Title

Shining a Light on Small Data Centers in the U.S.

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Abstract

Large data centers are well known for their high-energy intensity and have made dramatic efficiency improvements over the past decade. Small closet and room data centers have received much less attention, yet constitute a significant fraction of the total number of servers in the United States. The often makeshift, *ad hoc* nature of small data centers often results in little attention paid to energy efficiency and inadequate cooling equipment. The small physical footprint of these data centers, typically embedded within a larger building, makes it difficult to identify and target for efficiency measures. These conditions make small data centers notoriously inefficient relative to their larger counterparts. In this report, we present an analysis of small and midsize data centers in the US, drawing from surveys of commercial building stock. We find that servers in small data centers make up approximately 40% of installed server stock, with the vast majority of sites utilizing only 1-2 servers. We identify industries where small data centers are most prevalent, finding that the highest saturations are in medical, retail, office, and education sectors. Small data centers typically lack dedicated cooling equipment, often relying on building air conditioning and ventilation equipment for cooling. We further find that the type of cooling equipment used is highly correlated with the number of operational server racks, with less efficient cooling options used with fewer racks. We develop geospatial maps of small and midsize data centers to visually identify regions of high server concentration and calculate associated CO_2 emissions. Small data centers consume 13 billion kWh of energy annually, emitting 7 million metric tons (MMT) of carbon dioxide–the equivalent emissions of approximately 2.3 coal-fired plants. We discuss efficiency measures that could be implemented and estimate potential energy and CO_2 savings.

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1. Introduction

The digitization of the modern U.S. economy has made data centers essential infrastructure for commercial businesses across all industries. Modern data centers are populated by computing equipment, which operate continuously to support on-demand network requests. They range in size from individual servers found in literal closets to expansive warehouses filled with thousands of servers. Data centers of all sizes are used to manage communications, support business operations, and control access to data.

At the heart of data center operations are servers, networking, and data storage equipment. Servers typically run dedicated applications and process requests received via a distributed network. Even during periods of low utilization, the power draw of a conventional server may be as much as 150-350 W (Brown et al., 2008; Koomey, 2011; Masanet et al., 2011; Shehabi et al., 2016). Factoring in space conditioning and other facility overhead equipment can double data center electricity consumption (Center of Expertise for Energy Efficiency in Data Centers, n.d.). Consequently, buildings with data centers have a high energy intensity relative to other types of commercial buildings (EIA, n.d.). In aggregate, data centers are estimated to currently consume 70 billion kWh in the U.S. alone, representing approximately 1.8% of U.S. electricity consumption (Shehabi et al., 2016).

Several studies have analyzed the evolving landscape of data centers mostly focusing on largest data centers that house thousands of servers (Brown et al., 2008; Koomey, 2011; Masanet et al., 2011; Shehabi et al., 2016). In a recent study, Shehabi et al. (2016) found that although there is overall growth in the size and number of data centers over time, the total energy consumption attributed to data centers has remained relatively constant for the past few years. This result is a product of concerted efforts to optimize operations for the largest data centers, which are able to reap large operational cost savings from efficiency improvements. Technology companies operating large data centers benefit from economies of scale and have the resources to invest in efficiency measures. Given high operational costs of large data centers, upfront capital expenditures on efficiency measures are quickly recouped by operating cost savings. Google presents a case study in which a $25,000 expenditure on efficiency measures led to annual savings of $67,000 - a payback of 5 months (Google, 2011). For this particular data center, Google estimated a yearly energy savings of 670 MWh. When considering the large number of data centers operated by similar technology companies, undertaking efficiency measures leads to millions of dollars in savings.

Significantly less attention has been paid to small-scale data centers, typically referred to as data closets and data rooms (or "embedded" data centers). The small physical footprint of these data centers, typically embedded within a larger building, makes it difficult to identify and target for efficiency measures. These spaces are generally run by institutions less familiar with information technology systems and best practices for data center management. The often makeshift, *ad hoc* nature of small data centers results in little attention paid to energy efficiency and inadequate cooling equipment. These conditions make small data centers considerably less efficient relative to their large counterparts.

A study performed by Cheung et al. (2014) surveyed 30 small server closets and rooms with four sites selected for detailed assessments. The authors found that most sites were not designed for efficient server operation and noted many examples of poor server room management. For example, in many cases conditioned cool air was inefficiently directed within the server room leading to mixing with exhausted warm air. Many of the potential efficiency measures outlined in Cheung et al. range from no- to low-cost. However, the authors note barriers impeding more efficient operation are organizational rather than technological. Few organizations had policies to promote efficiency and most lacked properly trained staff to research and implement efficiency measures.

