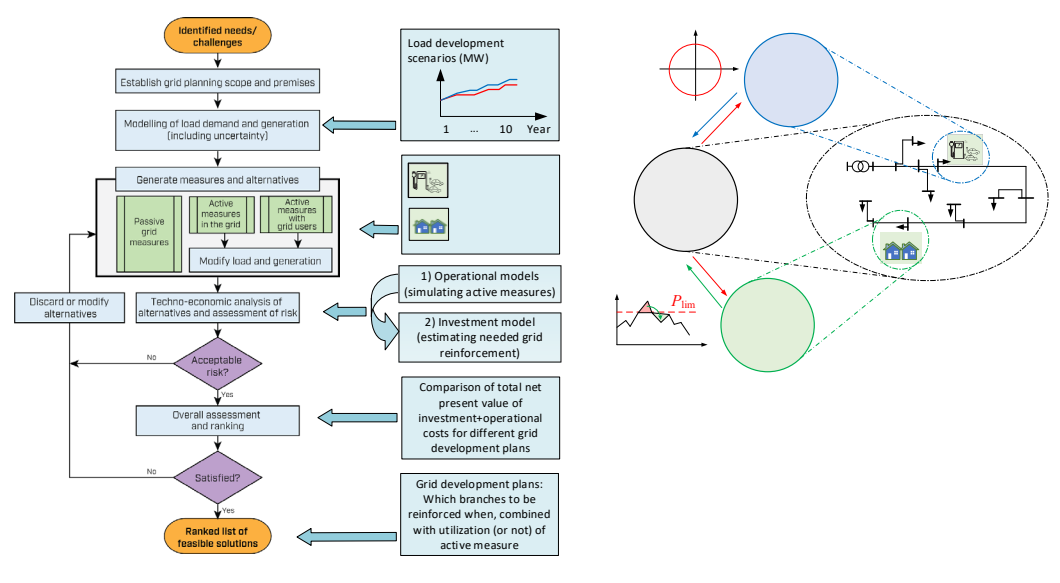
CINELDI result: Implementation of framework for distribution grid planning with active measures (WP1)

Challenge and objective:
DSOs need to compare cost-effectiveness of different active and passive measures, such as flexibility from fast-charging stations (FCSs) and local energy communities (LECs), and traditional grid reinforcement. This is addressed through implementing the framework for planning of active distribution grids previously developed in CINELDI.



Work performed:
- In collaboration with in-kind projects FuChar and FINE, operational models for FCSs and LECs as active measures are integrated in the CINELDI framework.
- Grid planning methodology implemented in Python.
- Demonstrated for the CINELDI MV ref. system.

Significant results:
- A model for estimating grid investment needs for combinations of active and passive measures.
- Economic assessment of active measures from both i) a DSO cost-benefit analysis perspective and ii) a willingness-to-pay / competitive-cost perspective.

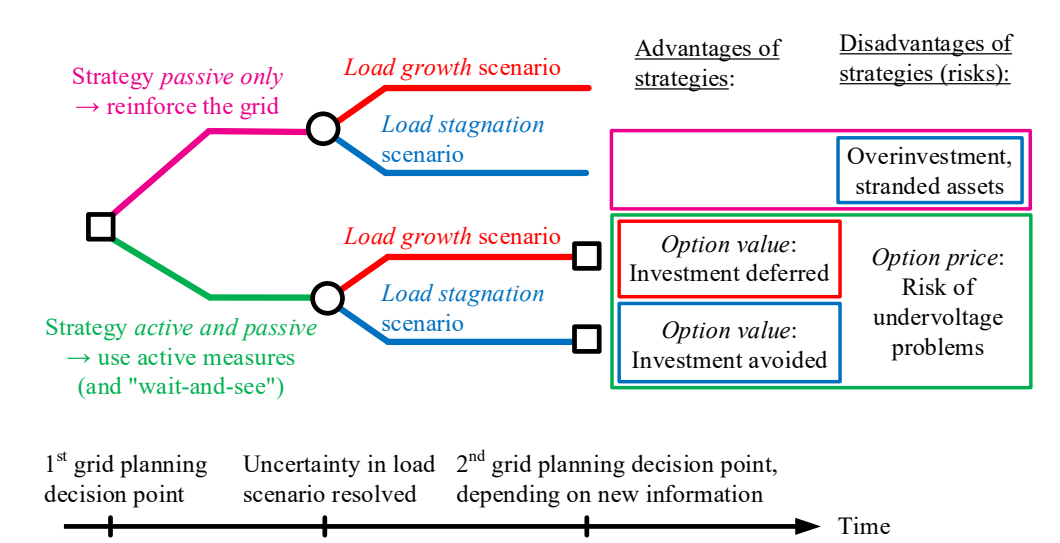
Impact for distribution system innovation:
- Can be used in negotiating the price of active measures between the DSO and distribution system actors such as LEC and FCS operators.
- The costs and benefits of other active measures can be assessed by integrating new operational models.

Reference in CINELDI:
- R. Rana, I. B. Sperstad, B. N. Torsæter, and H. Taxt: "Economic Assessment of Integrating Fast Charging Stations and Energy Communities in Grid Planning", pre-print version available at TechRxiv, 2022, DOI: 10.36227/techrxiv.21371817.v1

CINELDI result: Methodology for evaluating grid development strategies considering real option value and risk (WP1)

Challenge and objective:

Active measures gives the opportunity (real option) to postpone investment decision by waiting for new information about e.g. load growth. This is not captured in traditional net present value calculations. Moreover, active measures may come at the price of more operational problems, and this risk should be weighed against the option value of using active measures.



Work performed:

- Methodology for planning of active distribution grids was extended by 1) a real options approach to account for the uncertainty in load scenarios and 2) a method for assessing the risk of undervoltage.
- The methodology was tested for the CINELDI MV reference system considering flexibility from local energy communities as an active measure.

Significant results:

- An illustration of a scenario-based methodology for elucidating risks and real option values of different grid development strategies.

Impact for distribution system innovation:

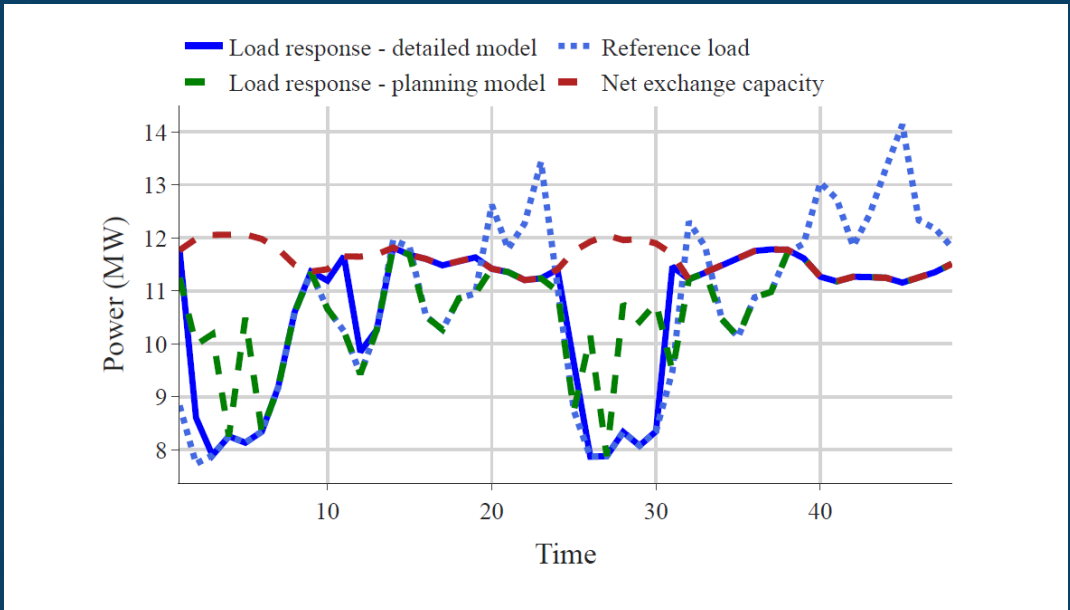
- The case study illustrates how some risk-taking is required to realize the value from using active measures to manage the long-term uncertainty in load scenarios.

