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Research, Development, and Education: Laying Foundations for Arctic and Northern Data Centers*

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Abstract. The global data center industry is a huge and rapidly growing sector. This growth has resulted in the development of significant data center clusters in various northern regions. Furthermore, the desire to attract new data center investments has been incorporated into regional development plans and strategies in different parts of the Circumpolar North. Although the policy-makers seem to have great expectations, they and the general public often know little about the industry, which consumes huge amounts of electricity and plays an immense role in the digitalization process that the world is experiencing. This article attempts to increase awareness, knowledge, and understanding of these matters among all relevant stakeholders by introducing data center-related research and development activities and education in the Arctic and the North, as well as research concerning the development of the data center industry in the cold, northern environment. After all, it is often argued that these particular conditions offer advantageous circumstances for the construction of environmentally friendly and sustainable data centers.
Keywords: *data centers, communications infrastructure, information technology, Arctic, North.*

Introduction

After Google opened its data center in Hamina, Finland in 2011 and Facebook established its data center in Luleå in 2013, the regional governments in northern Sweden recognized a need for — and created — a coordinated data center industry strategy. Completed in 2014, this document proposed, among other things, that northern Sweden should place emphasis on and invest in the development of data center-related research and education. Today, the Luleå–Boden–Piteå region forms a globally recognized data center cluster, and it hosts RISE ICE Datacenter, which is one of the leading data center research and innovation facilities in Europe. Therefore, it is clear that data center-related expertise has successfully been added to the local and regional skillset. They are seen as a new type of mission-critical infrastructure, adding to the traditional mining, hydropower, pulp and paper, and steel industries that are located in the region, and they have strong backing from the research, development, and education conducted in local universities and research facilities.[1]

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[1] Minde T. B. Strategi för att skapa en världsledande teknigkregion i Norbotten för klimatsmarta effektiva datacenter. Länsstyrelsen Norrbotten, 2014; Interview with Tor Björn Minde, Luleå, Sweden, 02.03.2018.

The strong regional technical know-how and availability of skilled staff has also been emphasized when Mo i Rana in northern Norway has marketed itself as a great location for data centers.[2] However, it is obvious that the Nordic countries' success in attracting data center investments is not based only on their human capital. Rather, the abundant reserves of power and the low price of (often green) energy, together with a cold climate, a stable society, suitable fiber-optic connectivity, reasonable land prices, low risk of natural hazards, and low seismic activity, have played a significant role as well. Although great developments have taken place in various Arctic and Northern regions since the late 2000s and early 2010s when these characteristics were first recognized as assets, both the industry itself and its presence in the circumpolar north is not well known among the general public. Furthermore, despite the existence of national and regional data center policies, it can be argued that the rapidly growing industry, which consumes huge amounts of electricity has not received a sufficient amount of attention from decision-makers and researchers.

The aim of this article is two-fold. First, it attempts to increase awareness, knowledge, and understanding among all relevant national, regional, and local stakeholders concerning data centers, the data center industry, and its role in the Arctic and the North. The data centers have been described as a type of building that most distinctly embodies the 21st century culture, and they are [1, Varnelis K.], together with the global fiber-optic cable network, at the core of the so-called Society 5.0, where cyberspace and physical space are highly integrated. Therefore, questions concerning data centers may no longer belong only to the sphere of information and communications technology (ICT), as they could be considered a new type of basic infrastructure upon which society is dependent. Second, in order to demonstrate the strengths and weaknesses of regional knowledge bases and skillsets, this study introduces data center research and education that was conducted in the Arctic and the North, as well as research concerning the past, current, and future development of the data center industry in the cold, northern environment.

The importance of the study of local and regional knowledge networks and skillsets can be traced back to discussion concerning clusters, regional development and competitiveness and even resilience. In general, clustering refers to the concentration of industries and companies in a specific geographic area and to their interrelationships. Furthermore, features such as the great number of firms in close proximity, competition and cooperation between these firms, the high proportion of small firms, dense social and economic networks, the rapid diffusion of information and ideas, adaptability and flexibility are typical for industrial clusters [2, Dawkins C.; 3, Piperopolous P.G.]. Due to the emergence and evolution of knowledge-based economies, universities have become recognized as key players in regional economic development and cluster formation [4, Wolfe D. A.]. Similarly, a growing body of literature highlights the importance of innovations and research and development (R&D) activities to the resilience of individual firms and regional

[2] Arctic Circle Data Center. URL: https://arcticcircledc.com/ (accessed 13 April 2020).

economies [5, Bristow G., Healey A.]. Rather than giving a detailed description of the role of R&D and higher education in the formation of a data center cluster in any pre-determined case study region, this article takes a holistic approach and attempts to identify characteristics common for several cold and northern regions.

The challenges of researching data centers, which are due to a limited amount of information that is openly available and an element of secrecy surrounding these industrial spaces, have been recognized by various researchers [6, Vonderau A. pp. 702, 707; 7, Hogan M., Vonderau A.]. While the information produced as a result of R&D activities of private enterprises is more difficult to access than the output of researchers who are committed to the principles of open science, this article covers both private and public knowledge production, as well as the cooperation between them. To achieve the set objectives, the authors interviewed stakeholders representing the data center industry, different levels of government, and academia to supplement the information that can be traced from openly available sources or from different media outlets covering issues concerning data centers. A significant portion of the information has also been collected through the process of participatory observation. Juha Saunavaara has approached the data center industry, government officials, and researchers to conduct highly technical studies as an outsider with a background in the social sciences. Meanwhile, Antti Laine has worked as a practitioner for ten years in private enterprises that design data centers. He also acted as the director of the Finnish Data Center Forum between 2019–2020, where he continues to serve in an expert role, and represented the industry in negotiations with public authorities. Therefore, the balance between the dimensions of 'observation' and 'participation' varies between the authors.

The particular features of the Arctic and Northern data center R&D activities

Although a recent study has shown that data centers' overall energy consumption has increased less than previously expected due to development of technology [8, Masanet E., Shehabi A., Lei N., Smith S., Koomey J.], it is an extremely energy-hungry business that does not seem to fit with energy-saving policies and goals to reduce carbon emissions. Therefore, the question of why many countries, regions, and cities try to attract data center investments through measures ranging from tax policies and supportive infrastructure construction to municipal zoning, helping with permits, and organizing communication with local contractors, may be a valid one. Besides approaching the answer from the viewpoint of employment and tax revenues, the rationale behind these attempts can also be found in the relative environmentally friendliness of data centers, especially those located in the North. Although data centers, which are facilities designed to enable concentrated and efficient usage of software and hardware in one place, consume vast amounts of energy, their consumption is still much less than it would be if the computing power/servers were distributed between various locations. In other words, significant savings in energy use can be achieved if a server running in a data center makes it possible to shut down a large number of other devices outside of the data centers [9, Peuhkuri M., Lääkkölä R., Costa-Requena J., Manner

J.]. The cold climate partially explains the high energy efficiency of the data centers located in the Circumpolar North, but it is worth noting that the increases in energy efficiency are often due to the R&D activities conducted in the area.