Bennett and Delforge (2012) performed a survey of 30 businesses operating small data centers looking specifically at the penetration of efficient operating practices. The survey covered data centers operating between 1-30 servers. In general, they found a lack of awareness and organizational prioritization of efficiency measures. Data center operators were typically not responsible for paying energy bills, limiting motivation for pursuing efficiency. Similar to the findings of Cheung et al., barriers to efficiency were organizational as opposed to technological. Bennett and Delforge highlight the need for local and state policy measures to create incentives to promote efficiency measures specifically aimed towards small data centers.

To date, no study has analyzed a representative sample of commercial businesses operating small data centers due to a dearth of data. The lack of data has limited the ability of policy makers to effectively craft policy to address energy waste in small data centers. In this report, we use recently released survey data of commercial building stock to analyze characteristics of small and midsize data centers. We use the recently released 2012 Commercial Building Energy Consumption Survey (CBECS) administered by the federal Energy Information Administration (EIA) to analyze how servers are distributed geographically and in what types of buildings they are located (EIA, 2015). These data represent a nationally representative survey detailing energy consumption practices of U.S. commercial buildings. Combining these data with occupation data from the Bureau of Labor Statistics (BLS) we construct maps of geographic location of small data centers in commercial enterprises, and of server location for small and data centers in the U.S. Additionally, we perform an analysis of the 2014 Commercial Building Stock Assessment (CBSA) administered by the Northwest Energy Efficiency Alliance (NEEA).[1] Although limited to data centers in the Pacific Northwest region, the survey provides a detailed glimpse into the space cooling and server virtualization practices within small data centers.

The report is organized as follows. In Section 2, we discuss the data sources and methodology used in our analysis of data centers. Although the focus of this report is small data centers, we also include analysis of midsize data centers, which fall in the gap between small data closets and rooms and large hyper-scale data centers. In Section 3, we discuss the results of our analysis of the CBECS and CBSA surveys. In Section 4, we present geospatial maps of server intensity of small and midsize data centers. We then discuss aggregate energy and CO_2 emissions from small data center consumption and potential

[1] http://neea.org/resource-center/regional-data-resources

energy savings from efficiency measures. Section 5 provides a summary of results presented in this report.

2. Data and Methods

In this section we describe the data used in our analysis of small and midsize data centers, as well as the methodology to estimate national energy consumption and CO_2 emissions. We will use the CBECS and CBSA studies of commercial building stock to characterize various aspects of the small and midsize data center market. We will also utilize the nationally representative CBECS data to estimate national energy use and CO_2 emissions from small and midsize data centers. We start with U.S. commercial building stock survey, estimate the number of servers, and disaggregate geographically based on regional employment statistics.

Commercial Building Energy Consumption Survey 2012

CBECS is a nationally representative survey of commercial buildings in the United States conducted by the EIA. The survey provides a snapshot of energy-related building characteristics of U.S. commercial building stock. CBECS defines commercial buildings as those that are not primarily (i.e., > 50% of floor space) used for residential, industrial, or agricultural purposes. For CBECS 2012, EIA surveyed 6,720 buildings and weighted their sample to be nationally representative of commercial building stock (EIA, 2015). The publicly released microdata used for this analysis is anonymized to remove any characteristics that could possibly be used to identify individual buildings. As part of this process, the location of buildings is only made available at the Census division level (groups of 4-9 states).

In 2012, EIA included survey questions to specifically target server usage in commercial buildings. When questioning respondents, CBECS defined servers as "usually just the CPU, or 'case,' portion of a computer that manages network resources such as computer files, printers, databases, or network traffic; servers do not require much human operation, so most do not have keyboards or monitors."

Buildings with 500 or more servers are coded in CBECS with '9,995' in place of the actual number of servers. These buildings correspond to 26 records representing approximately 2,000 buildings. These sites may represent large enterprise and 'hyper-scale' data centers outside the scope of this report and omitted from our analysis. However, they are not clearly identified as data centers by activity in the data set. It is also possible that these data centers are classified as industrial facilities outside the scope of CBECS.

CBECS characterizes the principal building activity (PBA) of each sampled building into categories to group buildings with similar energy consumption patterns. Activities cover a broad range of categories from 'Education' to 'Warehouse and Storage'.[2,3] Although CBECS

[2] For definitions see http://www.eia.gov/consumption/commercial/building-type-definitions.cfm
[3] CBECS also provides an additional more detailed characterization of the building activity coded as PBAPLUS. For example, the 'Education' PBA is further subdivided into 'elementary/middle school', 'high school',

includes a PBA for ‘Data Centers’ (separate from a question of whether there is a data center or server farm in the building), there are no buildings categorized as such in the data set.

