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Meeting New Electrification needs: How a Norwegian Grid Operator Is Seeking To Improve Coordination by Building a Public Capacity Simulation Service

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This paper describes the initial phase of the design of a front-end web solution for gathering information and coordinating electrification needs in southern Norway. The design work is part of the development of a simulation solution that aims to make electrification more socio-economically profitable as well as shortening the processing time for the customer's connection to the power grid, while ensuring security of supply. The paper presents findings from a series of stakeholder interviews identifying their individual characteristics and needs, and discusses implications for design. Further, the discussion considers input to effective ways of improving coordination and exploring alternatives (connection location, size and type).

Keywords: Electrification, Power Grid Capacity Simulation, Conceptual design.

1. Introduction

Electrification is considered key to ensuring access to affordable and sustainable energy. The number of electrification projects is currently increasing and will probably continue to do so in the years to come. In recent years the share of electricity in the energy mix has been increasing steadily, and to reach Net Zero emission goals, the speed of this increase will need to nearly double within 2030 (IEA, 2022). As a result, power grid operators are experiencing a growing volume of connection requests, and in many areas the demand is substantially higher than the grid capacity.

Currently there are few arenas for useful coordination between different actors in this area. From the supply perspective, grid operators need to justify and prioritize their efforts to increase grid capacity. To do this effectively and fairly they rely on timely access to quality information about electrification plans and projects, as well as their level of maturity/realism. Now such information is provided in a largely unstructured, case by case basis, demanding considerable time and resources for the grid operator. This leads to a growing que of applications and longer handling times.

From the perspective of the public – industrial actors as well as those involved in regional planning – this is a novel situation: In the past access to desired electric power has largely been regarded as a given, so there is a low awareness of the problem of grid capacity. Once the problem is acknowledged there is a lack of useful information about current and planned grid capacity, and of available alternative options.

Realising that electrification is intrinsically complex and multifaceted with capacity calculations, state regulation and legislation as well as the economical and environment considerations, the design work needs to embrace a wide range of input and actors. Consequently, the project described in this paper has used an iterative approach with involvement of many expertise disciplines and a wide selection of users. To ensure that the simulation service meets the grid companies' needs, the scope for service is set to 1-20 MW power. Effects below 1MW does normally not involve the transmission system operator and have a much simpler connection process. This means that normal effect size below 1MW is out of scope for this project.

This project is funded by the Norwegian Research Council and is running from 2022-2024. In this paper we present the initial phases:

- Users and needs: Findings from interviews with potential end users of the web-based grid capacity simulation service.
- Implication for design: Key conceptual choices that needs to be made regarding

capacity simulations and user interface design.

2. Method

The initial phases of the project have been guided by a user centred design process. To improve problem descriptions and the concept design development, a process with involvement of user groups was carried out through iterations with identification of user needs, design work and user testing. An early prototype of the service was developed to identify potential technical problems and gather feedback from users in the initial project phase.

Based on the grid company's customer portfolio and actors involved in the grid connection process, the project started with identifying and defining a selection of user groups that represent the future users of the service. Possible users were initially divided into categories depending on whether they represented customers or the industry. Furthermore, different customers were assessed based on the function they had in the connection process. Detailed input and clarifications of system functionality were collected throughout the whole project period in multidisciplinary weekly work meetings and monthly workshops with technical competence. In the period August to November 2022, 20 semi-structured interviews and simple user tests of early prototypes were completed with representatives of potential stakeholders. The results from the interviews were continuously incorporated into the conceptual design work, as well as compiled into a content analysis.

Interviews were used to identify and verify the various actors' role and need for support in the gird connection process. Up front of the interviews, potential candidates were identified on basis of the grid company's experience with the grid connection process. A sample of 20 respondents were recruited for a 1-hour interview. The interviews were used to clarify stakeholder roles and interests in the to be developed service, and to flesh out the description of various user groups and their need for functionality.

