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Expert perceptions of low-carbon transitions: Investigating the challenges of electricity decarbonisation in the Nordic region

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Abstract: The five Nordic countries of Denmark, Finland, Iceland, Norway and Sweden have perhaps the most aggressive and progressive climate, energy, and electricity policies in the world. This study asks: what are the greatest challenges to achieving the region's low-carbon goals in the domain of electricity? To provide an answer, the authors conducted 227 semi-structured interviews with 257 participants from 201 institutions across seventeen cities within the Nordic region. Those interviewed represent a diverse array of stakeholders involved with electricity technology, policy and practice. Although respondents identified 40 distinct electricity challenges, the integration of renewables was by far the most frequently mentioned (14.5%) of the expert sample. Five other challenges were also mentioned the most frequently by respondents: electrification of transport and other sectors (10.6%), managing intermittency (8.8%), carbon intensity (8.4%), supporting local grids (8.4%), and adequate capacity (8.4%). Interestingly, items such as energy efficiency, consumer awareness, industry, energy security, and public opposition were mentioned by only 1.8% (or less). The article concludes by what this heterogeneity and prioritization of challenges means for future Nordic research and policy.

Keywords: low-carbon electricity supply; Denmark; Finland; Iceland; Norway; Sweden

1. Introduction

The five Nordic countries have aggressive climate and energy policies in place and have already emerged to be leaders in renewable energy and energy efficiency (Sovacool 2017). At present, about 83% of electricity generation in Nordic countries is low-carbon, of which 63% comes entirely from renewable sources, but further decarbonisation of electricity is essential in meeting targets. According to The International Energy Agency and Nordic Energy Research (2013, 2016), although renewable sources of energy already comprise a substantial role in the region's electricity portfolio, their utilization is expected to grow rapidly between 2016 and 2050. As Figure 1 indicates, net electricity exports, bioenergy and waste, wind, geothermal, solar, and hydroelectricity all must expand significantly by 2050 to reach a carbon neutral society while the shares of coal, oil, and natural gas shrink.

INSERT FIGURE 1 HERE

A necessary and massive shift is therefore underway to further transition the Nordic electricity system to low-carbon forms of supply and use. This transition will involve multiple sectors and dimensions of electricity, transport, and other integrated systems (Mancarella 2014). For instance, a future Nordic energy system must become more flexible, balancing renewable power production through CHP, heat pumps, and storage systems (Levihtn 2017; Zakeri et al. 2015). Moreover, bioenergy systems must expand (Hagos et al. 2017) and carbon capture and storage systems further developed (Koljonen 2014). In other words, sociotechnical systems must be reconfigured for what Geels et al. (2017) call “deep decarbonisation.”

But how is such a transition perceived by dominant stakeholders and experts? What are the greatest national and regional electricity challenges facing Nordic countries as perceived by experts living within the region? To provide an answer, the authors draw on a question about electricity challenges posed in 227 semi-structured interviews about electric

mobility with participants from 201 institutions across seventeen cities in Denmark, Finland, Norway, Iceland, and Sweden. Those interviewed were selected to represent the diverse array of stakeholders involved with electricity mobility, including electricity supply technology and infrastructure, policy and practice, and included experts from national government ministries, agencies, and departments; local government ministries, agencies, and departments; universities and research institutes; electricity suppliers and utilities; and other private sector companies.

We find that those interviewed identified no less than 40 distinct electricity challenges facing the Nordic region. The integration of renewables was by far the most frequently mentioned (14.5%) of the expert sample. Five other challenges were also mentioned the most frequently by respondents: electrification of transport and other sectors (10.6%), managing intermittency (8.8%), carbon intensity (8.4%), supporting local grids (8.4%), and adequate capacity (8.4%). Interestingly, items such as energy efficiency, consumer awareness, industry, energy security, and public opposition were mentioned by only 1.8% (or less). After presenting these results, this article concludes by what this heterogeneity and prioritization of challenges means for future research and policy.

2. Research Methods

To explore the challenges, barriers, and obstacles facing electricity in the Nordic region, the authors relied primarily on original data collected through semi-structured research interviews.

By *semi-structured interviews*, the authors mean that our data collection involved the asking of semi-structured questions to respondents, sometimes referred to as “expert elicitation,” “guided introspection,” “intensive interviewing,” “responsive interviewing,” or soliciting “stated preferences” (O’Sullivan et al. 2010; Yin 2003; Hancke 2009). This technique asks participants a set of fixed questions but then allows the conversation to build

and deviate to explore new directions and areas. Such interviews are most appropriate when the research objective is to comprehend complicated programs or events and how they intersect with perceptions, beliefs, and values (Yin 2003). Interviews were also chosen because, unlike documents that can take months or even years to be published, they enabled the collection of recent data that (at the time of the interview) was not yet available in other formats.

