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A review of data centers as prosumers in district energy systems: Renewable energy integration and waste heat reuse for district heating

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HIGHLIGHTS

- Discuss data centers from perspective of energy prosumers in district energy system.
- Review renewable energy usage in data centers and the related advanced controls.
- Review data center's waste heat recovery and reuse for district heating.
- Review existing green data centers and related economic/environmental analysis.
- Identify future research directions for improving data center's overall performance.

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ABSTRACT

As large energy prosumers in district energy systems, on the one hand, data centers consume a large amount of electricity to ensure the Information Technologies (IT) facilities, ancillary power supply and cooling systems work properly; on the other hand, data centers produce a large quantity of waste heat due to the high heat dissipation rates of the IT facilities. To date, a systematic review of data centers from the perspective of energy prosumers, which considers both integration of the upstream green energy supply and downstream waste heat reuse, is still lacking. As a result, the potentials for improving data centers' performances are limited due to a lack of global optimization of the upstream renewable energy integration and downstream waste heat utilization. This study is intended to fill in this gap and provides such a review. In this regard, the advancements in different cooling techniques, integration of renewable energy and advanced controls, waste heat utilization and connections for district heating, real projects, performance metrics and economic, energy and environmental analyses are reviewed. Based on the enormous amount of research on data centers in district energy systems, it has been found that: (1) global controls, which can manage the upstream renewable production, data centers' operation and waste heat generation and downstream waste heat utilization are still lacking; (2) regional climate studies represent an effective way to find the optimal integration of renewable energy and waste heat recovery technologies for improving the data centers' energy efficiency; (3) the development of global energy metrics will help to appropriately quantify the data center performances.

1. Introduction

The rapid increase of needs for data processing, data storage and digital telecommunications has led to dramatic increase in the data center industry [1]. Data centers are buildings, dedicated spaces inside a building or a group of buildings that house the Information Technologies (IT) equipment used for processing and storage of data and communication networking [2] and the associated extensive supporting infrastructures to power and cool the IT equipment. Specifically, IT and HVAC are the two major energy end-user equipment. IT equipment needs to operate continuously without a stop nearly every day, consuming a huge energy quantity and producing very high internal loads. The HVAC systems in return consume energy to maintain the proper working environment temperature for normal functioning [3]. The statistics indicate that datacenters now consume about 3% of the global electricity supply and account for about 4% of total greenhouse gas

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(GHG) emissions [4]. Therefore, with the growing needs of Internet, storage and communication, the energy consumption of data centers are expected to increase, leading to high operational costs and environmental problems in the near future [5]. As an example, a recent report of 2018 from Cushman & Wakefield predicted annual growth of data centers to be 12–14% over the next two to five years, resulting in 1/5 of global electricity consumption by 2025 [6]. Therefore, with the concerns of environmental pollution, fossil fuels shortage and increasing grey energy costs, applying renewable energy has gain popularity in data centers in the past decades.

Some studies have been conducted to explore the integration of renewable energy in data centers in order to reduce their carbon footprint and costs. For instance, Sheme et al. [7] investigated the feasibility of using renewable energy to power data centers in 60° north latitude in terms of energy and cost savings. In fact, even though the higher latitudes can assure low cooling costs due to the cold climate, the high variance in solar output makes data centers more fossil fuel than renewable energy-based grid power dependent. By that end, the authors developed a method for determining the optimal ratio of wind turbine and photovoltaic (PV) panel capacities that can maximize the on-site renewable energy generations in a high latitude location. Moreover, in order to maximize the utilization of renewable energy, many advanced demand controllers and schedulers have been developed. It was found that the combination of solar energy and wind sources provided greater surplus hours compared to using only one source of renewable energy. Regarding the costs saving, the use of only solar energy source cannot produce significant saving values, as fossil fuel-based energy is provided to the data center when the solar energy is lacking. By mixing solar and wind energy to compensate the lack of wind, a less but a more stable income can be produced. With the aim to overcome the green energy dependency to the environmental changes, Aksanli et al. [5] developed a data center demand response strategy able to optimize the usage of green energy sources. This new job scheduling methodology will cancel or reschedules jobs whenever the instant green energy availability is low, and thus reducing data center dependency form grey energy during scarce green energy availability. Similarly, Goiri et al. [8] developed a scheduler named GreenSlot, which predicts the near-future solar energy generations and then schedules the data center workload to maximize the utilization of renewable energy while meeting the job's deadlines. By using this scheduler, the datacenter consumed significantly more green energy by lowering grey energy costs. Therefore, it was found that thanks to GreenSlot scheduler the datacenter's solar array could be amortized in 10–11 years, compared to 18–22 years required to amortize those cost under the conventional or even energy-aware schedulers. Integrating renewables with data center has been put into practice nowadays and there are already some well-known IT companies building new data centers that are partly or fully powered by renewable energy. For instance, Apple built a 40 MW solar array for its North Carolina data center in order to provide it additional 17.5 MW of power [9]. Facebook constructed a solar powered data center in Oregon and other three new utility-scale solar projects in Utah and New Mexico are expected to be realized in the near future [10].This new capacity will help Facebook to entirely power its operation with renewable energy, by reducing GHG emissions (related to its operation) by 75% by 2020. HP has used a bio-fuel based gas turbine to supply the demand in its net-zero data center making the entire system less fossil fuel-based grid power [11].

