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Full-length article

Energy consumption and emission mitigation prediction based on data center traffic and PUE for global data centers

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Abstract: With the rapid development of technologies such as big data and cloud computing, data communication and data computing in the form of exponential growth have led to a large amount of energy consumption in data centers. Globally, data centers will become the world's largest users of energy consumption, with the ratio rising from 3% in 2017 to 4.5% in 2025. Due to its unique climate and energy-saving advantages, the high-latitude area in the Pan-Arctic region has gradually become a hotspot for data center site selection in recent years. In order to predict and analyze the future energy consumption and carbon emissions of global data centers, this paper presents a new method based on global data center traffic and power usage effectiveness (PUE) for energy consumption prediction. Firstly, global data center traffic growth is predicted based on the Cisco's research. Secondly, the dynamic global average PUE and the high latitude PUE based on Romonet simulation model are obtained, and then global data center energy consumption with two different scenarios, the decentralized scenario and the centralized scenario, is analyzed quantitatively via the polynomial fitting method. The simulation results show that, in 2030, the global data center energy consumption and carbon emissions are reduced by about 301 billion kWh and 720 million tons CO_2 in the centralized scenario compared with that of the decentralized scenario, which confirms that the establishment of data centers in the Pan-Arctic region in the future can effectively relief the climate change and energy problems. This study provides support for global energy consumption prediction, and guidance for the layout of future global data centers from the perspective of energy consumption. Moreover, it provides support of the feasibility of the integration of energy and information networks under the Global Energy Interconnection conception.

Keywords: Data center, Pan-Arctic, Energy consumption, carbon emission, Data traffic, PUE, Global Energy Interconnection.

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1 Introduction

Along with the rapid development of new generation information technologies such as Internet of Things, cloud computing, big data and artificial intelligence, information technologies have become the main driving force for global economic development. Nowadays, the global data volume is growing at an average rate of 40%

per year. The computing power supported by Moore's Law is almost a thousand times faster for 10 years. The intensive use mode of cloud computing reduces the cost of informatization. Big data and artificial intelligence have accelerated the development of social intelligentization, which has led to rapid growth of global communication and computing data. It is estimated that in 2020, 97% of global network traffic will be related to data centers. To this end, more data centers are needed in the future to support the development of global intelligentization. However, data centers as information infrastructures have enormous energy consumption. For example, a typical data center can consume power the same as 25,000 homes, and it consumes 100-200 times energy than that of a standard office with the same size [1]. On the one hand, the energy costs of powering a typical data center doubles every five years [2], and electricity costs have become an important expense in current data centers. On the other hand, power usage in data centers has also brought a lot of environmental problems. For example, in 2005, the total energy consumption of data centers in America accounted for 1% of total national electricity consumption, and created as much emissions as a mid-sized nation like Argentina [3, 4]. In 2010, data center electricity consumption accounted for 1.1% to 1.5% of total global electricity consumption [5], while in the United States, it accounted for 1.7% to 2.2% of total domestic electricity consumption [6]. Globally, data centers will become the world's largest users of energy consumption, with the ratio rising from 3% in 2017 to 4.5% in 2025 [7]. Heddeghem et al. found that the energy consumption of global data center in 2012 was 270 billion kWh, and the annual energy consumption had a Compound Annual Growth Rate (CAGR) of 4.4% from 2007 to 2012 [8]. Data center energy consumption has become one of the important factors for data center location.

The energy consumption of data center can be decomposed into IT equipment system (50%, including servers, storage equipment and network equipment), air conditioning and cooling systems (37%, air-cooling system about 25%, air supply and return system about 12%), distribution system (10%) and auxiliary lighting system (3%). It is clear that the energy consumption of the air conditioning and cooling systems exceed the 1/3 of the entire data center. At present, more and more Internet companies are gradually realizing the natural advantages of the high latitude areas in the Arctic region, including the unlimited renewable energy, the cold air and the appropriate humidity. Instead of artificial cooling, some new data centers have been built or are being built in the Pan-Arctic region to reduce the consumption of the cooling system. In 2011, Google established a data center in Hamina, Finland, which was formerly a newsprint plant. The data center is one of Google's most advanced and efficient worldwide, employing seawater from the Bay of Finland in its high-tech cooling system, and it will be powered by 100 percent renewable energy via a new onshore wind park. In 2013, Facebook established the first data center outside of America in Sweden. In the early 2016, Facebook announced that it would establish a new data center in Ireland. In addition, some large companies such as Amazon have also established data centers in high latitudes in the northern hemisphere. In order to reduce energy consumption of the data center, Pan-Arctic has gradually become a competitive region for construction of data centers in the future.

