JUNE 2018 DANISH ENERGY AGENCY

ANALYSIS OF HYPERSCALE DATA CENTRES IN DENMARK

ENGLISH SUMMARY REPOORT

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Vocabulary

150 MW HSDC = A data centre size referring to installed capacity of IT-equipment considered representative for future HSDCs in Denmark. In practice, sizes of HSDCs will vary. HSDC sites will usually consist of a number of isolated data centre buildings. The HSDC site will in total have an installed capacity between 50 MW and 400 MW. When the number of HSDCs is mentioned in this report, it means number of 150 MW equivalents. The 150 MW specifies the installed capacity of electricity consumption for critical IT equipment (e.g. servers, data transmission and storage).

Cloud Computing = Delivery of online software and services. Cloud Computing is the alternative to have software installed at own devices and to handle workloads and storage on own devices.

Cloud HSDC = A cloud HSDC handles workloads, storage etc. for users who prefer this solution instead of owning and operating own infrastructure and devices to perform the tasks. Workloads etc. are allocated to HSDC via optical fibre connectors.

COP = Coefficient of Performance

Data centre = Data centres of all sizes. The term used here means data centres generally and not only HSDCs.

EB = Exabyte = 10^{18} byte

EER = Energy Efficiency Ratio

HSDC = Hyperscale data centre. The term used here means only hyper scale.

PUE = Power Usage Effectiveness – represents the data centre energy efficiency.

TSO = Transmission System Operator. In Denmark: Energinet.

Workloads = number of data handling or calculation sessions performed by a server. Typically workloads are triggered by users interacting with an application causing the application to perform data handling or calculations on a server.

ZB = Zettabyte = 10^{21} byte.

1 Introduction

The Danish Energy Agency has collaborated with Energinet to study the anticipated expansion of Hyperscale Data Centers (hereafter referred to as HSDCs) in Denmark. The Danish Energy Agency operates under the Ministry of Energy, Utilities and Climate and Energinet is the Danish TSO.

The Danish Energy Agency is tasked with projecting developments in the energy sector, including energy production, supply and consumption, but also supports Energinet's planning activities. The Agency aims to highlight the impact on electricity demand, and the potential impact on district heating systems, in view of the plans to establish up to six major HSDCs in Denmark in the near future.

COWI has prepared a thematic analysis of the HSDCs for the Danish Energy Agency dated February 2018, and has subsequently prepared this extended summary in English: a condensed version of the thematic analysis of the HSDCs. The extended English summary focuses on the parts of the thematic analysis that are considered relevant in a broader European/international context.

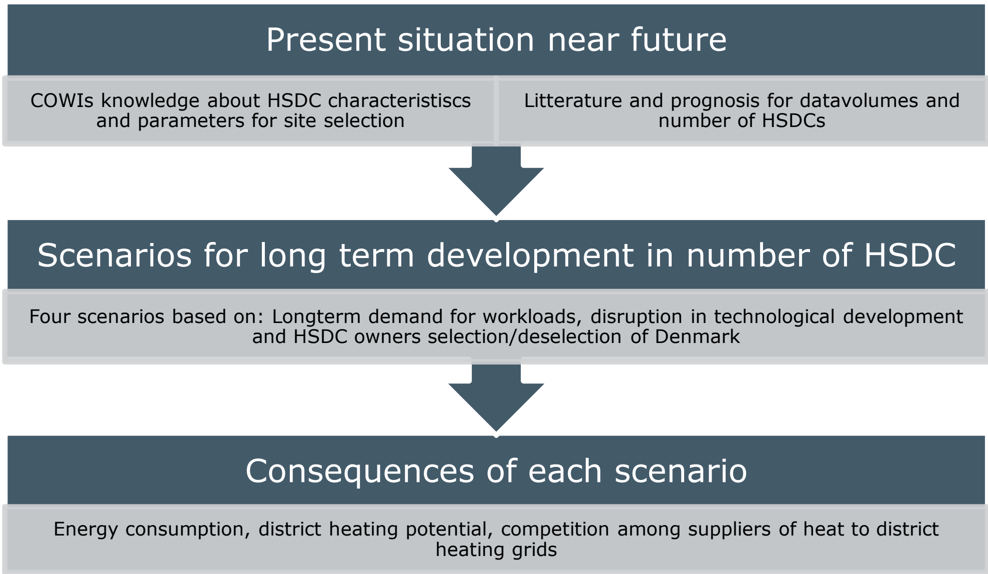
1.1 Methodology

The report analyzes and predicts the number of HSDCs that are expected to be established in Denmark by 2040. It is anticipated that significant technological advancements will be made in this area over a long time horizon. The estimation of the number of HSDCs is addressed in the short term through a literature review on data volumes and HSDCs, and COWI's knowledge of HSDC characteristics, as well as on parameters that determine or influence the location of HSDCs. Due to a lack of sources that can provide knowledge on long-term trends in Denmark, four development scenarios for the number of HSDCs have been defined.

