Research
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The "Eastern Data and Western Computing" Initiative in China Contributes to Its Net-Zero Target

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ABSTRACT

As the world's largest digital economy, China has a significant demand for data centers, which are energy-intensive. With an annual growth rate of 28% in installed capacity, these centers are primarily located in the developed eastern region, where land and energy resources are limited. This localization poses a major challenge to the industry's net-zero goal. To address this, China has launched a bold initiative to relocate data centers to the western region, leveraging natural cooling, clean energy, and cost-effective resources. By 2030, this move is expected to reduce emissions from the data center sector by 16%–20%, generating direct economic benefits of approximately 53 billion USD. The success of this initiative can serve as a model for other countries to develop their internet infrastructure.

1. Huge computing capacity requirements of national data centers

In the digital economy era, mobile technology and services have created an impressive global economic value of 4.5 trillion USD, representing 5% of the annual global gross domestic product (GDP) [1]. In addition to traditional production factors, data have emerged as a crucial element, with computing power driving economic advancement [2]. The global data volume is growing at an average annual rate of 40%; thus, efficient data acquisition, storage, and analysis are required, which highlights the importance of robust data management [3]. Data centers are crucial to computing and storage infrastructures, driving digital transformation across various industries. However, data centers are highly energy-intensive. Individual centers can consume up to 100 million kilowatt–hour per year [4], collectively accounting for 1%–1.5% of global electricity consumption, raising significant concerns [5,6]. Data center operators and industry associations in Europe launched the Climate Neutral Data Center Pact in January 2021. This pact commits to achieving climate-neutral data centers by 2030 and includes intermediate targets for power usage effectiveness (PUE) and carbon-neutral energy for 2025 [7].

In 2021, China had approximately 5.2 million data center server racks, which stored 10% of the world's data and provided 33% of the global computing capacity [8]. During the same year, data centers across China consumed a total of 237 billion kilowatt–hour of electricity, accounting for 3% of the nation's total social electricity consumption and generating nearly 160 million tonnes (Mt) of CO_2 emissions (CO_2e) [9]. By 2030, the number of data center racks is expected to increase by 110% compared to 2021, potentially increasing their electricity consumption by over 5%. This growth poses significant challenges to China's targets of achieving a carbon peak by 2030 and net-zero emissions by 2060 [9].

2. Resource allocation initiative for national data centers

To reduce transmission distances and meet the needs of end users, China's leading information technology (IT) companies and 65% of its data centers are concentrated in the eastern provinces. These regions offer various internet access functions, cloud computing, big data, and artificial intelligence services, requiring numerous data centers for adequate storage and operations (Fig. 1). Although eastern China accounts for only 11% of the total