3. Users and needs

By using the grid company customer base, knowledge of stakeholders in combination with interviews and testing, the project obtained an overview of the actors involved in the grid connection process by mapping:

1. Those who need electricity and their power requirements.
2. Infrastructure and systems that offer access to power (factors that determine whether power can be offered).
3. Area considerations - requirements and processes that form the basis for whether power can be delivered at a given location.

The system is characterized by laws and regulations that work across the three groups of actors. This includes the regulatory authority and all the principles and rights that belong to it.

3.1 *User groups*

The following users and stakeholders were identified with roles in the grid connection process and a need for use or potential gain from using the service (see also fig 1):

Customer: The actor who needs electrical power and who will pay the bill for getting a connection and future use of the power.

Consultant: Professional actor who investigates and assists in the practical aspects of finding solutions for customers or planners

Business developer: Private or public actor who facilitates or develops opportunities for business activity in geographically defined region or municipality.

Area regulator/planner: Person who represents a public body such as a municipality or county council and who takes care of the public responsibility of facilitating and approving the development of areas for public or commercial purposes.

Grid company employee: Employee in the power grid company with responsibility for helping the customer with information and guidance in the early phase of the grid connection process.

Property owner: Private or public actor that owns or operates existing building stock or land and that has a need for new or enhanced grid connection.

3.2 *Roles and information need*

Users have different characteristics and roles in the connection process. Users and their needs within and across user groups constitute input to what the simulator solution must be able to deliver. The interviews revealed the following areas where users had different roles, levels of understanding, expectations, and needs:

- Need for power
- Competence and information
- Flexibility in time and location for power connection

Seeking, gathering and sharing of information varies between the user groups. Knowledge of opportunities and limitations in the electricity grid in combination with knowledge of own needs is decisive for the information the various user groups seek. In the group of users with a power demand, consultants and business developers will typically have more experience and knowledge than the end customer and property owners. The consultant has experienced that power is a scarce resource and know that the connection process will take time. This group is therefore concerned with getting detailed access to effect and effect availability calculations in various geographical areas. An interview with a highway road planner revealed that information that indicate availability of power along the planned route was a useful contribution to early planning and cost calculation. The current tools available for this group is very limited and instead of timely request, use of maps with street view functionality or field observations are often used as an alternative to seeking information from the grid company.

Another dimension that describes users is geography. For property owners and business developers, as well as authorities that plan and regulate, the location of a new power supply is important. The need for grid power is by its very nature always associated with a fixed geographical point, but what characterizes some users is that they can be flexible about where they place their consumption.

Grid owners is the group of users who own the connection process and possess the domain expertise. With the formidable increase in connection requests in recent years, processing time for requests have increased significantly. This user group have an interest to make the process more self-service.

Grid operators often experience that customers have a lack of knowledge about their own power needs and that historically good access to power leads to situations where customers get started late with planning and investigations into availability of power on a geographical location. The solution must support the work with guidance of costumers in the early phase of connection. To be able to speed up the connection process there is a need to reach users early in their project planning with information about application technicalities relevant for expectations management. A main need is to provide a solution that give as detailed as feasible overview of power availability and potential cost of connection. Equally important, encourage users that have flexibility in their choice of location, to seek for locations with good power availability. The last point is particularly important in terms of making use of the power grid company's opportunities to coordinate development projects in a good socio-economic way. In the longer term, a user request from the grid company is to be able to utilize information that customers leave in the solution to predict future locations where the grid needs to be reinforced. A summary of user group properties identified is presented in table 1.

Table 1. Summary of user characteristics identified from interviews.