This report does not provide a technical model of the number of future HSDCs in Denmark, but rather an assessment of the Danish HSDC market, that considers scenarios for technological development. The report does not consider the implications of how the selected location of HSDCs, and other developments, might affect investments in the electricity transmission network – this is a subject for further analysis. Similarly, further analysis of technological developments that affects the need for HSDCs may be necessary.

Figure 1-1 presents a graphical illustration of the methodology used in this report.

Figure 1-1 Methodology or steps taken in the analysis



First, the present situation of HSDC in Denmark is described. Having presented the starting point, four scenarios have been made to chart the development of the number of HSDCs in Denmark from 2018 to 2040. For each of these scenarios, we examine the consequence of the electricity consumption by HSDCs, the potential for utilizing the surplus heat from the HSDCs in district heating systems, and the competition between suppliers of heat to Danish district heating systems.

This analysis describes the supply and demand for data processing according to technologies that create a need for transport, storage and workloads, and the solutions developed to meet this demand.

2 Global demand for HSDC

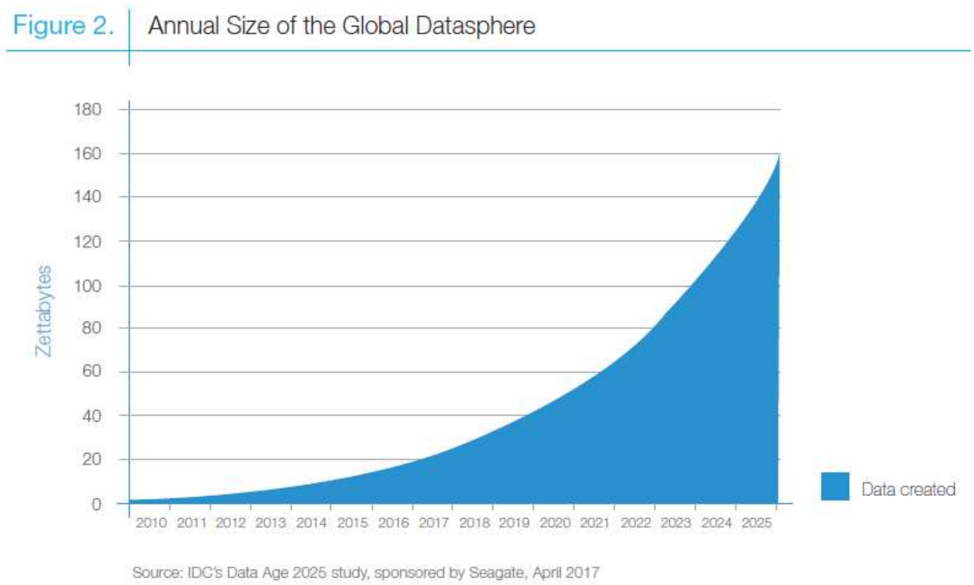
The energy consumption of data centres is increasing rapidly, despite technological improvements in the utilization of IT equipment, such as virtualization. The rapid expansion of the global data sphere over recent years has been caused by exponential growth in the number of smart phones and tablets, and the use of streaming services. The increasing use of cloud computing, by private enterprises, public institutions and households, also plays a major role. In the near future, robotics, the Internet of Things, autonomous cars, 3D printing, artificial intelligence etc. are expected to further drive demand. In 2016, data centres accounted for 3% of global electricity consumption – equivalent to the energy consumption of the aircraft industry. Data centres accounted for 2% of the global carbon footprint[1].

COWI reviewed literature on data volumes and data centres in the world, and found that many articles in this field refer to publications by Cisco.