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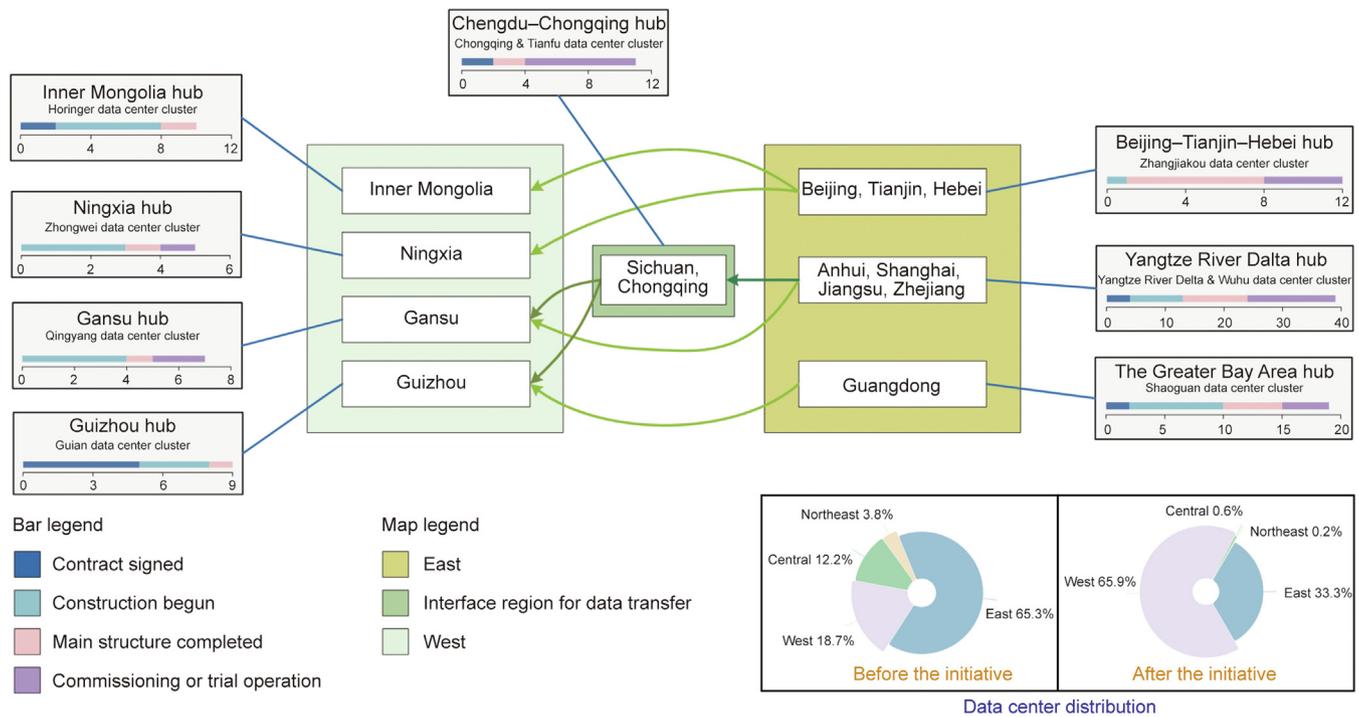
Fig. 1. Distribution of the eight computing hubs and ten clusters planned by the "Eastern Data and Western Computing" initiative and the number of data center projects in the first year of planning.

land area of China, it accommodates 43% of the national population and generates 55% of the total GDP. Consequently, the digital industry in eastern China faces significant resource challenges, including limited land availability, high electricity costs, and high energy intensity, coupled with a substantial carbon mitigation burden. This concentration of resources poses a dilemma: balancing economic development with the need to reduce emissions.

To address these challenges, the "Eastern Data and Western Computing" initiative was launched in 2022 as a national project. This initiative aims to leverage the advantages of land, energy, and lower mean annual air temperature in the western regions to build a robust computing infrastructure [10]. The western region, with its vast land and lower population density, offers 9.5 times the land area per capita compared to the eastern region and has four times the capacity to incorporate renewable energy into the grid [11]. The project aims to store offline and backup data (70% of the total data), which has lower network demands, in the western region, thereby optimizing the distribution of data centers. The western regions of China, including southwest China, are abundant in water resources, while northwest China boasts substantial solar and wind energy resources, making these areas ideal for harnessing renewable energy to power local grids. In addition, these regions experience longer cool seasons with an average temperature of 11.4 °C, which facilitates efficient heat dissipation in the data centers [12]. This initiative is expected to accommodate up to 95% of China's digital data needs through this reorganization. Data are classified based on their latency requirements into three categories: "warm data" (60%, such as office automation), which is used frequently; "subwarm data" (25%, such as disaster recovery), which is less sensitive to latency; and "cold data" (10%, such as backup data), characterized by low read/write frequency requirements [13]. The remaining 5% (e.g., financial transactions), comprising latency-sensitive "hot data," will be placed based on business needs (i.e., the data are stored in locations for immediate utilization and not integrated into the plan). Due to the practical limitations in China, where various data storage types cannot

depend solely on one type of hard drive, and considering the absence of specifications regarding the choice of hard drives in the mentioned initiative, energy consumption variations based on the differences in data types are not considered. The project involves creating eight computing hubs to distribute the resource burden between east and west China. The successful relocation of Apple's data center to an area with wind and solar energy sources fully powered by 100% renewables, achieving a 54% reduction in emissions, highlights the viability of such projects and reinforces confidence in China's strategic plan [14]. Within a year of implementation, more than 112 new data centers have either been authorized, under construction, or completed across the planned computing hubs (Fig. 1) [15]. This initiative mainly focuses on future data center planning because the decommissioning of existing data centers in the eastern region is rare.

