Analysis of urban scale factors for data center waste-heat use:

Three case studies in Sweden

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ABSTRACT: Data centers (DCs) bring important positive economic impacts to the cities and regions where they are established, however, in exchange of a high electricity consumption, which in the end is transformed into unused waste-heat. Only 10% of the DCs in Sweden utilize their waste-heat by generally plugging it into the district heating (DH) network. Despite having a DH tradition in most of Swedish cities, DC waste-heat utilization is not a rule. Data center strategical planning and urban strategical planning should be well coordinated, in order to offer alternative strategies to integrate the DCs waste-heat inside the local sectors/ services constellation in need of heat. Therefore this paper will focus on understanding how the urban planning practice can support DC's waste heat utilization by proposing an urban scale analytical approach to identify factors in relation to spatial and energy resource planning at a municipal level that may facilitate the DCs' waste heat utilization in cities.

KEYWORDS: Data center, Waste-heat, Urban planning, Circular cities.

1. INTRODUCTION

Public and private bodies in different countries, as Sweden, have been developing tailored regional strategies [1] to make their regions attractive for Data center (DC) investors. Scandinavian countries, including Sweden, are among the top ten countries with lowest risk in DC investment [2] due to the high score in relevant factors as; reliable power supply, energy resource abundance, renewable electricity supply, cold climate and low energy prices. Sweden, despite having a reliable power supply and energy abundance, faces local challenges in relation to the national energy distribution; the highest energy consumption occurs in the west and south of Sweden while the highest energy production comes from the North [3]. Hence, some studies have stated the relevance to shift these consumption patterns; attracting more big electricity consumers (e.g. data centres) to the North, where the energy is produced [1]. Since 2011, when Facebook established in Northern Sweden, the trend in Sweden has been to become more attractive for the DC sector and gain weight in the global market. DC activities require a great amount of electricity for data storage and processing. However, high amount of this electricity is transformed into hot air by the servers, and in most of the cases is going to waste [4]. Consequently, the DC sector is becoming more conscious of its high energy consumption and waste, and therefore has a will to create a so called green profile; already some of the biggest ICT companies in the world have signed up for 100% Renewable Energy Commitments [5]. There are fewer examples, where some DC companies are diverting part of their business focus into the local community benefits, as for example in the south of Sweden, in Stockholm, where DC's waste-heat warms surrounding homes. Nowadays, the DC sector seems to have two strategies to become more sustainable; improving energy efficiency, which includes waste-heat reduction among others, and increasing the use of renewable energy [6]. However, DC waste-heat utilization is still not included in the main design strategy. Process waste-heat, in this case from the DC sector, should not be just reduced, but actively reused [7]. As Pärssinen et al. state, there is a need to create supporting policies and strategies to accelerate the waste-heat utilization within the DC sector [8]. According to Weale (2015), the users demand for the DCs' waste-heat can play a role in the site selection and, consequently, the location of the DC within a city can determine its mechanical design (e.g. the cooling medium, the heat rejection method, air delivery path or air management) [4]. This highlights the relevance of coordinating data centre strategic planning with urban strategic planning in order to make DC waste-heat use increase. Therefore, this paper will focus in understanding how the urban planning practice can support DC's waste heat utilization.

2. BACKGROUND

The same way as the origin of modern urban planning practice arose to tackle the industrialization of cities [9], there is a need for the contemporary urban planning practice to address the digitalization of cities, and therefore the industry that supports this digitalization; the DC industry. The data center industry is an important pillar in the worlds' economy, having a major role in the worlds' globalization and consequently influencing urban developments [10] as DCs have been establishing progressively inside urban areas.

Initially, DCs were located far from the city as land and energy had lower cost. Later on, the expansion of the DC sector increased the competition, occasioning a higher interest in getting closer to cities, where high bandwidth and speed data transfer met the customer's needs. After that, the businesses became dependent in Cloud computing making the DCs move where the businesses were. In the last years, the fast IT development made it possible, for DCs from the same company, to be far from each other (e.g. in different countries) and still share resources and balance workloads [11].

