Postprint: Demand for Computing Power Development, Electricity Consumption, and Green and Low-Carbon Transition Strategies in China

Authors: Chen Xiaohong, Cao Liaoying, Jiaolong Chen, Jinghui Zhang, Cao Wenzhi, Yangjie Wang

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Abstract

Computing power, as a key driver for unleashing data value and activating data potential, has become the core productive force of the digital economy and a new engine supporting economic growth. Computing power infrastructure such as computing centers or data centers consumes a large amount of electrical energy while supporting rapid economic growth. Currently, China' s economy is in a transition stage from high-speed growth to high-quality development, making how to coordinate computing power development with green and low-carbon goals a critical issue requiring urgent research. Based on reviewing the current development status of China' s computing power, this article forecasts future development demands for computing power in China, and by analyzing the relationship between future growth trends of computing power and power consumption, proposes policy recommendations for accelerating the green and low-carbon transformation of computing power from the perspectives of top-level design, regional layout, platform construction, and market mechanisms, thereby providing support for the green and low-carbon transformation of computing power and enabling high-quality development of the digital economy in China.

Full Text

Preamble

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Development Demand, Power Energy Consumption and Green and Low-Carbon Transition for Computing Power in China

CHEN Xiaohong[1,2,3], CAO Liaoying[1,3], CHEN Jiaolong[2], ZHANG Jinghui[2], CAO Wenzhi[1,3], WANG Yangjie[2*]

Abstract

As a critical digital infrastructure, computing power has become the core productivity and a new engine driving economic growth in the digital economy. Nevertheless, the power-hungry nature of computing/data centers, representing the computing infrastructure, consumes a significant amount of electrical energy. Currently, China' s economy is transitioning from high-speed growth to high-quality development. It is imperative to study how to coordinate the development of computing power while ensuring its safety and achieving green and low-carbon goals. Based on an overview of the current status of computing power development, this study predicts the future demand for computing power in China, analyzes the relationship between future computing power growth and electricity consumption, and discusses the associated challenges. From the perspectives of top-level design, regional layout, platform construction, and market mechanisms, this study proposes strategies and measures to accelerate the green and low-carbon transformation of computing power, providing support for sustainable computing power transformation and empowering the high-quality development of the digital economy.

Keywords: computing power, electrical energy consumption, data center, green transformation

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With the rise and development of a new round of scientific and technological revolution, industrial transformation is accelerating, and global economic development is showing signs of recovery. Digital infrastructure plays a key foundational role in supporting and leading new directions for economic development[1]. President Xi Jinping pointed out, "We must accelerate the construction of new types of infrastructure, strengthen strategic layout, and build a high-speed, ubiquitous, integrated, intelligent, agile, green, low-carbon, and secure intelligent comprehensive digital information infrastructure with 5G networks, national integrated data center systems, and national industrial internet as the starting points, to open up the 'information artery' for economic and social development" [2]. The report of the 20th National Congress of the Communist

Party of China further emphasized, "Accelerate the development of the digital economy, promote the deep integration of the digital economy and the real economy, and build internationally competitive digital industrial clusters."

From intelligent driving, smart cities, and the metaverse, to generative artificial intelligence represented by ChatGPT, computing power is becoming a foundational technical element that empowers digital transformation across all industries[3]. Computing power refers to the computational resources for big data storage and analysis[1]. With the vigorous development of the digital economy, computing power is gradually penetrating from the internet industry to transportation, industry, finance, government affairs, and other sectors, with demand for computing resources continuing to rise across industries[2]. Against this backdrop, a sufficient and stable supply of computing power resources is not only a prerequisite for further iteration of digital technologies[3] but also a key driver supporting the development of the digital economy. However, as demand for computing power across industries increases significantly, the energy consumption and indirect greenhouse gas emissions caused by computing power have attracted widespread attention from scholars. Research shows that in 2022, China' s data centers consumed 270 billion kWh of electricity, accounting for approximately 3.13% of the country' s total electricity consumption[4]. The carbon emissions generated by electricity-driven computing infrastructure pose challenges to China' s carbon peaking and carbon neutrality goals[4].

