

PhD project

Resource metabolism and complex network analysis of data centers in urban context

Laboratoire Interdisciplinaire des Énergies de Demain (LIED), Université Paris Cité, CNRS

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Candidate profile and practical information

We seek a candidate with a Master's degree in physics or equivalent degree from an engineering school, with interest in interdisciplinary research, material and energy flows and stock analysis, complex systems and networks modelling. The PhD is part of the research project DC_Risk_City (funded by the ANR-PEPR-VDBI), which is led by three research institutes 1. [LATTS](#) UMR 8134, ENPC, Université Gustave Eiffel 2. [CSI](#) UMR 9217, Ecole Nationale Supérieure des Mines de Paris 3. [LIED](#) UMR 8236, Université Paris Cité.

The PhD is fully funded for 3 years and will be hosted at LIED, which is an interdisciplinary research institute specialized in energy transitions from a broad interdisciplinary perspective, located in Paris 75013, [Campus des Grands Moulins](#).

Context and Motivation

Data centers (DCs) have experienced rapid growth over the past decades, further accelerated by the development of artificial intelligence. DCs are material- and energy-intensive infrastructures, comprising on the one hand, computational components (electronic chips, semiconductors, rare earth elements) and, on the other hand, supporting infrastructures such as buildings, electricity and information networks (involving construction materials, metals like copper, aluminium etc). In addition, their development is land-intensive due to security restrictions in vertical deployment, water-intensive due to high cooling requirements and finance intensive due to extremely high investment costs expected to reach 1 trillion dollars in 2026, which is nearly half of worldwide military spending. As such, DCs are hotspot intersection nodes of multiple networks, including 1. electricity grids, 2. information and communication networks, 3. water networks, 4. financial networks, 5. material and high-technology networks.

Urban areas are increasingly competing to attract DCs due to their perceived benefits, including economic growth expectations for employment, civil engineering, data sovereignty, and others. However, DCs introduce significant challenges in urban environments. These include heat dissipation exacerbating urban heat islands (Molla, [2026](#)), freshwater competition with domestic, agricultural and industrial uses, land scarcity and real estate prices, and high and intermittent power demand, leading to grid strain, potential power grid instabilities and energy price increases. This project bridges three typically disconnected research communities:

1. Material and Energy Flow Analysis (MEFA, e.g. Krausmann et al., [2017](#)) integrating power dynamics;
2. Urban actor strategies (Tiwari et al., [2026](#)) and financial networks;
3. Complex network analysis (Barabási, [2016](#)).

Research Objectives

The PhD adopts a systems approach, treating DCs as nodes of intersection of multiple networks (electricity, information, water, real estate, and financial networks). Four complementary objectives are pursued:

1. Inventory and state of the art of how DCs are powered worldwide, distinguishing connection

to national grids from dedicated self-power stations (e.g., on-site thermal power plants), and identifying key trends. While DCs are traditionally integrated into centralized electricity grids and share the same energy mix as other consumers, their high and continuous power demand increasingly drives operators toward decentralized generation and renewable energy integration, challenged by intermittency and reliability concerns;

2. Material and energy flow analysis (MEFA) of data centers, covering both computational components (electronic chips, semiconductors, rare earth elements) and supporting infrastructures (buildings, electricity and information networks), providing quantitative inputs for the institutional analysis of material recovery and recycling after end-of-life durations;
3. Definition of the total installed power of DCs and their associated usage factor. This objective aligns with a broader research theme at LIED, targeting the reconstruction of the Installed Power of Energy Consumption Systems (IPECS), including engines, devices, appliances of sectors. While the installed power of production systems (i.e. power plants) is a standard metric, IPECS of sectors remains elusive. IPECS will be examined as a variable involved in material rebound effects of DCs. In addition, it will allow to assess the distribution of the load factor, defined as the ratio of effective power use during the systems operation to their IPECS.
4. Network analysis of DCs as nodes of intersection of multiple networks, developing a multiplex network modeling framework to understand the dynamic influence of network topologies across the involved networks.

Hypotheses

These objectives are grounded in the following hypotheses:

1. The need for highly responsive power systems to supply DCs results in higher material intensities for building batteries and reactive systems: power demand surges require higher battery requirements and material use than in other infrastructures. This raises in turn the question of safety requirements, as DCs may face unique risks (e.g., fire hazards from lithium-ion batteries, data security) whose standards may differ from those of other industrial buildings — a question that remains open and will be investigated;
2. The load factors of DCs have a complex distribution, including periods of high power mobilization, but also periods of intermediate and very low mobilization, as well as periods of low demand in terms of time — implying that the overall usage rate of DCs is also low.
3. Interactions with the broader research team — which brings together political scientists, sociologists, geographers, and infrastructure specialists — will make it possible to interpret network structures and to reconstruct the development trajectories of the DC sector. In this framework, quantitative databases will need to be combined with qualitative material derived from stakeholder interviews.

References

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