For this work, we adopt a classification system of either a small or midsize data center for each building in CBECS with at least one server based on the number of reported servers. Our classification is rooted in the data center taxonomy defined by market reports released by the International Data Corporation (IDC). IDC categorizes data centers into 5 types, ranging from small closets (1-4 servers) to enterprise-level, high-end data centers (> 500 servers). In descriptions of each space, IDC reports that both closet and room data centers are housed in relatively small spaces (< 500 square feet), often lack dedicated space cooling (Bailey et al., 2007), and are used primarily by small businesses. For our paper, we define a small data center as having between 1-25 servers, capturing both closet and room servers. All other data centers having more than 25 servers, but less than 500 are classified as a midsize data center. Table 1 provides typical properties for IDC’s data center taxonomy data centers and the relationship to our classification.

Table 1: Data center characteristics

Classification This Work	Taxonomy IDC	Space Dimensions (square feet)	Typical Number of Servers
Small Data Center	Closet	<= 100	1-4
	Room	101-1000	5-25
Midsize Data center	Localized Data center	1,001-2000	26-100
	Mid-tier Data center	2,001-20,000	101-499
Not Analyzed	High-end Data center	>20,000	>500

CBECS reports data center square footage for those buildings where respondents identified a dedicated space for servers. Ideally, these data can be used to inform our server space categorization. However, we find these data not useful for categorizing server space for all buildings that report having servers. For example, 98% of respondents with 5 or less servers did not identify having a data center and thus did not report a data center square footage. Respondents who identified a data center in their building appear biased to larger space types. Based on the lack of reporting for all buildings with servers, we do not use the data center square footage estimates from CBECS in our categorization of server space type.

‘university/college’, and ‘other education’. In general, our analysis does not benefit greatly from the extra detail provided by these more specific PBAs. In general, we will present results in terms of PBA. However, when noteworthy, we highlight interesting trends by the more specific building activity within discussion of results.

It is unclear how CBECS reports buildings with multiple separate data centers. We assume that CBECS reports the total number of servers in the building correctly, but does not differentiate between multiple data centers. Although this adds a level of uncertainty to our estimates of the number of data centers, we do not expect this to greatly impact our data center classification of buildings given the broad categorization used in our classification.

It is possible that CBECS results may suffer from various forms of reporting bias depending on how respondents chose to estimate the number of servers in their building. Respondents answering questions in CBECS are not necessarily the individuals maintaining IT equipment. CBECS relies on estimates from respondents and responses are not verified independently. In particular, our data center categorizations assume that the respondent can (1) positively identify servers and (2) provide a reasonably accurate estimate of the number of servers on-premise. There is little we can do towards characterizing uncertainties due to the first assumption. The survey could potentially under- or over-report the number of servers depending on each respondent's ability to recognize and quantify servers. For the second assumption, our classification of data centers as either small, midsize, or high-end de-emphasizes the need for exact estimates for classification. For example, a respondent may potentially confuse 5 servers for 7 or 8 servers, but is unlikely to confuse 5 servers for more than 25.

Commercial Building Stock Assessment 2014

The 2014 CBSA survey was conducted by NEEA in order to provide a snapshot of energy-consuming devices found in regional commercial sites (Navigant Consulting, 2014; Northwest Energy Efficiency Alliance, 2014). The survey is specific to commercial buildings in the Pacific Northwest covering Oregon, Washington, Idaho, and Montana. Detailed audits of commercial stock were gathered for 859 randomly selected commercial sites across twelve building types. Selected sites covered both urban and rural commercial locations. Data were anonymized to avoid identification of individual sites and weighted to be representative of the Pacific Northwest. Although limited to data centers in the Pacific Northwest region, the survey provides a detailed glimpse into the space cooling and server virtualization practices within small data centers.

CBSA 2014 included many questions specific to data center characteristics and operation. Unlike CBECS, which provides server data for each building, CBSA data are provided at the data center level, allowing for a single commercial site to report multiple data centers. For each data center, the survey recorded the total number of racks in the server room, data center floor space, and type of space cooling. Although there were additional questions regarding the presence of uninterruptible power supplies (UPS), most responses were left blank. The survey did not include rack dimensions or the number of servers in each data center, making direct comparisons to CBECS difficult.

NEEA specifically surveyed heating, ventilation, and air conditioning (HVAC) characteristics for each site. Onsite surveyors recorded the presence of dedicated data center cooling and the type of conditioning provided (e.g., computer room AC, building transfer, water chillers, etc.), even if conditioned air was shared with space outside of the data center.

Data collection for hospitals and universities followed a different survey protocol than other building types due to the complexities in recording results for a large campus. For hospitals and universities, CBSA records the data center square footage, but does not record the number of racks.

Additional data for 521 buildings was collected for the 'CBSA Oversample Study' (Northwest Energy Efficiency Alliance, 2014). These data were collected as a utility- or stakeholder-funded extension of the original survey. Although these data represent a significant addition of the data set, NEEA recommends use of the Core data set, presumably to avoid introducing bias from the addition of targeted commercial sites. Our analysis makes use of the Core data set.