The content of the studies and projects carried out in the Arctic and the North have often been connected with the prevailing conditions. In other words, while the cold climate, the presence of wide district heating networks [3], and the abundance of water and wind power resources may seem to be far from the core business, i.e. the storage of data, they have affected both the research into and the actual design of the data center facilities. Furthermore, the research concerning data centers have not started from scratch but rather been built on an existing knowledge base. The researchers involved in data center research, as well as the personnel who have started to work in the data centers, come from various backgrounds. The design and construction of the buildings require experts, for example from architecture and construction, fire protection, power distribution and energy systems, cooling, (fluid) mechanics, and automation. Meanwhile, the running and optimization of the data centers demand knowledge of embedded systems, cloud, software, big data, and so on. Some of the skillsets needed already existed in the northern regions, and it has been possible to recruit researchers from other fields and skilled labor from other industrial sectors [4].

The labor mobility between firms leading to knowledge transfers and fostering of innovations as well as the possibility to hire experienced workers from the local labor market are identified as typical features for established clusters [10, Lundmark M., Power D.; 11, Simonen J., Svento R., Karhinen S., McCann P.]. However, as a result of inter-sectoral mobility, many northern data center companies have been able to benefit from these kinds of fruits of agglomeration already at the early stage of the cluster formation processes. While it can be challenging to indicate what R&D (issues related to heat, ventilation and air conditioning, for example) is directly or only related to data centers, the need for expertise on how to coordinate and synchronize the design of various systems in data centers has become obvious [5].

Although cooling and energy efficiency of facilities have attracted the attention of data center operators and researchers globally as a means to reduce energy costs and lessen the carbon footprint [12, Wahlroos M., Pärssinen M., Rinne S., Syri S., Manner J., p. 1750], the utilization of the cold climate can be recognized as one of the particularities of the R&D conducted in the North. The idea of utilizing the cold climate is not new. Microsoft, for example, opened a data center in Quincy, Washington, in 2006, and in 2007 it was reported that the company had signed a memorandum of understanding with regional authorities from Irkutsk, Russia, one of the coldest places on earth, concerning the possibility of building a data center. While Quincy also had other

[3] In Finland, for example, district heating produces approximately 90 percent of the total heat demand of the largest cities.
[4] Interview with Tor Björn Minde, Luleå, Sweden, 02.03.2018.
[5] Interview with Tor Björn Minde, Luleå, Sweden, 02.03.2018.

assets, such as extremely low power costs and access to 100 percent renewable hydro-power, that had drawn data center investments prior to the arrival of Microsoft and the project in Russia did not materialize, the attractiveness of a cold climate for free-air cooling as a competitive solution was recognized [6].

When the data center industry emerged in Iceland, in particular on the Reykjanes Peninsula, as a new avenue for economic growth during the years following the collapse of the banking business in 2008, the cold climate and abundant renewable energy resources were identified as highly valuable assets. Similarly, Canada, which hosts various co-location data centers, has advertised its cheap energy, stable society, and data sovereignty (relevant when compared with the Patriot Act in the United States, which enables governmental access to data) when describing itself as a natural fit for free-air cooling since the beginning of the 2010s [7].

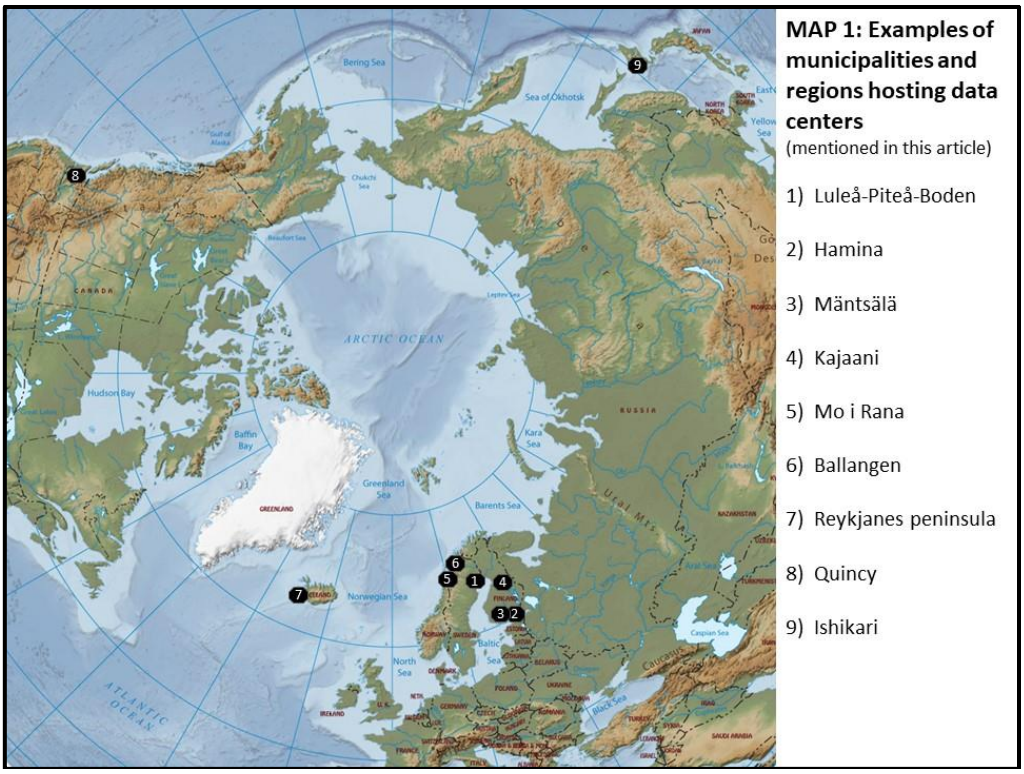

Fig. 1. Examples of municipalities and regions hosting data centers.

[6] Fried I. Microsoft plans Russian data center. URL: https://www.cnet.com/news/microsoft-plans-russian-data-center/ (accessed 13 April 2020); Miller R. Microsoft Plans Data Center in Siberia. URL: https://www.datacenterknowledge.com/archives/2007/11/26/microsoft-plans-data-center-in-siberia (accessed 13 April 2020); Hassell J. Take a look inside Microsoft's Quincy, Wash. Data center. URL: https://www.computerworld.com/article/3136160/take-a-look-inside-microsofts-quincy-wash-data-center.html#slide2 (accessed 13 April 2020); Chernicoff D. Inside Microsoft's Quincy data center. URL: https://www.datacenterdynamics.com/en/analysis/inside-microsofts-quincy-data-center/ (accessed 13 April 2020).

[7] McCarthy S., Saitta E. IMMI Research Report: Islands of Resilience – Comparative Model for Energy, Connectivity and Jurisdiction. Realizing European ICT possibilities through a case study of Iceland. September 2012. URL: https://www.greens-efa.eu/files/assets/docs/study_islands_of_resilience.pdf (accessed 15 April 2020); BroadGroup. Iceland's competitive advantages as a global Data Centre location. URL: https://docplayer.net/6699149-Iceland-s-competitive-advantages-as-a-global-data-centre-location.html (accessed 13 April 2020); Beal V. Why Putting Your Data Center in Canada Makes Sense. URL: https://www.cio.com/article/2391505/why-putting-your-data-center-in-canada-makes-sense.html (accessed 13 April 2020); Brent P. Quebec firm investing in Canadian data centres. URL: https://renx.ca/quebec-firm-investing-canadian-data-centres/ (accessed 13 April 2020).