In recent years, scientists have paid increasing attention to the energy consumption issues caused by computing power. Schwartz et al.[5] noted that as demand for greater computational power and more accurate training results grows rapidly, the increasing power consumption required by AI applications runs counter to the development concept of "green AI." Dhar et al.[5] recently published a study in *Nature* stating that artificial intelligence itself is also a significant source of carbon emissions, and the research team called for enhanced attention to the carbon impact of infrastructure deployment in AI. Additionally, Jiang et al.[6] conducted a detailed measurement and assessment of the energy consumption and carbon emissions of blockchain technology represented by Bitcoin, concluding that without policy intervention, blockchain technology will consume 296.59 TWh of electricity in 2024, generating 130.5 million tons of carbon emissions. While these studies provide rich literature support for understanding the relationship between computing power development and energy consumption, there are few targeted analyses of this relationship and response strategies under China's specific national conditions. This paper predicts China' s future computing power demand based on an overview of the current status of computing power development, analyzes the relationship between future computing power growth and power energy consumption and potential problems, and proposes targeted policy recommendations for China's green and low-carbon transition in computing power.

1. Typical Application Fields' Computing Power Demand and Forecasting Analysis

1.1 Current Status of Computing Power Development

Based on computer processing capabilities, computing power can generally be divided into basic computing power, intelligent computing power, and supercomputing power[7]. (1) Basic computing power, typically composed of central processing units (CPUs), can generally meet daily basic data computing needs such as office applications, web browsing, and media playback. (2) Intelligent computing power, mainly composed of heterogeneous computing chips such as graphics processing units (GPUs) and application-specific integrated circuits, is commonly used to process large-scale data and complex algorithm models, such as image recognition, speech recognition, and natural language processing. (3) Supercomputing power, with extremely high computing performance and large-scale parallel processing capabilities, typically consists of multi-processors, large memory, and high-speed interconnect networks, and is commonly used in scientific fields such as weather forecasting, wind tunnel experiments, and energy development to assist in complex calculations.

As the main carrier of computing power, China' s computing power infrastructure is developing rapidly, and a tiered and optimized computing power supply system has been initially established. Over the past five years, the average annual growth rate of China' s computing power scale has been 46%, and its supporting role in driving economic, social, and industrial development has been continuously strengthening[6]. In 2021, China's intelligent computing power scale reached 104 EFlops, basic computing power scale reached 95 EFlops, and supercomputing power scale was approximately 3 EFlops[6].

From the perspective of application fields, China' s computing power application fields have gradually expanded from the early internet industry to industry, education, medical research, and other fields [Figure 1: see original paper][8], becoming an important support for the intelligent transformation and digital transformation of traditional industries. Computing power is comprehensively empowering innovative development in production, operation, management, financing, and other fields.

(1) **Large-scale application of computing power in the industrial field.** With the gradual deepening of artificial intelligence technology applications in the industrial field, intelligent manufacturing has achieved intelligence and automation in manufacturing processes[9]. According to statistics, China's industrial manufacturing computing power expenditure accounts for 12% of global computing power expenditure, and computing power expenditure in the robotics field has exceeded 60% of global computing power expenditure[8]. In industrial production processes, intelligent equipment and sensors can collect and monitor production data in real time, providing a foundation for automated control such as equipment status monitoring, fault prediction, and production parameter adjustment[9],

enabling real-time adjustment and optimization of production processes. This real-time control and optimization require massive computing power to process and analyze large datasets, ensuring greater precision and efficiency in production processes. Therefore, sufficient computing power support is a key element for achieving automated control in industrial production processes[10]. According to statistics, one Tesla vehicle requires 20 sensors. Based on Tesla' s global delivery of 1.31 million vehicles in 2022, the total computing power demand for Tesla vehicles in one year is approximately 94 EFlops[9]. In the industrial field, image recognition and visual inspection technologies are widely used in production management and automated quality control on production lines. Machine vision systems train on massive datasets through deep learning algorithms, enabling precise identification of target objects. For example, recognizing 5 million facial images requires 0.04 EFlops of computing power[11].