This gradual establishment of DCs in urban areas arises questions about the levels of integration of DCs inside the city. Focusing on Sweden, DCs have been offered the possibility to establish in different types of location with different land use (e.g. industrial areas, green areas, urban areas…), following a long list of requirements (e.g. high power capacity, renewable energy, water storage, political stability, etc.) [12] , but with little consideration for waste-heat utilization. Tools and guidelines, on how to identify waste heat sources in the city and implement waste-heat recovery projects, have been developed in central Europe [13]. However, this approach focuses mainly on techno-economic aspects but does not include the environmental and social perspectives fully. There are studies where DC strategic planning and urban strategic planning were coordinated to facilitate waste-heat utilization in new neighbourhoods. For example in Harbin, China where DCs were placed together with different buildings to utilize the DC waste heat: a fitness center, offices, housing, teaching and exhibition rooms [14]. Other examples, which show the potential of this coordination, are the Sparkcity and Kolos data center projects in Norway. There are many low temperature urban waste-heat sources inside the city apart from DCs waste-heat, as for example, waste-heat from water treatment plants or subway lines. All this low temperature waste-heat in general needs a Waste Heat Reuse System (WHRS) (e.g. a heat pump) to increase the temperature and meet the heating demand [15]. The use of certain types of WHRSs, which is part of the mechanical design of DCs, can be influenced by the waste-heat users' location in the city [4]. In addition, Lund and Hansen have highlighted that more concrete case studies and city analyses should be done to give a better understanding of the kind of systems and configurations that are needed to utilize the urban waste-heat [15]. The location inside a city can determine, as well, the way the waste-heat is used, "on-site" or "off-site", depending for example on how close the waste-heat user is to the network or to the source. The DC waste-heat can be utilized on-site, when having a heat user nearby as for example connecting the DC waste-heat to a swimming pool [16], to a greenhouse [17] or to a fish farm [18]. The other option is off-site, connecting the DC waste-heat to a heat distribution network (district heating, DH) [15], which will eventually reach the heat users, even if they are placed close or far away from the waste-heat source. Stockholm city has one of the most complex DH systems in Europe where DC waste-heat utilization takes part successfully [19].

Traditionally the waste-heat management (distribution and supply), in Swedish municipalities, has been centralized through DH networks since 1948 and managed by DH companies. In 1996 the electricity market in Sweden was deregulated affecting the DH, which had to be sold at a market price [20]. Waste-heat utilization has been since then, led mainly by profitability (defined by technical and economic factors) keeping high competitiveness against other decentralized heating solutions as local heat pumps.

As Wahlroos et al. state "For the waste heat utilization to be realized, the business case has to be mutually attractive; i.e., there has to be economic potential for both the heat provider and the DH operator" [28]. The waste-heat in Sweden comes mostly from industrial processes, and as the traditional industries did (steel and pulp industry), the emerging DC industry has been trying to integrate their waste-heat into the well-established heat distribution networks [20]. However, despite having Stockholm municipality as a successful case of DC waste-heat utilization and having a tradition in DH networks, DC waste-heat utilization has not become yet a strategy when establishing DCs in most of Swedish municipalities. For this reason, this paper will propose an urban planning analytical approach to identify urban scale factors at a municipal level that influence the DCs' waste heat utilization, and aims to answer the main question; What can be learnt from the existing urban set-ups inside different Swedish municipalities where data centers utilize their waste-heat? As well as the following sub-question: Which urban factors inside the city influence the data center waste-heat utilization?

3. METHODS

In order to answer the research question "what can be learnt from the existing urban set-ups inside different Swedish municipalities where data centers utilize their waste-heat?" a GIS mapping of the data centers in Sweden was done to identify and select the cases of DCs with waste-heat utilization strategies inside Swedish municipalities. Once these cases were selected, a data collection was performed following a Multiple Case Study approach guided by the sub-question "what are the urban factors inside the city that influence the DC waste heat utilization?" As a final step, the different factors for each case were presented through a Radar chart to facilitate a comparative analysis between the cases.

3.1 Case studies selection methods

To identify and select the case studies the first part of the study was taken as a "phenomenon driven-research" [21]. In this case to track the DC-waste heat utilization phenomenon, a GIS mapping of the different DCs in Sweden was performed using interviews and site visits as primary sources and as secondary sources the following were used (e.g. DataCenterMap, Cloudscene, Business Sweden, Nodepole, Allabollag). However, there were clear limitations when doing the mapping. Some of the existing DCs could not be counted, as they are not reported as a company themselves, remaining "invisible" as a small part of a bigger corporation. Other DCs are not officially reported in their real location for security reasons, becoming untraceable. Despite these challenges, the GIS mapping is still considered accountable enough to give an overview of how the DCs are distributed within Sweden. The results from the GIS mapping were analysed to select relevant cases. The DCs mapped were divided up into two groups; DCs with Waste Heat Reuse System (WHRS) and DCs without WHRS. This division helped identify the cases that are relevant for this study; the DCs with WHRS. Only three cities (Falun, Stockholm and Helsingborg) had DCs with WHRS, which represent 10% of the total DCs counted in this study. Of those included in the 10%, 75% are located in Stockholm Region. All current DCs with WHRS found through the mapping are located in municipalities in the south of Sweden (mainly Falun, Stockholm and Helsingborg) and none in the north. The study focuses the data collection and analysis part on these three identified municipalities.