IDC (idc.com) is another source that uses one of the longest time horizons for their projections. In the IDC report from April 2017: "The Evolution of Data to Life-Critical", the following graph on data volumes is presented:

[1] http://www.independent.co.uk/environment/global-warming-data-centres-to-consume-three-times-as-much-energy-in-next-decade-experts-warn-a6830086.html

Figure 2-1 IDC-projections of data volumes



IDC predicts an exponential development of data at the global level. However, these data volumes are difficult to connect specifically to the number of HSDCs. Nevertheless, IDC also predicts that the proportion of data stored locally on PCs, mobile devices and entertainment devices will fall from 75% to 50%, from 2010 to 2025. Therefore, IDC's figures indicate that the number of data centres is growing substantially.

It should be noted that in 2010, Cisco estimated the Annual Global Data Centre Traffic in 2015 to be 4.8 ZB, whereas the realized traffic was 4.7 ZB – close to the predicted level. Cisco should therefore be considered to be a relatively credible provider of estimates for underlying factors driving the proliferation of data centres. This analysis is based on Cisco's estimations of growth in data volumes, which will be interpreted linearly and exponentially in different scenarios.

Table 2-1 Data Center Growth

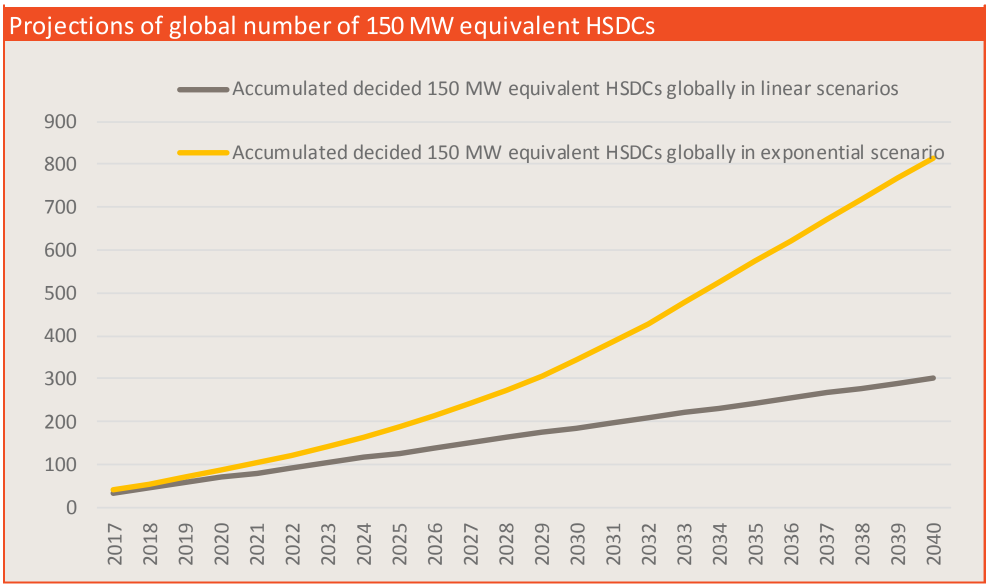
	2015	2016	2017	2018	2019	2020
Annual Global Data Centre traffic (ZB)	4,7	6,8	8,9	11,1	13,2	15,3
Cloud DC workloads in millions	136	190	225	322	383	440
HSDC (number) [2]	259	304	349	395	440	485

Source: Cisco Global Cloud Index 2015-2020[3] dated November 2016.

[2] Cisco Cloud Index Forecast, Quote: *"Twenty-four hyperscale operators were identified using the preceding criteria. The data centers operated by these companies are what we consider as hyperscale. The hyperscale operator might own the data center facility, or it might lease it from a colocation/wholesale data center provider."*

To obtain an idea of energy requirements, the number of HSDCs in Table 2-1 is converted to 150 MW HSDC equivalents. Converting the number of HSDCs estimated by Cisco into 150 MW equivalents requires a number of assumptions to be made, and is therefore subject to uncertainty. It makes a huge difference whether we expect linear or exponential growth in the number of HSDCs – especially in the long run. This difference is illustrated in Figure 2-2 below.

Figure 2-2 Global number of HSDCs



In 2017 the HSDCs amount to approximately forty 150 MW HSDC equivalents. In the linear scenario, this will increase to 300 in 2040, and to 800 in the exponential scenario. The figure shows that by 2040, the number of 150 MW HSDC equivalents in the exponential scenario is more than double that of the linear scenario.

The main assumptions behind the scenarios are: that developments in workloads reported by Cisco in the Global Cloud Index 2015-2020 continue to increase demand on world server capacity, and; that the vast majority of this server capacity will come from HSDCs in the future[4].

The linear and exponential trend lines form the basis of scenarios to be elaborated later.