Energy Calculations

The most common industry metric for quantifying overall data center energy efficiency is measurement of the Power Usage Effectiveness (PUE) coefficient (The Green Grid, 2012). PUE is defined as the ratio of the total energy used for data center operations to the electricity drawn by IT equipment:

$$PUE = \frac{E_{datacenter}}{E_{IT}}$$

PUE captures the overhead energy required to maintain data center operations including space cooling, lighting, electricity distribution, etc. For example, a PUE of 2 indicates that for every kilowatt-hour drawn by IT equipment, another kilowatt-hour is required to maintain server operations.

The energy draw of IT equipment can be expressed as the sum of the energy required to power servers, network, and data storage equipment

$$E_{IT} = E_{servers} + E_{network} + E_{storage}$$

The total data center energy consumption can be expressed as

$$E_{datacenter} = E_{IT} \times PUE$$

$$E_{datacenter} = \left(E_{servers} + E_{network} + E_{storage}\right) \times PUE$$

By the very nature of data center operations, servers operate continuously in an active mode. Server power draw depends on utilization. Studies have found that servers rarely operate at high levels of utilization (Brown et al., 2008; WSP Environment & Energy and Natural Resources Defense Council, 2012). Shehabi et al. (2016) found that active servers in small data centers typically operate at around 10-15% utilization assuming 10% of servers are "zombie" servers which are connected to power but never utilized (Koomey and Taylor, 2015). We assume that a typical server found in a small or midsize data center consumes, on average, approximately 180 W (Shehabi et al., 2016), based on the power-scaling ability and computational processor count generally found in these data center types.

Following Masanet et al. (2011), we use a top-down approach to estimate energy consumption from network and storage devices. We assume network and external storage energy consumption is proportional to the energy consumption of server hardware. We assume no external storage in small data centers and 20% for midsize data centers based on their calculations for the number of external hard drives derived from shipments in Bailey et al. (2007). On top of the server energy consumption, we attribute an additional 5% of server energy consumption to network equipment in small data centers and 10% of server energy consumption to network equipment in midsize data centers.

Previous work has found that smaller data centers are more likely to exhibit higher PUE values due to poor space cooling (Cheung et al., 2014; Shehabi et al., 2016). Detailed onsite case studies of small data centers performed by Cheung et al. (2014) found that data rooms and closets were often fashioned out of repurposed space not intended for servers. Many closets and rooms started as temporary housing for small-scale server needs which incrementally expanded over time to a dedicated server space. The lack of attention paid to proper space cooling led to warm air exhaust from IT equipment mixing with cooled air from HVAC equipment. In some cases, the authors noted that server cooling was provided by building cooling equipment, the impact of which is reduced cooling efficiency. Detailed assessments of four small data spaces found PUEs ranging from 1.5-2.1, with two data centers having PUEs of 2.1. Shehabi et al. (2016) report values of 2.5 for closet data centers and 2.0 for room and localized data centers. For comparison, very large data center operators reported PUEs as low as 1.1 through concerted efficiency efforts (Google, 2016). For this work, we adopt a typical PUE value of 2.1 for small and midsize data centers.

Occupational Employment Statistics

CBECS provides geographic data at the resolution of Census division (i.e., groups of 4-9 states) allowing us to quantify server ownership as a function of census division and PBA. To produce higher spatial resolutions, we make the assumption that servers are spatially distributed proportionally to workers who would work in a building with a server. For this purpose, we make use of occupational employment data, available at a higher geographic resolution, to approximate the number of servers by U.S. zip code.

We utilize Occupation Employment Statistics (OES) released in May 2014 from the Bureau of Labor Statistics (BLS, 2015). The survey is conducted semi-annually via mail and designed to collect employment and wage estimates for 821 occupations. The data are provided for over 650 geographical areas that are a combination of metropolitan statistical area (MSA) and non-metropolitan areas. The U.S. Office of Management and Budget defines MSAs as having a relatively high population density with close economic ties through the area. MSAs generally include a large city and associated surrounding areas, often covering multiple counties. Regions within each state that do not fall into an MSA are defined as "nonmetropolitan areas". Although a state may have multiple non-metropolitan areas, we combine employment statistics for all non-metropolitan areas within a state.

The BLS collects data on the number of employed persons in 821 detailed occupations that are grouped into 22 major occupation categories for each regional unit. We use the major occupation categories provided by BLS and identify CBECS PBAs where those occupations are most likely to be found. For some occupations there is a direct correspondence between occupation and PBA. For example, "Legal Occupations" can be mapped directly to "Office" buildings. However, a majority of occupations in OES have a one-to-many mapping of occupation to PBAs. In such cases, workers for that occupation, in a given MSA/non-metropolitan area, are split proportionally according the number of workers in those CBECS PBAs for the census division corresponding to the area. Table 2 shows our mapping of occupations codes to PBA.