	Asking for power	Level of competence	Flexible time or location
Customer	Yes	Low	Varies
Consultant	Yes	Medium	Varies
Business developer	Yes	Medium	Varies
Area planner	No	Low	Varies
Property owner	Yes	Medium	Varies
Grid company	No	High	Yes
Regulator	No	High	Yes

The regulator has a vested interest in knowing forecasts for demand as they must plan supply in the overhead grid, as well as approve the DSO's investment projects. The grid companies have a need to put in place data that enables prioritization of investments. In terms of socioeconomics, there

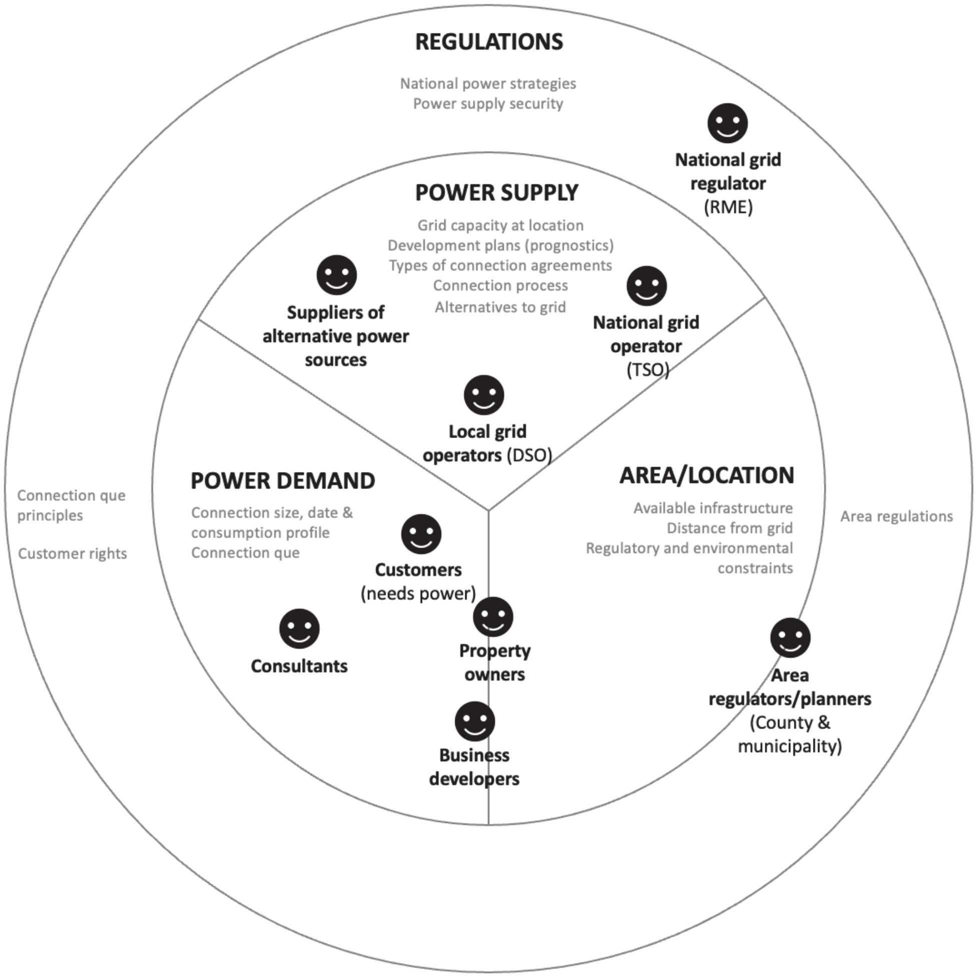

Figure 1. Overview of actors in the connection process, divided by role.

is a potential in the grid companies getting an early overview of interests in an area. Early access to information about plans for the use of electricity enables the grid companies to reduce risk when developing excess capacity. A visualisation of user groups, their roles and needs is shown in figure 1.

3.3 *Key factors that influence connecting customers*

The following factors that influence a specific consumer/prosumer connection case were identified (the end-user perspective).

What the grid operator considers "available" capacity: At Glitre Nett, grid availability is currently estimated based on what is considered "operationally viable" – the maximum grid load that enables them to maintain full operability of the regional grid in case of a single transformation station failure (so-called "N-1"). Other grid operators are using variants of this concept depending on local grid topologies, as strict adherence is only feasible for highly "meshed" grids (meaning that transformation stations can be served by several grid routes). In the end this is a continuous risk assessment that the grid operator needs to make, both from a societal and economical perspective, and they are fined for not delivering agreed effect.