Reference in CINELDI:

- I. B. Sperstad, R. Rana, and S. Sandell: "Methodology for Evaluating Grid Development Strategies Considering Real Options and Risks", preprint version available on TechRxiv, 2022. DOI: 10.36227/techrxiv.21731489.v1

CINELDI result: Demand flexibility modelling for optimal distribution grid planning (WP1)

Challenge and objective:
Tools for long-term optimal grid planning considering flexibility resources require aggregated flexibility models that are not too computationally demanding or complex. Still, they should capture the operational benefits of flexibility sufficiently accurately for planning purposes.



Work performed:
- In collaboration with in-kind project H2020 FlexPlan, an aggregated flexibility model is implemented in an open-source grid planning tool.
- This "planning model" is compared with a detailed demand flexibility model for electric water heaters and white goods.

Significant results:
- A case study demonstrates that it is important to take into account time dependences, rebound effects etc. characterising the flexibility resources (such as electric water heaters).

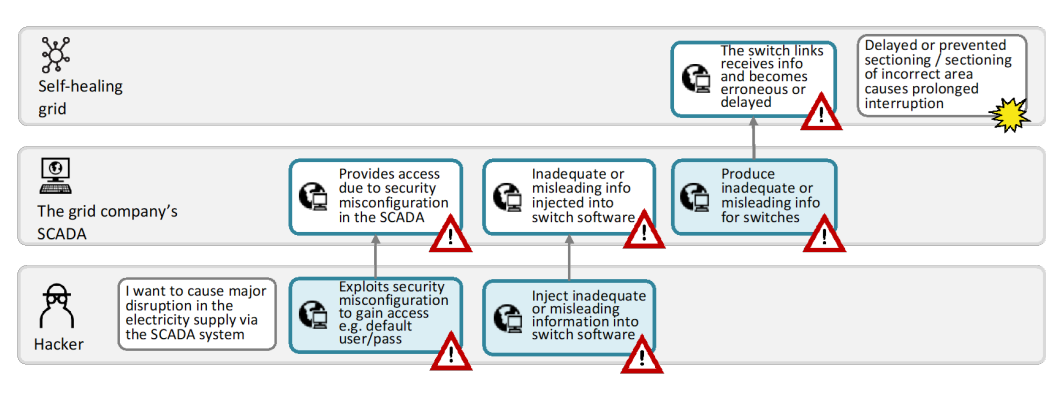
Impact for distribution system innovation:
- In assessing flexibility in grid planning studies, one should be aware that a too simple model of the operational behaviour of demand flexibility may overestimate the benefits as an alternative or supplement to grid investments.

Reference in CINELDI:
- E. F. Bødal, V. L., I. B. Sperstad, M. Z. Degefa, M. Hanot, H. Ergun, M. Rossi: "Demand flexibility modelling for long term optimal distribution grid planning", *IET Generation, Transmission & Distribution*, vol. 16, no. 24, pp. 5002–5014, 2022, DOI: 10.1049/gtd2.12651

CINELDI result: Cyber-risk assessment method for the planning phase of cyber-physical smart grids (WP1)

Challenge and objective:

- We need to consider cyber-risks when assessing and comparing planning alternatives for cyber-physical smart grids
- Available information will typically be at an aggregated level at this stage, and non-experts must carry out the cyber-risk assessment
- There is a need for a low threshold risk evaluation method to assess high-level cyber-risks already in the grid planning phase



Work performed:

- Using "Customer Journey Modelling Language" (CJML) high-level cyber-risks are modelled
- The concept is tested on a case assuming a hacker gets unauthorized access to a SCADA system and manipulates breakers in a self-healing grid, leading to power outages (attacking security of supply)

Significant results:

- An initial version of a cyber-risk assessment method for the planning phase of cyber-physical smart grids.
- Preliminary case testing suggests that it is possible to create high-level cyber-risk models with limited information about the planning alternatives.

Impact for distribution system innovation:

- Comparison of different alternatives can be significantly improved, if cyber-risks are included already at the planning stage.
- Better informed decisions can be made.

Reference in CINELDI:

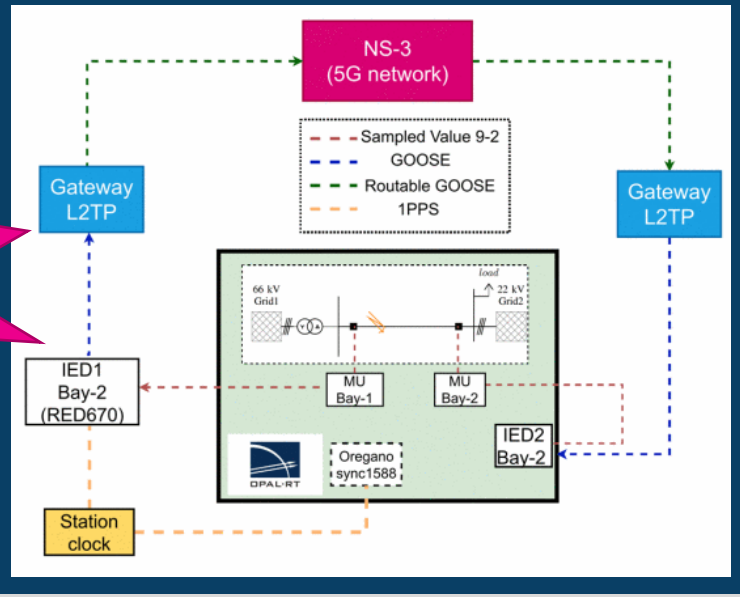
- G. Erdogan, I.B. Sperstad, M. Garau, O. Gjerde, I.A. Tøndel, S. Tokas, M.G. Jaatun: "Adapting Cyber-Risk Assessment for the Planning of Cyber-Physical Smart Grids Based on Industrial Needs", CCIS, Springer, 2023.

CINELDI result: A real-time cyber-physical testbed to assess protection system traffic over 5G networks (WP2)

Challenge and objective:

- The fifth-generation (5G) mobile network promises to offer low latency services. Hence, there is interest in assessing various power distribution grid applications that can be deployed with a 5G infrastructure. However, as these systems are quite new, there is a lack of cyber physical testbeds and tools to assess the use of 5G for smart grid applications such as protection functions.

BEST PAPER IEEE SmartGridComm 2022



Work performed:

- a real-time cyber-physical testbed/co-simulation platform for analysing protection systems deployed in 5G networks is developed.
- 5G emulation based on open-source ns-3 (using 5G New Radio (NR) modules and 4G EPC) is developed.
- Characterisation of the testbed using a case study.