In addition to geographical redistribution, the Chinese government is making efforts to improve PUE in data centers. PUE is the ratio of the total facility (i.e., data center hardware, power delivery components, cooling systems, and lighting systems) energy consumption to IT equipment (i.e., servers, storage devices, and networking gear) energy consumption, with overall efficiency improvement as the quotient decreases toward 1.0 (Eq. (1)) [9]. IT equipment and cooling systems are the major energy consumers in data centers, accounting for 85% of the total energy consumption [16]. Currently, China's PUE value is 1.49 [17]. As part of these initiatives, efforts are being made to reduce the energy intensity of cooling systems and associated emissions by approximately 30% (Fig. 2(a) [9,15,23,24]).

$$\frac{\text{Energy used for total facility}}{\text{Energy used for IT equipment energy}}$$
$$= \frac{\text{Energy used for non} - \text{IT equipment}}{\text{Energy used for IT equipment energy}} + 1 = \text{PUE} \quad (1)$$

Driven by the increasing use of intelligent computing applications, power emissions from information and communications technology devices have increased sharply, especially in eastern
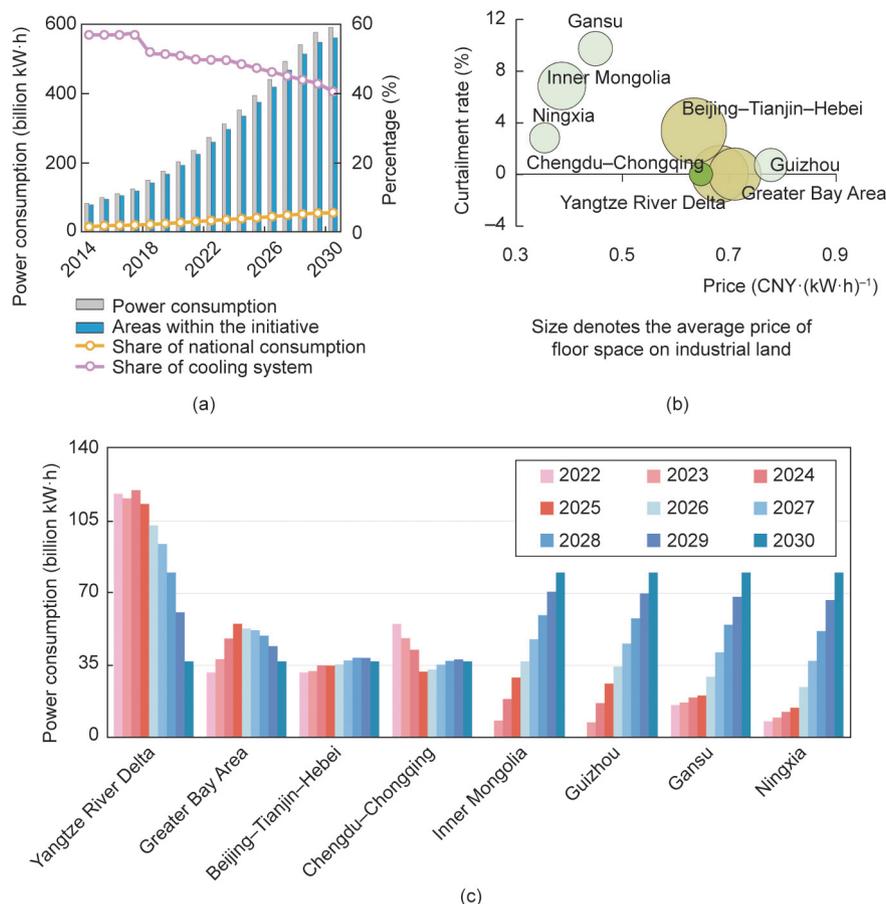
Fig. 2. Power consumption and supply optimization potential of data centers in China. (a) Electricity consumption of data centers and their proportions of the total national electricity consumption; (b) curtailment rates of solar and wind power in 2019 in the eight computing hub regions (indicating an inability to consume and idle power that can be used by data centers, particularly in the West) and the industrial tariffs (bubble size represents average industrial floor area price); (c) energy consumption of data centers under the initiative. Data for 2014–2025 are from official reports and publications, and data between 2025 and 2030 are estimated by cubic spline interpolation [9,15,23,24]. Data inventory and approaches can be found in the Appendix A (Tables S1–S3 and S35, and Method section in Appendix A).