[3] Since the full Danish version was prepared, CISCO has published Global Cloud Index 2016-2020, expecting mere rapid developments.

[4] Cisco Global Cloud Index 2015-2020, Figure 1: the increase of the HSDC share of server capacity from 21 % to 47 %, means that the majority of new server capacity will come from HSDCs.

3 European demand for HSDC

Several factors draw major HSDC investors to Europe. The European market makes up a significant portion of global GDP[5]. Furthermore, the EU aspires to achieve a "Digital Single Market"[6], which the Inter-European Data Protection Regulation (GDPR) – having entered into force in May 2018 – is expected to support. This requires that data from European citizens be treated uniformly, and may encourage technology companies to coordinate their activities with the location of HSDCs in Europe to their advantage. It is apparent that developments in technology will support more real-time applications. Here, data latency plays a key role, as providers get closer to customers with services offered by secure redundant cloud regions, for example in Europe. In addition, Cisco's articles show that Europe has a relatively stable share of data centres worldwide, from approx. 17 % in 2015 up to 18.4 % anticipated in 2020.

3.1 Site selection in Europe

Where can we expect HSDCs to be located in the future? To provide possible answers to this question, COWI has prepared scorecards for site selection in Europe, enabling scenarios for the Danish market share of European HSDCs to be generated.

The scorecard is COWI's estimate of the market conditions in about five years' time. The scores and the estimated share of the markets are of course only indicative. Moreover, the lists of countries and factors are not exhaustive, but serve to analyze the Danish case.

[5] EU-28 accounts for 23,8 % of global GDP cf.: http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Share_of_world_GDP,_2004_and_2014.png

[6] https://ec.europa.eu/commission/priorities/digital-single-market_da

Table 3-1 Indicative scorecard for future site selection in Europe

Weight		Ir	Se	NL/B	DK	Fi	Is	No	Other
10%	Taxes	1	5	2	6	7	4	3	
10%	Ease of doing business	7	3	1	2	6	5	4	
10%	Political stability	5	1	6	2	7	4	3	
10%	Electricity prices	5	3	7	4	6	1	2	
10%	Natural disasters	1	4	1	1	4	7	4	
8,3%	Capacity and spots on transmission grid	1	2	4	3	6	5	7	
8,3%	Suitable sites	2	1	6	3	4	5	7	
8,3%	Fibre connections	1	6	3	2	5	4	7	
8,3%	Renewable power supply	7	3	6	4	5	1	2	
8,3%	Power supply security	5	3	7	1	6	4	2	
8,3%	Climate	6	4	7	5	3	1	2	
100%	Total	3,7	3,2	4,5	3,0	5,4	3,8	3,9	
100%	Share of attracted HSDCs	15%	15%	10%	15%	0%	0%	10%	35%

The scores have been estimated by COWI based on accumulated market knowledge and knowledge about how the site selection teams work. However, it must be emphasized that the site selection teams of different HDSC owners do not have the exact same priorities nor interpretations of local conditions. Therefore, the scores seen in Table 3-1 can only be indicative and serve as examples illustrating the parameters that affect site selection choices. In the table a low score indicates that a country is among the most attractive in Europe on a specific parameter.

Developments in recent years have shown that owners of HSDCs quickly shift focus from one country to another. These shifts may be based on different parameters ranging from "ease of doing business", to electricity prices, security of electricity supply, the bandwidth of fiber-optic connections crossing the Atlantic, to assessing the political stability of the country.

These and other factors are analyzed, and used to prepare scorecards that indicate where HSDCs will be located, and which market shares are realistic for different European countries. In some years, the Danish market share of new HSDCs has been found to be around 30 % of the European market. COWI estimates that this level of market share cannot be maintained for several consecutive years, as investors will seek to diversify their investments for various reasons. Therefore, the Danish market share is estimated to fall to 15 % in three scenarios, and to 0 % in one scenario. In the 0 % scenario, developments in technology such as trans-national fiber-optic networks, as well as expansion of the electricity grid, and other conditions such as taxes and ease of doing business, are not anticipated to favor the establishment of HSDCs in Denmark compared to other European countries.

4 Scenarios for number of Danish HSDCs

The development in the number of HSDCs in Denmark can be illustrated in a number of scenarios. This section presents four different scenarios, in which the expansion of HSDCs in Denmark could take place.