The authors conducted 227 semi-structured interviews with 257 participants from 201 institutions across 17 cities in the five countries of Denmark, Finland, Iceland, Norway and Sweden from September 2016 to May 2017. Those interviewed were selected to represent the diverse array of stakeholders involved with electricity technology, policy and practice, and included members of:

- National government ministries, agencies, and departments including the Ministry of Industries & Innovation (Iceland), Ministry of Environment and Energy (Sweden), Ministry of Finance (Finland);
- Local government ministries, agencies, and departments including the Akureyri Municipality (Iceland), City of Stockholm (Sweden), Aarhus Kommune (Denmark), City of Tampere (Finland), City of Oslo (Norway), and Trondheim Kommune (Norway);
- Universities and research institutes including the University of Iceland, Swedish Environmental Institute, DTU (Denmark), Aalborg University (Denmark), VTT Technical Research Centre (Finland), NTNU (Norway), and the Arctic University of Norway;
- Electricity supply, transmission, and distribution companies/utilities including Energinet.dk (Denmark), Statnet (Norway), Fortum (Finland), Elenia (Finland), E.ON (Sweden), Vattenfall (Sweden), ON Energy (Iceland);

- Private sector manufacturing, service and information technology companies including, Nord Pool (regional), DONG (Denmark), IBM (Norway), Microsoft (Norway) and Schneider Electric (Norway).

Interviews lasted generally between thirty and ninety minutes in their duration, and participants were asked a number of questions around electric mobility, including this question specific to the study: “What do you see as your country’s or the Nordic’s greatest energy or electricity challenges?” Participants were not prompted for responses and were permitted to answer as long or as detailed as they wished. Each interview was recorded and then fully transcribed and analyzed. Each interview was also given a unique respondent number (which we refer to whenever presenting interview data), note that some interviews involved up to four respondents.

Admittedly, the nonrandom sample relied upon for primary data is limited in several ways. First, although the interviewees listed in Appendix I come from many disciplines and organizations, the sample was confined primarily to researchers that spoke English, and to some degree it was moderated by location and knowledge of local context. Furthermore, a fair number of researchers were unavailable for interviews, creating a potential selection bias (only those who said “yes” are included). In summary, this analysis should not be interpreted as representing the full diversity of approaches to expert perspectives on Nordic transport challenges. Rather, it is an analysis of what a nonrandom or ‘convenience’ sample of leaders of the field, or a network of people with prominent field positions, perceive to be important challenges – creating an illustrative rather than fully representative sketch.

Two other elements of our research design deserve mentioning: anonymity and grounded theory. The data from these interviews is presented here as *anonymous* for multiple reasons. Confidentiality protects respondents from retaliation over divulging potentially controversial information. Also, it can encourage candor, as people often speak their minds if

they no longer have to worry about their statements coming back to haunt them. Moreover, although institutional affiliation were relevant for sampling purposes, individuals were not speaking on behalf of their institutions and were instead giving their personal opinion. Although participants were therefore guaranteed anonymity, Appendix I offers a high-level summary of the interview respondents.

Finally, the research was *grounded* in the sense that we commenced our project without any preformed hypotheses. This method is sometimes called “grounded theory” because it is an inductive discovery method that starts with no theoretical preconception. Instead, researchers develop a conceptual account from the “ground up,” the analysis grounded in the data collected itself (Geertz 1970; Strauss and Corbin 1990). We did this because we maintain a grounded approach helps minimize interpretative bias caused by researchers trying to force responses into preset cognitive frameworks (Blaikie, 2000, Cook and Campbell, 1979).

3. Results

As both Table 1 and Figure 2 summarize, the respondents in our 227 interviews discussed and classified 40 different electricity related challenges. The most frequently mentioned in order are (1) integration of renewables, (2) electrification of transport and other sectors, (3) managing intermittency, (4) carbon intensity and climate change, (5) supporting local grids, and (6) ensuring adequate capacity. We explore these top six choices in greater detail in the rest of the paper.

INSERT TABLE 1 and FIGURE 2 HERE

3.1 Integration of renewables

By far the most frequently identified challenge among respondents was how to integrate more diffuse, renewable forms of electricity supply into the Nordic grid. Here, we discuss how respondents framed the integration of renewables as a daunting economic, social,

or political challenge—it is also a technical challenge in terms of intermittency and grid management, but we discuss that aspect separately in section 3.3.