China. To reduce these emissions, it is crucial to improve energy efficiency and switch to low-carbon electricity sources. The relocation of data centers to the western region provides a promising solution that will enable increased use of renewable energy and climate resources.

If the initiative is successfully implemented by 2030 and the data volume is evenly distributed across the western hub centers, we can estimate the energy consumption of the eight hubs (Fig. 2(b)). The energy consumption in the eastern region, particularly in the economically developed Yangtze River Delta region, will gradually decrease, whereas the western area will take on industries that have shifted from the eastern region and will assume most of the new data in the future. Although the relatively small local market size in the western region may limit the effective consumption of renewable energy, this challenge can be addressed by leveraging the availability of affordable industrial electricity and industrial land in the western region (Fig. 2(c)).

3. Environmental and economic benefit evaluation

3.1. Contribution to net-zero emissions

Estimations based on different scenarios involving PUE optimization and data center relocation represent a potential cumulative reduction of 361 Mt of CO_2e by 2030. If the plan's goals are achieved by 2025 (ahead of schedule), an additional 77 Mt reduction could be achieved, resulting in a total reduction equivalent to 16%–20% of the business-as-usual emissions.

To achieve the maximum reduction in emissions, it is essential to increase the proportion of data transferred to the western region, which is currently less than 50%, and to focus on developing and promoting technologies that reduce PUE. Failure to address PUE alongside spatial distribution adjustments can lead to a potential loss of 278 Mt of CO_2e reductions. Thus, efforts to improve the adoption and implementation of energy-efficient technologies across the data center industry are critical.

In summary, this initiative is expected to meet at least the interim "net-zero objective" by 2025, which involves reducing the carbon intensity of GDP across industries by 18% compared to 2020 levels. In addition, it can reduce the industry's emission intensity by 52%.