The scenarios are primarily driven by the development of workloads to be handled by HSDCs, as well as changes in key assumptions and framework conditions for locating HSDCs in Denmark. These scenarios should not be interpreted as the most likely or only possible development processes for HSDCs in Denmark, but should rather serve to illustrate how different changes to underlying assumptions may affect the number of HSDCs in Denmark. In practice, the development of HSDCs may materialize somewhere within or beyond the described scenarios – both in terms of growth in data volumes, and other underlying factors.

The table below presents the analyzed scenarios for HSDC locations in Denmark. Four different scenarios are outlined. These are: a linear growth scenario; a deselection scenario; a disruption scenario, and; an exponential growth scenario. In this analysis we have chosen to use the linear growth scenario as the main scenario. The scenarios are driven by the growth in HSDC workloads, technological developments, and assumptions of Danish market shares.

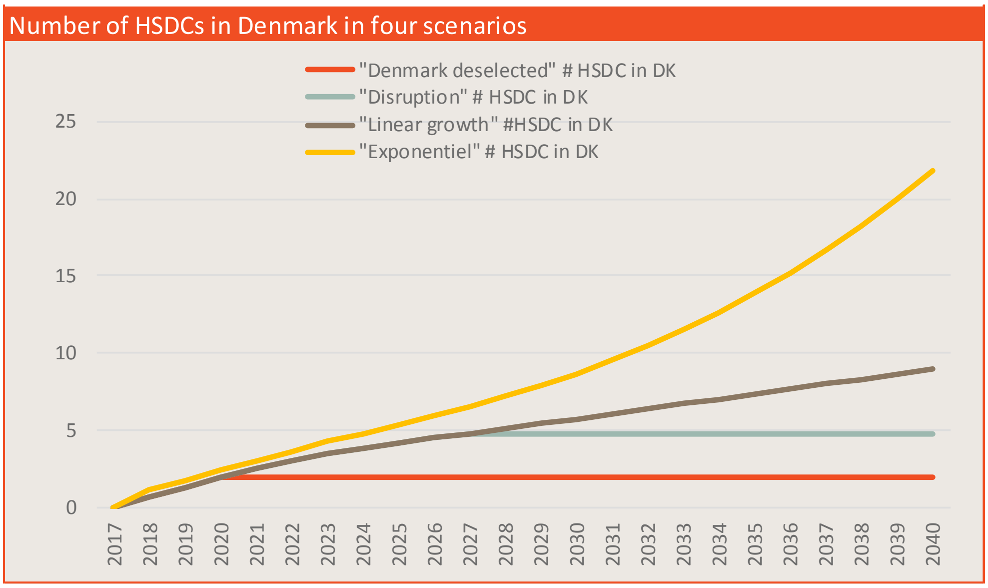
Table 4-1 Overview of scenarios

	Linear growth	**Deselection of Denmark**	**Disruption**	**Exponential growth**
Growth in HSDC workloads	Linear	Linear	Linear	Exponential
Tecnological development	Insignificant	Insignificant	Disruptive	Moderate
DK market share[7]	30 % » 15 %	30 % » 0 %	30 % » 15 %	30 % » 15 %

[7] Development from 2017 to around 2022 (around 5 years from now).

The results of the scenarios in terms of the number of HSDC located in Denmark are summarized in Figure 6-1 below.

Figure 4-1 Development in the number of HSDCs 150 MW equivalents in Denmark[8] in the four scenarios



It can be seen that if demand for HSDCs develops linearly in a case were Denmark has a market share of 30 % dropping to 15 %, we can expect 6 HSDCs in 2030, and up to 9 in 2040.

If the demand for HSDCs develops exponentially, and if Denmark has a European market share of 15 % in the future, we can expect 9 HSDCs in 2030 and more than 20 HSDCs in Denmark in 2040. The two scenarios, "Disruption" and "Denmark deselected" show the development if HSDC-owners were to suddenly stop building HSDCs in Denmark.

These scenarios generated for the Danish case serve as an example of how other countries might investigate the matter.

An HSDC takes time to build. If Denmark is consequently deselected, or 'disruptions' change the context of their operation, it is possible that established HSDCs are not outfitted with modules. Therefore, "Denmark deselected" and "Disruption" cover HSDCs that are not fully outfitted regarding the number of modules, and electricity consumption. Moreover, electricity consumption depends on the profile of electricity consumption for an HSDC.