Table 2: Mapping of OES job codes to CBECS PBA

OES Job Code	CBECS PBA
Management Occupations	Office
Business and Financial Operations Occupations	Office
Computer and Mathematical Occupations	Office, Laboratory
Architecture and Engineering Occupations	Office, Laboratory
Life, Physical, and Social Science Occupations	Office, Laboratory
Community and Social Service Occupations	Office, Religious worship
Legal Occupations	Office
Education, Training, and Library Occupations	Education, Public assembly
Arts, Design, Entertainment, Sports, and Media Occupations	Public assembly
Healthcare Practitioners and Technical Occupations	Outpatient health care, Inpatient health care, Nursing
Healthcare Support Occupations	Outpatient health care, Inpatient health care, Nursing
Protective Service Occupations	Public order and safety
Food Preparation and Serving Related Occupations	Food service
Building and Grounds Cleaning and Maintenance Occupations	Office, Laboratory, Lodging
Personal Care and Service Occupations	Service
Sales and Related Occupations	Food sales, Retail other than mall, Enclosed mall, Strip shopping mall, Food service
Office and Administrative Support Occupations	Office, Lodging
Farming, Fishing, and Forestry Occupations	Agricultural
Construction and Extraction Occupations	Industrial
Installation, Maintenance, and Repair Occupations	Other
Production Occupations	Non-refrigerated warehouse, Refrigerated warehouse, Other

Transportation and Material Moving Occupations	Non-refrigerated warehouse, Other

We first determine the number of workers in a given metropolitan/non-metropolitan area, MSA_i, and in a given PBA, PBA_j, which we denote as $N_w\left(MSA_i, PBA_j\right)$:

$$N_w\left(MSA_i, PBA_j\right) = T(OCC_h \rightarrow PBA_j) \times N_w(MSA_i, OCC_h)$$

In this equation, we apply our mapping of occupations to PBA, $T(OCC_h \rightarrow PBA_j)$, to $N_w(MSA_i, OCC_h)$ which is the number of workers in MSA_i in each occupation code, OCC_h. $T(OCC_h \rightarrow PBA_j)$ is a matrix of 0s and 1s which describes how each occupation code is related to each PBA.

Next we calculate the parameter η, which is the fraction of workers in a given MSA_i and PBA_j relative to the total number of workers associated with PBA_j in the census division that contains MSA_i, $CDIV_{MSA_i}$:

$$\eta\left(MSA_i, PBA_j\right) = \frac{N_w(MSA_j, PBA_j)}{\sum_{MSA_k \in CDIV_{MSA_i}} N_w(MSA_k, PBA_j)}$$

From CBECS, we have the number of servers is a given census division and PBA. To get the number of servers in a given MSA_i and PBA_j, we multiply the number of servers found in the $CDIV_{MSA_i}$ and PBA_j by η:

$$N_s\left(MSA_i, PBA_j\right) = N_s\left(CDIV_{MSA_i}, PBA_j\right) \times \eta(MSA_i, PBA_j)$$

And finally to determine the number of servers in MSA_i, we sum over all PBAs:

$$N_s(MSA_i) = \sum_{l = All\ PBAs} N_s(MSA_i, PBA_l)$$

A simplified example follows to illustrate the process, beginning by mapping occupational codes to a given PBA. Consider a universe where there are two occupations (OCC_1 and OCC_2) with two possible PBAs (PBA_1 and PBA_2). All workers in $OCC_1$are assumed to map onto PBA_1. Workers in OCC_2can be in either PBA_1or PBA_2. We assume that 50% of workers in OCC_2will be in $PBA_1$and 50% will be in PBA_2. So if we assume that there are 100 workers in $OCC_1$and 100 in OCC_2, 150 workers will be in $PBA_1$and 50 workers will be in PBA_2.

Next, consider a census division that contains 3 MSAs (MSA_1, MSA_2, and MSA_3). In this census division, we find 100 servers associated with the retail PBA. From occupation data, we find 100 workers in MSA_1, 150 in MSA_2, and 250 in MSA_3resulting in 500 total workers in our census division associated with retail. We would then assume that 20% (100/500) of the 100 servers associated with retail are in MSA_1. Similarly, 30 servers are found in MSA_2 and 50 servers are in MSA_3.

Lastly, for the purposes of creating geospatial maps, servers within an MSA are distributed evenly across the zip codes in that MSA.