There are already some studies on energy consumption modeling and energy consumption prediction for the single data center or its subsystems, rather than the global data centers [9–13]. Besides, Venkatachalam et al. [14] proposed a method to reduce the total power consumption through the relationship of microprocessor systems over time. Mittlal et al. [15] proposed a model to improve GPU energy efficiency. Bostoen et al [16] discussed energy reduction technology for the storage system of the data center. Hammadi et al. [17] studied the impact of the data center network architecture evolution on energy efficiency. Ebrahimi et al. [18] studied data center cooling technology and discussed related power consumption indicators of different components of the data center in details. In summary, the above-mentioned researches are usually about energy consumption of the data center subsystems, such as computing, storage and data management, network, infrastructure systems, and so on. Avgerinou et al. [19] analyzed the energy consumption and energy efficiency of the European data centers, and this study mainly employed data from the companies involved in the European Data Center Energy Efficiency Code of Conduct. This voluntary initiative was launched in 2008 with 325 data centers' participation. However, there is no prediction and analysis of energy consumption and energy efficiency for the entire global data center in the future. Berkeley National Laboratory [20] proposed a method for forecasting energy consumption of the US data centers in 2020, which considers the future demand for IT equipment and the change of its power. YoleDéveloppement [21] predicted the energy consumption of the global data center in 2020, but assumed that the PUE is fixed. Heddeghem et al. [8] conducted a retrospective analysis of the energy consumption of global data centers from 2007 to 2012, and this study is based on the analysis of the major energy-consuming subsystems in the data center. Anders et al. [22] predicts global data center energy consumption based on the average annual growth rate of global data center traffic. In fact, data center traffic has grown exponentially in recent years.

In brief, there are a few reliable methods for prediction and analysis of global data center energy consumption, especially for the Pan-Arctic area, where is the key area of future global data center. To the best of our knowledge, there is no study about the energy consumption prediction of data centers located in the Pan-Arctic area. Aiming at the above problems, an energy consumption prediction method based on data center traffic is presented in this paper. Global data center traffic growth is firstly predicted based on the Cisco's research, and then the dynamic global average PUE and the high latitude PUE via the Romonet simulation model are obtained. Lastly, global data center energy consumption with two scenarios, including decentralized scenario (assuming that data centers to be constructed with the current distribution pattern) and centralized scenario (assuming that 80% data centers to be constructed located in the Pan-Arctic region), is analyzed quantitatively via the polynomial fitting method by 2030. The proposed method fully considers the impact of PUE and new technology development on energy consumption of data centers in different regions at different times. This study is of great significance. First of all, it provides support for global energy consumption prediction; secondly, it helps to guide the layout of future data centers from the perspective of energy consumption; moreover, it provides a theoretical support for energy and information networks integration development under the Global Energy Interconnection conception.

The remainder of this paper is organized as follows. Section 2 presents a detailed description of related works. Section 3 gives a general description and presents the implementation of our proposed method. Section 4 describes the simulation experiments and results. Section 5 concludes the paper.

2 Related works

2.1 Power Usage Effectiveness (PUE)

Power usage effectiveness (PUE) is a ratio that describes the energy use efficiency of a data center, especially the energy consumption by computing equipment (other than cooling and other overhead). It has become an internationally accepted measure of data center power efficiency, and is defined as:

$$PUE=\frac{Engergy_{DC}}{Engergy_{IT}} \tag{1}$$

where, $Engergy_{IT}$ represents the power consumption of IT equipment, including the servers, network equipment, storage units and peripherals, and all equipment used to manage, process, store or route data in the data center; $Engergy_{DC}$ denotes the total power consumption of a data center, including the power consumption of the IT equipment and the infrastructure, and the infrastructure consists of power supply system, lighting system, air-conditioning and cooling systems. The lower the PUE value of the data center, the higher its power usage efficiency. An ideal PUE is 1.0, which means that all energy consumption is used on IT equipment. In recent years, companies such as Google and Facebook have dramatically reduced PUE by improving the efficiency and individual hardware design. Google reported a 12-month (trailing 12-month, TTM) average PUE of 1.12, and a single-site PUE ranged from 1.09 to 1.31 [23]. Facebook has not yet disclosed the average PUE, but has provided a dashboards with real-time PUE value for its two largest data centers, and the average value of TTM are 1.08 and 1.09, respectively [24,25].

2.2 Prediction method for US

Berkeley National Laboratory proposed a prediction method for the energy consumption of US's data centers [20]. In this method, the IT energy consumption is divided into server energy consumption, storage energy consumption and network energy consumption, and the energy consumption of each module is analyzed separately. Fig. 1 shows the general illustration of the modeling process.

The total power demand (including the infrastructure power consumption) of the data centers is the product of the power usage efficiency (PUE) and the IT power consumption. The module concludes server, storage and network three submodules. For the server submodule, the model divides servers into six types, the demand quantity and power status of each type are predicted, and then the energy consumption of each type of server is obtained by the number of servers multiplied by power. As a result, the total energy consumption is available through the sum of the energy consumption of the six types of servers. For the storage submodule, considering two types of hard drives including SSD (solid-state drives) and HDD (hard disk drives), the unit power consumption of SSD is related to capacity, while the power consumption of HDD is relatively fixed, and not dependent on disk capacity. Thus, the power consumption is evaluated by the drive unit. Firstly, the data center storage capacity to be installed and the average capacity of SSD and HDD drives, are analyzed and predicted. Then, the number of each type drive in US was predicted. Finally, the energy consumption of data center