(2) **Education is another potential field for computing power application.** The demand for computing power in the education field is mainly distributed in research experiments, intelligent learning, and interactive learning[12]. (1) In the research experiment field, basic theoretical research such as big data intelligence, brain-inspired intelligent computing, and quantum intelligent computing places huge demands on computing power resources[13]. Among them, maintaining brain-inspired computing operations on supercomputing platforms requires 1 EFlops, equivalent to the computing power of 16,000 CPU core processors[10]. (2) In the intelligent learning field, intelligent education cloud platforms such as Massive Open Online Courses (MOOCs) involve the integration of multiple technologies including video compression and decompression algorithms, bandwidth management, and network transmission optimization, all of which require stable and massive computing power support to ensure real-time communication between students and teachers. (3) In the interactive learning field, computing power can support the construction of virtual experiments and simulated learning environments[14]. Huawei' s *Intelligent World 2030* report points out that the computing power demand for 3D modeling has increased 100-fold compared to traditional modeling techniques. A single run of Huawei Cloud' s 3D modeling technology requires approximately 0.011 EFlops of computing power[13].

(3) **Medicine has become another potential field for computing power application.** Currently, artificial intelligence technology has been widely adopted by medical institutions and life science organizations. Computer vision and image processing technologies are used to analyze and interpret medical images such as X-rays, CT scans, and genomic analysis[15]. Medical images typically require preprocessing to improve image quality and reduce noise, involving steps such as denoising, artifact removal, geometric correction, and image enhancement. Non-invasive imaging using X-ray irradiation requires 24,576 GPUs, achieving computing power of 0.065 EFlops[16]. In genomic analysis research, processing and

analyzing large-scale genomic data requires high-performance computing clusters or distributed computing systems. These complex tasks often rely on GPU-based genomics analysis software such as BWA-MEM algorithm, GATK toolkit, and STAR software. Running genomics analysis software 10,000 times requires approximately 0.01 EFlops of computing power[14].

1.2 Forecast of China' s Future Computing Power Demand

With the development of the digital economy, diverse computing power demand scenarios such as artificial intelligence and industrial digitalization continue to emerge. By 2030, global computing power demand driven by AI development is expected to increase 500-fold from 2020 AI computing power demand, exceeding 1.05$×10^{5}$ EFlops[11]. To further explore China' s computing power development scale in the next five years, this paper establishes an Autoregressive Integrated Moving Average (ARIMA) model (see "Appendix 1" for details) based on various types of computing power scale data, capturing long-term dependencies in time series data to forecast China' s future computing power demand.

Based on China' s computing power demand historical data from 2016 to 2021[6], we trained the characteristic sequence to capture long-term dependencies in time series data and predict China' s future computing power demand. [Figure 2: see original paper] shows the basic framework of the computing power forecasting model. On the basis of successful model development, this paper further optimized the computing power forecasting model using stationarity tests and white noise tests. The main forecasting results for China' s future computing power development scale and structural changes obtained from our model are presented in [Figure 3: see original paper] and [Figure 4: see original paper], with key conclusions as follows.

(1) **China' s computing power development scale continues to grow.** According to the forecast results, China' s total computing power scale reached 315 EFlops in 2022 and is expected to enter the era of 10 trillion billion floating-point operations per second by 2026, reaching 767 EFlops.

(2) **Basic computing power, intelligent computing power, and supercomputing power show stable growth, rapid growth, and sustained growth trends, respectively, with average annual growth rates of 18.99%, 78.97%, and 23.45% from 2016 to 2026.** Driven by new-generation information technologies such as big data, artificial intelligence, and cloud computing, intelligent computing power is developing rapidly. It is estimated that by 2026, China' s intelligent computing power scale will reach 561 EFlops. This growth trend is mainly due to the accelerating pace of intelligent upgrading across various fields, with increasing demand for intelligent computing power continuously driving the sustained high-speed growth of intelligent computing power scale.

(3) **China' s computing power structure continues to optimize.** As

demand for intelligent computing power continues to grow across various fields, China' s computing power structure is also evolving [Figure 4: see original paper]. Although basic computing power shows a stable growth trend, its proportion of total computing power scale is expected to decrease from 95% in 2016 to 26% in 2026. The proportion of intelligent computing power will increase from 3% in 2016 to 73% in 2026, while supercomputing power shows a stable upward trend in overall computing power scale.

2.1 Analysis of China' s Computing Power Energy Consumption

This paper calculates China' s computing power electricity consumption from two perspectives.