Significant results:

- The performance of the testbed was evaluated by demonstrating a Permissive Underreaching Transfer Trip (PUTT) protection scheme utilising a 5G network and the evaluation of showed promising results.

Impact for distribution system innovation:

- The real-time testbed especially the network emulation using ns-3 is a low-cost solution that offers researchers in acadamia or industry, the ability to identify network challenges when testing performance of IEDs and protection schemes under 5G network conditions.

Reference in CINELDI:

- C.M. Adrah, M.K. Katoulaei, T. Amare, D. Palma: "A real-time cyber-physical testbed to assess protection system traffic over 5G networks. In 2022 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm) (pp. 71-75). IEEE, 2022, DOI: 10.1109/SmartGridComm52983.2022.9961007

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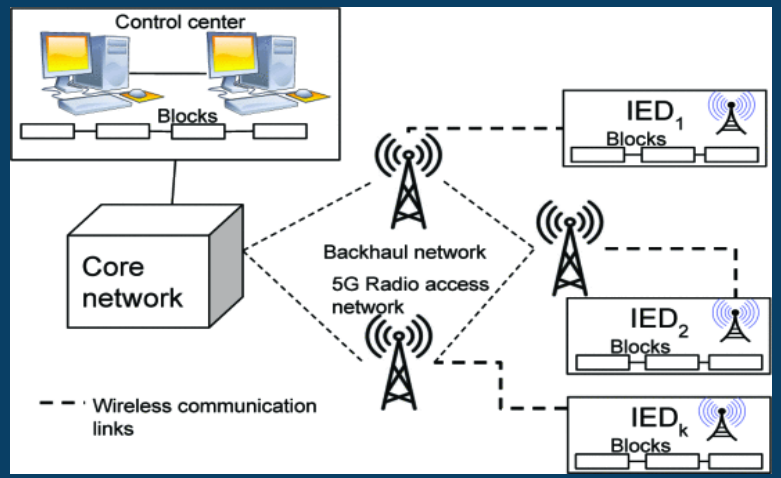
CINELDI result: Blockchain Support For Time-Critical Self-Healing In Smart Distribution Grids (WP2)

Challenge and objective:

- Self-healing is a function whereby Intelligent Electronic Devices (IEDs) can automatically reconfigure the power circuits to isolate faults and restore power to the relevant sections. A self-healing application may be faced by challenges of emerging cyber-physical security threats, affecting the power system reliability. In this work, a novel concept using blockchain as a second-tier security mechanism to support time-critical self-healing operations in smart distribution grids is proposed.



Work performed:

- Proposed architecture that utilise blockchain as a second-tier security layer to validate the time critical messages in a self-healing application.
- Simulation study was conducted to illustrate how the proposed method performs.

Significant results:

- The simulation analysis showed that the proposed architecture results in less downtime (no power state) for the DSO considered when compared to a normal self-healing.

Impact for distribution system innovation:

- The proposed architecture can improve the cyber-physical security for real-time self-healing in the distribution systems (by reversing some actions) thereby increasing the grid immunity towards cyber-physical attacks.
- The proposed blockchain technology can also maintain the bookkeeping which can be used to learn and analyse the vulnerabilities from successful cyber-attacks and improve the cyber security of the grid in the long term.

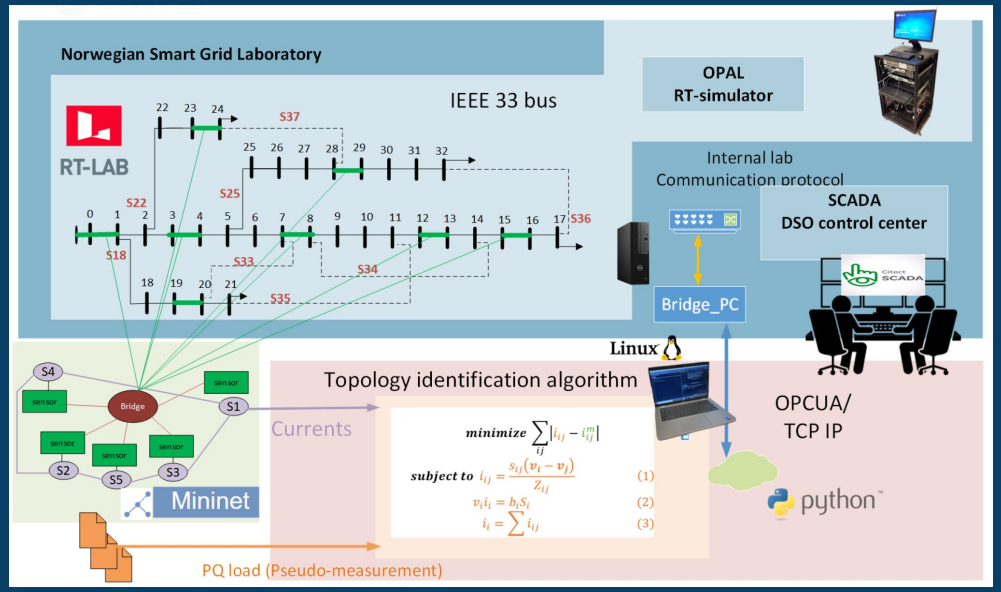
Reference in CINELDI:

- B.G. Gebraselase, C.M. Adrah, T. Amare, B.E. Helvik, P.E. Heegaard: "Blockchain Support For Time-Critical Self-Healing In Smart Distribution Grids", 2022 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe) (pp. 1-6). IEEE, DOI: 10.1109/ISGT-Europe54678.2022.9960615

CINELDI result: Cyber-Physical Power System Testing Platform for Topology Identification in Power Distribution Grids (WP2)

Challenge and objective:

- The transformation of passive electric power distribution grids (PDG) towards active ones relies heavily on digital and communication technologies to perform advanced functionalities such as optimal power flow or state estimation. The knowledge of the PDG topology is a fundamental requirement for enabling these functionalities.



Work performed:

- Analyze the topology identification algorithm developed in the literature under conditions of errors in the measurements and the pseudo-values inside a cyber-physical power platform.

Significant results:

- Topology Identification accuracy and robustness against error in the sensor and pseudo-measurements are tested in the CPPS platform. The results show that errors in the line current sensor with the communication layer are not as significant as the errors in the pseudo-measurements.

Impact for distribution system innovation:

- Helps the Distribution network operators to be able to identify topology of their MV and LV network by using different mix of measurements.