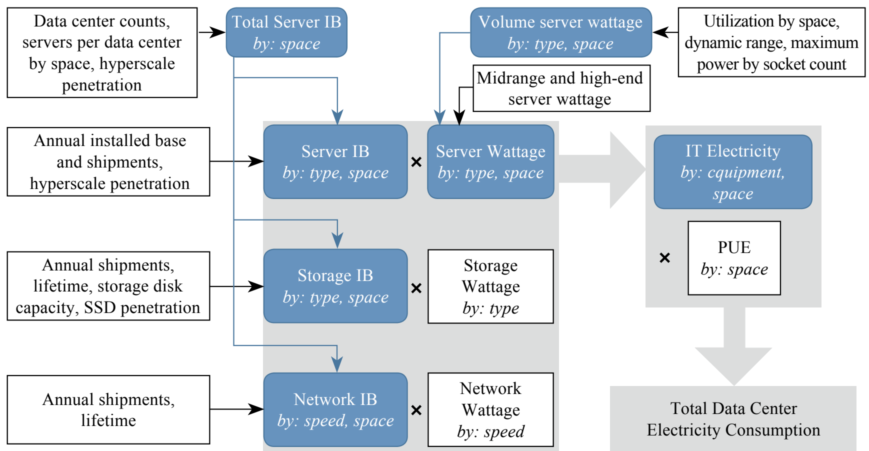

Fig. 1 Schematic of modeling US's data center electricity consumption

storage is obtained by the number of drive installations multiplied by the predicted power of each drive. Moreover, 25% of storage energy consumption, energy consumption of controller and related components for operating the hard drives, is added to obtain the total storage energy. The total amount of network energy consumption is calculated by multiplying the number of installed network ports and the assumed power of each port. Above all, the model is based on the server, storage and network of data center and their developments to predict the energy consumption of the US data centers. In practice, however, number of demand of servers, storage and networks, and their powers are changing over time due to many factors, such as new materials and new technologies etc., thus, there are many uncertain factors in this model. In addition, the development level of data center in US is generally higher than the global average level, which is difficult to apply to other countries and regions.

2.3 Prediction method for Europe

Avgerinou et al. [21] used the data submitted by the companies participating in the European Data Center Energy Efficiency Code of Conduct program to evaluate, analyse and present the current trends in energy consumption and efficiency in data centers in the European Union. The data they collected including detail information of 289 of 325 data centers (the locations of data centers is shown in Fig. 2). The method employed the more data, including building information, operational data, IT measurements, power data, etc., where building information involves data center type, building type, building area, construction date and location; operational data involves rated IT load, temperature and relative humidity (RH) set point and mechanical system type. IT measurement is total IT plug energy from UPS / PDU meter in KWh, and start and end date of meter readings. Power data involves power consumption (kWh), and the start and end dates of the meter readings. Table 1 lists the average data of reported facilities.

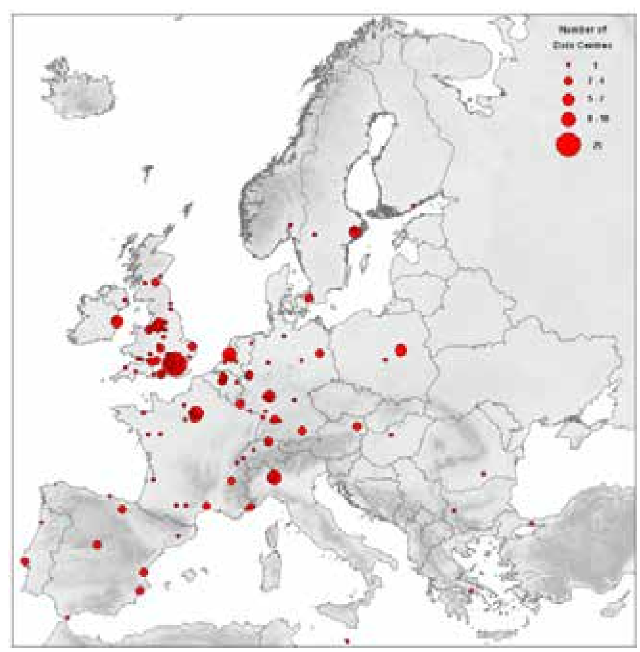

Fig. 2 Geographical distribution of the data centers under the European Code of Conduct

The PUE value is calculated based on the reliable data about the energy consumption provided by each data center. In this method, the PUE is compared against various parameters such as the facility size, the construction year and the rated IT electrical load, and it is concluded that the PUE of European data centers fluctuates with year, but it shows a downward trend generally. The study did not specifically quantify the energy consumption of data centers in the future. At the same time, the research is an analysis based on real data of European data centers, and it is difficult to apply to global data centers.