(1) **Forecasting energy consumption of computing power infrastructure (such as data centers).** Data center electricity consumption mainly comes from information technology (IT) equipment, cooling equipment, power supply and distribution systems, and other equipment such as lighting. Electricity costs account for 60%-70% of total operating costs. According to reported data, in 2022, all data centers in China consumed approximately 270 billion kWh of electricity, exceeding the annual power generation of two Three Gorges Hydropower Stations[8]. By analyzing China' s computing power scale and data center electricity consumption data from 2016 to 2021, we estimate that each EFlops of computing power requires approximately 0.8-1.2 billion kWh of annual electricity consumption, and this value shows a downward trend over time. This decline can be partly attributed to the widespread application of energy-saving and environmental protection innovation technologies and related energy-saving policies. The replacement of emerging technologies and adoption of energy-saving solutions have effectively improved the energy utilization efficiency of data centers, gradually reducing the electricity consumption required per unit of computing power. In 2022, China' s data center computing power scale reached 315 EFlops, with 85,000 data centers, equivalent to an average computing power of 3.7$×10^{-3}$ EFlops per data center. Based on the forecast of China' s total computing power scale and annual electricity consumption per EFlops of computing power, by 2026, the annual electricity consumption required by all data centers in China will reach at least 600 billion kWh. The proportion of data center electricity consumption in China' s total electricity consumption is expected to grow from 1.86% in 2016 to 6.06% in 2026 [Figure 5: see original paper][17].

(2) **Energy consumption analysis of computing power application examples.** Computing power plays an important role in the field of artificial intelligence, as it can perform complex calculations and provide necessary computational support for training deep learning models.

ChatGPT example. As an AI-based natural language processing model, ChatGPT operates under stable and sufficient computing power support and represents a typical example of collaborative innovation between large enterprises and research institutions in AI technology applications. This paper uses ChatGPT as an example to explore its computing power resource usage and power consumption, and to estimate the computing power resource demand and power consumption of large-scale model applications in China in the future. Taking OpenAI’s training of a 13-billion-parameter GPT-3XL model as an example, it requires approximately 0.0275 EFlops of computing power. Considering that ChatGPT’ s training model is fine-tuned based on the 13-billion-parameter GPT-3.5 model, with a parameter count close to that of the GPT-3XL model[18], this paper assumes that one training session of ChatGPT requires approximately 0.0275 EFlops of computing power. Assuming 1.375 EFlops of computing power, the annual electricity consumption would be at least 1.183 billion kWh. Considering factors such as input text length, model dimension, and number of model layers, this paper estimates that each ChatGPT query requires approximately 2.92$×10^{-10}$ EFlops of computing power, consuming about 0.00396 kWh of electricity. Assuming ChatGPT receives 200 million queries daily, it would require at least 0.0584 EFlops of computing power daily, consuming 792,000 kWh of electricity.

Examples of China’ s large models. As of May 2023, China has released 79 large models with over 1 billion parameters. Assuming each model needs to be trained at least 50 times per year, with computing power resources and power consumption per training session similar to the ChatGPT model, the annual demand would be 109 EFlops of computing power, with annual electricity consumption of at least 93.46 billion kWh. It should be noted that this result only reflects the computing power energy consumption demand in the AI field. If we consider all vertical application scenarios, China’ s demand for computing power resources and power energy will surge.

Overall, whether from the perspective of basic energy consumption of data centers or future development in emerging fields, the demand for computing power resources and power energy consumption will continue to rise, which may further increase China’ s energy burden and total carbon emissions.

2.2 Challenges Facing China’s Green and Low-Carbon Transition in Computing Power Development

China’s computing power demand shows an overall explosive growth trend, with prominent high energy consumption issues. Moreover, China’s computing power development also faces problems such as resource supply-demand imbalance and insufficient collaborative utilization efficiency, which constrain the green and low-carbon transition of computing power. These challenges specifically include three aspects.

(1) **Overall layout is relatively dispersed with low intensification levels.** Although data centers in various industries continue to emerge and

computing power scale grows explosively, the lack of effective connectivity between units leads to frequent phenomena such as "data center islands" and "cloud islands" [19], resulting in low computing power resource utilization. In addition, individual data centers are generally small in scale, making later expansion difficult. They face problems such as low utilization rates (e.g., average data center utilization rate below 60%, computing power utilization rate only 30%), high energy consumption (average PUE>1.5)[20], and increased migration costs.