3.2 Case studies data collection method

After identifying and selecting the three case studies (Falun, Stockholm and Helsingborg municipalities), the study followed Yin's Multiple Case Study Approach (MCSA), and create a data collection criterion[22]. An explorative literature review was done to identify urban scale factors that are later organized by two categories; spatial factors and energy factors. The three municipalities are described through the same data collection criterion to later compare and understand the factors that could have facilitated the DCs waste-heat utilization in each municipality.

3.3 Comparative analysis method

To make a simultaneous analysis and compare each factor through the three case studies, a graphical method known as "Radar chart" is used. This graphical method enables a representation of multivariate cases with an arbitrary number of factors [23], and is usually recommended for cases with small-moderate dataset, appropriate for this study with only nine factors as dataset. To facilitate the analysis between the cases, the factors are grouped by category next to each other in the Radar chart, in order to avoid a random star structure that can guide to misleading interpretations. Each factor has to be represented in the diagram by dimensionless indicators, therefore a conversion from diverse-unit indicators to dimensionless indicators is done using normalization (or scaling), usually ranging the values between 0 and 1 with a common direction (e.g. a score of 1 is more desirable than a score of 0) [24]. For the normalization process, 'Zero-max' scoring approach is taken, meaning that the scores on criterion are expressed as a proportion of that criterion's best performer [24].

4. RESULTS AND DISCUSSION

A combined Radar chart where all factors in the three cases are shown is represented in Fig. 1. This, in order to make an analytical description of each factor and to compare them along the three cases.

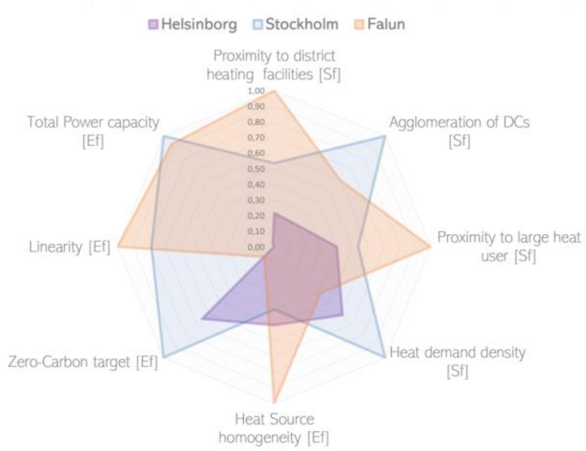

Figure 1: Identified urban scale factors that may influence DC waste-heat utilization.[Sf] Spatial factor. [Ef] Energy factor.

As a first clarification, this study does not intend to present these factors as the causality of the DC waste heat utilization, but does want to represent a co-relation of each factor with the phenomenon of DC waste-heat utilization, by looking at the three case studies identified. To do a list of factors as a causality of DC waste-heat utilization would require a larger amount of cases of DCs with WHRS in the study in order to do such statement. However, it is considered relevant to initiate the discussion of which factors can influence DC waste heat utilization from an urban scale perspective, as it can guide the strategical planning, at a municipal level, of future DC locations in order to utilize the DC waste heat.

4.1 Proximity to district heating facilities

In Stockholm the DCs in the park is 300 m from the closest heat production plant and in Falun case, the DC is at 600 m from a heat production plant. In Helsingborg case the closest heat production facility from the DC is 1,5 km, five times further than Stockholm cases. Stockholm and Falun cases use WHRSs that can replace part of the heat generated initially from the boilers inside the district heating network, making the DC waste-heat utilization a technological-economic feasible solution for the heat supplier [15]. In the case of Helsingborg, the DC is connected to the network directly through the DCs' WHRS (heat pump), without being part of an existing district heating facility. Despite the possibility of having high technologic-economic feasibility when being spatially close to the district heating infrastructure, there is also a need of trust from the DC company to let the heat suppliers manage their "cooling system" [20]. However, Helsingborg case is an exception; the DC pumps water from the Oresund Sea to cool the servers, having their own cooling system without depending on the heat supplier's reliability.