Table 1 Average data of reported facilities

Total Dataset	289 Data Centers Which Have Reported the Data
Total annual electricity consumption	3,735,735 MWh
Average DC floor area	2616 m^2
Average rated IT load	1956 kW
Average annual electricity consumption	13,684 MWh
Average annual IT consumption	7871 MWh
Average PUE	1.80
Average high temp set point	25 ℃
Average low temp set point	19.5 ℃
Average high RH set point	59% RH
Average low RH set point	35% RH

3 Proposed methodology

In this paper, we propose a method for energy consumption prediction based on data center traffic. The dynamic global average PUE and the high latitude PUE based on Romonet simulation model are analyzed, and then the energy consumption of global data centers is predicted, based on global data center traffic, by the polynomial fitting method. The overall framework is shown in Fig. 3. In general, it contains three sub-contents: (a) Using the traffic in data centers to predict the global data center energy consumption $Engergy_{DC\text{-}current}$ by a year-by-year equation (shown in (2)). (b) Based on the Romonet simulation model and the site location information, using the polynomial fitting model to analyze the relationship between latitude and the high latitude PUE_{arctic}, and the trend of the dynamic global average PUE_{global}. (c) Predicting the energy consumption of global data centers in the centralized scenario $Engergy_{DC\_arctic}$, which is defined as follows:

$$Engergy_{DC\_arctic} = \alpha \times \frac{Engergy_{DC\_current}}{PUE_{global}} \times PUE_{arctic} + (1\text{-}\alpha) \times Engergy_{DC\_current} \quad (2)$$

where, α is the proportion of data centers in high latitudes to the total number of global data centers.

The left part of framework in Fig. 3 is the model of the relationship between latitude and data center PUE. This paper obtains all the data center PUE values based on the reality simulation data from the Romonet website, and obtains the geographical location related information according to the data center location. The latitude values and the PUE values are selected for polynomial fitting to analyze the change trend. According to the polynomial fitting model, the PUE value corresponding to any latitude of the Pan-Arctic region can be obtained, thereby determining the average PUE value of the high latitude region (the latitude range from 62 to 73).

At the right part of the framework in Fig. 3 is the prediction model of global data center demand for different scenarios, aiming at comparing the power demand of the global data center in the decentralized scenario with the centralized scenario. It involves three steps: Firstly, calculating the power consumption of the global data center in the decentralized scenario. Then, predicting energy consumption of IT load and the average PUE values of global data center in 2010-2030 PUE_{global}. Finally, according to IT load energy consumption of global data center in 2010-2030 in decentralized scenario and PUE in the Pan-Arctic region PUE_{arctic}, predicting the amount of electricity demanded by the data center in the centralized scenario.

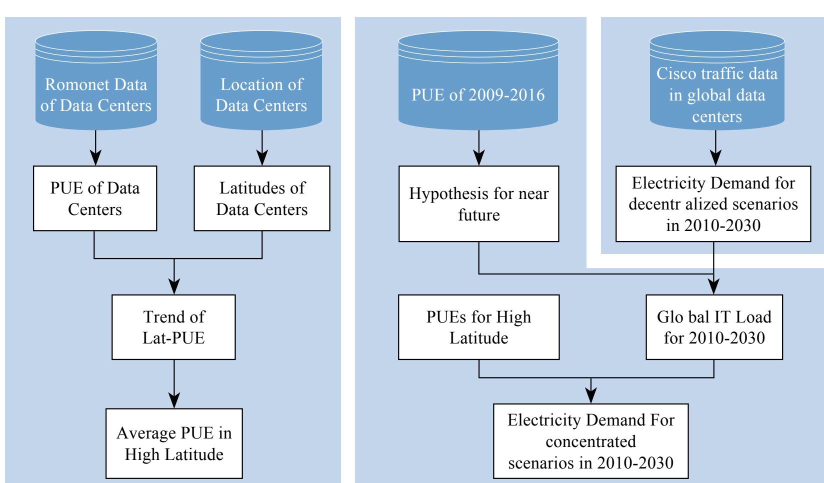

Fig. 3 Framework in this paper

3.1 Global energy consumption prediction

The decentralized scenario energy consumption is defined as the global data center power consumption with the current distribution pattern in this paper. The research by Anders et al. [22] shows, that data center energy consumption has a certain relationship with its traffic, and the data center traffic here refers to the sum of traffic from the data center to the user, traffic between the data centers, and internal traffic in the data center. Simultaneously, the normalization basis adopted here, for the quantification of electricity efficiency/intensity, is traffic expressed as TWh/ExaByte (EB), and electricity per data values is 0.14 TWh/EB [5, 26].

Considering the development of new materials and new technologies of electronic components and the evolution of data center architecture to promote and improve the efficiency of power consumption, this paper adopts data centers traffic to predict the energy consumption of data centers, and the model is defined as follows:

$$Engergy_{DC\_current,\ 2011+n} = \left(\frac{TDC_{2011+n}}{TDC_{2010+n}}\right) \times Engergy_{DC\_current,\ 2010+n} \times \left(\frac{100\% - EE}{100\%}\right) \quad (3)$$

where, $Engergy_{DC\_current,\ 2010}$ and $Engergy_{DC\_current,\ 2011}$ are the amount of energy consumption of the global data centers in 2010 and 2011, respectively, with meter in TWh. TDC_{2010} and TDC_{2011} represent the global data centers traffic in 2010 and 2011, respectively, with meter in EB, n=0,1,2,…,19, EE denotes annual electricity efficiency improvement factor, and the value usually is set between 0-20%.