To better understand the immensity of the integration challenge, consider some context. The most recent low-carbon electricity projections from the International Energy Agency and Nordic Energy Research (2016) underscore that the entire electricity sector will need to undergo substantial shifts towards decentralized renewables. Those projections suggest that bioenergy comes to surpass oil as the largest energy carrier, increasing to 1,600 PJ, and also helping account for 40% of all emissions reductions (by displacing oil). Nordic hydropower expands, backed largely by the deployment of larger-scale, reservoir based installations supplemented with some “run of river” or microhydro. Wind energy also rises to displace fossil and nuclear electricity generation. In fact, wind energy production increases so much—five-fold from 7% of Nordic generation to 30% by 2050—that its generation comes to far exceed domestic demand, even with the drop in nuclear power—this excess capacity starts to serve a lucrative export market in Europe. Much (70%) of this wind capacity is projected to occur in Denmark, and two-thirds of it is expected to be onshore, demonstrating the necessity of proper siting and public approval.

For countries like Iceland, this shift could be even more pronounced, particularly when referring to the provision of clean energy access outside of the capital region. R15 remarked that:

The greatest energy challenge is the total stationary energy system of Iceland, by which I mean electricity generation, distribution, and also the heating the hot water in houses from renewable recourses. Iceland is a country with 330,000 people living on 1,500,000 km². Taking the district heating to 90% of population is quite a challenge. We have 3 persons/km². Kazakhstan has 6 persons/km². So that is a big thing. We have 63 Km between sources and customers. Of course the electrification of rural

areas is also a challenge, we have islands in the north, they are based on diesel, which is not a good alternative for them yet but they are 100 people. That why it is difficult. It will be hard transitioning Iceland into the renewable energy age.

Underscoring that, despite the country already has 99% of renewable hydro and geothermal generating and consumption mix, it still faces considerable challenges in terms of developing the necessary infrastructure to deliver clean energy across the entire country.

Other respondents took a regional perspective, and noted how this shift to renewables will create a series of social, political, and economic integration challenges. As R39 in Sweden put it succinctly:

To me, the major challenge will be to have a secure, stable energy system until 2040, after 2040 when it is supposed to be completely renewable, so it's the same time we'll have a phase out of nuclear power. So the question is how to manage a transformation from the energy system that we mostly have today, with a large share of nuclear power and hydro, to a system that is completely renewables-based, mostly wind, a little bit solar, hydro, and other sources. This involves a substantial shift from centralization to decentralization that is a profound social and political problem.

R80 in Denmark concurred that the conversion of all energy to renewable sources was a transformational challenge:

We have an objective that in 2035, it's all renewable energy. In Denmark. Everything. And I think in 2020 we have eighty percent renewable. That's a lot. So we need to have more flexible consumption, energy consumption, and we need to use more electricity. We basically need to change the entire system.

R97 in Denmark mentioned the political and economic costs that come with a further integration of renewables, such as ensuring stability and interconnection:

The challenge is not so much having technically stable renewable systems, it is more about the cost of having that stable system. Politically it also creates dependence on other countries such as Norway and Germany. The interconnections, the dependencies in Norway and continental Europe in order to maintain a high degree of renewables, I think that's a key challenge.

R118 from Denmark suggested that the need for interdependence across countries and regions comes intertwined with greater geopolitical dilemmas and concerns about affordability and self-sufficiency. As they said:

The biggest barrier is probably going to create a self-sufficient Danish renewable electric grid. Something like sixty percent or seventy percent of all the countries in the EU-28 are looking to balance the grid and depend on cross national connections. And if sixty to seventy percent of the countries, including Spain, France, Germany, if these countries are depending on foreign production in order to balance and provide sufficient energy into their grid, and Denmark as well does that, then the remaining two countries really, really, have to provide excessive amounts of energy. I've met people who've said that "don't worry about energy, energy is going to be abundant in the future". And that's probably right. But the transition time is the problem, and that's going to be the problem as well in Denmark, at some point we will see price, unless we do something, we will see prices skyrocketing because we have to import them from Norway, probably, to some extent Sweden, and that's going to be more and more expensive, because demand is going to rise.

These three perspectives highlight the broader general challenges beyond simple technology that come with a sociotechnical shift from a centralized to a decentralized yet highly interconnected electricity system.

Danish respondents were not the only one to raise such concerns about renewable energy integration. R127 in Finland also emphasized some of the specific economic challenges in the current transition phase, in particularly how to incentivize RES while maintaining existing capacity:

The problem we have in Finland is similar to all the European countries at the moment, there are numerous subsidies to renewable energy production and it pushes prices down. At the same time, it's pushing certain types of production units out from the market, making them non-profitable to the asset owners, and for that since they are also needed from time to time in certain market areas they have introduced kind of capacity mechanisms, where they will actually pay for the assets owner to keep the assets available if needed. So the integration challenge is a massive economic one of how to both decarbonize and maintain profitability at the same time.