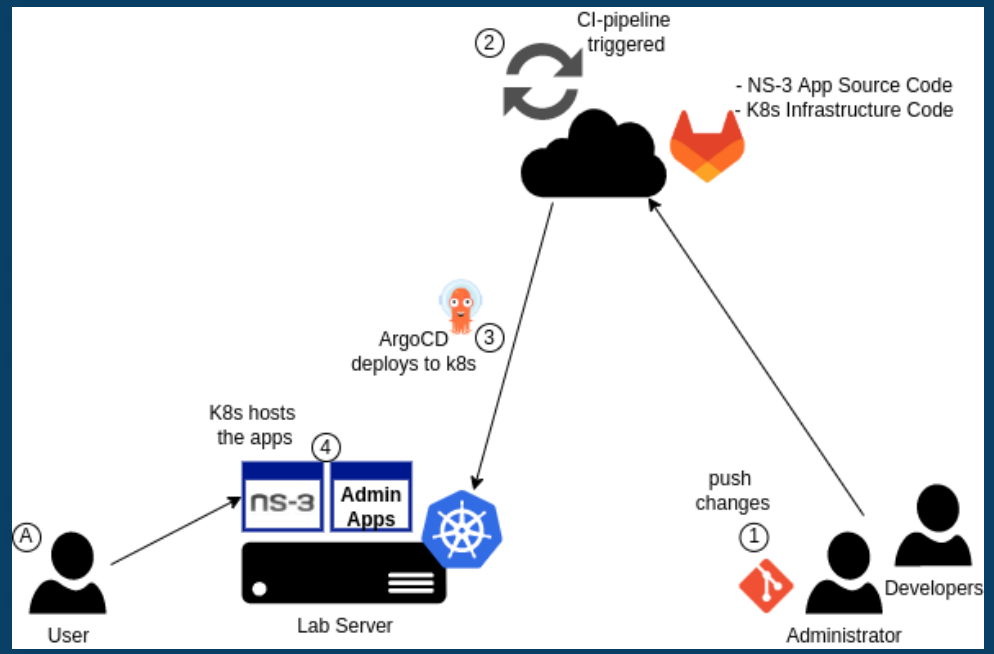
Reference in CINELDI:

- R.E. Torres-Olguin, S. Sanchez-Acevedo, O. Mo, A. Garc´es-Ruiz: "Cyber-Physical Power System Testing Platform for Topology Identification in Power Distribution Grids", PowerTech 2023, DOI: 10.1109/PowerTech55446.2023.10202733

CINELDI result: Infrastructure-as-Code SmartGrid lab (WP2)

Challenge and objective:

- Wanted an Infrastructure-as-code "Lab in a box"
- Highly configurable
- As automated as possible
- An on-premises solution based on cloud technology



Work performed:

- Installation of a self-managed, on-premise Kubernetes platform running ns3 network simulator

Significant results:

- Prototype solution documented in MSc thesis https://uis.brage.unit.no/uis-xmlui/handle/11250/3007299

Impact for distribution system innovation:

- Easier access to laboratory facilities for small-scale virtual experiments

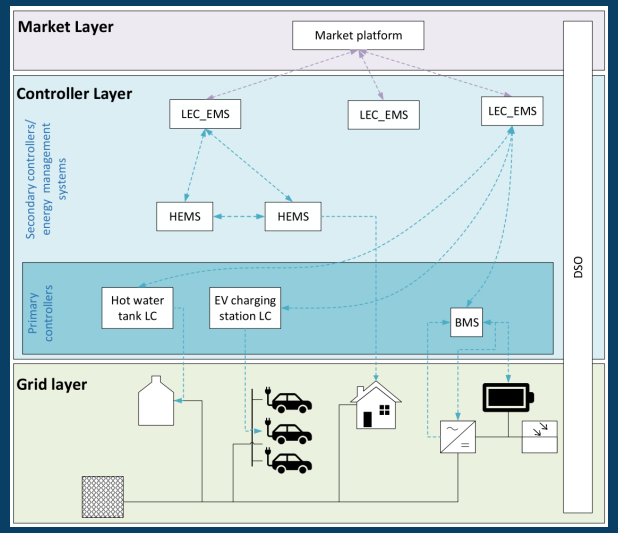
Reference in CINELDI:

- H. Teppan, L.H. Flå, M.G. Jaatun: "A Survey on Infrastructure-as-Code Solutions for Cloud Development", 2022 IEEE International Conference on Cloud Computing Technology and Science (CloudCom) (pp. 60-65). DOI: 10.1109/CloudCom55334.2022.00019

CINELDI result: Modelling and Simulation Approaches for Local Energy Community Integrated Distribution Networks (WP2/FINE)

Challenge and objective:

- Modelling and simulation of Local Energy Communities (LECs) and their operation is essential for studying and planning LECs integrated in the distribution network, recommending the right regulatory measures and designing market architectures. The aim of this work was to do a literature review of modelling practices to study a LEC integrated in a distribution network.



Work performed:

- Modelling LECs and the environment they operate in involves a holistic approach consisting of different layers: market, controller, and grid.
- Different LEC modelling approaches are reviewed and presented, several multilayered concepts for LECs are proposed, and a case study is presented to illustrate a holistic simulation where the different layers interact.

Significant results:

- The review found that the grid layer is missing in most simulation studies concerning LECs

Impact for distribution system innovation:

- DSOs will have methods to model and analyze impacts of LEC integration in their system.

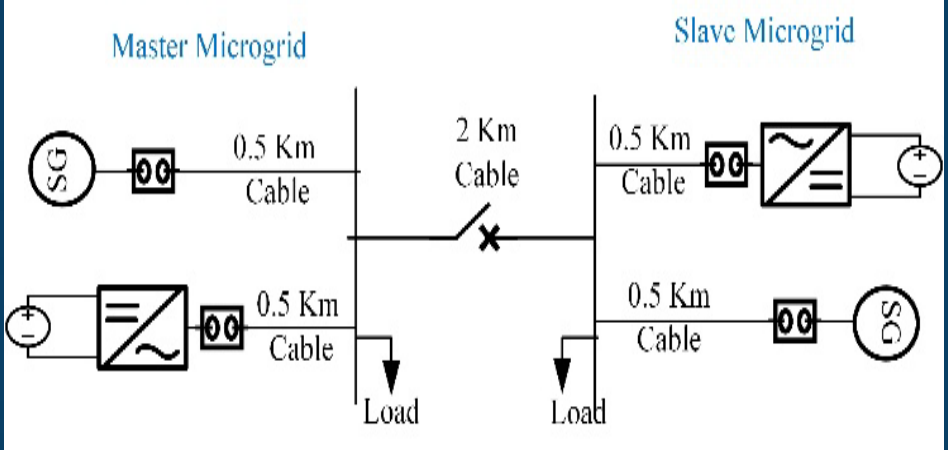
Reference in CINELDI:

- R. Rana, K. Berg, M.Z. Degefa, M. Löschenbrand: "Modelling and simulation approaches for local energy community integrated distribution networks", *IEEE Access*, *10*, pp.3775-3789, **DOI:** 10.1109/ACCESS.2022.3140237

CINELDI result: Synchronization Controller for Seamless Interconnection of Mirogrids with Heterogeneous Sources (WP2/MultiGrid)

Challenge and objective:

- Proposes a synchronization controller to enable a seamless transition from standalone to interconnected operation of two microgrids.



Work performed:

- The necessity of following synchronization protocols and the flexibility one can have when interconnecting different microgrids with inverter and rotating machine based systems, as well as homogeneous and heterogeneous sources are investigated. In addition, a simple controller is proposed to have seamless, quick and stable interconnections when the microgrids consist of rotating machines.

Significant results:

- Implications on interconnection protocols while synchronizing multiple microgrids with each other are highlighted.

Impact for distribution system innovation:

- More insight to host multiple microgrids in the distribution network.