3.2. Economic efficiency

The economic benefits of this initiative are substantial, as electricity costs in data centers account for a significant 70% of operational expenses [18]. Improving energy utilization in the western region can result in favorable economic outcomes. By leveraging affordable resources available in the West, the initiative can foster collaboration between companies and governmental entities in data center projects (Fig. 2(c)). Based on China's stable commercial electricity grid structure (Fig. 3), the fixed industrial electricity prices offered by local power companies can be harnessed to optimize spatial location and enhance energy efficiency, resulting in significant power cost reductions estimated to amount to 53 USD billion between 2022 and 2030 (Fig. 3(c)). Given the significant
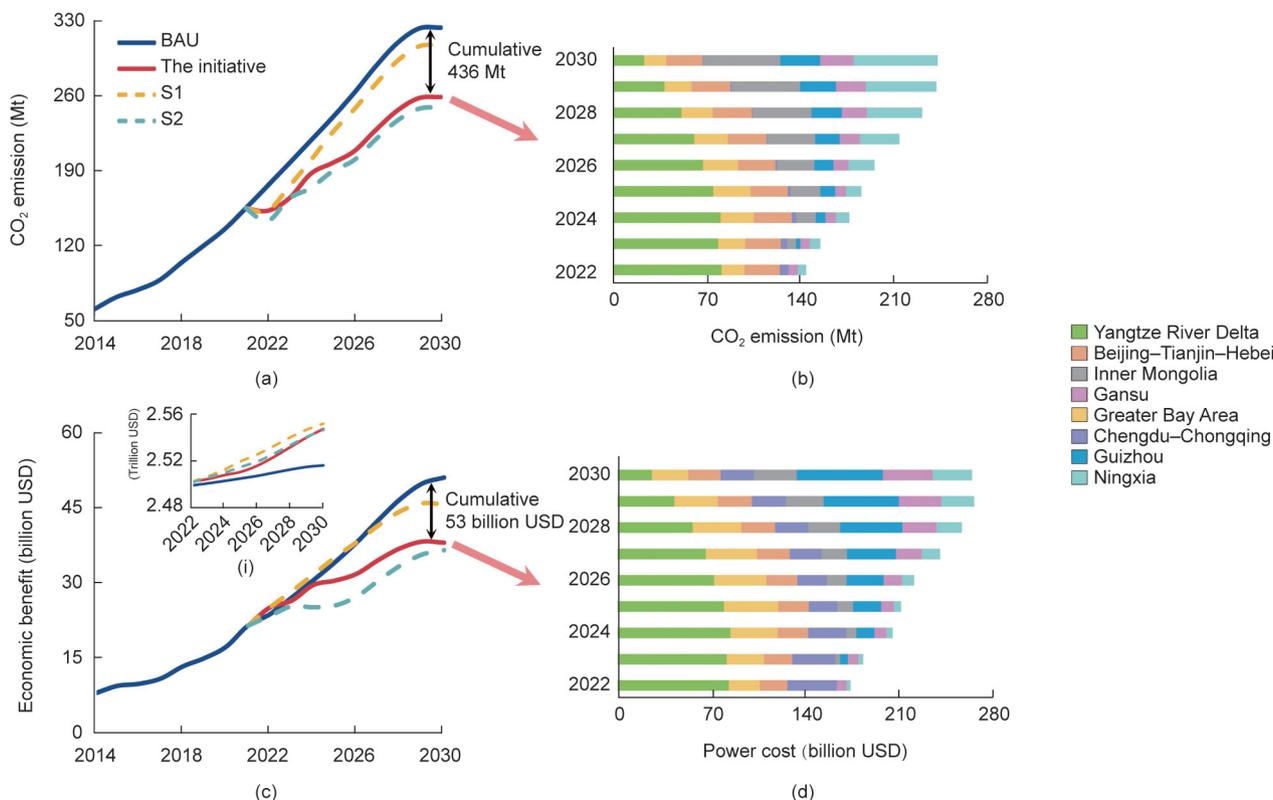
Fig. 3. Environmental and economic benefits from the initiative. (a) CO_2 estimation; (b) spatial distribution of CO_2e in the initiative; (c) power cost estimation; (c-i) indirect economic benefits in the western region; (d) spatial distribution of power cost in the initiative. The energy consumption data were obtained from the China Electricity Council and cubic spline interpolation. Regional grid emission factors are estimated based on the power sources obtained from the annual electricity statistics provided by the China Electricity Yearbook for each region over the years (nuclear, hydroelectric, coal, solar, wind, and other). The emission computation for the business-as-usual (BAU) scenario considers the regional distribution of data centers before implementing the initiative. In the scenario analysis, S1 and S2 are set based on the objectives of the initiative. S1 assumes no change in PUE (1.49), whereas S2 assumes the migration goal is achieved by 2025. Scenario estimates are derived from analysis of national project plans. Indirect economic benefit estimates are generated from an environmentally extended multi-regional input–output model and assumed fixed production coefficients following the Leontief framework (estimations and methods can be found in Economic data, Environmental data, and Method sheets in Appendix A).

changes in electricity costs and investments in communication equipment, computers, and other electronic equipment, we explored the potential for increasing value-added along supply chains. We used an environmentally extended multi-regional input–output model for Chinese provinces and assumed fixed production coefficients based on the Leontief framework [19]. In this context, we can evaluate the impacts of sector-specific changes in final demand on the economic benefits for all upstream sectors. Our results indicate that during this period, cumulative indirect economic gains could peak between 117 billion and 172 billion USD (Fig. 3(c-i)).

4. Challenges of the initiative in China

The implementation of the proposed initiative in China presents various economic and technological uncertainties and challenges. It is essential to address the limitations and considerations related to its execution.

4.1. Immediate economic effects

Compared with the eastern region, the western region lacks a well-developed big data industrial chain. Establishing and maintaining data centers involves significant financial investments, including infrastructure development, hardware procurement, and talent development. Due to the high costs and extended payback periods, depending solely on fiscal subsidies could strain local government finances and be unsustainable in the long term. Cur-

rently, data centers in the western region mainly provide limited market appeal services such as server leasing and hosting, which does not fully capitalize on the potential value of data centers.