The need for a capacity market was echoed by R139 in Finland, who also stated that:

The problem is the same headache that the whole Europe is having. If you have the energy only market, not a capacity market, the price of electricity goes sometimes very low when you have a lot of wind or solar power, and then sometimes you don't, but the volatility of price goes down. Electricity systems basically have either stiff nuclear, hydro, or fossil fuel supply or very volatile wind and solar power. The system is not that well balanced.

This volatility between existing baseload capacity and new renewable sources led many experts to question the low wholesale electricity prices. R144 from Finland for example added that:

From a power system perspective, the greatest challenge is something as fortunate as low electricity prices. Which is of course good for consumers, when it comes to producers trying to make a profit from their production assets. However, low

electricity prices on a long-term perspective puts some challenges on that, which means that we are losing certain types of production units that are needed to kind of when we have peak consumption hours for instance.

This comment emphasizes the economic and affordability issues that come from cheaper, or more stably priced, sources of electricity such as wind and solar. R158 in Finland also emphasized economic aspects and how it is difficult to derive revenue from them:

I think the main problem here is that, unlike Norway and Sweden we do not have much hydropower. So sustainable ways of producing electricity are mainly wind, solar and biomass. And even biomass is a matter of definition, how sustainable it is. So we need more. Wind and solar we can increase the amount of those. But still we cannot control the production very well. So we need something to adjusting power for the grid. Traditionally this has been done by CHP plants and coal plants, but those are being shut down currently. Because the price of electricity in general in the Nordic countries and in Finland. So we're in a bind.

3.2 Electrification of transport and other sectors

The electrification of society was the second most frequently identified challenge. Experts discussed two elements in particular, transport—the promotion of electric mobility—and other sectors such as heat.

The many comments focusing on transport, specifically passenger cars or light duty vehicles. R13 in Iceland put it pithily:

The challenge is to electrify transport in Iceland.

In Sweden, while R39 noted the importance of electric vehicles, this energy expert also stated skepticism in the temporal feasibility of such a transition:

To create infrastructure for electricity fuels in [the] countryside, that is the challenge.

I don't think it is possible at all, at least in our lifetime.

R80 in Denmark connected the main electricity challenge as explicitly a transportation challenge:

The greatest transportation challenge is the electrification of transportation, because there have been several occasions where we have discussed electrification and how to deal with the greenhouse gas targets for Denmark. So the biggest challenge is how to get transportation electrified, that's the main one.

This electrification of transport challenge is therefore equally prevalent in all five Nordic countries.

A second theme arising from the interviews was the electrification of heat. As Figure 3 suggests a concomitant further decarbonisation of district heat generation and heat supply must occur if Nordic climate and energy targets will be met. Oil, coal, and natural gas must be almost completely phased out by 2040; biomass and waste, geothermal, and electric heat must be ramped up. Heating networks transition not only from fossil fuels but also to heat pumps and electric boilers, adding flexibility to an integrated power and heat system. R114 in Denmark commented that:

We need to start on converting district heating to electricity, nearly all houses in Denmark are covered by district heating, we need to convert them to heat pumps. But that is very slow because of the big taxes on electricity. So that is the challenge that shall go ahead with electrifying heating and cooling.

R123 in Denmark discussed heating as more than just electrification and heat pumps, but rather as better connections between the existing district heating systems and the electricity system:

Electrifying heat is a huge priority, but also a challenge. I have for example calculated if we in Denmark turned all houses into electric heating as just as they are right now instead of district heating and gas and what we have, if we did that, then the peak hour on electricity will be four times as high as it is today. We have a very, very well-functioning heating infrastructure in Denmark, where more than half of the houses are heated by district heating, where we recycle a lot of waste heating, that also means that we don't have to build so many wind turbines as we had to if it was electric heating, and it's a lot more. If we should heat the houses by electric heating, that would take sixteen thousand megawatt of wind power approximately. And right now we have five or six all together, I mean this is extreme.

Moreover, this issue is further complicated given that the scenarios from the International Energy Agency and Nordic Energy Research predict that by 2050, space heating will come to comprise more than half of total building final energy consumption.

INSERT FIGURE 3 HERE

Others discussed electrification beyond the domain of personal vehicles and heat. For example, R17 in Iceland noted that:

We are so fortunate to have green electricity for use in industry and households. We have geothermal, and a good district heating system for most homes. That's maybe not a challenge. The challenge is maybe to have this green electricity for fishing vessels or industry. Maybe that is one of the biggest challenges for the near future if you look at Iceland as a whole.

R82 in Denmark also emphasized the importance of electrifying its existing diesel powered rail:

One of the challenges is that in Denmark they chose to have diesel powered trains, unlike Germany, Norway, and Sweden. So we need to connect the rail system directly

to the grid in Denmark, and that's a one or two phase system, whereas we have three phase. So there is a risk, and many issues arise related to synchronization, grid stability, and profit maximization.