Reference in CINELDI:

- A. Gupta, C. Perumalla, M.Z. Degefa, S. D'Arco, J.R.A. Klemets: "Synchronization Controller for Seamless Interconnection of Mirogrids with Heterogeneous Sources", 1st National Power Systems Conference (NPSC) (pp. 1-4). IEEE, 2022, DOI: 10.1109/NPSC57038.2022.10069869

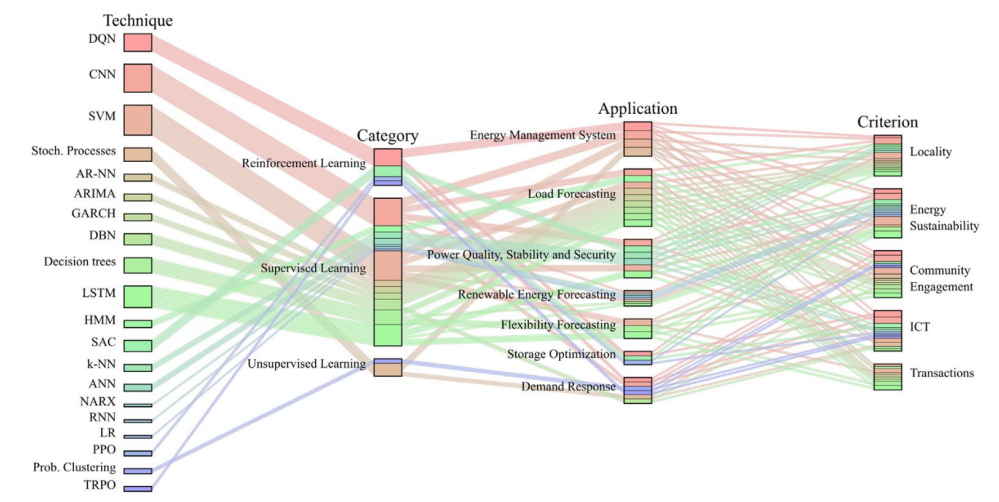
CINELDI result: A systematic review of machine learning techniques related to local energy communities. (WP2/FINE)

Challenge and objective:

In summary, the contributions of this paper are as follows:
1. A conceptualisation of LECs from a European perspective
2. An extensive review of state-of-the-art machine learning literature associated with LECs
3. Detailed applications of machine learning methods within LECs
4. An evaluation of and the future outlook on machine learning methods that are utilised in LECs

Work performed:

- This result presents the conceptualisation of a local energy community on the basis of a review of 25 energy community projects. Furthermore, an extensive literature review of machine learning algorithms for local energy community applications was conducted, and these algorithms were categorised according to forecasting, storage optimisation, energy management systems, power stability and quality, security, and energy transactions.



Reference in CINELDI:

- A. Hernandez-Matheus, M. Löschenbrand, K. Berg, I. Fuchs, M. Aragüés-Peñalba, E. Bullich-Massagué, A. Sumper: "A systematic review of machine learning techniques related to local energy communities. Renewable and Sustainable Energy Reviews", 170, p.112651, 2022, https://doi.org/10.1016/j.rser.2022.112651

CINELDI result: A data set of a Norwegian energy community (WP2/FINE)

Challenge and objective:

- There is limited data and experience on Norwegian energy community.
- Dataset is required for studying LECs and their impact.

Data set	Sheet	Data in sheet
Household consumption[a]	*Households_raw*	Ratio of maximum load [ratio]
	Households_filtered	Filtering of groups A-D [ratio], fitted to a normal distribution.
Appliance consumption	*Appliances_filtered*	Ratio of maximum load for dishwasher, dryer and washing machine [ratio], fitted to an exponential distribution.
Electric vehicle charging	*EVcharging_filtered*	Filtered values of charging start probability [%] and charging duration [h], fitted to an exponential distribution.
Photovoltaic power generation	*PV_raw*	Power [Wh/h] for measuring locations in areas NO1-NO5
	PV_filtered	Filtered values [Wh/h] for areas NO1-NO5, fitted to a normal distribution.
Wholesale electricity price	*WholesalePrice_filtered*	Elspot price [Eur/MWh] for areas NO1-NO5, fitted to a log-normal distribution.

Work performed:

- Publish a data set designed to represent Norwegian energy communities.
- All data sets are filtered by season, weekday/weekend and time segment, and then fitted to either a normal, exponential or log-normal distribution.

Significant results:

- Data set consisting of a composition of previously unpublished data sets, filtered data sets and simulated data.

Impact for distribution system innovation:

- DSO can use dataset to study by simulation the impact of LECs in the distribution network.

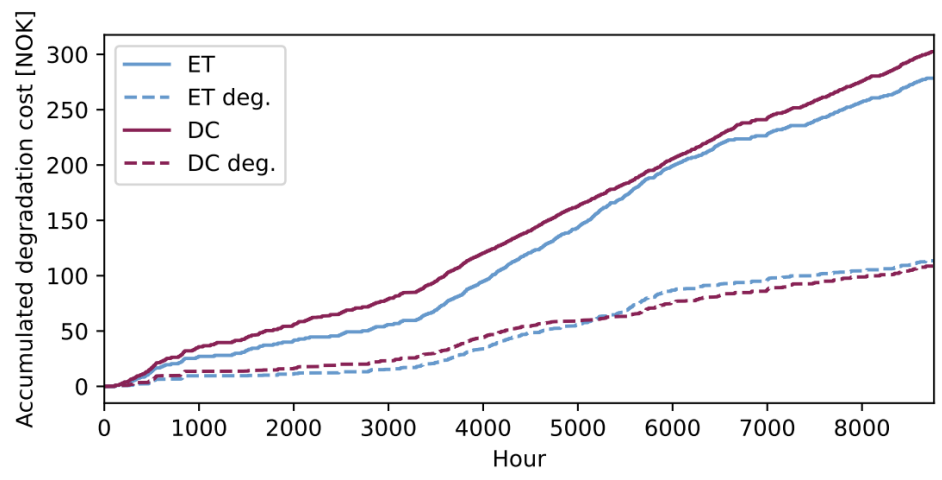
Reference in CINELDI:

- K. Berg, M. Löschenbrand: "A data set of a Norwegian energy community", Data in Brief, 40, p.107683, https://doi.org/10.1016/j.dib.2021.107683

CINELDI result: The impact of degradation on the investment and operation of a community battery for multiple services (WP2/FINE)

Challenge and objective:

- The aim of this work is to investigate how degradation impacts the investment and operation of a community battery which performs multiple services in a LEC.



Accumulated degradation costs for each case [ET: Energy Tarrif; ET deg: Energy Tarrif with degradation; DC: Demand Charges; DC deg: Demand Charges with degradation], with and without degradation

Work performed:

The main contributions of the work presented in this article are:

- Optimisation models for investment and operation of shared PV and battery system in a LEC, including cyclic degradation cost.
- Evaluation of how two different grid tariff schemes impact battery operation and degradation.
- Evaluation of how the battery performs multiple services for the LEC when degradation cost is included.

Significant results:

- The case study set in Norway 2030 shows that the lifetime of the battery is significantly shortened when not considering degradation, highlighting the need to include cyclic degradation in models that investigates the profitability in investment and operational problems with batteries.

Impact for distribution system innovation:

- Network operators will get more insight on how to use battery for multiple services without compromising ageing.