3.2 Global dynamic PUE prediction

With the development of technology and the improvement of people's awareness of environmental protection, the global average PUE is decreasing year by year. Considering the historical data of PUE in European data centers and efficiency predictions of data centers made by new materials and technologies [19, 21], this study presents some hypotheses for predicting the PUE of global data centers. First, the global average PUE index would fall to 1.60 by 2020. Second, by 2026, the global average PUE index would fall to 1.50. Above two hypotheses are reasonable. Firstly, due to the continuous improvement of various cooling technologies in the data centers, the energy loss will be reduced. Secondly, some new materials like the silicon photonics have reached the critical point, and will be applied more in 2025 mainly for communication in the data centers, thus, there will be a huge improvement in the IT performance of data centers. In addition, the Wide-Band Gap devices (such as GaN/ SiC equipment) will be used in data centers, which will further improve the energy efficiency. Lastly, the DC power will be gradually applied to the data centers.

It is worth noting that because of the small amount of data with the above-mentioned assumptions, it is difficult to analyze the model error. Therefore, we employed a polynomial fitting model, with strong generalization ability and flexible ability to combine prior knowledge, to predict the global average PUE. The details of the model will be described in following section. The global average PUE from 2010 to 2030 is fitted and predicted, as shown in Fig. 4. It can be seen from Fig. 4, the global average PUE index is expected to reach 1.40 by 2030.

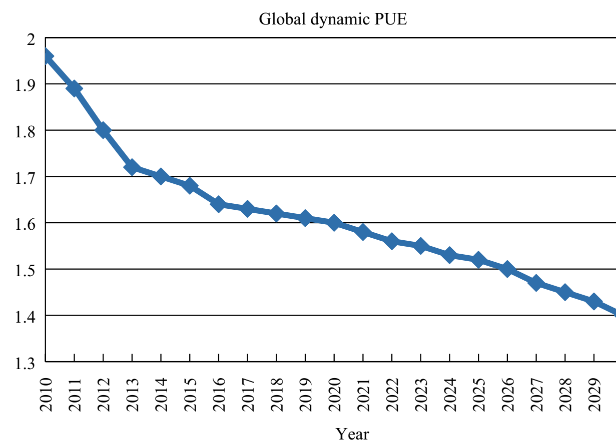

Fig. 4 Regression results of the global average PUE of data centers

3.3 Analysis of high latitude PUE

The prediction analysis of the PUE in high latitude region can be performed through the determination of the correlation between latitudes and PUEs. The typical correlation defined as:

$$r(X,Y) = \frac{Cov(X,Y)}{\sqrt{Var[X]Var[Y]}} \quad (4)$$

where X denotes the latitude, Y is the PUE value. X and Y are n-dimensional vector. $Cov(X,Y)$ is the covariance of X and Y. $Var[X]$ is the variance of X and $Var[Y]$ is the variance of Y. The correlation between the variable latitude and the PUE value can be calculated through the above definition in (4). The variable X can be adjusted to represent the primary, quadratic, and cubic of the latitude value Y, respectively. The correlation between PUEs and latitude values with the different powers can be calculated by (4), and then the most relevant parameters will be determined.

Assuming that the PUE is most correlated with the

q−*th* power of the latitude value ($q \geqslant 1$), the PUE value can be regressed by the q−*th* order polynomial. As a result, a mapping function for the latitude and PUE variables can be obtained as follows:

$$y = f(x) = \sum_{i=1}^{q} w_i x^i + w_0 \tag{5}$$

where $w_i(i=1,\ldots, q)$ denotes the weighted factor, and w_0 is a constant. The gradient descent was employed to determine the coefficient w_0, w_1, $w_2,\ldots$, w_q. The input of the above model in (5) is the training samples $\{(x_0, y_0), (x_1, y_1), \ldots, (x_n, y_n)\}$ and the model can be obtained by learning from training samples.

Based on the model, the average PUE can be determined according to the latitude values, and then, combining the changes of global dynamic PUE, the trend of high latitude PUE with time can be obtained.

4 Simulation and analysis

4.1 Global energy consumption prediction in decentralized scenarios

In this study, the traffic of data centers is mainly from the Cisco Research Report [27, 28], Global Data Center Traffic 2012-2020 shown in Table 2. The global data center traffic from 2010 to 2030 can be obtained by the polynomial fitting model in Eq.(5). Compared with other regression models including the linear regression model, ridge regression model, the employed polynomial fitting model has the smallest prediction error. As shown in Fig. 5, the global data center traffic will reach 60,000 EB in 2030. Therefore, a large number of data centers are needed for the enormous traffic.

Table 2 Cisco Global Data Center Traffic Forecast

YEAR	2012	2013	2014	2015	2016	2017	2018	2019	2020
Types (EB/Year)									
Data center to user	427	560	711	744	933	1164	1438	1772	2183
Between data centers	167	221	281	346	515	713	924	1141	1381
Inside the data centers	1971	2560	3123	3587	5074	6728	8391	10016	11770
Total (EB/Year)									
IP traffic	2565	3341	4115	4677	6522	8605	10753	12929	15334

Based on the prediction model of energy consumption of global data centers, here, *EE* is set 10%, and *EE* is set 5%