Free-air cooling is not the only method that has been adopted in the Arctic and the North; Google, for example, utilizes sea water to cool its hyperscale data center in Hamina, Finland. However, in order to lower the Power Usage Effectiveness (PUE) ratio describing how efficiently a data center uses energy, free-air cooling has inspired various studies in the past decade. One article, published in 2011 by researchers from Aalto University and claiming to be the first research paper on data centers from Finland, concentrated on the air management and energy performance of the cooling system and paved the way for further studies to be conducted in this Helsinki-based university [13, Lu T., Lu X., Remes M., Viljanen M.].

RISE ICE Datacenter [8], the Infrastructure and cloud research and test environment in northern Sweden, was inaugurated in January 2016 with close proximity to the Luleå University of Technology. From the very beginning, initiatives to minimize energy consumption in data centers have belonged to its research portfolio. While the early projects, initiated in cooperation with the local university to develop new ways to utilize the air pressure differences within the data center in order to control the air flow and reduce the use of fans received funding from national and regional sources [9], the ongoing BodenTypeDC-project has earned awards, attracted attention in the media, and received funding through EU's Horizon 2020 program. During the project, a highly efficient prototype data center with low PUE (reportedly as low as 1.007) was built and tested. The data center, located in the city of Boden, uses only renewable power and advanced cooling technologies [10].

Table 1

Different types of Data centers [11]

Hyperscale DC	Facilities above 20 MW. Owned and operated by the company it supports. Offer robust, scalable applications and storage portfolio of services. Normally located close to the power grid in areas with power abundance. Has typically more than 500 Cabinets (minimum of 5,000 servers) and is at least 10,000 sq. ft. in size.
Enterprise DC	Owned and operated by the company it supports and often built on-site. May use external companies for initial fit-outs and network installation before being maintained internally. Has more than 10 Cabinets and can be as large as 40MW.
Co-location DC	Data center owner selling space, power, and cooling to multiple enterprise, cloud, and hyperscale customers in a specific location. Offers interconnection to Software as a Service (SaaS) or Platform as a service (PaaS). Enables enterprises to grow with minimum complexity at a low cost. Customers can rent as many cabinets they need. Can house hundreds to thousands of individual customers.
Cloud	Facilities owned and operated by the cloud companies delivering the on-demand availability

[8] The ICE Datacenter facility is operated and owned by RISE SICS North, which is a subsidiary of the non-profit organization RISE SICS that carries out advanced and focused research in strategic areas of computer science in close collaboration with Swedish and international industry and academia.

[9] ICE RISE SICS North, DRAFT: A new project to save energy in datacenter. URL: https://ice.sics.se/draft-new-project-save-energy-datacenter/ (accessed 13 April 2020).

[10] European Commission, Novel data centre enters the spotlight thanks to its energy- and cost-saving concept. URL: https://cordis.europa.eu/article/id/413286-novel-data-centre-enters-the-spotlight-thanks-to-its-energy-and-cost-saving-concept (accessed 13 April 2020); ICE RISE SICS North, Inauguration of the Boden Type Data Center One. URL: https://ice.sics.se/inauguration-boden-type-data-center-one/ (accessed 13 April 2020).

[11] Based on: Nordic Council of Ministers. Data Center Opportunities in the Nordics. An analysis of the competitive advantages, 2018; AFL Hyperscale, Understanding Different Types of Data Center. URL: https://www.aflhyperscale.com/understanding-different-types-of-data-center (accessed 14 April 2020).

	of computer system resources, especially data storage and computing power, to clients. Available to many users over the Internet. Large cloud providers build multi-site networks.

Hokkaido, the northernmost island of Japan, is south of the Arctic, but its natural conditions, i.e. cold winters with heavy snowfall, have a great resemblance to those of higher latitudes. Its cold climate has been recognized as a potential asset in regional development plans, and attempts to attract data centers began to be launched already a decade ago [14, Saunavaara J., p. 329]. While cheap land prices and low-risk of earthquakes have been utilized in the marketing, Hokkaido-based actors have also carried out R&D activities utilizing snow that is collected during the winter for cooling during the summer. Although the different techniques of snow and ice cooling have a longer history in other sectors of industry in Hokkaido, applications suitable for data centers have already been introduced [12]. However, the utilization of snow has not spread widely in other northern regions.

While PUE is clearly the best-known data center infrastructure metrics, it has been criticized as an imperfect measurement if one wants to describe overall energy efficiency. The PUE equation does not, for example, take into account how energy efficient the IT equipment is, and there is no globally agreed-upon standard to measure PUE. The emergence of new metrics, such as Energy Reuse Effectiveness (ERE) or Energy Reuse Factor (ERF), reflects recent developments in the data center industry and research. In other words, largely due to the greater attention being paid to the ecological footprint of the industry, questions concerning the collection and re-use of waste heat that is born inside data centers have attracted attention within both the industry and academia. Although the re-use of heat is studied in different parts of the world [15, Patterson, M.K., VanGeet O., Tschudi W., Azevedo D.; 16, Marcinichen J.B., Oliver J.A., Thome J.R.; 17, Ebrahimi K., Jones G. F., Fleischer A.S.; 18, Ebrahimi K., Jones G.F., Fleischer A.S.; 19, Davies F.F., Maidment G.G., Tozer R.M.] [13], the Nordic countries are considered to be the global forerunners in research and the pioneers in the actual utilization of data center waste heat [14]. Therefore, they are well prepared if legislation either guides or forces the data center industry toward the re-use of heat in the future.

The utilization of the side streams of an industrial process is according to the widely supported principles of a circular economy; however, the waste heat that can be captured has problems as well. Most notably, the temperature of data center waste heat is often too low (30–40 degrees Celsius) to be used as-is in many applications and processes. However, this problem has

[12] Hokkaido Government, Hokkaido Business Location Guidebook – As of May 2019; Kyocera Communication Systems, 100% saisei kanō enerugii, zero emisshon – deeta sentaa wo hokkaidō ishikari ni kaigyō. URL: https://www.kccs.co.jp/news/release/2019/0107/ (accessed 13 April 2020).

[13] However, for example the 682-page long Data Center Handbook (edited by Hwaiyu Geng) published in 2015 (by Wiley) dedicates only one short paragraph to this topic.

[14] Examples of data center heat reuse in the Nordics: Vela J., Helsinki data centre to heat homes. URL: https://www.theguardian.com/environment/2010/jul/20/helsinki-data-centre-heat-homes (accessed 14 April 2020); Lähienergia.Mäntsälässä hukkalämpö on arvokas energianlähde. URL: https://www.lahienergia.org/mantsalassa-hukkalampo-arvokas-energialahde/ (accessed 21 April 2020).

been at least partially solved through the development of heat pump technology. Furthermore, the recovery of data center waste heat only makes sense technically if meaningful ways to utilize it are available. Economically, the re-use of data center waste heat is only reasonable if it is priced competitively against heating plants and waste heat flows from other industries. In the Nordic countries, for example, the high-quality (high-temperature) waste heat of the forest, chemical, and steel industries is already relatively widely utilized [15].

MAP 2: District heating plants in Finland, 1 July 2015. (Author: Energiateollisuus ry. Kaukolämpö Suomessa.png. This file is licensed under the Creative Commons Attribution 4.0 International license.)