4.2 Agglomeration of data centers

Stockholm has the highest agglomeration of DCs with WHRS within a 1km radius, where three are already established and two more are planned. This high value is due to the spatial set-up of a DC park, called Kista Data Park. In Stockholm municipality, an organisation called Stockholm Data Parks is managing specific areas within the municipality to form urban scale DC clusters or so called data parks. Consequently, this spatial set-up facilitates the harvesting of DC waste-heat in the same place, having the possibility of sharing costs of a common WHRS. In Falun, only one existing DC with WHRS was identified. However, two more DCs are planned at the same location as the existing one, having then a moderate agglomeration value if compared to Helsingborg with just one DC with WHRS.

4.3 Heat demand density

The heat demand density was retrieved from the European project "Peta4, Heat Road Map". This heat demand density is based on an aggregation of factors as population density, census data, GDP, soil sealing data analysis, among others [25]. The heat demand influences how the district heating network is dimensioned. An expansion of a district heating network is determined by how cost efficient that expansion is. The higher heat demand in an urban area, the more cost efficient an expansion to connect that area will be [26]. An expansion of the district heating network sometimes requires installing auxiliary heat production facility (heat booster). As mentioned before, this booster can be replaced by the DC waste heat recovery system [15]. Therefore, if the DC is placed in an urban area without DH network, but close to it, the higher the possibility of installing a DC as booster to expand the current DH network in that area. The heat demand density is high or moderate in all the cases, meaning that this factor can influence positively DC waste-heat utilization, as it is interesting for the DH Company to reduce heat loses in their system by using the available waste-heat "on-site" if possible.

4.4 Proximity to large heat user

Falun is the only case providing DC waste-heat to a user in need of heat, a wood pellet dryer industry, placed 300 meters far from the DC. In Helsingborg and Stockholm there are also heat users less than 1 km far from the DCs (a hospital in Falun, and a swimming pool and sports hall in Stockholm), but do not use directly the DC waste-heat. In Falun as well as Stockholm and Helsingborg, the DCs have connected their waste-heat to the DH network. However, Falun is a unique case, as the heat user, the wood pellet industry, is at the same place as the main heat production facility, therefore providing the DC waste-heat for both, when needed. All the three cases are located very close to urban centers, where large low-temperature heat users can be found. This urban set-up makes the DC waste-heat become a cleaner source of low temperature heat in the middle of the town, if compared to a non-electrical boilers ran by diesel, biomass generating CO_2 emissions when burnt. This alternative seems an attractive solution especially for cities with the ambition to have attractive and healthy urban centers equipped with public services free of CO_2 emission sources.

4.5 Total power capacity

Falun and Stockholm have both a DC cluster spatial set-up. Falun has planned a DC campus of 65 MW and Kista Data Park in Stockholm has planned for 70MW. Both have a high potential in providing high amounts of waste-heat. This factor could be relevant to know if the DC waste-heat from a data park could provide enough heat to a certain area in a city, (e.g. to a neighborhood, or to a public service as a swimming pool). This factor could be informative in both ways, when planning a new DC location or when planning a new public swimming pool, as the location of a DC with enough heat to offer to meet the heat users' demand can lead to DC waste-heat utilization. This factor can be relevant in terms of profitability, as Pärssinen et al. states, the higher the power capacity of a DC the more profitable utilizing the DC waste-heat will be. However, there is a large difference when comparing Stockholm and Falun (65 and 70 MW) with Helsingborg case having a DC with approx. 1MW power capacity.

This might be due to a low cost of the WHRS, becoming then a profitable solution for this case. However, if the cost of the WHRS was high, this could mean that despite having a low profitability when utilizing waste-heat from a small DC [8], there is still a will to utilize the DC waste-heat. Profitability can be in most of the cases a condition to utilize the DC waste-heat, having exceptions where other qualitative conditions from the DC owner or DC customers have preference (e.g. will to be environmentally friendly or will to innovate).