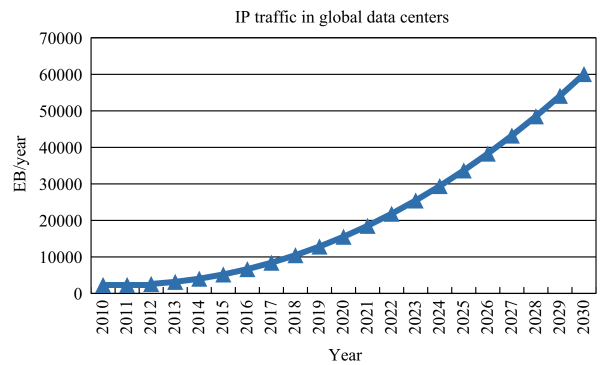

Fig. 5 Global data center traffic forecast (2010-2030)

from 2022 [5, 29], the energy demand of global data center energy in the decentralized scenario can be quantized, which can be seen from Fig. 6. In 2030, the electricity consumption of global data centers will reach 1800 TWh, which is more than 1/4 of the total annual electricity consumption of China in 2017. Obviously, after 2012, the electricity consumption of global data centers is rising at a constant rate. However, the rising rate of 2020 is faster than the other years, which mainly results from the rapid growth of data traffic under the development of global intelligentization.

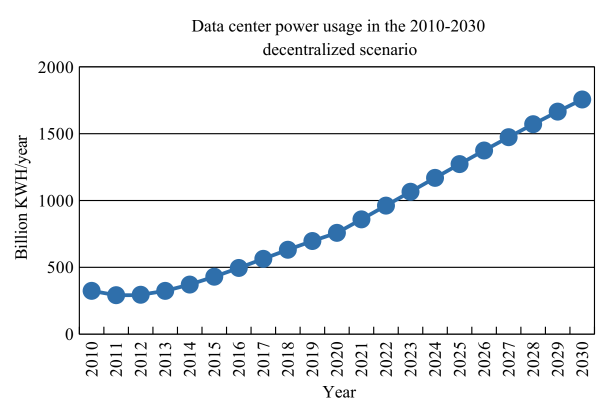

Fig. 6 Decentralized scenario global data center power demand (2010-2030)

4.2 PUE analysis in the Pan-Arctic region

Romonet’s Global Site Analysis Tool (SAT) provides an effective way to study the PUE in the Pan-Arctic data centers. SAT’s results are generated using over 1,600 simulation years’ worth of data processed with Romonet’s patented Data Center Analytics technology. The tool gives 69 locations in the United States and 22 locations in Europe (the distribution is shown in Fig. 7). Some metrics of the data centers under different IT load conditions are shown in Table 3. In this study, PUE data and CO_2 data were obtained from different regions with the 100% IT load. For each region, the data centers are divided into five types: chilled water with cooling tower, economized chilled water with cooling towers, indirect air economized, adiabatic direct air economized and OCP adiabatic direct air economized. Due to the different PUEs of different types of data, the average value of PUE is employed as the PUE index of the region.

Fig. 7 The data center distribution of SAT model

Table 3 Describe of dataset

Data Sources	Variable	Description
SAT Simulation Data	Location	
	Data Center Type	5 species
	Annual average PUE	1~2
	Annual Energy	GWh
	Annual Energy Cost	US-$m
	Annual CO_2 Emissions	kT
	Utility Energy Cost	USD ¢/kWh
Simulation Site Data	Longitude	−180~180
	Latitude	20~61
Average PUE Data	Year	2009~2016
	Value of PUE	1~2

Based on the simulated location, we crawled the latitude and longitude information of each station. And then the PUE data is used to fit the relationship curve between the PUE and the longitude of the Pan-Arctic regions at the current time, as shown in Fig. 8.

In Fig. 8, as can be seen that when the latitude continues to increase, the PUE of the data centers has a decline trend. However, at each stage, the rate of decline of PUE is also different. When the latitude is 20, the value of PUE is about 1.37. However, when the latitude is between 30 with 60, the decline of PUE is relatively slow. When the latitude is higher than 60, the decline of PUE is abruptly accelerated. The reason for the different rates of PUE decline is that the PUE may be related to the topography and climate of different latitudes.

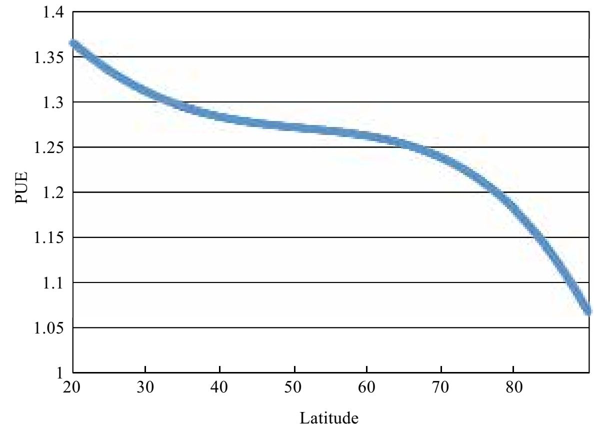

Fig. 8 Trend of PUE and Latitude

Thus, the region of the north latitude 62 to 73 degrees is chosen, and its average PUE is obtained. Then, the energy consumption of the centralized scenario (as shown in Fig. 9), can be predicted. The energy consumption contrast between the centralized scenario and the decentralized scenario can be seen from Fig. 10. It shows that the centralized scenario in 2030 will directly save power for 301 billion kWh compared with the decentralized scenario, which is equivalent to the annual electricity consumption of 800 million British households.