(2) **Uneven resource allocation with mismatched supply and demand.** Currently, China' s computing power resources show an overall imbalance of "insufficient in the east, surplus in the west." Data center scale is typically measured by the number of standard racks; generally, more racks mean larger computing power scale. Although the ratio of rack numbers between eastern and western regions is approximately 7:3, with eastern regions having far richer computing power resources than western regions, the concentration of computing power demand in innovative eastern regions means that eastern areas still face computing power resource shortages. For example, first-tier cities such as Beijing, Shanghai, Guangzhou, and Shenzhen face computing power resource shortage pressures, with an average gap rate of 25%. Central and western regions have abundant energy but suffer from computing power resource overcapacity, with the surplus phenomenon particularly prominent in western regions where supply exceeds demand by more than 15%[21].

(3) **Lack of collaborative sharing mechanisms for computing power facilities.** After the full launch of the "East Data West Computing" project, various computing power hub nodes and data center clusters have increased investment and construction efforts, effectively improving the overall level of digital infrastructure and further optimizing data processing and storage efficiency. However, the lack of task collaboration and resource sharing mechanisms results in insufficient ability of computing power nodes to flexibly and efficiently allocate computing power resources through networks. Computing power facilities suffer from "uneven busyness," greatly constraining energy efficiency improvements. According to statistics from the China Data Center Industry Development Alliance, the overall vacancy rate of data center resources in western China exceeds 50%, with rack utilization rates in some regions below 10%[21]. Computing power infrastructure primarily uses electricity for energy. Even when computing power resources are not fully utilized, to ensure data security and equipment stability, computing power infrastructure must continue operating, generating ineffective energy consumption.

3. Policy Recommendations for China' s Green and Low-Carbon Transition in Computing Power

Computing power has become a key driver supporting the development of the digital economy. Its green and low-carbon transition must balance both development and security perspectives. In response to China' s massive computing power development demand and existing problems, how to achieve green and low-carbon transition while ensuring sufficient and stable power supply for computing power infrastructure has become an important breakthrough for solving this problem. This paper proposes the following six policy recommendations for China' s green and low-carbon transition in computing power.

(1) **Strengthen top-level design of computing power and promote integrated computing-network development.** Transform the concept of computing power resource construction and strengthen coordinated development of computing power resources. Shift computing power resource construction from disorderly development to coordinated promotion to resolve the contradiction between computing power supply and demand. According to policy orientation and specific local conditions, the information industry department should establish a specialized computing power planning and management department responsible for overall computing power resource planning, energy consumption management, and standard formulation to optimize computing power resource allocation efficiency and promote green and low-carbon transformation. Optimize the multi-level computing power infrastructure system. The top layer of this system consists of high-performance computing centers (such as national supercomputing centers), the middle layer consists of regional or industry computing centers, and the bottom layer consists of enterprise-level computing resources (such as private cloud computing power and edge computing power). Relevant departments should implement unified management and scheduling measures to achieve interconnectivity among computing power resources at all levels, effectively improve resource utilization efficiency, and promote energy-saving and consumption-reducing development of computing power resources. Coordinate layout and build regional computing power scheduling command platforms. Connect dispersed computing power across regions to achieve integrated scheduling management of regional computing power resources, allocate computing power resources on demand, unlock the value of social computing power, improve computing power utilization efficiency, and reduce unit energy consumption.

(2) **Optimize computing power resource layout to reduce computing power utilization energy consumption.** Optimize computing power infrastructure regional layout from multiple levels and dimensions. Optimize the layout of new data centers based on comprehensive data on user distribution, economic and technical feasibility. Through distributed design, migrate high-frequency computing equipment to regions with lower

temperatures and abundant hydropower resources to further solve heat dissipation problems and reduce energy consumption costs. Further optimize the allocation of computing power to energy consumption indicators. Local government departments should strengthen approval processes and not support planning for new data center projects in regions where the overall rack utilization rate of data center rooms is below 50%. Scientifically evaluate and improve the matching degree between data center construction scale and regional digital economic development needs, allocating limited energy consumption indicators to greener and more efficient projects. Accelerate the transformation and upgrading of "old, small, and scattered" data centers. Promote the integration, migration, and transformation of existing "old, small, and scattered" data centers into new data centers to improve their energy utilization efficiency and computing power supply capacity.