Reference in CINELDI:

- K. Berg, S. Bjarghov, R. Rana, H. Farahmand: "The impact of degradation on the investment and operation of a community battery for multiple services", 18th International Conference on the European Energy Market (EEM) (pp. 1-8). IEEE, 2022, DOI: 10.1109/EEM54602.2022.9921037

CINELDI result: Designing grid tariffs and local electricity markets for peak demand reduction in distribution grids (WP3)

Challenge and objective:

- Designing grid tariffs that are cost reflective, fair and efficient?
- Ensuring efficient coordination of flexible resources in distribution grids through price signals and local electricity markets

Work performed:

- PhD thesis submitted, including three articles from 2022:

1) Capacity subscription grid tariff efficiency and the impact of uncertainty on the subscribed level
2) Grid Tariffs for Peak Demand Reduction: Is there a Price Signal Conflict with Electricity Spot Prices?
3) A Comparison of the Peak Demand Reduction Performance of Various Energy-based and Capacity-based Tariffs at Different Grid Levels

Significant results:

- Ph.D. thesis defended
- Large comparison of grid tariff design performance on multiple grid levels on a realistic case study

Impact for distribution system innovation:

- Provides knowledge for decision-makers on grid tariff design choice, as well as the importance of good coordination mechanisms that handles coincidence factors in distribution grids

Reference in CINELDI:

- Doctoral thesis, "Designing grid tariffs and local electricity markets for peak demand reduction in distribution grids", Sigurd Bjarghov, NTNU, December 2022

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CINELDI result: A Long-term Strategy Framework for Flexible Energy Operation of Residential Buildings (WP3)

Challenge and objective:

- How to represent long-term price signals to short-term operational models for energy management in buildings to better operational performance?
- Represent the long-term value of flexibility and incorporate long-term price signals into residential building operation

LOSTFUTURE – **Lo**ng-term **St**rategy Framework for **Future** Building Operation

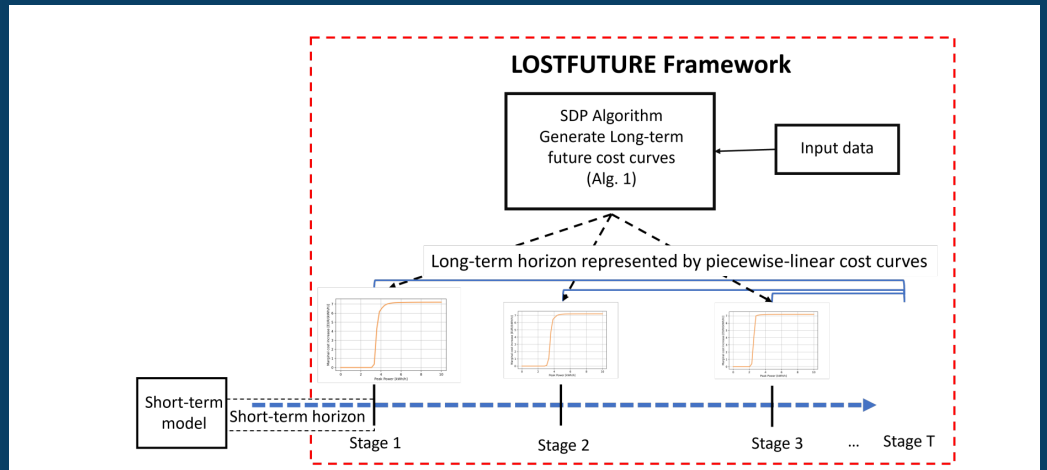


Figure 3.1: Illustration showcasing the purpose of the LOSTFUTURE Framework. The framework generates future cost curves that act as future price signals for a short-term operational model.

Work performed in 2022:

- PhD-thesis submitted, where:

1. A general long-term strategy framework has been formulated for energy management of buildings (LOSTFUTURE)
2. A paper published in IJEPES June 2022 looked at long-term value of flexibility for demand charge reduction by individual contribution from flexible assets in a household

Significant results:

- PhD-thesis successfully defended
- The framework has multiple purposes for representing long-term price signals, all from monthly demand charge grid tariffs to seasonal storage units

Impact for distribution system innovation:

- Framework provides a way to make better use of flexibility in buildings for more long-term use, which could be extended to also include system perspective needs such as system services

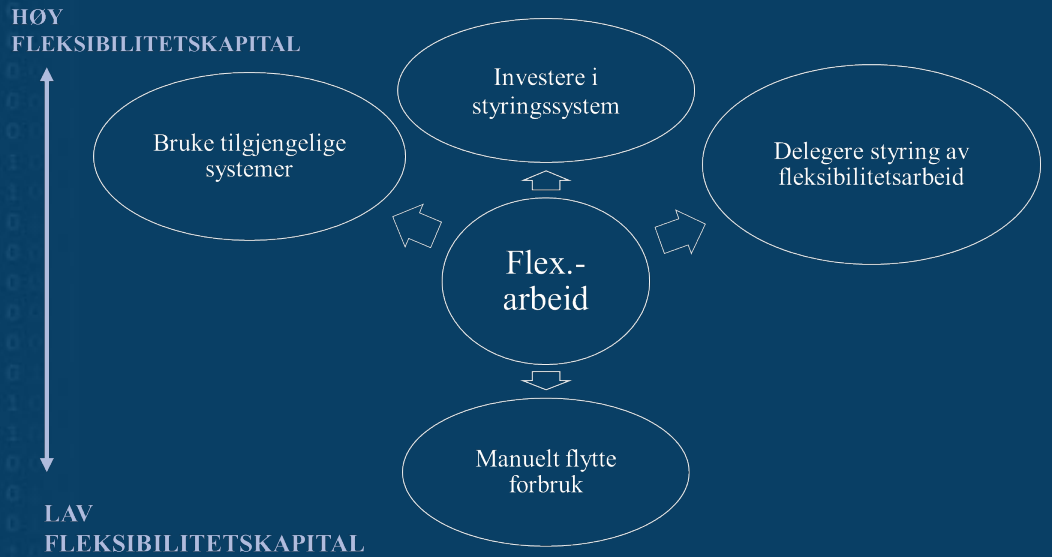
Reference in CINELDI:

- Doctoral thesis, "A Long-term Strategy Framework for Flexible Energy Operation of Residential Buildings", Kasper Emil Thorvaldsen, NTNU, November 2022

CINELDI result: Just Flexibility? The Envisioned Role of End Users in Future Electricity Systems (WP3)

Challenge and objective:

- Energy demand and everyday energy use has gained increased attention as an element of reducing carbon emissions and combating climate change
- The thesis draws on social science perspectives on energy, primarily from science and technology studies (STS).



Work performed:

- PhD-thesis submitted, including four articles:

1) identifies how expert actors in industry and researchers who work within smart energy developments envision solutions to encourage more flexible electricity consumption among end-users.
2) deals with different framings of flexibility among traditional householders and experts and the potential social consequences of more flexible electricity consumption for the users.
3) studies material, structural and social factors of students' electricity consumption and their under-standings of flexible consumption, individually and collectively.
4) focuses on rigid and flexible household consumption and studies changes in energy cultures in recent decades, and how these changes relate to increased demand for flexibility.

Significant results:

- Highlighting the role of electricity consumption in daily life, and how social life and societal structures enforce temporal rhythms that create peaks of electricity consumption.

Impact for distribution system innovation:

- Knowledge about households and their focus on electricity consumption

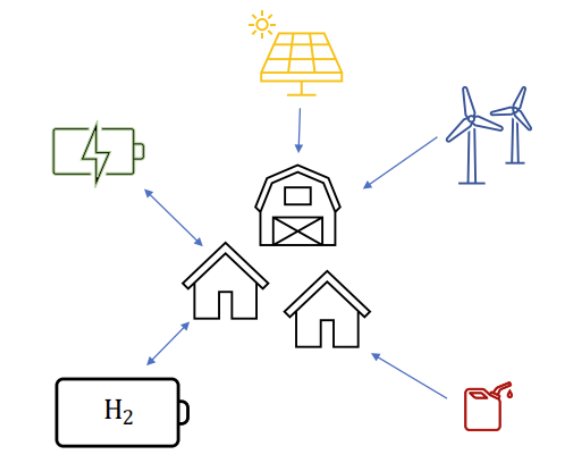
Reference in CINELDI:

- Doctoral thesis, "Just Flexibility? The Envisioned Role of End Users in Future Electricity Systems", Ingvild Firman Fjellså, NTNU, October 2022

CINELDI result: PhD thesis - Optimal coordination of renewable sources and storage in energy-constrained power systems (WP3)

Challenge and objective:

- Develop methods for providing cost efficient and safe operation strategies of local power systems with energy storage systems (ESSs) and high levels of variable renewable energy sources (VRESs).
- Develop stochastic optimization methods for operating VRESs and ESSs considering both short- and long-term uncertainties.