Similarly, R114 in Denmark supported the electrification of rail on the grounds that it could help decarbonize trucks and freight:

We need more electrification of train transport, so that we can begin to remove transport on trucks to trains instead. As I see it, it is a challenge in 2020 the focus is so little on how to develop train transport, and that is surprising because it is so obvious end using trucks to run each place for getting goods, where we need to develop the trains.

Building on the first challenge of the integration of renewables, here experts highlight further decarbonisation challenges by touching upon transport, private and public/freight, as well as a broader integration of energy systems.

3.3 Managing intermittency

The third most frequently mentioned challenge, closely linked with the economic integration of renewables, is technically managing the intermittent nature of renewable resources.

In contrast to Norway and Iceland with their abundant hydro, respondents from Denmark in particular seemed sensitive to this challenge given that the country has such a plentiful national supply of wind energy. As R83 explained:

The greatest electricity challenge is the imbalance between demand and supply from solar PV and wind power. Even in Denmark, where we have a very strong TSO net and have very good DSOs, this is a challenge. They say we have the perfect grid: we have a lot of capacity, and we have about one power outage here in Denmark every

fifteen years. But balancing the grid on a very local level at very short intervals, that's the challenge we have now.

R117 also concurred that the “*hour to hour balances with wind are going to be a great challenge.*” R126 added that:

In general I think the greatest challenge is that we will have a lot of renewable energy integrated and mainly wind power energy, and this is fluctuating according to weather conditions, and the same with the PV, which is the sector that is starting up to be installed. All of this production is very much fluctuating so we have to balance this, and secondly also that it is actually replacing some of the central power plants which were, let's say, back up, providing ancillary service and a balancing function, so we have to have something else to replace that. So there's a whole set of balancing issues, where to store all the energy, how to get the best efficiency out of the energy, now that we have decided we should have this amount of renewable energy integrated.

There is hence a technical challenge of how to organize the intermittent nature of RES, solar and wind particularly, in a power grid system without substantial renewable baseload sources.

Following, other respondents discussed how the technical matters of intermittency spillover into economic concerns. As R209 in Norway explained:

The big challenge is basically that we have a system that is highly interrelated. We have massive amounts of intermittent energy. Fortunately, we do have water and hydro that can balance wind and solar. But it is becoming a very dynamic system, where you are going to shift huge volumes of energy. So you need massive build up, you need to modernize systems, you need new cables between countries and interconnectors, which all add to the price.

R48 in Sweden added that:

In the Nordics, we see more and more renewable energy coming into the system. Wind generation, for example, pushes the system to be more volatile and more difficult to keep in balance. It is hard enough to predict weather forecasts and wind prognoses, which are needed for trading on the market, so planners and companies know how much power they need to buy and sell tomorrow. The Nordic countries have gone in the same direction as Germany, where they have very huge amount of solar and wind generation, and negative prices.

Both these experts touch upon the overall dynamism that is expected to characterize future electricity systems – a dynamism that extends beyond more volatile input sources, but includes growing flexible demand, multiple storage technologies, more geographic production sides, and consequently, multiple integrated markets trying to address the dynamism of electricity prices.

That this nexus of technical interconnection issues extends into the economic realm is not lost on the most recent projections and scenarios from the International Energy Agency and Nordic Energy Research (2016). Their forecasts suggest that trade and interconnection with Europe are instrumental to the Nordic countries reaching their electricity targets. If average renewable electricity generation costs in continental Europe are expected to stay higher than in the Nordic region, then it becomes a major exporter of 53 TWh of electricity in 2050. As Figure 4 illustrates, Nordic electricity trade must expand considerably—underscoring the need for paralleled, coordinated grid development and interconnections with Great Britain, the Netherlands, Germany, Poland, Lithuania, Latvia, and Estonia.

INSERT FIGURE 4 HERE

3.4 Carbon intensity and emissions

The carbon intensity of energy supply, and climate change and greenhouse gas emissions, was the fourth most mentioned challenge, although it often had less to do with the

electricity sector itself, and more with other carbon intensive areas in the Nordic region such as industry or transport. These issues were still seen as relevant, however, when discussing the challenges to meeting Nordic low-carbon electricity targets.

When it comes to carbon emissions, R56 in Sweden stated quite simply that:

Reduce carbon emissions. That's the one and the only priority. Number one. First.

Unfortunately, this is difficult as on its own R85 in Denmark said that:

We are not really seeing a transition going on towards low-carbon transport. We are still based more or less in the same technologies and we have seen a very strong increase this year in auto ownership and, so transport's share of emissions and climatic impact is not going down, it's still going the wrong way ... So we really have a big challenge to more or less transform everything in our transport system towards a low carbon future.