Together with the increasing effort to integrate renewable energy sources to produce electricity in order to drive IT and HVAC equipment, there is a growing effort to capture and reuse waste heat of electronic facilities in all types of energy conversion systems. In fact, the amount of data centers' waste heat is large, and it has been estimated that 68% of it can be recovered. However, due to a low cooling temperature, the grade of data centers' waste heat is usually low, which is a major hurdle to its large-scale applications. By that end, with the advancement of heat pump and many other low temperature heat low-grade heat recovery technologies, utilization of the waste heat from data centers is becoming easier.

In this regard, many studies have been conducted to explore new systems and ways to recover and reuse the waste heat from data centers. For instance, through conducting numerical simulations in TRNSYS, Oró et al. [12] analyzed the energy and economic feasibility of applying an air-cooled data center's waste heat in district heating (DH) networks for improved energy efficiency. Specifically, two types of cooling solutions (CRAH + chiller and rear door technology) for air-cooled data centers were numerically evaluated and for both of them, different waste heat recovery solutions were provided. It was found that the Energy Reuse Factor (i.e. reused energy divided by power consumed by the data center) resulted the best metric to quantify the heat reuse integration in data centers. This metric resulted equal to 55% for heat recovery in the condenser of the vapour-compression chiller, while between 25 and 45% for heat recovery in the return hot aisle. Similarly, Davies et al. [13] explored the use of heat pumps to boost a data center's waste heat temperature to meet the DH requirements, and also analyzed the feasibility of applying the data center's waste heat for DH in London. It was found that coupling 3.5 MW data center with a heat recovery system could lead to savings of over 4000 tons of CO_2e and nearly £1 million per annum. Finally, also MikkoWahlroos et al. [14] investigated the utilization of a data center's waste heat for district heating in Espoo of Finland and analyzed the overall system efficiency from the perspectives of both the data center and district heating network operators (by considering them as one system). Owning to the waste heat utilization, the operating hours of both the combined heat and power plants and heat-only boils were largely reduced. Yu et al. [15] conducted a simulation study on a novel heat recovery system from a data center in Harbin of China to serve the subsidiary buildings. The main novelty of this system relies on the fact that it is able non only to recover the waste heat but also to shift between space cooling and heating for secondary buildings such as apartment, offices, fitness centers etc.). They found that this new heat recovery system had a better economic viability, with total operational costs 458.3 thousand yuan lower than the one with air source heat pump. Haywood et al. [16] investigated the thermodynamic feasibility of recovering a data center's waste heat, by using water as heat transfer fluid, to drive an absorption chiller. The main feature of this technology is its capability to relive the cooling load on conventional date centeŕs air conditioner, thanks to the utilization of the waste heat to drive an abortion system. By this way, a very efficient power usage effectiveness (PUE) ratio (less than 1) can be achieved. Marcinichen et al. [17] developed a novel hybrid two-phase cooling cycle for direct cooling of the chips and auxiliary electronics in data centers. The main advantage of using two-phase microchannel flow relies in the fact that the latent heat capacity of the fluid is more effective, in the heat removal process, than using sensible heat of single-phase fluid. Based on the developed cycles, they explored applying the waste heat recovered from the condenser in a feed-water heater of a coal power plant and found that over 2.2% improvements in the power plant thermal efficiency can be achieved. Deymi-Dashtebayaz et al. [18] investigated the feasibility of reusing the waste heat from a data center by employing an air source heat pump for space heating of an adjoining office building in Mashhad city of Iran. Specifically, the heat pump has the dual benefit of providing space heating and removing the heat generated by the data center. Their analysis results showed that the waste heat recovery system could achieve significant reduction in natural gas and electrical energy usage, thus reducing the economic costs and CO_2 emission. However, it was found that the main limitation affecting this system is related to its capital cost that could be reduced by utilizing more efficient heat transfer techniques.

To date, a number of studies have been conducted to review the interaction of data centers with the surrounding district energy systems. This means that data centers actively participate as energy consumer and producer to the district energy metabolism. Considering data