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[8] Accumulated number of established HSDCs. However, the most recent HSDCs on the curve are not fully deployed with modules

5 Profile of electricity consumption

This section describes operating patterns in terms of electricity consumption and heat production for HSDCs using adiabatic cooling. The section is based on a Danish operating situation, with Danish temperature conditions. All indications of operating patterns are based on a constant level of electricity consumption for IT operations, due to an efficient allocation of workloads between global HSDCs levelling out local peaks in demand for workload processing. As such, the local weather conditions are the most important factor in explaining variations in electricity consumption of the HSDC.

To analyze the operating pattern of an HSDC, the following examples are based on a fully developed HSDC with an IT-effect dimension at 150 MW_{el}[9] consumption. A design PUE of 1.1 based on adiabatic cooling, and an IT load of 95% of the design capacity, have been used. The HSDC provides a total average power of 160 MW_{el}[10], with a current IT power of 143 MW_{el}[11].

Electricity consumption of an HSDC is modelled below using the measured minimum and maximum temperature, based on the last 20 years of data from the Billund weather station, located in western Denmark near planned HSDCs.

Since adiabatic cooling on hot summer days is performed by mixing water into the air, the power consumption for cooling will not be significantly affected by the outside temperature. However, the figure below shows a significant effect at about 28 °C.

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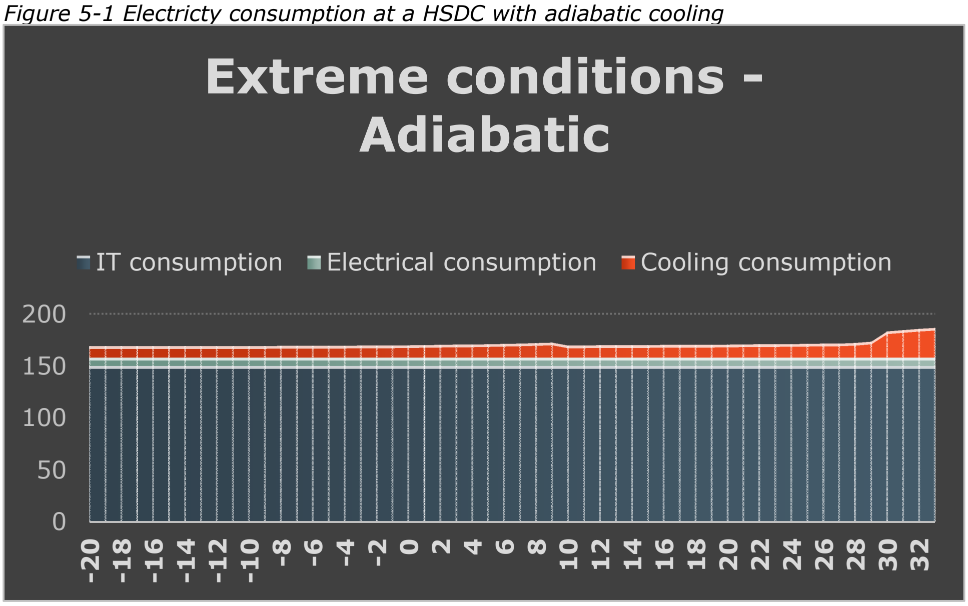
[9] 150 MW electricity installed capacity on IT equipment is used as the size of a "standard HSDC" in the report as this size is considered representative for HSDCs being planned in recent years. In practice we will see other sizes of HSDCs, but COWI considers HSDCs deployed with 3-7 modules each of 30-50 MW as realistic in the future.

[10] 150 MW * 95 % * 1.1 ≈ 160 MW

[11] 150 MW * 95 % ≈ 143 MW

Figure 5-1 Electricty consumption at a HSDC with adiabatic cooling



Electricity consumption for cooling ranges between 12 and 15 MW, until the temperature reaches about 28 °C, after which consumption will increase. When the temperature reaches 32.5 °C, consumption will have risen to about 28 MW.

During warm weather conditions (i.e. above 25 °C) electricity consumption for mechanical cooling is somewhat higher than for adiabatic cooling.

While there may be fluctuations in electricity consumption and surplus heat output from established HSDCs, it is for analytical purposes assumed that the profile of the HSDC is flat over the year and day. The upward trend of surplus production of surplus heat coincides with hot days, where heat cannot be utilized.

One of the most critical sources of uncertainty regarding electricity consumption and utilization of surplus heat lies in the rate of expansion of the planned HSDCs. Thus, it is uncertain how quickly modules are built and how rapidly each module is filled up with servers.