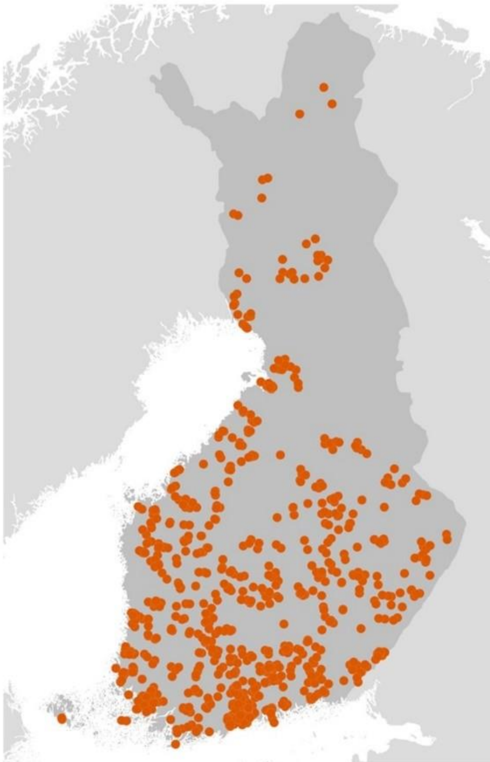

Fig.2. Map 2: District heatingplants in Finland, 1 July 2015

The research on the re-use of heat can be divided roughly into two tracks. The first track includes research concentrating on the re-use of heat through the district heating system and has been conducted both in the RISE ICE Datacenter [16] and at Aalto University [20, Wahlroos M., Pärssinen M., Manner J., Syri S.; 12, Wahlroos M., Pärssinen M., Rinne S., Syri S., Manner J.; 21, Pärssinen M., Wahlroos M., Syri S., Manner J.]. These studies have often focused on attempts to increase the temperature of heat coming out of data centers. While heat pumps, which have often been at the core of such research, are already in use (for example, the Yandex data center in

[15] Interview with Tor Björn Minde, Luleå, Sweden, 2 March 2018; Interview with Petri Hyyppä, Oulu, Finland, 5 February 2020; Interview with Suvi Linden, Oulu, Finland, 06.02.2020.

[16] Interview with Tor Björn Minde, Luleå, Sweden, 02.032018; ICE RISE SICS North, Our challenging and exciting EU H2020 project application on datacenters and fuel cells was granted. URL: https://ice.sics.se/challenging-exciting-eu-h2020-project-application-datacenters-fuel-cells-granted/ (accessed 13 April 2020); ICE RISE SICS North, We have received a positive funding decision from Energiforsk for our project Virtual heating plants. URL: https://ice.sics.se/received-funding-decision-energiforsk-project-virtual-heating-plants/ (accessed 13 April 2020).

Mäntsälä, Finland, sells its waste heat to the local energy company, utilizing heat pumps to reach 85 degrees Celsius), liquid cooling methods have also been tested for reaching higher temperature levels to make the use of data center waste heat in district heating more efficient. At the same time, attention has been paid to the efficiency of the heat pumps and the development of district heating networks, as the new networks will be better suited for the utilization of lower temperature waste heat. The research on these technologies have been accompanied with an economic investment assessment and studies analyzing business models and the district heating system level operational cost savings in the case data center waste heat is utilized. Map 2 uses Finland as an example to demonstrate the wide distribution of district heating systems (exceeding 15.000 kilometres and expanding) in the Nordic countries. The availability of the district heating network in different parts of the country makes decisions concerning the location of data centers more flexible.

The second track of research on the re-use of heat has concentrated on other applications in need of low-grade heat. Greenhouses, fish farms, and biomass drying are examples of potential activities that both academic researchers and data center businesses have paid attention to. While these applications might bring greater energy efficiency, as they would not demand the use of heat pumps, they are not without trouble. Most importantly, the utilization of the low-temperature waste heat demands that the interdependent facilities are located close to each other.[17] Although the limitations of the existing sites and question of business models acceptable to all parties may have hindered the development, there are already examples of synergetic cooperation between data centers and greenhouses [18].

The discussion concerning Smart Grids and industrial facilities' capability to respond, for example to grid emergencies or congestions jeopardizing the electricity supply-demand balance, is not new [22, Ghatikar G., Piette M. A., Ganti V., p. 577]. However, the integration of data centers into the national and regional energy supply-demand system can be recognized as another distinctive feature of the R&D activities conducted in the North. The attempts to answer questions concerning the optimization of energy supply and consumption, smart grid integration, and data centers' role in grids where the increased renewable electricity production that is dependent on natural conditions increases volatility has led to academic research papers and cooperation between

[17] Interview with Tor Björn Minde, Luleå, Sweden, 02.03.2018; RISE, Data Center for Greenhouse farming. URL: https://www.ri.se/en/what-we-do/projects/data-center-greenhouse-farming (accessed 13 April 2020); ICE RISE SICS North, Vinnova has granted funding for our project DC-Farming together with LTU and The Food Print Lab. URL: https://ice.sics.se/vinnova-granted-funding-project-dc-farming-together-ltu/ (accessed 13 April 2020); ICE RISE SICS North, Vinnova granted a pre-study on heat re-use from datacenters in biomass drying. URL: https://ice.sics.se/vinnova-granted-pre-study-heat-re-use-datacenters-biomass-drying/ (accessed 13 April 2020); ICE RICE SICS North, Biomass drying using residual heat from datacenters. URL: https://ice.sics.se/biomass-drying-using-residual-heat-datacenters/ (accessed 13 April 2020).

[18] ePressi, Yritykset laajentavat ja rakentavat uutta Mänsälässä. URL: https://www.epressi.com/tiedotteet/yrittajyys/yritykset-laajentavat-ja-rakentavat-uutta-mantsalassa.html (accessed 13 April 2020); Phone interview with Ari Kurvi, Finland, 20.04.2020.

industry and academia, as well as to concrete actions taken by commercial data centers operating in competitive markets.

One of the earliest projects in northern Sweden to recognize the growing amount of intermittent power sources and increased need for pro-active load and power balancing was launched in 2016 and aimed at data center operations with a local power supply of both solar panels and grid power. This study concentrated on the data center's interaction with the grid power supply and examined possibilities to balance the power requirements. As an example, the project tested local thermal storages, such as whether chilled water could be produced when the electricity demand was low and used when the electricity demand was high [19]. The succeeding projects in RISE ICE Datacenter have been aimed at electricity cost and peak loads reduction by studying how to optimize the operations for a data center with its own microgrid. Through the implementation of machine learning, optimal decisions were to be made after the forecasts for the temperature, solar radiation, electricity costs, and working load had been analyzed. Recently, these kinds of questions have also been studied in cooperation with partners from Central Europe [20].

The particularities of renewable energy and the need for flexible power reserves have been recognized in the industry. For example, the Aurora Datacenter, which is located in Oulu in northern Finland, has initiated a pilot project in cooperation with Eaton and Fortum to transfer their data center from a facility that demands power to a facility that can support the grid and generate revenue through this kind of activity. The data center that hosts two 3000 kilo lithium batteries and has its uninterruptible power supplies (UPS) connected to the national grid can make immediate adjustments in its power consumption and receive compensation from the transmission system operator [21].