Notions of hypocrisy also came up frequently when on this point. As R100 from Denmark explained:

To me, the biggest challenge is simple, and two words: carbon emissions. That is the key. In Denmark and Norway, they have done a lot of effort, a lot of incentives. Some people believe there are too many incentives. Norway also has hydro power, so they have a fairly clean electricity. But they still produce oil. They sell the oil to other countries. They say they are very green, that's a question you can ask, they say they are very green right, but they have not reduced the production of oil.

Similarly, R109 in Denmark noted about the Danish electricity system that:

Although better than most countries and regions, the Nordic area still uses fossil fuels to generate electricity. We must continue to reduce dependence on oil and gas and coal. We have been a net exporter for years, so the main concern would be climate from a Danish perspective.

R229 in Norway added that:

Norway is hypocritical living on oil, exporting oil for transportation in the rest of the world and at the same time electrifying the Norwegian car fleet. It is a kind of contradiction in a way.

These comments remind us that the Nordic region is an actual net exporter of primary energy based largely on the trading of oil products, natural gas, and crude feedstock—exports (by volume) that more than double the amount of domestic production (Sovacool 2017). Volvo also remains the second largest heavy duty automotive original equipment manufacturer in the world.

3.5 Reliability of local grids

The fifth most frequent challenge mentioned by respondents was the need to maintain the reliability of local grids, especially pertaining to network upgrades and the local transmission and distribution of electricity. This challenge follows both the further integration of renewables and the expected effects of electric mobility on local grids, their demand and potential storage capacity.

For instance, R189 in Norway argues that there is not necessarily a supply problem, but instead a distribution of electricity problem, with accompanying investment challenge:

Norway has more than 90 percent hydropower, so our challenge is not so much on supply. We have enough installed power. Our challenges regard the power grids.

There are many power lines that are facing high age, so they need to be replaced but we're talking billions of dollars of needed investment.

R203 from Norway added a consumer focus and placed the local grids against the expected increasing electrification of consumer life:

We have a surplus of renewable energy in the market as we're part of the Nord Pool market. So I think the greatest challenge is to make sure we have a significantly strong grid all the way from the high power transmission network down to the local grids. We need to be able sustain this electrification and level of reliability so every family can have their own electric car, their own solar panel, their own storage unit like a PowerWall.

The focus on electric mobility returned in other countries, again partly influenced by the topic under discussing. For example, R119 in Denmark stated that:

To me, the big problem is supporting local grids so they can handle smarter, renewable, more flexible supply. I spoke with Better Place, a company that tried to provide battery swapping and charging infrastructure for electric vehicles. Even in their parking lot, they had to do something intelligent to avoid overloading the local grid. And that's just for 20 or 30 cars. Our national grids are state of the art, and our sources of supply are getting cleaner, but local grids are lagging behind.

R149 in Finland characterized it this way:

It's the last five meter challenge. We've been focusing so much on decarbonizing electricity supply, and large grids and power pools, less attention has been paid to local grids and distribution networks. There are stories circulating about people disrupting the entire village or town grid because they tried to charge an electric vehicle. That is a monumental challenge for local networks.

Therefore to some extent the growing demand from a further electrification of society has affected the current state of local networks, as policy, funding and development has focused primarily on the core infrastructural pillars of centralized power supply systems; the transmission network and large-scale generation capacity. Noteworthy, for some, this challenge is exacerbated by the ownership and business model of local grids, where the DSOs

often decide against full line development, and rather opt for maintenance and incremental localized upgrades.

The concern among interviewees with local reliability relates not only to the addition of new technologies to the grid such as wind and solar, storage, or the charging of electric vehicles, but simply to maintaining reliability in terms of blackouts and winter storms. As R157 in Finland put it:

The security of supply of local networks is of paramount concern. In 2011 we had huge winter storms here in Finland, and we had blackouts all over the Finland which have never ever occurred before, and that was a huge political pressure to change the legislation and enhance the security of supply on networks. There was a new legislation put in place in 2013 which stated the cities can only allow up to six hours of a blackout, and areas outside of cities, 36 hours. This sounds reasonable, but it's very harsh for DSOs that are working with a local grid that has not been modernized for decades. These DSOs have a lot of overhead lines and all that, so they have to invest a lot in cabling and securing the network. So that is the starting point and they have fourteen years to go, so by 2029 they have to have these security issues handled and the investment has to be done, so it's kind of a big task for them. It means that they have to invest more than eight billion euros to network in the near future. Normally you would have thirty or even forty years to do these investments in normal conditions.

R246 in Norway concurred this challenge existed there as well, noting that:

Here in Norway, even our TSO Statnett has had some historical difficulties in serving the northern community with reliable power. We see frequent outages - a few years ago we actually had three to five hour blackouts across the whole area - due to faults in distribution. We also have polar storms that come out of nothing and sweep across

power lines, from the seaside into the land, which introduces another problem of preparedness and resilience.