Our method to disaggregate server location by zip code explicitly assumes that the spatial distribution of employed workers in buildings with servers is a reasonable proxy for servers.

eGRID 2012

The Emissions and Generation Integrated Database (eGRID) administered by the U.S. Environmental Protection Agency (EPA) collects electricity generation and emissions data for the majority of power plants that supply electricity on the U.S. electric grid (EPA, n.d.). These data provide detailed profiles of electricity generation and associated greenhouse gas emission rates across the U.S. Data are collected at the power plant level, then aggregated into 26 eGRID subregions defined by the EPA. Variations in emission factors among subregions are due to the mix of resources used to power the regional grid. Subregions with an electricity portfolio with significant contributions from renewable resources (i.e., hydro, wind, solar, nuclear) have lower emission factors in comparison to regions that rely predominantly on coal and natural gas.

eGRID provides emission factors for both baseload and non-baseload electricity demand. For our estimates, we use baseload emission factors when calculating current CO_2 emissions from servers. Reductions in electricity consumption impact power supplied by ancillary power plants that operate coincidently with peak demand. We use non-baseload factors when calculating potential reductions in CO_2 from reduced electricity demand.

eGRID emission factors are based on electricity generation at the power plant and not at the point of consumption. To capture losses from distribution and transmission from the power plant to the consumer, eGRID derives gross grid loss factors for 5 sections of the U.S. electric grid: Alaska, Hawaii, Eastern U.S., Western U.S., and ERCOT which covers most of Texas. The gross grid loss factors are then mapped onto the 26 eGRID subregions and applied to our estimates for greenhouse gas emissions to accurately account for all losses. Total CO_2 emissions are therefore:

$$CO_2\ emissions\ = \frac{E_{site}}{1 - GGL_{region}} \times F_{region}^{CO_2}$$

where E_{site} represents energy at the point of consumption, GGL_{region} is the grid loss factor, and $F_{region}^{CO_2}$ is the emissions factor relating the amount of CO_2 emitted per unit of electricity generated. Note that GGL_{region} and $F_{region}^{CO_2}$ are functions of eGrid subregion as denoted by their subscript.

We use EPA's Power Profiler spreadsheet tool to map U.S. zip code to eGRID subregion (EPA, 2015). In a minority of cases (2801 out of 41335), a zip code is covered by multiple utilities belonging to different eGRID subregions. In these cases, we use the listed "Primary eGRID Subregion" assuming this represents a majority of the electricity supplied to the zip code.

3. Results

Servers by data center space type

In Table 3, we report general statistics for small and midsize data centers found in CBECS. We find approximately 3.7 million servers reside in small data centers corresponding to 72% of installed stock in CBECS buildings. Small data centers are reported in 31% of all commercial buildings in CBECS and in 99% of buildings with servers.

Table 3: Summary of the Number of Datacenters and Servers in CBECS*

Data Center Type	Number of Buildings (millions)	Number of Servers (millions)	Average Number of Servers	% of Servers in CBECS	Number of CBECS Records
Small (1-25 servers)	1.725	3.70	2.1	72%	3163
Midsize (26-500 servers)	0.021	1.47	69.4	28%	360

*Excludes buildings that contain more than 500 servers.

IDC estimates the total number of volume servers installed in 2012 across data centers of all types to be 13.2 million (IDC, 2014a). Our estimate of the total number of servers in small and midsize datacenters in CBECS is 5.2 million servers, implying 40% of servers are found in small and midsize datacenters.

Figure 1 provides a detailed look at the distribution in the number of servers within our data center classifications. The top two panels display the distribution in the number of servers per building relative to the total number of servers for small and midsize data centers, respectively. Each distribution is normalized by the total number of servers in that data center space type. The bottom panels display the distribution in the number of servers per building relative to the number of small and midsize data centers. In these panels, each distribution is normalized by the total number of data centers in each data center space type.