Connection location: Capacity varies throughout the grid. There are local, regional, and national grid variables determining the capacity at a certain connecting point.

Connection date: Prognosed grid capacity is a function of current installed capacity, grid development plans and the effect demand (connection applications).

Connection cost: Cost is dependent on the required strengthening grid measures (if needed), method of delivery (e.g. whether the customer wants to handle on-site connection himself or not), as well as distance to grid connection point. In certain cases multiple customers might share this cost.

The connection queue – customers competing for the same capacity: The competition in each case is determined by the nature of the applications as well as the grid topology. By Norwegian legislation one's position in the queue is determined by 1) application date (first come first served), and 2) maturity level / realism of the connecting project. The operating definition of "maturity" seem to vary somewhat among grid operators. This means that the que is not static, it will change as new applications are made and existing ones are maturing or withdrawn. Also, there are some opportunities for negotiating one's position in the que.

Special connection agreements: Currently the most common connection agreement determines a maximum consumption effect valid at all times. However, other types are possible: For example, by agreeing to adjust consumption/production when requested by the grid operator, customers could get access to a higher effect than otherwise. This exploits the fact that the grid is usually operated well below maximum load. Customers could further exploit this by timing their consumption to periods where the grid load is usually low, such as during the night. Customers might also get access to a certain capacity for a certain time, relevant in cases where there is available capacity until future planned connections are realised. All cases result in better overall grid utilization.

Alternative power sources: A connecting customer can influence grid consumption by utilizing alternatives power sources, such as solar and wind. Typically, such customers will be so-called "prosumers" – both consumers and producers from a grid perspective. Both production and consumption needs must be considered in such cases, as both are relevant for availability calculations.

Customers´ own needs: Connecting users´ understanding of their own realistic power needs and load profile, as well as their flexibility will influence available opportunities, both in terms of the capacity that is relevant as well as opportunities for "special" connecting agreements.

The connection application process: The required actions to take, information to provide, and steps involved. Expected processing times.

Other location-specific factors: Area suitability and regulations, such as infrastructure, zoning regulations and environmental concerns. There may also be legislations related to power consumption that apply, such as mandatory connection to local heating facilities, and installing solar power on the roof for certain types of buildings.

4. Implications for design

The following discusses key implications for the conceptual design of the capacity simulation service.

4.1 *Overall strategies for interaction design*

The stakeholder interviews identify large variations in relevant competence among the user groups. Some are professionals within the electrification area, others have a limited understanding of what their effect needs really are, how the power grid works, and how their application is processed and queued. The project ambition is to support both these groups, thus this needs consideration in the design.

The interviews also indicate that some users will mostly be interested in a particular location, while others are more flexible and will want to explore a larger geographical area looking for effect opportunities. From a socio-economical perspective it also seems desirable to offer guidance towards alternative connection opportunities, which includes different locations. Therefore, to be most useful the service needs to address both these use-cases, offering capacity prognostics and other guidance on a regional level as well as at any specific user-defined location.

A possible overall approach to the design of end-user interaction flow is illustrated in figure 2, outlining three major steps in what we may call the "customer journey" as they search for effect and compare alternatives.

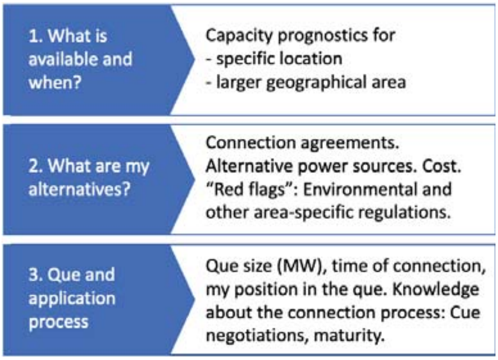

Figure 2 Key steps in the customer journey

4.2 *Definition of "available" capacity*

One of the key design questions throughout the conceptual design phase turned out to be related to "available" capacity - what is the best strategy for simulating and presenting such information in a public, "early-phase" service. As there are considerable uncertainties related to capacity prognostics one could imagine different approaches to this. From a socio-economic point of view, one might want to "nudge" commercial applicants towards specific areas that regional planners consider desirable, regardless of any current concrete plans for strengthening the grid here. A purely technically oriented approach is to use the working definition of "operationally viable" that the grid operator is currently using when considering connection applications, as presented above.