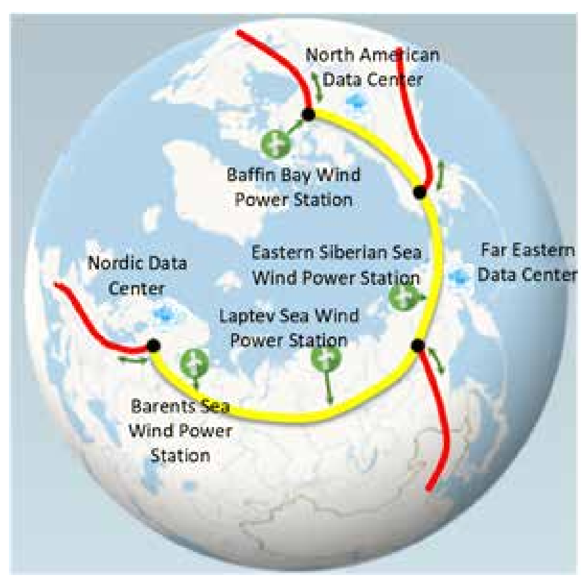

Fig. 9 Centralized scenario of new data centers to be concentrated in the Pan-Arctic region

In addition, based on the prediction results of energy consumption, carbon emissions have also been quantitatively assessed. According to the CO_2 emissions emitted by electric power and heat generation in different countries and regions issued by Ministry of International Energy Department, and considering the proportion of data

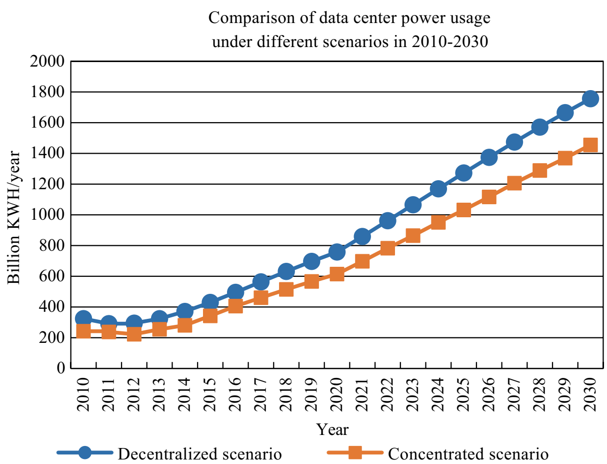

Fig. 10 Energy Consumption of decentralized scenario vs centralized scenario

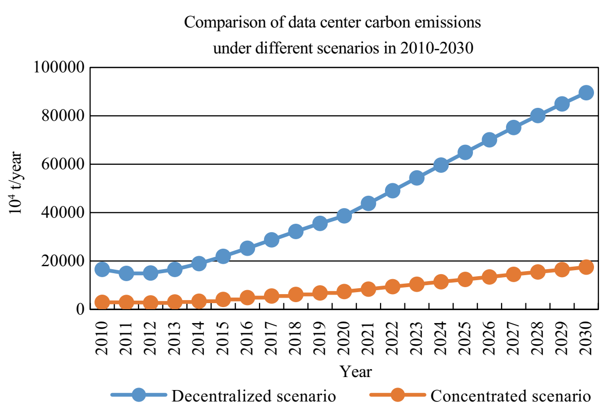

Fig. 11 CO_2 emissions of decentralized scenario Vs centralized scenario

centers in different regions, the CO_2 emissions is 0.51 tons/MWh for the decentralized scenario, and 0.12 tons/MWh for the centralized scenario [30]. Thus, the CO_2 emissions with the different scenarios can be evaluated, which can be seen in Fig. 11.

It can be seen from Fig. 11 that, it is expected in 2030, the carbon emissions in the centralized scenario can be directly reduced 720 million tons CO_2 compared with the decentralized scenario.

5 Conclusion

Facing the huge energy demand of global data centers, the Pan-Arctic region have gradually become hotspots for data center location selection in recent years, due to their unique climate advantages. Based on this, this paper considers the centralized data center scenario in the Arctic region and the decentralized scenario of the current data center. Based on global data center traffic and the Romonet simulation model, combing the global dynamic PUE and the high latitude region PUE, the global data center energy consumption and carbon emissions in the different scenarios are predicted via the polynomial fitting method. The simulation results show the energy consumption and the carbon emissions in the centralized scenario, in 2030, will be directly reduced 301 billion kWh and 720 million tons CO_2, respectively, compared with the decentralized scenario, which suggests that the establishment of data centers in the Pan-Arctic region in the future can effectively solve the climate and energy problems. This study provides support for global energy consumption prediction, and can guide the layout of future global data centers from the perspective of energy consumption. Moreover, it provide important support for the feasibility of the integration development of the energy and information networks under the Global Energy Interconnection conception.