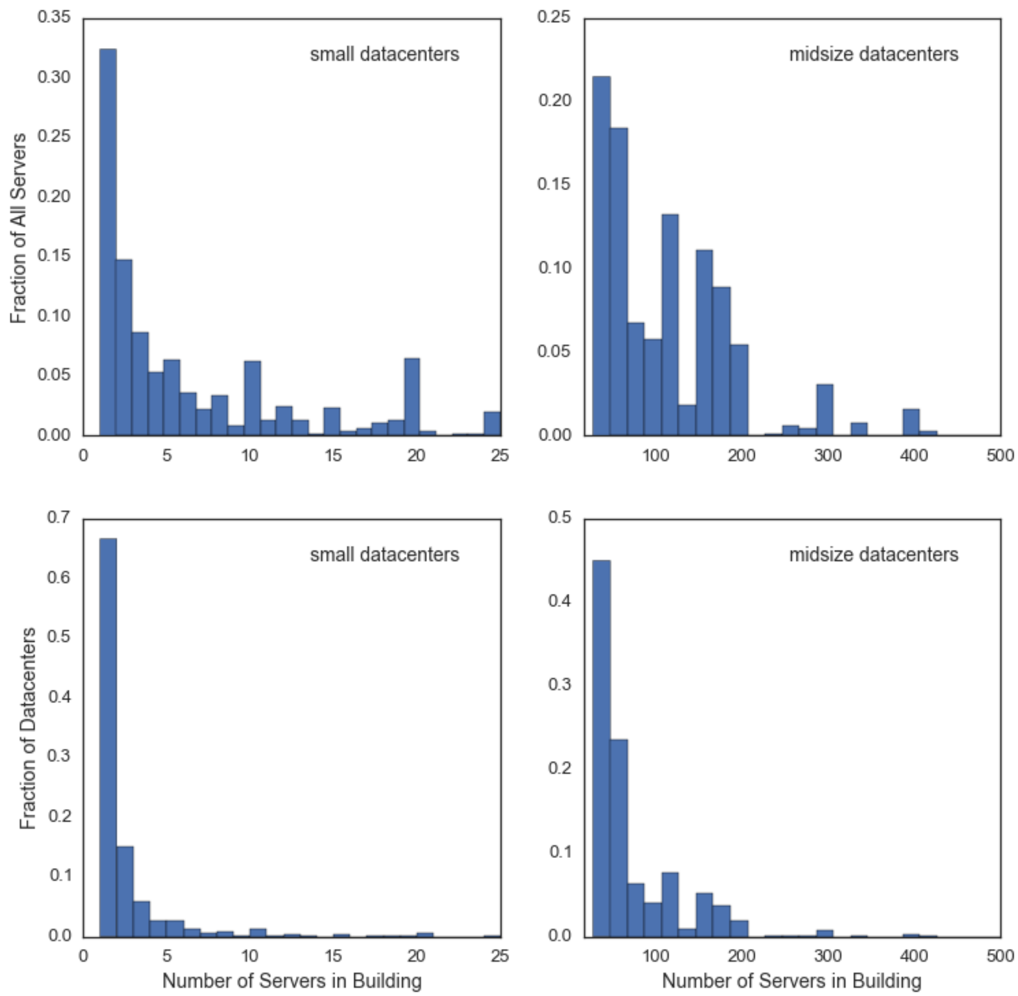

Figure 1: Distribution in the number of servers by data center type

The top-left panel shows that approximately 30% of the total number of servers in small data centers are found in locations with only one server. Data centers with a single server may represent a use case where operators need just one server for file sharing across an office or for e-mail or web hosting. As with other results from CBECS, this result is dependent on the reporting accuracy from the survey respondent.

An interesting feature in the top-left panel of Figure 1 is the slight, yet significant, increase in frequency at 10 and 20 servers. This may be a reporting bias towards a value rounded to the nearest 10 or possibly an indication that server operators are biased towards owning servers in increments of 10 servers. As seen in the bottom-left panel, an overwhelming majority of commercial buildings with small data centers operate one server (~70%). The frequency of small data centers with multiple servers drops off dramatically, with less than 6% having more than 5 servers. This result indicates that although single server data centers only make up 30% of the fraction of servers in small data centers, such data centers are far more prevalent and represent a popular use case for businesses.

When looking at midsize data centers, most locations have less than 100 servers. There is a notable relative dearth of data centers within the range of 200-500 servers indicating this may be an intermediate scale of infrastructure that does not serve a practical purpose in business or industry.

CBSA reports 36,500 data centers in its sample of Pacific Northwest commercial sites. The CBSA survey did not record the number of servers in each data center, instead counting the number of server racks in operation (see section 2 for details). This difference from CBECS, which records the number of servers, likely indicates that CBSA may be excluding locations that operate with only a few servers. As discussed previously, our CBECS analysis shows that single-server operation is a major use case.

Figure 2 shows the distribution of data centers as a function of the reported number of operational server racks. The majority of data centers report having between 1-5 racks (84%), with over half having a single rack (55%). Details regarding the dimensions of the rack were not recorded. Depending on the size and type of rack, an individual rack could hold anywhere from 1 server up to 40 servers making it difficult to translate rack count to server count for a comparison to results from CBECS. However, these results qualitatively support the assertion that the majority of data centers are relatively small in size.