The capability to balance the demand and make adjustments if natural conditions become temporarily unfavorable for wind or solar power is not the only connection between data centers and renewable energy production. The data center operators with facilities in different parts of the world can control their energy consumption by producing the same services in different geographical locations at different times of day. This method, which allows data center companies to consume cheaper electricity during off-peak hours, can also be used to avoid regions where, due to the environmental conditions, the amount of renewable energy available is temporarily low. Furthermore, many data center companies, especially those that are consumer brands, already advertise that their data centers run with renewable energy, and the pressure toward an industry-wide shift to green data centers is getting heavier. If the roots of this trend are studied, one runs into projects like the GreenStar Network project, which originated in Canada in 2010. The aim of

[19] ICE RISE SICS North, Swedish energy agency is funding our project on data center and grid integration. URL: https://ice.sics.se/swedish-energy-agency-funding-project-datacenter-grid-integration/ (accessed 13 April 2020);

[20] ICE RISE SICS North, Swedish Energy Research Centre has granted a project on AI for datacenter micro-grid integration. URL: https://ice.sics.se/swedish-energy-research-centre-granted-project-ai-datacenter-micro-grid-integration/ (accessed 13 April 2020).

[21] Interview with Petri Hyyppä, Oulu, Finland, 5.02. 2020.

the project, which focused on data centers built in proximity to green energy sources, was to provide cloud-based ICT services based entirely on renewable energy [23, Nguyen K. K., Cheriet M., Lemay M., Reijs V., Mackarel A., Pastrama A., pp. 2538–2539]. Nowadays, the data centers either purchase green energy from conventional producers or make direct investments in renewable energy.

Sakura Internet has established one of Japan's largest data centers in Ishikari, Hokkaido and built its own solar power capacity. In addition, Kyocera Communication Systems, which is planning to build Japan's first data center using 100 percent renewable energy in the same city, will invest in wind, solar, and biomass energy [22]. While the high local price of electricity may partly explain these companies' decisions to invest in own-energy production, examples of similar activity can also be found in other northern regions that are much closer to the Polar Circle and where energy is cheaper. An informant representing a data center in northern Finland pointed out that solar power is a good match for the data center industry. This is especially true in the North, where the number of annual sunlight hours can be relatively high, as the midnight sun in the summer compensates for the lack of sunny days during the winter, creating an annual balance that is a good fit for data centers, which have higher energy needs during the summer months due to a need for cooling [23]. However, it is doubtful whether the data center giants, such as Amazon, Apple, Facebook, Google, or Microsoft, will take a positive stance toward regulation as is planned, for example, in Denmark, which would force them to build and operate powerplants serving their hyperscale data centers.

According to one definition, a green data center is all about getting the most computing productivity out of least energy [24, AlLee G., p. 416]. This concept is used in, for example, the Cloudberry Datacenters research project, which has been coordinated by the Luleå University of Technology to bring a wide array of activities, ranging from cooling and energy recovery and reuse, to resource efficiency in software processes, to integration with national and local energy systems, under one umbrella. The studies from this research regarding automated control, maintenance, and management have preceded the development of autonomous data centers, which can be recognized as another trend of current and future R&D activities [24]. In principle, an autonomous data center should be able to continue its operations effectively and self-heal without any human intervention, even when facing unexpected circumstances, such as a power failure or faulty components. In the North, questions related to this kind of paradigm shift in data center operations have led to cross-border cooperation involving academic research institutes and pri-

[22] Sakura Internet. URL: https://www.sakura.ad.jp/en/corporate/datacenter/ (accessed 13 April 2020); Kyocera Communication Systems, 100% saisei kanō enerugii, zero emisshon – deeta sentaa wo hokkaidō ishikari ni kaigyō. URL: https://www.kccs.co.jp/news/release/2019/0107/ (accessed 13 April 2020).
[23] Interview with Petri Hyyppä, Oulu, Finland, 5.02.2020.
[24] Cloudberry. URL: https://www.cloudberry-datacenters.com/subprojects-20315292 (accessed 14.04.2020); ICE RISE SICS North, A holistic approach on automation in data centers – a new EUREKA project. URL: https://ice.sics.se/a-holistic-approach-on-automation-in-data-centers-a-new-eureka-project/ (accessed 14 April 2020).

vate enterprises. For example, in the case of the AutoDC project, the partners come from Sweden, Finland, and Canada [25]. Meanwhile, already in 2016 Google had reported successful use of artificial intelligence (AI) — controlling about 120 variables, such as the cooling system, in the data center — to achieve significant reductions in power consumption [26]. Although there is still some skepticism, the future steps in the field of AI remote monitoring and optimization may lead to the establishment of the human-free data centers. This concept would take the already existing 'lights out' model further, striving for higher efficiency by abandoning energy consumption related to on-site staff, such as human comfort needs and access [27].

Decentralization and the growing importance of edge computing is another trend taking place, and it is molding the future of Arctic and Northern data center business. Edge computing is real-time (or extremely low response time) processing of huge volumes of (sensor) data. If and when smaller computing and data storage units are created and a large number of them are brought closer to the users, the concept that the sparsely populated Arctic and northern regions can best serve as the hosts of a data that is not latency dependent may be strengthened. However, there are also great differences within the Arctic countries, and different regions are not equally matched to fulfill the demands of different types of data. In the case of Russia and Canada, the development of edge computing will likely concentrate on the largest metropolitan areas. Furthermore, the southern parts of Sweden, Norway and Finland as well as Denmark (excluding Greenland and Faroe Islands), which are close to major data hubs in Europe and where population and industry have concentrated, are clearly better suited to serve latency-dependent services than areas in the north. While not an issue that could be identified as a particularly strong point for the R&D carried out in the Circumpolar North, the examples of studies concentrating on edge data centers and a link between different types of data centers can be found [28].

Studies describing the economic impact of northern data centers and their societal meaning

While the research concerning data centers have been conducted in various locations in the Circumpolar North, the data center industry, as well as the individual sites and facilities that exist in the region, have also inspired a number of studies. The reports and articles produced can

[25] AutoDC. URL: https://autodc.tech/about/ (accessed 14 April 2020).

[26] Moss S. Google uses DeepMind AI to cut data center PUE by 15%. URL: https://www.datacenterdynamics.com/en/news/google-uses-deepmind-ai-to-cut-data-center-pue-by-15/ (accessed 15 April 2020); DeepMind. DeepMind AI Reduces Google Data Centre Cooling Bill by 40%. URL: https://deepmind.com/blog/article/deepmind-ai-reduces-google-data-centre-cooling-bill-40 (accessed 15 April 2020).

[27] Donoghue A. Beyond Lights-Out: Future Data Centers Will Be Human-Free. URL: https://www.datacenterknowledge.com/design/beyond-lights-out-future-data-centers-will-be-human-free (accessed 21 April 2020).

[28] Interview with Tor Björn Minde, Luleå, Sweden, 02.03.2018; Mehta R., Are Autonomous data centers on the horizon? URL: https://www.datacenterdynamics.com/en/opinions/are-autonomous-data-centers-on-the-horizon/ (accessed 15 April 2020); RISE. Inauguration of a unique edge test datacenter. URL: https://news.cision.com/rise/r/inauguration-of-a-unique-edge-test-datacenter,c2720659 (accessed 15 April 2020); Nishimoto S. Hakodate miraidai – sakura intaanetto kyōdō kenkyū. [chūshō] renketsu de nōryoku kōjō. Hokkaido Shinbun, 14.11.2019.

be divided into two categories. The first consists of research concentrating on the data centers' economic impacts and regional advantages and investment decisions. The papers representing the second category have typically been interested in the materiality of clouds/internet and approached data centers through the lenses of anthropology or media studies. These articles have been written in and published through academic institutions, but the studies falling into the first category have often been commissioned by private enterprises or public authorities and conducted by consultants.