A focus on local grids is definitely timely, however, some of those interviewed suggested that local grid challenges could be solved more or less organically within already available maintenance and investment forecasts. So, while these challenges are definitely a concern, some of the interview sample primarily saw a challenge with a further integration of more intelligent systems in terms of organizational knowledge and expertise.

3.6 Adequate capacity

A final frequently mentioned challenge encompasses actually having adequate capacity of energy, electricity, or energy services to meet growing demand and peak demand. This relates to a growing demand itself from consumers and industries, difficulties and increasing resistance in constructing new supplies, the impact of seasonal weather conditions, and dependency on interconnectors.

In some places, such as Iceland, this challenge related to forecasted shortfalls in the supply of electricity due to growing demand and difficulties around building more capacity, with local resistance and occupied 'low hanging fruit' for hydro and geothermal. As R12 explained:

The current situation in Iceland is that there is no available power to be sold. And we foresee a shortage in a year or two. Because those who want more power can't get it. Unless that is very small amounts. But for new industries, for startups, there is no power available. And in my view, that is bad for the economy, it is bad for the society because that has to do with job creation, welfare and you know development of the nation and the society.

R3 in Iceland added that this challenge of meeting demand extended from the residential sphere to cover industrial and commercial sectors as well:

One troublesome trend is that demand for electricity continues to exceed supply. This is due in part to increases in residential use and population growth, but it mostly comes from industry, at least in Iceland. Industry is knocking on the door here.

It has to be said that the Icelandic energy circumstances are rather unique, in terms of supply (hydro and geothermal), but also in terms of demand as the country has a low population and relatively large share of high capacity electricity industries (aluminum smelters and so on); as compared with Norway for example with surplus generation, and a challenge of how to manage such excess power in the system.

In other places, such as Finland, the challenge of adequacy or security of supply related more to seasonal peaks in the winter. R159 in Finland argued that:

I think the greatest challenge will be lack of capacity in the winter time in a few years. Because the power prices are low and it does not encourage investments and of course there's risk that in a dry year there might be a power deficit in Finland or another country. You do not have enough flexible consumption, and like expensive production that cannot participate in market or auxiliary services, it has the potential to be a major adequacy and reliability issue.

R185 from Finland agreed on a systemic level when they stated that:

The biggest issue in our electricity system is the controlling of the peak hours. There are certain times, like Christmas Eve between five to seven o'clock, where every Finnish family is cooking their ham at home, in an electricity oven, and it's a terrible peak on the electricity grid. And if it happens at the same time to be minus thirty degrees, then your grid is on the limits. The quality of the network is superb, the technology is one of the best on the world, but we are entirely dependent on borrowing electricity from Russia, Norway, or Sweden to meet these kinds of peaks.

Thus linking local peak loads through networks and markets to a ‘dependency’ on production in neighboring countries.

Interestingly, more than one respondent commented on how the situation of adequate capacity intersected with some of the other challenges identified here. R45 in Sweden was not alone when noting how the adequacy issue extended not only over electricity, but feedstock for renewables, notably biofuel, if targets would be met. As they said:

We lack the production capacity to manufacture sufficient environmentally friendly biofuels. There is simply not enough production to cover the demand.

R103 in Denmark was worried about adequate backup capacity for renewables, which intersects with challenges such as integration of renewables and managing intermittency:

As we continue to cut down on baseload power supply in Denmark, phasing out of coal and fossil fuels, we will begin to rely on getting power exclusively from renewables. And if we have a dark, high pressure winter, there can be quite a large high pressure in Northern Europe, so we don't have any sun or any wind for a period, we can have serious adequacy issues by 2025.

The adequacy issue also connects with some of the economic and geopolitical aspects of the challenges identified in 3.1 and 3.3. As R155 in Finland suggested:

In a highly interconnected system, where the Nordic region shifts to greater imports of electricity, there is an increasingly important question of security of supply. If something happens with the power lines, or power stations go out in a particular country, how can we manage the situation?

R170 from Finland echoed these concerns by noting that:

In Finland, this is a kind of a politically very delicate question because our most of our electricity is coming from abroad. You know, Minister Putin and the big bear behind the border, if they make a decision that we just turn the power off, we are in

trouble. We have water power in Finland, but that's not enough and we have some wind power, but that's not enough, and of course a general opinion against nuclear power means it's dangerous when something happens. So without Russian imports and nuclear power, and a small amount of hydropower or wind power, we are dependent on others.

In other words, although Nord Pool offers one of the most integrated electricity markets in the world, dependence and interdependence are still cause for concern.