Work performed:

- Describe the electricity price formation process in competitve local power systems with ESSs and high level of VRESs.
- Analyse the operation of an islanded microgrid with ESSs and VRESs where the dispatchable generation capacity is a limiting factor.

Significant results:

- Stochastic methods can both reduce the operation costs and reduce the risk of lost load compared to determinstic and rule-based operation strategies.

Impact for distribution system innovation:

- Active operation of distributed resources, such as ESSs and demand side flexibility, can reduce operation costs and increase the security of supply.

Reference in CINELDI:

- Doctoral thesis, "Optimal coordination of renewable sources and storage in energy-constrained power systems", Per Aaslid, NTNU, June 2022

CINELDI

CINELDI result: Electric Vehicle Adoption Dynamics on the Road to Deep Decarbonization (WP3)

Challenge and objective:

- Quantify the role of electric vehicles in deep decarbonization pathways
- Illustrate implications of long-term electrification targets for near-term EV policy
- Review electric vehicle economics, technology, and policy

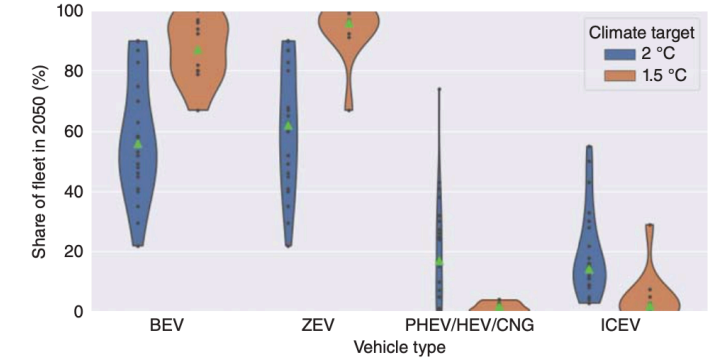


Figure 8.1 Shares of vehicle technologies in the passenger vehicle fleet across decarbonization scenarios. Each dot represents a scenario. Green triangles represent median values computed across all scenarios. The shaded areas represent densities, with the width illustrating the prevalence of scenarios at a given value. Where scenarios presented a range of values, the figure uses the central estimate. Several scenarios [4, 58, 60] were categorized under 2 °C. BEV, battery electric vehicle; ZEV, zero emission vehicle; PHEV/HEV/CNG, plug-in hybrid electric vehicle/hybrid electric vehicle/compressed natural gas; ICE, internal combustion engine vehicle. For each scenario, ZEV, PHEV/HEV/CNG, and ICE shares add up to 100%. Some differences in fleet definitions exist between scenarios (see Table 8.1).

Work performed:

- Meta-analysis of deep decarbonization pathways for 2C and 1.5C
- Stock-flow simulation modelling of fleet turnover
- Literature review of EV economics, technology and policy

Significant results:

- The fleet share of zero-emission vehicles ranges between 22% and 90% (median of 62%) in 2 °C scenarios and between 67% and 100% (median of 96%) in 1.5 °C scenarios.
- Reaching 1.5C requires that policy makers both increase EV sales and accelerate the retirement of internal combustion engine vehicles

Impact for distribution system innovation:

- System planners can better understand the role of EVs in the clean energy transition

Reference in CINELDI:

- E Dimanchev, D Qorbani, M Korpås: "Electric Vehicle Adoption Dynamics on the Road to Deep Decarbonization", Book chapter, Wiley - The 4Ds of Energy Transition: Decarbonization, Decentralization, Decreasing,, 2022, https://doi.org/10.1002/9783527831425.ch8

CINELDI result: Driving forces and mini scenarios for the future electricity distribution grid (WP6)

Challenge and objective:

- The electricity distribution grid is undergoing major changes due to electrification to meet climate goals and a transition is needed to the future Smart Grid. Identification of driving forces and scenarios for the transition will help understand the opportunities and challenges for the future grid.

Mini scenario example

Flexible data centres

Data centres are new types of consumption/loads connected to the MV distribution grid. The data centres are flexible, using the grid in low load periods of the day, and they provide flexibility in terms of voltage regulation and backup-solutions for high-load situations. Thus, the need for grid investments is reduced.

Work performed:

- Driving forces for the electricity distribution grid are updated and new mini scenarios are developed in accordance with trends and development since the start of the FME CINELDI.

Significant results:

- Some driving forces are strengthened and enhanced (such as climate change and electrification), and *geopolitics* is a new group of driving forces.
- New mini scenarios are developed related to digitalisation, electrification, flexibility, and security of electricity supply.

Impact for distribution system innovation:

- The driving forces and mini scenarios provide a foundation for developing appropriate strategies for the transition towards a flexible and intelligent electricity distribution grid that is also robust and cost-efficient.

Reference in CINELDI:

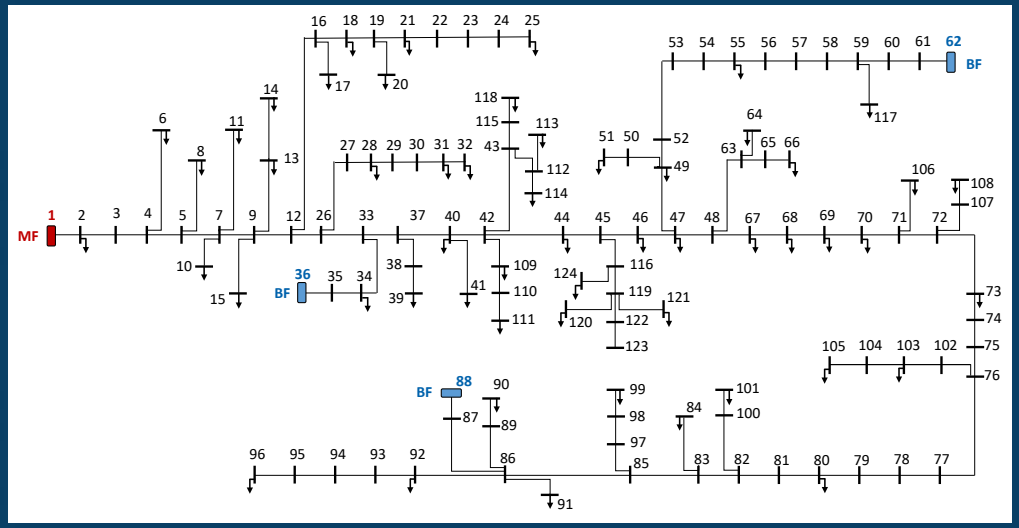
- G. Kjølle, "Drivkrefter og miniscenarier for fremtidens elektriske distribusjonsnett", CINELDI-report 01:2022

CINELDI

CINELDI result: MV Reference grid data set (WP6)

Challenge and objective:

- International academic test grid data sets are often not suitable for studying realistic problems. It is important to establish reference grid data sets representative for real distribution grids, to enable new technologies, scenarios, and solutions to be tested and validated in realistic environments.