(3) **Increase green R&D innovation and improve the computing power ecosystem.** Increase R&D of key technologies for green computing power infrastructure. Data centers should collaborate with universities and research institutions to vigorously develop green and efficient technologies such as liquid cooling, high-voltage direct current, and modular UPS[23], and promote "green electricity" innovation technology R&D in hydrogen energy, renewable energy, and carbon capture and storage. Focus on promoting existing advanced green and energy-saving achievements. Industry leaders and their consortia should accelerate the transformation and application of existing green and low-carbon technologies and products to provide new solutions for addressing high energy consumption in data centers. For example, Shenzhen HiLan Data Center Technology Co., Ltd. has built the world's first commercial undersea data center, providing a solution for cooling and energy reduction. Traditional data centers consume about 1/3 of total electricity for cooling, while undersea data centers of equivalent size consume only about 10% of electricity[22]. Build green data center power supply systems. Data centers should adopt energy-saving and environmentally friendly hardware equipment and operation methods, combined with renewable energy and energy storage technologies, to achieve green and clean power supply for data centers. Formulate unified industry standards and product generalization to promote the formulation of compatibility testing specifications and standards, ensuring good interoperability and compatibility among different computing power products.

(4) **Improve energy consumption supervision mechanisms and strengthen computing power regulatory systems.** Establish and improve a full lifecycle evaluation system for computing power infrastructure. Local governments should strengthen computing power infrastructure and intelligent operation and maintenance construction, connect computing power equipment to energy consumption monitoring

platforms, collect electricity data in real time, achieve real-time monitoring of the entire computing power system, effectively schedule computing power resources and computing tasks, use computing power resources during off-peak periods, and improve energy efficiency. Improve green supervision and evaluation systems for data centers. Take key indicators such as power usage effectiveness, water resource utilization efficiency, and carbon utilization efficiency as entry points to accelerate the improvement of green and low-carbon management systems for computing power infrastructure, including management of energy-saving products and systems and renewable energy utilization. Form a baseline list of data center scale, rack utilization rate, and energy consumption level, and improve a green data center evaluation system including basic electricity and energy consumption and computing power efficiency indicators.

(5) **Improve computing power leasing systems and innovate computing power business models.** Build a unified computing power operation platform open to users to achieve "one-click ordering" and "elastic adjustment" of computing power services. The government should encourage enterprises to jointly use frontier technologies such as blockchain with universities and research institutes to improve multi-party computing power supply trading platforms and address trust deficits in multi-party trading processes. Establish and improve computing power leasing systems. Achieve intelligent, fair, ubiquitous, traceable, and trustworthy computing power trading to reduce waste of ineffective computing power resources. Build dynamic pricing strategies. Local development and reform commissions need to price and manage computing power resources by time periods, using price mechanisms to drive green and efficient computing power resources.

(6) **Utilize computing power waste heat resources to achieve green and intensive development.** Explore and expand the energy recycling and utilization system for data centers. Establish effective waste heat utilization systems that convert high-temperature waste heat from data centers into electricity or heating energy for building heating and industrial heating, achieving resource recycling. Strengthen policy support for data center waste heat recycling technologies. Increase the weight of waste heat recycling technologies in the *Green Data Center Evaluation Index System*, provide corresponding financial subsidies for computing/data centers that invest in waste heat recycling equipment, and promote green and intensive computing power development.

Appendix 1: ARIMA Model

The ARIMA model is a classic autoregressive time series forecasting model that can capture data trend changes and handle data with sudden changes and high noise. It is commonly used to predict the development of different things.

Prerequisites for ARIMA model establishment:

(1) China' s future computing power demand data is somewhat stable. If the data shows obvious trend changes, the ARIMA model may not accurately capture these features, leading to inaccurate forecasting results.

(2) The historical computing power demand data used is reliable and accurate, without bias or errors in data quality. If historical data has missing values, outliers, or other quality issues, it will affect the accuracy and reliability of the ARIMA model.

(3) The impact of external factors on demand patterns and trends can be ignored or simplified to a certain extent. If external factors have a significant impact on computing power demand and these impacts are not considered, the ARIMA model cannot comprehensively and accurately forecast.

Since the original data collected on China' s computing power demand shows a continuous upward trend and non-stationary characteristics, it needs to be differenced. In the ARIMA(p,d,q) model, p is the autoregressive order, d represents the differencing order, and q is the moving average order. The forecast for China' s future computing power demand development can be expressed as ARIMA(p,d,q), with the following expression:

$$y_t = \mu + \sum_{i=1}^{p} \gamma_i y_{t-i} + \sum_{i=1}^{q} \theta_i \varepsilon_{t-i} + \varepsilon_t$$

where y_t is the current value, μ is the constant, γ_i is the autocorrelation coefficient, and ε_t is the error term.