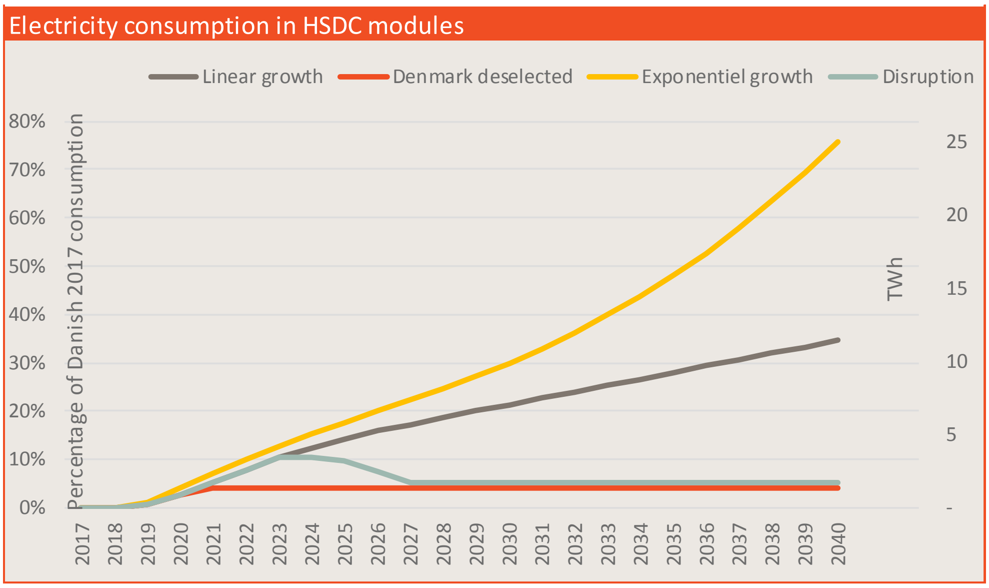
The HSDCs that will be built may have different sizes, but will often have between 100-200 MW_{el} installed capacity for IT equipment. An HSDC is gradually filled up with modules, which currently have a typical size of about 30 MW_{el} for IT equipment per unit.

In case of a power outage, they typically have emergency generators to operate critical IT installations. However based on the IT operation strategy, the individual HSDC may also only have a limited emergency power capacity e.g. to forward traffic to other HSDCs in case of a power failure rather than running at 100% capacity itself.

6 Electricity consumption of HSDCs

Based on the power profile and the assumption of increasingly rapid deployment of future HSDCs in Denmark, the following projection of electricity consumption has been made in four scenarios. The electricity consumption of the HSDCs is shown as a percentage of the total electricity consumption in Denmark in 2017.

Figure 6-1 Electricity consumption



It can be seen from Figure 6-1 that electricity consumption differs significantly between the four scenarios. In both the linear and the exponential growth scenario, the HSDC electricity consumption increases continuously and significantly compared to the present Danish 2017 electricity consumption. However, in the "Denmark deselected" and "disruption" scenarios the share of the Danish electricity consumption will stabilize at a constant share of the 2017 electricity consumption. The development in electricity consumption is driven by the number of HSDC established in the different scenarios.

Table 6-1 Projected electricity consumption of HSDCs in Denmark

	2030		2040	
Scenario	% of con-sumption	Total GWh	% of DK con-sumption	Total GWh
Linear growth	21 %	7,000	35 %	11,400
Exponential growth	30 %	9,900	76 %	25,000
Denmark deselected	5 %	1,300	5 %	1,300
Disruption	4 %	1,700	4 %	1,700

As can be seen, there is considerable uncertainty about the number of HSDCs placed in Denmark, and their electricity consumption. Thus, the development of the different scenarios differ significantly – particularly in the long run. Actual development may also prove to be a combination of the scenarios shown.

In the two scenarios "linear growth" and "exponential growth", the Danish share of European HSDCs is estimated to 15%. Hence, the European electricity consumption for HSDCs will – other things held constant – be 6.7 times larger. According to Eurostat, the European electricity consumption amounts to 2,786,137 GWH in 2016.[12]

	2030		2040	
Scenario	Share of Eu-ropean con-sumption	Total GWh	Share of Eu-ropean con-sumption	Total GWh
Linear growth	1.7 %	46,900	2.7 %	76,400
Exponential growth	2.4 %	66,300	6.0 %	167,500

[12] http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do

As can be seen, the HSDC share of the European 2016 electricity consumption is much smaller than in the Danish case. That is because the Danish market share of European HDSCs is estimated to 15 % whereas Denmark - according to Eurostat - accounts for just 1.1 % of European electricity consumption.