The reports describing the overall economic impact of the hyperscale facilities that Google and Facebook have established in the Nordic countries are well-known examples of business and regional development-oriented studies. According to these reports, which were commissioned by the companies in question and carried out by international consulting companies, the investment decisions concerning hyperscale data centers are measured in hundreds of millions of euro, and they can create tax revenue and employment (directly and through subcontracting) for thousands of people. While the impact on local employment is the highest during the construction period, the cases studied have shown that this phase can continue for years as the companies continue investing in their selected sites [29].

Furthermore, several reports concentrating on the development of industry in general or on the (hypothetical or previous) arrival of hyperscale data centers into northern communities have been made, for example in Sweden and Norway, based on initiatives taken by national and regional authorities [30]. Although competition between different countries attempting to attract data center investments is a reality, a report commissioned by the Nordic Council of Ministers is an example of intergovernmental cooperation. In describing the factors affecting site selection and the strengths of the Nordic region, the report seems to suggest that the markets are growing rapidly and opportunities are available for all countries involved [31]. What this and other reports concerning the young industry often seem to miss is an analysis that covers the entire life cycle of the data centers. Although many data centers have been opened within facilities that were originally serving other types of heavy industry, hardly any attention has been paid to the question of what happens to the data center facilities when they eventually close.

[29] The Boston Consulting Group. Digital infrastructure and economic development. An impact assessment of Facebook's data center in Northern Sweden, 2014; Oxford Research. Finland's Giant Data Center Opportunity. From the Industrial Heartland to Digital Age, 2015; Copenhagen Economics. Finland's economic opportunities from data centre investments: A study prepared for Google, 2017; Copenhagen Economics. Google's Hyperscale Data Centres and Infrastructure Ecosystem in Europe: Economic Impact Study, 2019.

[30] Ylinenpää H. Etableringen av Facebooks europeiska datacenter I Sverige och Luleå. Tillväxt Verket Rapport 0170, 2014; Granberg A. Effecten av Facebooks etablering för Luleå Science Park som regional nod. Luleå Science Park, 2014; The Boston Consulting Group. Capturing the Data Center Opportunity: How Sweden Can Become a Global Front-Runner in Digital Infrastructure, 2016; Menon Economics. Rapport: Gevinster knyttet til etablering av et hyperscale datasenter I Norge. Menon-Publikasjon Nr. 39/2017, 2017; Sweco. Effekter av Facebooks etablering I Luleå: En studie av effekter på regional och nationell nivå, 2017.

[31] Nordic Council of Ministers. Data Center Opportunities in the Nordics. An analysis of the competitive advantages, 2018.

The anthropological studies focusing on data centers in Sweden, Denmark, and Iceland have been conducted by researchers who are affiliated with universities both inside and outside of the Arctic and the North. This kind of research has typically included long-term field work, interviews, and participatory observation in northern communities that host large-scale data center facilities. The scholars have investigated the infrastructures that comprise cloud computing and thus challenged and problematized the myth of an immaterial or ethereal internet, which has been described as something appearing to be everywhere and nowhere in particular. These studies have described the cloud infrastructures' philosophical, political, social, and environmental impacts, as well as the socio-technical assemblages that emerge in the course of infrastructuring processes. Some scholars have emphasized the influence of infrastructural inheritances and studied localization and integration in industrial landscapes. They have pointed out that many data centers have been built in the premises of other industries that are no longer functioning and shown how the new industrial activity becomes a part of state-making and regional identity-building processes. Finally, attention has also been paid to the lack of public engagement, as well as to the expectations and imaginings woven into data center projects that are often carried out in great secrecy [25, Vonderau A.; 6, Vonderau A.; 26, Johnson A.; 7, Hogan M., Vonderau A.; 27, Johnson A.; 28, Maguire J., Winthereik B.R.].

Challenges of educating and recruiting a competent workforce

The general level of education and technological knowhow is high in the Nordic countries and the above-mentioned report commissioned by the Nordic Council of Ministers, for example, emphasizes human capital as an asset to the region. However, the report also points out that when the attractiveness of the Nordic region is compared to Frankfurt, London, Amsterdam, Paris and Dublin (so-called FLAP-D), the latter scores better in a category referring to the availability of competent workforce [32]. Participatory observation and discussions with representatives of various companies have also shown that the lack of a workforce and problems in recruitment are familiar to data centers in many northern regions including the Nordic countries. Due to the rapid global growth of the industry, skilled workers can choose the company and region where they want to work. Furthermore, although the need to mobilize educational systems to better serve the demands of the data center industry and the importance of establishing educational programs have been recognized [33], these tasks have not been enacted. Degree programs are infrequently revised, often inflexible, and do not necessarily meet the changing requirements of the data center industry. With rapid advances of technology, new types of jobs demanding a particular core competence appear and disappear quickly, and a need for supplementary and task-specific education often emerges. In addition, tailor-made solutions that serve only one or a few sites have also been

[32] Ibid.

[33] See for example: Oxford Research. Finland's Giant Data Center Opportunity. From the Industrial Heartland to Digital Age, 2015, p. 18.

typical for the industry where many R&D breakthroughs have been achieved — often learning by doing — within private enterprises that may be unwilling to share their knowledge.

While the lack of institutionalized university education in many places has led to the establishment of trainings provided by private companies and consultants [34], there are also examples of Arctic and northern higher educational institutes that offer formalized data center education and thesis supervision. In the Nordic countries, several MA and BA theses have already been completed in the already mentioned LTU and Aalto University [35] and in other universities [36]. One thesis, completed at the Lappeenranta University of Technology, even played an important role in the creation of the Mäntsälä region's successful policy aimed at attracting data center investments through the utilization of waste heat [37]. Furthermore, South-Eastern Finland University of Applied Sciences (XAMK) and the Joint Authority of Education of Kotka-Hamina Region Group (Ekami), which are in close proximity to Google's hyperscale data center in Hamina, have offered study modules and programs concentrating specifically on data centers [38]. The highly specialized data center cluster in the city of Kajaani is also an interesting case, both because of the strong presence of the public sector and because of the investments made in the development of the data center-related education.

The origins of these activities go back to 2012 when the IT Center for Science (CSC), which is owned by the Finnish state, and higher education institutions established a data center and supercomputer, and Herman IT, a locally owned private enterprise, opened its data center in the Renforsin Ranta business park. Despite Kajaani's early success owed to the business park, which

[34] Examples of education: Uptime Institute. URL: https://uptimeinstitute.com/education (accessed 29 September 2020); CNet Training. URL: https://www.cnet-training.com/programs/masters-degree/ (accessed 29 September 2020); CISCO. URL: https://www.cisco.com/c/en/us/training-events/training-certifications/certifications/associate/ccna-data-center.html (accessed 29 September 2020); DCPro. URL: https://www.dcpro.training/allcourses (accessed 29 September 2020).