In this project it was decided to utilize the grid-oriented for the presentation of capacity while exploring other means of "nudging" users towards specific areas if considered desirable. A concept for calculating available capacity prognostics for normal connection agreements was developed based on a "operationally viable" simulation that ensures security of power delivery, accounting for concrete grid development plans as well as "reserved" capacity for mature applicants, illustrated in figure 3.

Generally, more effect may be provided if the customer agrees to certain terms that allows the grid operator to reduce capacity or disconnect the customer to offload the grid in given circumstances.

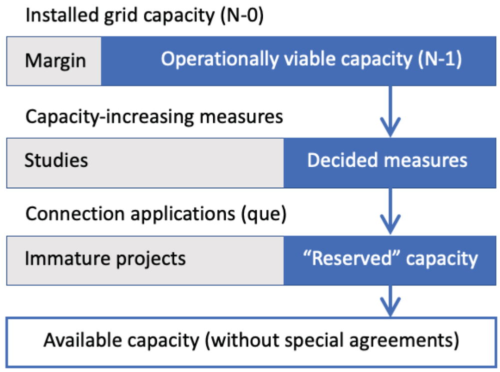

Figure 3 Concept for simulating available grid capacity

From the point of view of the grid operator there are both pros and cons related to announcing such specifics publicly, as there is a risk of confusing users and generate more work clearing this up afterwards with individual applicants.

4.3 *Capacity visualization*

Available grid capacity can be visualized in many ways. For example, it could be based on the grid topography – illustrating availability information connected to power lines and net stations, or one could take a purely geographical approach – visualizing capacity as points or areas on a map decoupled from the delivery system. Different types of visualizations might suit different user groups. For example, a user with little electro-technical knowledge might be confused by visualization that are strongly linked to the technical infrastructure, while more knowledgeable users might find this information useful. Again, these two approaches are not mutually exclusive, but prioritizations might need to be done to create a user-friendly experience for all. One could consider a layered approach – visualizing grid capacity in a way that does not require technical knowledge as the foundation and offer opportunities for supplementing or adjusting this with layers of more advanced information. In any case, utilizing some kind of geographical map for this seem like a promising visualization strategy. Figure 4 illustrates three different visualization strategies.

Figure 4 Examples of possible capacity visualizations. From left: Aggregated capacity points, capacity regions, and grid topography.

4.4 *Other potentially useful information and functionality*

The following information has been identified as potentially useful for potential connection applicants as a supplement to simulated availability data:

- Alternative power sources as supplements to grid consumption, such as wind and solar. Illustrating alternatives with cost examples.
- Areas regulated for commercial use (current and prognosed).
- Other regulations, legislations and that may influence commercial establishments in a specific area.
- Information about the connection que: The "competition" (accumulated effect applied for in a certain area) as well as information about the application process and opportunities for advancement in the queue.
- Guidance about customer´s own needs: Information targeted towards consumers and prosumers on how much effect they might actually need, e.g. by providing examples of (anonymized) experience-based consumption data.

The grid operator wants to use the service to gather knowledge about regional electrification needs. The project has identified two main conceptual approaches to this. One is to track users interaction with the service in the background, another is to more specifically let users signal their need. Both can be done anonymously or by allowing users to create a user profile (login). Design considerations needs to be made concerning users willingness to share information and trade-offs related to creating potential barriers to use.