7 Utilizing surplus heat

Every MWh of electricity used for servers etc. in the HSDCs turn into heat. Therefore, the HSDCs generate massive amounts of surplus heat that potentially can be used for district heating purposes. However, only the largest Danish cities are able to utilize all the surplus heat from a 150 MW HSDC.

Once HSDCs are established, the use of surplus heat for district heating is considered to be a good solution. General interest in heat pumps in Denmark has increased over recent years, and is expected to be a significant part of the future green heat supply. Should a district heating company establish a heat pump plant, it will be possible to achieve a significantly better coefficient of performance (COP) by utilizing surplus heat from HSDCs, as opposed to natural heat sources such as air, groundwater, sea water, etc.

COWI has collected data on district heating systems near nine transformer stations in Western Denmark, all having a size of 150 or 400 kv. HSDC owners have so far selected sites near four of these transformer stations, and in no other locations in Denmark. Therefore, densely populated areas near transformer stations are considered to be most relevant for surplus heat.

For eight of the nine locations analyzed, it is considered to be both technically possible and profitable to utilize surplus heat. The amount of surplus heat that can be incorporated into the main scenario for HSDC development in Denmark – linear growth – is estimated at 685 - 3,400 GWh per year. This depends on whether the HSDC is optimally located for utilizing surplus heat, or not. A qualified estimate is that approximately 2,500 GWh can be utilized annually by 2030, corresponding to approx. 30 % of the surplus heat from the HSDCs in 2030, and almost 20% of surplus heat by 2040.

Utilization levels will vary between locations, and will depend on a number of factors, such as heat demand, distance to the district heating system, and the price of heating. Hence, assessing whether these systems are actually profitable for an individual installation requires a significantly more detailed analysis.

For example, a fully deployed HSDC with an IT effect of approx. 150 MW_{el} can deliver approx. 1,194 GWh in the Fjernvarme Fyns district heating system. This corresponds to approx. 45% of the city's annual heat production. In the case of "Fjernvarme Fyn", the use of coal for CHP production can be reduced, further helping the phase out of fossil fuels. However, the potential impacts on the electrical system have not been analyzed in this report.

COWI's assessment of possibilities for using surplus heat from HSDCs in the district heating systems is shown in Table 7- below.

Table 7-1 Overview of possible utilization of surplus heat from HSDCs in the selected district heating systems

District heating system	Capacity of surplus heat [MW]	Utilization of surplus heat [MWh]
Metropolitan areas	700	2,962,000
Towns	101	465,000

The metropolitan areas have between 50,000 and 300,000 inhabitants. The eight towns have between 3,000 and 50,000 inhabitants. A surplus heat price has been estimated for all the systems analyzed, and the possibility of fitting is assessed in relation to the estimated heat price for other heat generating units in these systems.

8 Conclusion

The analysis shows that the establishment of HDSCs in Denmark can potentially have a huge impact on Danish electricity consumption, and on the heat supply to several Danish cities. It also shows that the development is subject to major uncertainty, especially concerning site selection choices to be made by the HSDC owners, and technological development. The site selection choices depends on factors like "ease of doing business", capacity of the transmission grid, stability of the electricity supply, and political stability.

The owners of data centres are likely to assess these factors, and may quickly turn their focus to other countries if they encounter uncertainty. It is expected that the need for data storage, transmission and workload handling will continue to increase rapidly. However, it is uncertain if technological development in, for example, workload handling, will be more or less rapid than the increase in demand for workload handling. Therefore, the future demand for HSDCs remains uncertain. Currently, significant emphasis is being placed on site selection, indicating that technological development in workload handling capacity has not kept up with demand. In the long run however, it is a possible that technological developments will reduce the need for HSDCs.

The future electricity consumption of HSDCs could account for more than 30 % of total Danish electricity consumption in 2017 (and possibly more if growth in HSDCs is exponential), while the corresponding European figures are much lower. Denmark is expected to attract a relatively high number of HDSCs, compared to the current level of Danish electricity consumption.

In western Denmark, where site selection for HSDCs has taken place so far, most cities are too small to effectively utilize surplus heat from HSDCs though district heating supplies most of the households in those cities. To utilize surplus heat, HDSCs should be located near large cities with extensive district heating coverage. Alternatively, surplus heat could be utilized for industrial purposes, greenhouses and fish farms etc.

9 References

The sixth annual Cisco® Global Cloud Index (2015-2020), 2016
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