References

1. Shi Y. Digital economy: Development and future. *Bulletin of Chinese Academy of Sciences*, 2022, 37(1): 78-87. (in Chinese)
2. Mo Y J. Discussion on computing network scenarios and scheduling mechanisms. *Information and Communications Technologies*, 2022, 16(2): 34-39. (in Chinese)
3. Zheng W M. Computing power and data are key elements for the development of the Metaverse and Digital Economy. *Democracy & Science*, 2022, (1): 62-63. (in Chinese)
4. Feng Y S, Zhou Y M. Construction of carbon market and electricity market under dual carbon target. *Financial Minds*, 2021, 6(4): 102-123. (in Chinese)
5. Dhar P. The carbon impact of artificial intelligence. *Nature Machine Intelligence*, 2020, 2(8): 423-425.

6. Jiang S, Li Y, Lu Q, et al. Policy assessments for the carbon emission flows and sustainability of Bitcoin block-chain operation in China. *Nature Communications*, 2021, 12(1): 1-9.
7. Guo L. Overview of data center development. *Information and Communications Technology*, 2023, 49(5): 2-8. (in Chinese)
8. China Academy of Information and Communications Technology. *White Paper on China' s Computing Power Development Index (2022).* (2022-11-04)[2023-7-13]. http://www.caict.ac.cn/kxyj/qwfb/bps/202211/P020221105727522653499.pdf.
9. Moyne J, Iskandar J. Big data analytics for smart manufacturing: studies semiconductor manufacturing. *Processes*, 2017, 5(3): 39.
10. Qiu T, Chi J, Zhou X, et al. Edge computing in industrial internet of things: Architecture, advances and challenges. *IEEE Communications Surveys & Tutorials*, 2020, 22(4): 2461-2488.
11. Qiu T, Chi J, Zhou X, et al. Edge computing in industrial internet of things: Architecture, advances and challenges. *IEEE Communications Surveys & Tutorials*, 2020, 22(4): 2461-2488.
12. Yang Z K, Wu D, Zheng X D. ICT in education 2.0: Key historical transition of ICT in education in the new era. *Educational Research*, 2018, 39(4): 16-22. (in Chinese)
13. Mehonic A, Kenyon A J. Brain-inspired computing needs a master plan. *Nature*, 2022, 604: 255-260.
14. Barker M, Olabarriaga S D, Wilkins-Diehr N, et al. The global impact of science gateways, virtual research environments and virtual laboratories. *Future Generation Computer Systems*, 2019, 95: 240-248.
15. Ozaki S, Haga A, Chao E, et al. Fast statistical iterative reconstruction for mega-voltage computed tomography. *The Journal of Medical Investigation*, 2020, 67(1.2): 30-39.
16. Zhang Q, Liu H, Bu F. High performance of a GPU-accelerated variant calling tool in genome data analysis. (2021-12-12)[2023-5-15]. https://www.biorxiv.org/content/10.1101/2021.12.12.472266v1.
17. Chen X T, Zhou L Y, Zhang C B, et al. Research status and development trends of green high-efficiency data center heat dissipation and cooling technologies, *Chinese Engineering Science*, 2022, 24(4): 94-104. (in Chinese)
18. Brown T, Mann B, Ryder N, et al. Language models are few-shot learners. *Advances in neural information processing systems*, 2020, 33: 1877-1901.
19. Wu S. Connecting data silos requires the collaboration of all parties in the computing power ecosystem. *People' s Posts and Telecommunications News*, 2022-07-29(04). (in Chinese)

20. Pu X L. Completion of the top-level layout of the national data center. *Legal Daily*, 2022-10-11(05). (in Chinese)

21. Shi W Y, Zhu H, Xia T, et al. The emergence of energy consumption issues: How many hurdles to overcome for achieving green new infrastructure? *Economic Information Daily*, 2022-03-24(08). (in Chinese)

22. Fang L L, He Y. Data center undersea construction, science and technology to develop the sea to add another weapon. *Science and Technology Daily*, 2022-09-22(05). (in Chinese)

23. Kezhi Consulting. *China IDC Industry Development Research Report (2022-2023).* (2023-03-17)[2023-7-13]. http://www.idcquan.com/Special/2023quanguoBG/.

Note: Figure translations are in progress. See original paper for figures.