5. Discussion and further work

One of the hypotheses for this project is that the simulation solution can contribute to more socio-economic savings through stimulating cooperation between different actors. Through the work with user needs, the project has identified several challenges a web-solution will need to address to obtain economic gain. The most obvious is the current lack of public information available for capacity in a geographical location. Providing a better overview of capacity will give the users a better opportunity to optimize cost according to location. Increased knowledge and understanding among users of the opportunities and limitations within the grid will make it easier for all actors to focus on the best projects. However, estimation of cost for connection to the power grid has a high number of dependencies between different factors to be considered for calculation. Various actors in a connection process are on very different levels of competence and understanding of the mechanisms that play together in this process. Providing all users, a complete overview and knowledge of these factors is not feasible, but developing a user interface that can provide high level cost estimates and a set of alternatives at an early stage is a realistic solution.

One of the remaining challenges is to establish more knowledge about the mechanisms that contribute to the right projects finding each other and being able to collaborate about locations. This places great demands on coordination among the user groups and the web solution must find the right level of detail in data sharing and develop properties to nudge users towards co-location.

One concern throughout the project has been whether the proposed solution will give speculators and rogue actors looking for short-term profit an easier way to establish e.g. bitcoin mining. The question then becomes whether the grid companies should make information about the grid easily accessible to everyone. There are several examples from Norwegian municipalities where crypto mining seizes important power resources and the socioeconomic effect of this power used is in fact negative. At the same time, it is important that ordinary data centers that contribute to strengthening the national data storage and processing power have good prerequisites for growth. (Kommunal og distriktsdepartementet, 2023). The simple answer for this project and the grid companies is to continue the strive to make grid connection as smooth as possible and let the legislation decide upon prioritization of national resources. When it comes to national security and the protection of critical infrastructure, the project has carried out the necessary risk and vulnerability analyzes to ensure that the information presented is not in conflict with the applicable regulations.

For this early phase study, early prototyping showed effective to help building momentum and enthusiasm among stakeholders by giving them a tangible sense of the product's potential and helping them to visualize how it might work in practice. For the further work in the project, the prototype will incrementally be expanded with functionality. This allows evaluation and further development to med done in more realistic user tests with the various user groups.

6. Conclusion

In this paper, we have presented a survey of user needs and stakeholders, as well as implications for conceptual design. The overall goal of the project is to improve efficiency in the power grid connection process. In the next phase the project will develop and implement a first version of this service based on the findings presented in this paper. This will be used to further investigate what mechanisms for decision-making characterize the different groups and which competence challenges may hinder effective use. Another question for further investigations is how willing users are to share their own data with other users of the service and which areas offer the greatest potential for profit and what kind of collaborative support is suitable for facilitating and motivating collocation of power consumers.

The Net-zero transition has resulted in strong political pressure on social actors to increase the pace of electrification. This project tries to draw as realistic a picture as possible of limitations in the power grid and the challenges that society faces in the work of communicating the realities around power grids and the net-zero transition.

Unlike similar solutions, this solution already from the start of development considers the limitations the infrastructure (N-1), making visible the consequences of the basic safety limitations that the developer of a power grid must deal with. By presenting, testing and evaluating with end-user involvement on actual estimates and limitations, the solution ensures that risks are made visible and handled throughout the entire development process.

By uncovering the inherent complexity of grid connection and establishing a solution that approaches this from the user's side, this helps to contribute to an increased understanding of the challenges we face in the electrification of society. It is expected that the project's approach will contribute to faster, easier and more informed communication in connection cases, give case managers more time for quality in application processing and thus a safer and more reliable electricity supply.

Acknowledgements

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References

IEA (2022), Electrification, IEA, Paris https://www.iea.org/reports/electrification, License: CC BY 4.0

Kommunal og distriktsdepartementet (2023). Etablering av datasentere - rettleiar for kommunene. https://www.regjeringen.no/no/dokumenter/etablering-av-datasentre/id2971352/?ch=3

NOU 2023:3 Mer av alt - raskere. Energikommisjonens rapport. https://www.regjeringen.no/contentassets/5f15fcecae3143d1bf9cade7da6afe6e/no/pdfs/nou202320230003000dddpdfs.pdf