4.6 Source homogeneity

The data used for this factor is retrieved from SCB database, and refers to the "district heating production and fuel consumption sources". Considering that all the three cases are inside an area covered by the district heating this factor can be relevant to encourage DC waste-heat utilization. Stockholm has highly diversified heat sources (35% biomass, 24% non-renewable solids, 21% wastewater treatment plant, 11% electricity, 5% biodiesel). Helsingborg has a high-moderate diversification of heat sources (35% biomass, 29% waste-heat from industry, 17% non-renewable solids, 10% electricity), and Falun the lowest with only two heat sources, having wood pellets as the dominant heat sources with a 76% share of the total amount of heat sources. One could think that the more diversified the heat sources, the lower the need to add a new sources to diversify. However, if the district heating network has already a flexible and adaptable system to include many different sources, the easier it can be for this "experienced" system to add a new source. The lesser diversified heating network the more reluctant the heat supplier might be to adapt the system for a new (low-grade temperature) heat source. Therefore, Stockholm having a highly diversified system has a greater experience in including multiple sources and even low-grade heat source (as DC waste-heat), makes it a good set-up which can facilitate DC waste-heat utilization.

4.7 Zero-Carbon target

Here the amount of non-renewable sources is presented in relation to the total amount of sources. Falun has the lowest amount of non-renewable as it is mainly using wood pellets to heat the town. Stockholm has the highest share in non-renewable followed by Helsingborg. Both cities, Stockholm and Helsingborg, have a higher heat demand than Falun, as their population density in the urban area is higher. This high heat demand could force them to use "any" source available to cover the need. This situation might encourage using more secondary resources with a "cleaner primary energy" as the DC sector powered by Swedish electricity, having a 58% of renewable and 42% non-renewable [27].

4.8 Linearity of heat sources

The linearity of sources is considered as the opposite to circularity of sources. The indicator used is the amount of primary sources in relation to the total amount of sources. Helsingborg has very low linearity (or high circularity) which means that they use many secondary sources to generate heat. Helsingborg has a heat production plant powered by solid waste (67% renewable, 33% non-renewable). They have a high circularity in their heating system. Falun on the contrary has a high linearity as they consume high amounts of primary sources; wood pellets to produce heat from the town. Stockholm has as well very high primary energy source share but lower than Falun. Stockholm, despite of having a complex and highly diversified district heating system, has a high heat demand that needs high amount of primary resources. Stockholm has many boosters in their system that are powered by oil, wood pellets, and other primary sources. Here the DCs could play their part by substituting these sources by DC-waste-heat, in order to reduce primary source consumption and their related cost and as well reduce their environmental impact. The heat pumps used could increase the amount of CO_2, however, the electricity mix in Sweden has high percentage of renewables, still making a positive environmental impact even if using the electrical heat-pumps. If a system is circular the lower need to use and add more secondary sources, and if the system is linear, the higher need to use available secondary sources (e.g., DCs waste-heat).

5. CONCLUSION

The results point that DCs which are located in cities with moderate-high heat demand density and with a tradition of DH network (as in the three cases studies presented), seem to have multiple possibilities to utilize the waste heat in different urban set-ups. All the factors show a considerable variability in all of the case studies, and no specific pattern has been detected. This reflects that there is a greater possibility than the current situation in Sweden to utilize the DC waste-heat in different urban set-ups, where many combinations of these urban factors are possible. However, other factors (e.g. business-model factors, political factors…etc.) which not have been included specifically in this study, may have revealed less variability and more similarities between the cases.

In addition, some factors can influence DC waste-heat utilization, in both directions (positively or negatively) as in the factor called "source homogeneity" case.

Having a low heat source homogeneity (or high diversification) as in Stockholm case, can have less need to diversify but can be more flexible to include any new source than a case with high homogeneity (e.g. Falun case), having a higher need to diversify. Both categories, factors related to the municipalities' energy profile and spatial factors, appear to have as high influence to utilize DC waste-heat in Stockholm, where as in Falun and Helsingborg the energy related factors appear to encourage the DC waste-heat utilization more than the spatial factors. However, this would depend on the municipalities will (political agenda) to e.g. improve resource resilience, aim for circular city approach or reach Zero-carbon target. A municipality can have an energy profile (e.g. high linearity) that encourages the DC waste-heat utilization but can have no planned agenda to do so.

It should be noted that all presented factors are directly or indirectly dependent on the current available technology and that a new technological shift or development within the DC sector could change the rules of the game. However, until that occurs, it is relevant to rise the discussion on how to facilitate the DCs waste-heat utilization in our cities.

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