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References

[1] Poess M, Nambiar RO (2008) Energy cost, the key challenge of today's data centers: a power consumption analysis of TPC-C results. In: Proceedings of VLDB 2008, Auckland, New Zealand, August 23-28, 2008

[2] Buyya R, Vecchiola C, Selvi ST (2013) Mastering Cloud Computing: Foundations and Applications Programming. Morgan Kaufmann Publishers Inc., Burlington

[3] Mathew V, Sitaraman RK, Shenoy P (2012) Energy-aware load balancing in content delivery networks. In: 2012 Proceedings IEEE INFOCOM, Orlando, FL, 25-30 March 2012

[4] Whitehead B, Andrews D, Shah A et al (2014) Assessing the environmental impact of data centres part 1: Background, energy use and metrics. Build. Environ 82:151-159

[5] Corcoran PM, Andrae ASG (2013) Emerging Trends in Electricity Consumption for Consumer ICT. Nat. Univ. Ireland, Galway, Ireland, Tech. Rep

[6] Koomey J (2011) Growth in data center electricity use 2005 to 2010. Analytics Press, Burlingame, CA

[7] Su N (2017) The proportion of central energy consumption in the global total energy consumption is increasing year by year. http://tech.idcquan.com/133093.shtml. Accessed 16 July 2018

[8] Heddeghem WV, Lambert S, Lannoo B et al (2014) Trends in worldwide ICT electricity consumption from 2007 to 2012. Comput Commun 50(13):64-76

[9] Rong H, Zhang H, Xiao S et al (2016) Optimizing energy consumption for data centers. Renew Sust Enery Rev 58:674-691

[10] Oró E, Depoorter V, Garcia A et al (2015) Energy efficiency and renewable energy integration in data centres. Strategies and modelling review. Renew Sust Enery Rev 42:429-445
[11] Ni J, Bai X (2017) A review of air conditioning energy performance in data centers. Renew Sust Enery Rev 67:625-640
[12] Zhang H, Shao S, Xu H et al (2014) Free cooling of data centers: A review. Renew Sust Enery Rev 35:171-182
[13] Dayarathna M, Wen Y, Fan R (2017) Data Center Energy Consumption Modeling: A Survey. IEEE Commun Surv Tut 18(1):732-794
[14] Venkatachalam V, Franz M (2005) Power reduction techniques for microprocessor systems. ACM Comput Surv 37(3):195-237
[15] Mittal S, Vetter JS (2014) A Survey of Methods for Analyzing and Improving GPU Energy Efficiency. ACM Comput Surv 47(2):1-23
[16] Bostoen T, Mullender S, Berbers Y (2013) Power-reduction techniques for data-center storage systems. ACM Comput Surv 45(3):1-38
[17] Hammadi A, Mhamdi L (2014) A survey on architectures and energy efficiency in Data Center Networks. Comput Commun 40(2):1-21
[18] Ebrahimi K, Jones GF, Fleischer AS (2014) A review of data center cooling technology, operating conditions and the corresponding low-grade waste heat recovery opportunities. Renew Sust Enery Rev 31(2):622-638
[19] Avgerinou M, Bertoldi P, Castellazzi L (2017) Trends in data centre energy consumption under the European Code of Conduct for data centre energy efficiency. Energies 10(10):1470. doi:10.3390/en10101470
[20] Berkley National Laboratory (2016) United States Data Center Energy Usage Report, June 2016,LBNL-1005775
[21] YoleDéveloppement (2016) Data Center Marketand Technology Trends in Power Electronics.APEC 2016 –Long Beach (CA). https://www.slideshare.net/Yole_Developpement/data-center-market-and-technology-trends-power-electronics-presentation-held-at-apec-2016-from-yole-dveloppement. Accessed 13 March 2018
[22] Andrae ASG, Edler T(2015) On Global Electricity Usage of Communication Technology: Trends to 2030. Challenge 6(1):117-157
[23] Google (2018) Efficiency: how we do it. Google—Data Centers, https://www.google.com/about/datacenters/efficiency/internal/. Accessed 15 March 2018
[24] Facebook (2018)a Forest City Data Center—PUE/WUE. https://www.facebook.com/ForestCityDataCenter/app/288655784601722/. Accessed 15 March 2018
[25] Facebook (2018)b Prineville Data Center—PUE/WUE. https://www.facebook.com/PrinevilleDataCenter/app/399244020173259/. Accessed 15 March 2018
[26] Dagher JC, Marcellin MW, Neifeld MA (2007) A Theory for Maximizing the Lifetime of Sensor Networks. IEEE T Commun 55(2):323-332
[27] Cisco (2016) Cisco Global Cloud Index: Forecast and Methodology, 2015–2020. White paper. https://www.cisco.com/c/dam/m/en_us/service-provider/ciscoknowledgenetwork/files/622_11_15-16-Cisco_GCI_CKN_2015-2020_AMER_EMEAR_NOV2016.pdf. Accessed 20 October 2017
[28] Cisco (2013) Cisco Global Cloud Index: Forecast and Methodology, 2012–2017. White paper. https://d2sr9p9v571tfz.cloudfront.net/upload/images/10_2013/131028130134.pdf. Accessed 20 October 2017
[29] PCWorld. (2015) Available online: http://www.pcworld.com/article/2887275/intel-moores-law-will-continue-through-7nm-chips.html. Accessed 10 March 2018
[30] Douglas A (2013) Grow a Greener Data Center,Cisco Press, Indianapolis,USA

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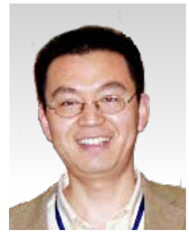

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