To implement the initiative, the government is likely to introduce mandatory measures to require state-owned enterprises to operate their new data centers in the western region or relocate existing ones. However, persuading non-state-owned IT companies with large data volumes to restructure their industrial chains will require efficient economic incentives. Although experts have proposed attractive solutions such as tax reductions and electricity subsidies, these measures have yet to be implemented nationwide. In addition, attracting skilled talent is a significant challenge for developing the industrial chain in the western region, which lags behind the eastern region in terms of development. Data preprocessing is labor-intensive, and data storage, computing, and mining require specialized hardware, software, and services.

4.2. Technical requirements

Careful attention must be given to managing long-distance data transfers and PUE control. Even minimal packet loss during data transfer from eastern to western regions can lead to substantial waste of computing power and increased energy consumption. Furthermore, achieving the low PUE targets set by China requires adhering to rigorous technical standards. Numerous existing data centers in the country currently have PUE values exceeding 1.8 or even 2.0 [12]. To meet the low PUE requirements, the initiative aims to leverage the cool climate conditions in the western region

and use liquid cooling technology to achieve PUE values below 1.2 or even closer to 1, leading to energy savings of 30%–50% [20]. Although this technology can be easily integrated into newly constructed data centers, retrofitting older data centers in the eastern region poses challenges due to variations in building height, load-bearing capacity, and power distribution.

4.3. Regional imbalances still exist

The initiative aims to reorganize offline and backup storage to the western regions. However, the potential for emission reductions in spatial planning exhibits a peak rather than a gradual increase due to constraints related to data volume. Data transfer is heavily dependent on network infrastructure, and efficient transmission of large volumes of digital data is dependent on network speeds. Researchers have conducted comparisons and concluded that using vehicles for physical transportation in short-distance transfers can be more efficient for ultra-large file transfers, leading to reduced packet loss rates [21]. Nevertheless, this approach could pose initial challenges. In the initial phases, the straight-line distance of data transfer is 400–1600 km. If physical transfer using vehicles with consideration for time savings and data security is used for large data volumes, additional investment and increased transportation emissions could be realized.

Our projections indicate that the initiative can help meet mid-term net-zero targets by 2025. However, achieving comprehensive carbon neutrality in the data center industry by 2060 depends on China's ability to enhance access to renewable energy. The country has outlined plans for transitioning to renewable energy, focusing heavily on power generation in the western regions. Nevertheless, the densely populated eastern regions, constrained by limited land resources, face challenges in the widespread implementation of photovoltaic, wind power, and energy storage hydroelectric projects. Addressing these challenges is essential for data centers in the eastern region to achieve carbon neutrality. Strengthening emission reduction efforts requires addressing existing spatial disparities and investigating opportunities for renewable energy development in the eastern region while also promoting economic growth in the western region.

5. Conclusion and lessons from China

Internet usage frequency in a region generally reflects its population density and economic development, leading to intense competition for land and energy resources in the development of data centers, both in China and globally. Emerging economies such as India and Brazil together, with over 1 billion internet users, have also set net-zero targets. However, they have yet to fully recognize the high energy consumption associated with data centers [22]. This initiative in China could benefit net-zero and regional development. We strongly encourage countries that are experiencing similar development trends as China to recognize the unsustainable path of current digitization practices and implement measures to address it gradually. Since not all countries have the same investment capacity for spatial reorganization, we recommend focusing on integrating data centers with renewable energy through grid reforms and small-scale relocation. These strategies can contribute to global carbon neutrality and reduce the environmental impact of data center operations. Prioritizing the sustainable development of digital infrastructure and the adoption of renewable energy is crucial for the long-term well-being of the planet.

CRediT authorship contribution statement

Ning Zhang: Writing – original draft, Visualization, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptu-

alization. **Huabo Duan:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Yuru Guan:** Methodology, Formal analysis, Data curation. **Ruichang Mao:** Writing – review & editing, Visualization. **Guanghan Song:** Writing – review & editing. **Jiakuan Yang:** Writing – review & editing, Supervision. **Yuli Shan:** Writing – review & editing, Supervision, Resources, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eng.2024.08.010.

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