[35] Examples: Sorvari J. Konesalin ylijäämälämmön hyödyntäminen Levin Koutalaella. Aalto University, MA Thesis, 2015; Stenberg Å. Tietokonesalien hukkalämmön hyödyntämismahdollisuuksien teknis-taloudellinen optimointi. Aalto University, MA Thesis, 2015; Pärssinen M. Analysis and Forming of Energy Efficiency and GreenIT Metrics Framework for Sonera Helsinki Data Center HDC. Aalto University, MA Thesis, 2016; Linna O. Kansainvälinen katsaus datakeskusten hukkalämmön hyödyntämiseen. Aalto University, BA Thesis, 2016; Olofsson M. Use of Waste Heat from a Data Center. Luleå University of Technology, Independent thesis Advanced Level, 2013; Gille, M. Design of Modularized Data Center with a Wooden Construction. Luleå University of Technology, Independent thesis Advanced Level, 2017; Erikson, M. Monitoring, Modelling and Identification of Data Center Servers. Luleå University of Technology, Independent thesis Advanced Level, 2018.

[36] Kupiainen M. Lämpöpumppu konesalin jäähdytyksessä ja lämmöntalteenotossa. Mikkeli University of Applied Sciences, BA Thesis, 2014; Juvalainen J. Initial Business Concept for the Neighborhood Data Center. Helsinki Metropolia University of Applied Sciences, MA Thesis, 2016; Vuorinen L. Kannattavuusmalli datakeskuksen hukkalämmön hyödyntämiseen kaukolämpöverkossa. Lappeenrannan Teknillinen Yliopisto, Diplomityö, 2019.

[37] Porkka A. Matalalämpöisen hukkalämmön hyödyntäminen kaukolämmön tuotannossa. Lappeenrannan Teknillinen Yliopisto, Diplomityö 2013; Lähienergia.Mäntsälässä hukkalämpö on arvokas energianlähde. URL: https://www.lahienergia.org/mantsalassa-hukkalampo-arvokas-energialahde/ (accessed 21 April 2020); Phone interview with Ari Kurvi, Finland, 20.04.2020.

[38] Oxford Research. Finland's Giant Data Center Opportunity. From the Industrial Heartland to Digital Age, 2015, pp. 15–16, 18; XAMK, Datakeskuksen korkeakouludiplomi, 60 op. URL: https://www.xamk.fi/avoimen-amkn-kurssit/datakeskuksen-korkeakouludiplomi-60-op/ (accessed 14 April 2020); YLE. URL: https://yle.fi/uutiset/3-7763608 (accessed 14 April 2020); EKAMI, Green Data Center. URL: https://www.ekami.fi/kehittaminen/hankkeet/green-data-center (accessed 14 April 2020).

had been set up on the former premises of a paper mill that offered ready-made facilities, great amounts of power, and fiber-connectivity, the attempts to attract further (private) data center investments and anchor clients failed in the succeeding years. However, this did not lessen the region's commitment to the development of data center-relevant skillsets that took form in the education offered by the local University of Applied Sciences. This data center specialization program has provided students with skills related to the key server and workstation products and modern organizational network solutions. During their training, the students of the Kajaani University of Applied Sciences have been able to work in their own data center training facility, the DC lab, and attempts have been made to widen the ecosystem around the data centers, for example, in the direction of data analytics. Another big step was taken in 2019 when it was announced that the CSC datacenter in Kajaani had been selected to host a pan-European high-performance supercomputer supported by the European countries and the European Union. The supercomputer is expected to start operations in 2020, after which the waste heat produced in the data center will contribute up to 20 percent of the district heating needs of the region [39].

While the possibilities of the re-use of heat produced by supercomputers have also been realized elsewhere, such as at the University of Tromsø (UiT) the Arctic University of Norway [40], informants representing private enterprises have pointed out that some of the Arctic universities that seem to have had opportunities to develop a data center-related education have failed to do so due to a lack of vision and leadership. In the meantime, the data center industry has organized, and the national data center associations in Sweden, Finland, and Denmark have emphasized the importance of education and training in their activities. The practical methods for reaching the set objectives have ranged from seminars in which students can participate to networking, exchange of information, and cooperation with the public sector and institutes of higher education [41].

Conclusion

Currently, most of the data center clusters utilizing the cold climate are located on the outskirts of the Arctic or in sub-Arctic areas. In Russia, for example, the data center industry is heavily

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[39] Interview with Petri Hyyppä, Oulu, Finland, 05.02.2020; Phone interview with Jukka-Pekka Partanen, 21.02.2020; KAMK University of Applied Sciences, Data Center Specialization. URL: https://www.kamk.fi/en/KAMK/Schools-at-KAMK/School-of-Information-Systems/Data-Center-Specialization (accessed 14 April 2020); KAJAK DC. URL: https://kajakdc.fi/?page_id=772&lang=en (accessed 14 April 2020); KAMK University of Applied Sciences, CSC ja KAMK käynnistävät Data-analytiikan kiihdyttämön Kainuussa. URL: https://www.kamk.fi/news/CSC-ja-KAMK-kaynnistavat-Data-analytiikan-kiihdyttamon-Kainuussa/hh0ylnqe/e80efd92-c4cc-49e6-8168-5b7e9e0ea1cf (accessed 14 April 2020); CSC, News. URL: https://www.csc.fi/en/-/one-of-the-most-competitive-supercomputers-in-the-world-to-be-placed-in-kajaani-finla-1 (accessed 14 April 2020); Granlund, Environmentally friendly cooling for a supercomputer. URL: https://www.granlundgroup.com/finland/news/environmentally-friendly-cooling-for-a-supercomputer/ (accessed 14 April 2020).

[40] HPC Wire. UiT Recycles Supercomputing Power with Asetek's RackCDU. URL: https://www.hpcwire.com/2014/06/23/uit-recycles-supercomputing-power-aseteks-rackcdu/ (accessed 14 April 2020).

[41] Swedish Datacenter Industry. URL: https://sdia.se/about/ (accessed 14 April 2020); Finnish Data Center Forum. URL: https://www.fdcf.fi/ (accessed 14 April 2020); Danish Data Center Industry, Skills & Education. URL: https://datacenterindustrien.dk/focusareas/skillsandeducationworkinggroup/ (accessed 14 April 2020).

concentrated, both in terms of market share (the top three companies have 42 percent of the market) and spatial distribution favoring southern locations (65–70 percent of all data center racks are in Moscow, and a further 15–18 percent are in St. Petersburg). The Russian market is, however, developing rapidly, and growth is expected outside of the traditional focus regions. Therefore, the peripheral Russian areas, some of which already host large-scale cryptocurrency mining activities, that can offer both a cold climate and one of the cheapest forms of electricity in the world may be potential locations for data centers as well [42]. Meanwhile, Toronto, Montreal, and Vancouver have dominated the data center markets in Canada [43]. The submarine fiber-optic cables projects, most notably the Arctic Connect and that of the Alaska-based company Quintillion, aiming at the improvement of international connectivity in and through the Arctic may, however, alter this situation in the future. Regional development plans in Alaska have referred to the importance of improved connectivity, and cities such as Rovaniemi and Kirkenes have directly invested in the Arctic Connect project, materialization of which is hoped to bring data center investments. The fiber-optic cables form the backbone of international communication, and the planned cables would surely cause a huge change in the Arctic regions' strategic position within the global flow of information [29, Saunavaara J.]. However, they would not be the only factor considered by companies that are choosing locations for new data centers.