4. Discussion and Conclusion

Our sample of 227 expert interviews and 257 respondents in the Nordic region suggests that the electricity challenges facing Denmark, Finland, Iceland, Norway and Sweden are diverse and varied. The integration of renewables was mentioned most frequently as a challenge, but five other challenges were also identified frequently across the interview sample. The combined six challenges—integration of renewables, electrification of transport and heat, technically managing intermittency, carbon intensity and emissions, reliability of local grids, and ensuring adequate capacity—may serve as a useful ordering of priorities for energy and climate planners and policymakers.

Interestingly, however, is that some of these six priorities touch upon intricate technically oriented organizational concerns, such as maintaining adequate capacity, managing intermittent flows of wind, solar, or hydroelectricity, or ensuring the reliability of local transmission and distribution grids. Others touch on environmental concerns, such as climate change or decarbonizing transport via the electrification of rail and cars, or political and economic concerns, such as accommodating renewable sources of energy in an affordable way. Furthermore, within the sample some challenges were more prioritized in certain places. As Table 2 indicates, in Iceland local grids and adequate capacity were most frequently mentioned, whereas in Sweden and Denmark, it was integration of renewables. In

Finland it was intermittency and carbon dioxide emissions, in Norway, electrification of other sectors.

INSERT TABLE 2 HERE

In addition, the six challenges we discuss in detail interconnect in numerous ways. As the dendrogram depicted in Figure 5 attempts to capture, based on Jaccard's coefficient, the challenge of integrating renewables is closely aligned with managing intermittency and in some ways electrification of transport (as vehicles can store excess or intermittent energy flows) and the reliability of local grids. Similarly, the electrification of transport is connected with phasing out fossil fuels so that carbon intensity and emission drop. Ensuring adequate capacity intersects with some of the dependence issues that arise from integrating renewables and managing intermittency as well. Granted, our clustering of challenges here is inductive, and could be verified by further statistical analysis or principal component analysis in future research. Nonetheless, the implication here is that the electricity challenges facing the Nordic region are synergistic, and as a result policies to promote electricity sustainability and stability must be comprehensive.

INSERT FIGURE 5 HERE

Lastly, while the six most mentioned challenges serve as a useful short-list, what is also noteworthy is what was infrequently mentioned or under-discussed. As Table 3 indicates, despite featuring prominently in the International Energy Agency and Nordic Energy Research (2016) assessments and projections, both energy efficiency and decarbonizing industry were infrequently mentioned as distinct, pressing needs. Similarly, although they could radically reconfigure Nordic electricity markets (Parag et al. 2016), the importance of consumer awareness, users, and prosumers was seldom mentioned, as was the digitalization of grids as a distinct challenge. Experts did touch upon these topics but always as the solution to the challenges above, seeing the obstacles that come with it as secondary.

Furthermore, although previous research has found that energy users in Denmark strongly considered energy security to be a key concern (Sovacool and Tambo 2016; Sovacool and Blyth 2015), it was also mentioned infrequently. In turn, while Ladenberg (2015) and Devine-Wright et al. (2017) emphasize the importance of issues of social acceptance and public opposition, these did not arise frequently from the interview material. Issues of energy justice and consumer vulnerability arising from electricity supply or demand (Sovacool 2017) were not even mentioned once, basically because experts interviewed inherently framed their responses in terms of more centralized energy and electricity supply systems.

INSERT TABLE 3 HERE

Therefore, our short-list of challenges is not meant to be absolute or all-encompassing: it illustrates the intricacy of regional electricity challenges and the flux that characterizes the difficulty in decarbonizing electricity and energy systems, made all the more pressing when one considers the full range of 40 distinct challenges mentioned in our expert interviews.

5. Appendix I – Overview of Semi-Structured Research Interviews

Country (5)	Cities (17)	Interviews (227)	Visit (9 months)
Iceland (n=29)	Reykjavik	1-22, 29	Sept/Oct 2016
	Akureyri	23-28	Sept/Oct 2016
Sweden (n=42)	Stockholm	30-43, 66-68, 70	Nov 2016
	Gothenburg	44-61	Nov 2016
	Lund and Malmo	62-65, 69, 71	Nov 2016
Denmark (n=45)	Other*	72, 103	Jan 2017, Feb 2017
	Greater Copenhagen Region	73-100, 113, 115	Jan/Feb/Mar 2017
	Aarhus	101-102, 104-107	Feb 2017
	Aalborg	108-112, 114, 116	Feb/Mar 2017
Finland (n=50)	Greater Helsinki Region	117-144, 154, 163	Mar 2017
	Tampere	145-153, 155, 164	Mar 2017
	Oulu	156-162, 165-166	Mar 2017
Norway (n=61)	Greater Oslo Region	167-208	Apr 2017
	Trondheim	209-220, 222	May 2017
	Tromsø	221, 223-227	May 2017

Source: Authors. Note: * Two Danish towns are not mentioned by name to ensure the anonymity of interviewees.

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