Work performed:

- Grid data from a real MV distribution grid are anonymised and adapted to establish reference grid data representative for Norwegian distribution grids:
- Topological data, load profiles, new types of loads, reliability data, standardised component data.

Significant results:

- A basic MW distribution grid data set is established, providing data relevant for Smart Grid research and further extended for studying new loads, utilisation of flexibility, and reliability of supply.

Impact for distribution system innovation:

- Reference grids may be used for comparison purposes, as well as for quantifying the socio-economic costs of the future grid in relation to investments, operation, power supply interruptions and electrical losses in different scenarios.

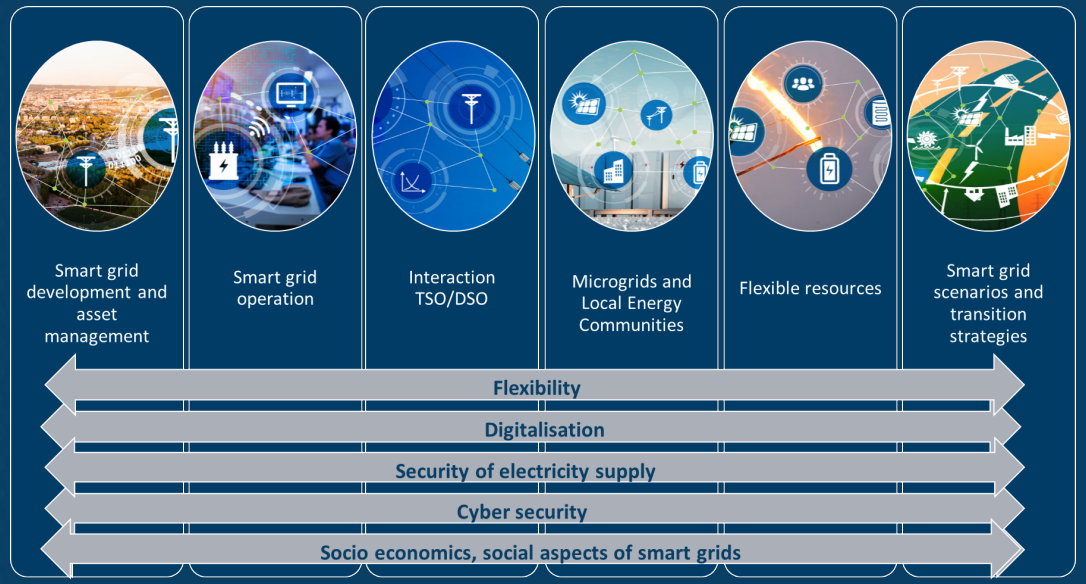
Reference in CINELDI:

- I. B. Sperstad, O. B. Fosso, S. H. Jakobsen, A. O. Eggen, J. H. Evenstuen, and G. Kjølle, "Reference data set for a Norwegian medium voltage power distribution system," Data in Brief, Vol. 47, April 2023, doi.org/10.1016/j.dib.2023.109025. Data set available in Zenodo- repository: https://doi.org/10.5281/zenodo.7133505

CINELDI result: CINELDI knowledge base (WP6)

Challenge and objective:

- To facilitate dissemination and utilisation of results research results and results from pilot projects, the objective is to establish the CINELDI knowledge base collecting and structuring research and pilot project results, data sets, open source code etc.



Work performed:

- A knowledge base is established containing results from the various research areas in CINELDI, inlcuding results and innovations from lab tests and pilot projects. The base will be updated continuously adding new results and innovations.

Significant results:

- A web-site is established for the knowledge base providing an overview of results and categorisation in subtopics, linked to main research areas.

Impact for distribution system innovation:

- The knowledge base gives an overview of all results from research and pilots, with a high potential for innovation through facilitating the utilisation of results for various types of actors.

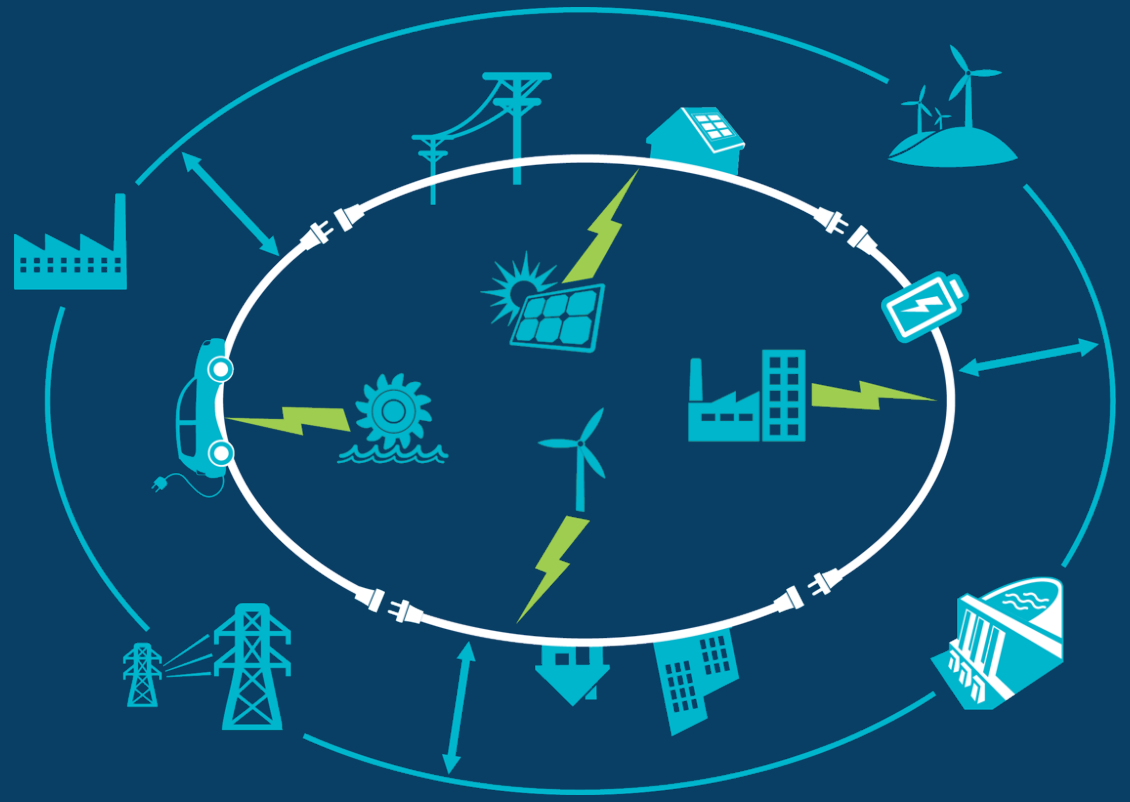
Reference in CINELDI:

- https://www.sintef.no/projectweb/cineldi/cineldi-kunnskapsbank/

CINELDI

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

Norwegian Centre for Environment-friendly Energy Research



This work is funded by CINELDI - Centre for intelligent electricity distribution, an 8 year Research Centre under the FME-scheme (Centre for Environment-friendly Energy Research, 257626/E20). The authors gratefully acknowledge the financial support from the Research Council of Norway and the CINELDI partners.

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