Many of the Arctic and northern areas, which may soon see their international connectivity problems largely solved, may also lack human capital and regional skillsets that are clearly factors affecting site selection and the potential development of a data center cluster. Therefore, despite the inter-sectoral worker mobility may help in regions that have hosted other types of industrial activity, new investments in research and education may be needed. Otherwise, the skilled workers have to be brought into northern communities from outside. This may lead to recruitment problems, creation of different types of incentives increasing the personnel cost and challenging the competitiveness of remote areas, and to the underdevelopment of regional knowledge networks important for the cluster formation.

It is also worth emphasizing that the market-driven data center business is aimed at the maximation of profit. Therefore, the incentives affecting the return on investment, the total cost of ownership through the set-up, and long-term operational costs impact locational decisions. While the national regulations concerning the level of energy tax paid by data centers have played

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[42] Moss S. Rostelecom opens a data center next to a nuclear power plant, could be Russia's largest in 2021. URL: https://www.datacenterdynamics.com/en/news/rostelecom-opens-data-center-next-nuclear-power-plant-could-be-russias-largest-2021/ (accessed 14 April 2020); Willner G. Why the Russian Data Center Market Is the Next Frontier. URL: https://www.datacenterknowledge.com/industry-perspectives/why-russian-data-center-market-next-frontier (accessed 14 April 2020); Baydakova A. Bitcoin Mining Farms Are Flourishing on the Ruins of Soviet Industry in Siberia. URL: https://www.coindesk.com/bitcoin-mining-farms-are-flourishing-on-the-ruins-of-soviet-industry-in-siberia (accessed 14 April 2020); Fedorinova Y., Atkinson G. Russia's Largest Bitcoin Mine Turns Water Into Cash. URL: https://www.bloomberg.com/news/features/2019-11-24/seo-inside-russia-s-largest-bitcoin-mine (accessed on 13 April 2020).

[43] Data Center Map. URL: https://www.datacentermap.com/ (accessed 14 April 2020).

a significant role in the Nordic countries by defining their attractiveness when compared to one another, the competition between states and counties in the United States has led to generous incentives and aggressive promotional activities. The data center companies have thus been able to shop around with the potential hosting communities in the US. However, EU legislation has curbed the possibility for similar activity in Europe [44]. Despite the competitive nature of business, the kind of cross-border research cooperation that has already taken place in the Nordic countries could help the small Arctic and Northern regional and national economies in competition against Frankfurt, London, Amsterdam, Paris and Dublin, which are still hosting a great majority of data centers in Europe.

The rapid growth of the data center industry has already caused counter-reactions in some key areas in Central Europe. Amsterdam, for example, has temporarily banned the construction of new data centers, and other regions, such as Stockholm, face challenges with the capacity of their grid. Although these kinds of developments may strengthen the position of the energy-rich northern regions, the failure of, or at least significant delays in, previous large-scale data center projects that received a lot of publicity, such as the Kolos Data Center project in Ballangen, Norway and the Silent Partner Group's gigantic plans including three sites in northern Finland [45], may cause suspicion toward the industry among local inhabitants and decision-makers. Furthermore, decisions concerning investments are always made by humans. Ken Baudry has used to term "server huggers" when referring to business leaders who want to have their IT equipment nearby in spite of being located in areas facing serious natural hazard risks [30, Baudry K., p. 99]. It can thus be argued that the future development of Arctic and northern data center business is not only connected with the measurable technical, economic, or environmental parameters, but it also depends on human perceptions and attitudes.

When investigating the role that data centers can play in the advancing of green information technology (IT), Santhanam and Keller performed a literature review studying peer-reviewed journal articles and conference papers in the Scopus database. They identified five pillars of a framework describing the role of data centers in green IT: (1) power savings, 2) cost savings, 3) sustainability and green energy, 4) information technology for greening data centers, and 5) aligning business requirements with resource utilization [31, Santhanam A., Keller C.]. All of these features are also present in the R&D activities in the Arctic and the North. However, the results of this study further reinforce the idea that studies related to power savings have concentrated on

[44] Interview with Petri Hyyppä, Oulu, Finland, 05.02 2020; Interview with Suvi Linden, Oulu, Finland, 6.02.2020; State of Washington Department of Commerce. State of Data Center Industry: An analysis of Washington's Competitiveness in This Fast-Growing High-Tech Field. Report to the Legislature, January 2018.

[45] BBC. Record-sized data centre planned inside Arctic Circle. URL: https://www.bbc.com/news/technology-40922048 (accessed 14 April 2020); Smolaks M. Kolos data center park in Norway is being acquired by cryptocurrency miners. URL: https://www.datacenterdynamics.com/en/news/kolos-data-center-park-in-norway-is-being-acquired-by-cryptocurrency-miners/ (accessed 14.04.2020); Opiah A. Silent Partner Group To Build Up Four Hyperscale Data Centre Hubs in Finland. URL: https://data-economy.com/silent-partner-group-to-build-up-four-hyperscale-data-centre-hubs-in-finland/ (accessed 14 April 2020); YLE. URL: https://yle.fi/uutiset/3-10492984 (accessed 14 April 2020).

energy efficiency and cooling, and the interest in renewable energy and the re-use of heat can thus be identified as a feature particular to northern, especially Nordic, data center research. Besides the academic publications, similar trends can also be seen in private companies' R&D activities and in the composition of organizations brining actors involved in the data center industry together.

The concept of green IT, which, according to one definition, "denotes all activities and efforts incorporating ecologically friendly technologies and processes into the entire lifecycle of information and communication technology" [32, Hedwig M., Malkowski S., Neumann D., p. 2], guides in the taking of a long-term perspective with questions concerning the sustainability and carbon footprint of the data center industry. Although energy-related issues play a significant role, they are only a part of the package including also the materials used during both the construction and operative phases. Discussions concerning the efficiency, costs, and environmental friendliness of materials is relevant at all levels, whether the materials be for the computer components or are what will be used in the data center buildings. In this respect, the wooden data center constructed in Sweden [46] should be mentioned, as it is an example of cooperation between the emerging data center industry and the more traditional industries that utilize northern natural resources.

Finally, in order to make sense of the discussion concerning the sustainability of data centers and energy consumption, it should be emphasized that data centers are built to answer the demand originating from the growth of other businesses that utilize their services. The servers never run (and consume energy) without reason. While the pressure from legislators and consumers will most likely push the data centers to perform in more sustainable ways in the future, the initiatives carried out by the industry have already made the situation much better than it was, for example at the end of the 1990s. Back then, an article published in Forbes titled 'Dig more coal — the PC's are coming' opened many peoples' eyes to the connection between electronic equipment and energy consumption [47]. However, the data center industry is not immune to a divergence in ways of understanding the meaning of 'sustainable' or 'green', or to the differences between the various Arctic and northern countries that affect the operational conditions of other industries as well. Therefore, the pressure and methods utilized to achieve greater energy efficiency will most likely continue to vary in the future, and there will be different opinions, such as those concerning the combined development of nuclear power and data centers [48].

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[47] Huber P., Mills M., Dig more coal – the PC's are coming. URL: https://www.forbes.com/forbes/1999/0531/6311070a.html#4b8baf822580 (accessed 14 April 2020).

[48] Example of such development: Moss S. Rostelecom opens a data center next to a nuclear power plant, could be Russia's largest in 2021. URL: https://www.datacenterdynamics.com/en/news/rostelecom-opens-data-center-next-nuclear-power-plant-could-be-russias-largest-2021/ (accessed 14 April 2020).

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