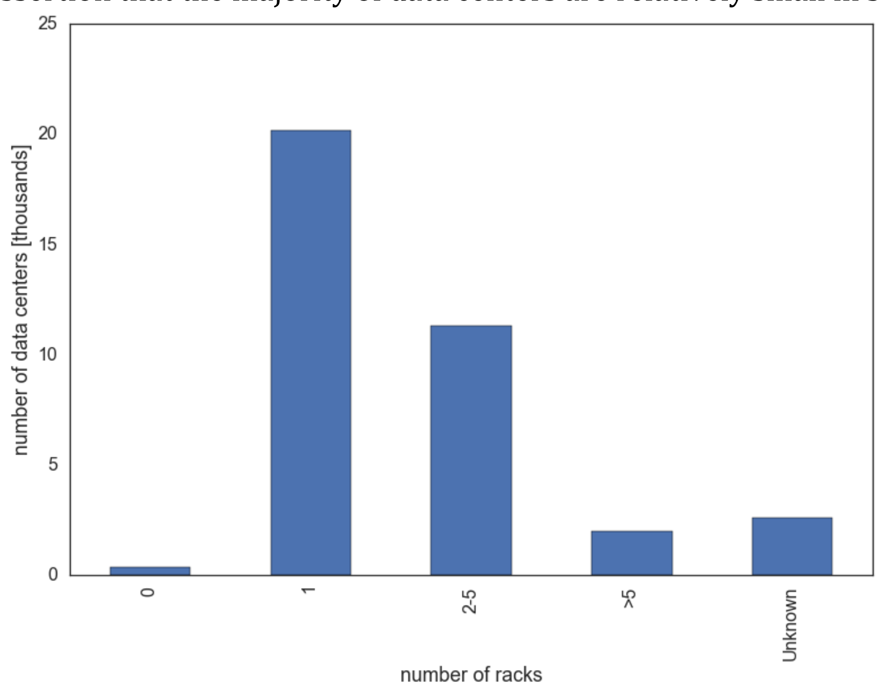

Figure 2: Distribution in the number of racks in CBSA data centers

Notably, 1% of identified data centers (corresponding to 11 records) do not report having any operational racks. This leads to questions regarding how hardware is operated and space conditioned. These sites may be operating hardware in *ad hoc* spaces not intended for server operation and may benefit from simple efficiency measures.

CBSA classifies each site as either urban or rural based on the Rural-Urban Continuum Code of the site county.[4] Approximately 33% of surveyed data centers are found in rural locations. Figure 3 shows the urban and rural breakdown for each rack category. Of data centers that reported 0 racks, 59% are found in rural locations, significantly more than the overall breakdown. For other data centers that reported having a rack, the fraction of responses in rural locations is roughly 33%, as expected from the overall breakdown between urban and rural locations.

Rural areas have a larger fraction of data centers with 0 racks compared to urban areas. The skew towards smaller, less efficient (in terms of PUE) data centers in rural areas potentially indicates an opportunity for energy savings.

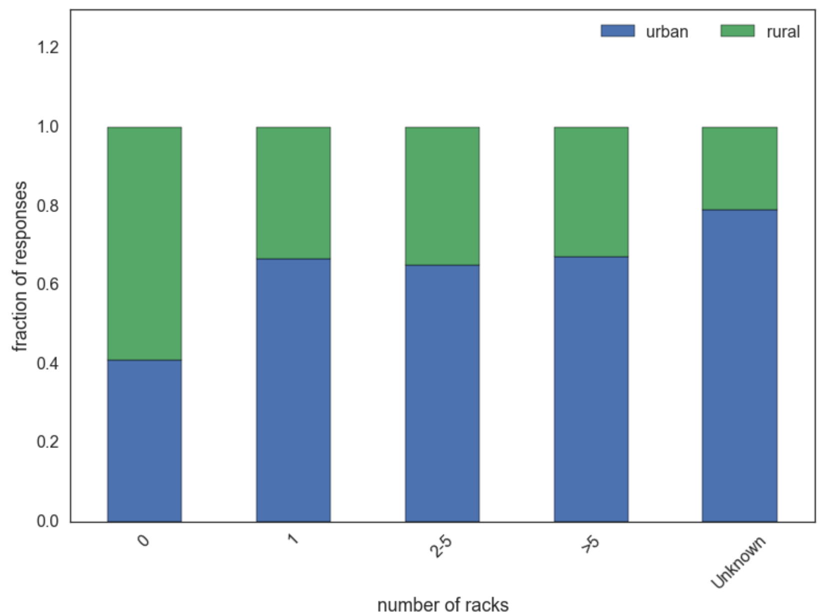

Figure 3: Urban and rural breakdown by rack size in CBSA data

Servers by Census Division

In this section we report geographic results from data centers in CBECS aggregated by census division. Table 4 shows the percentage of servers in each census division for the considered data center types. We also show the percentage of commercial buildings in each census division (CBECS Weight) for comparison.

Table 4: Geographic distribution of data centers by Census Division.

Census Division	Small Data centers	Midsize Data centers	CBECS Weight
New England	5.8%	2.7%	5.4%
Middle Atlantic	9.2%	19%	9.1%
East North Central	13%	12%	13%
West North Central	6.7%	4.8%	9.0%

[4] For more details, see http://www.ers.usda.gov/data-products/rural-urban-continuum-codes.aspx

South Atlantic	21%	8.2%	20%
East North Central	5.6%	7.3%	6.7%
West South Central	13%	16%	14%
Mountain	6.1%	10%	6.1%
Pacific	20%	20%	17%

The spatial distribution of small data centers generally tracks the distribution of commercial buildings in CBECS with a few notable exceptions. We find that there are more small data centers in the South Atlantic and Pacific relative to the number of commercial buildings. There are fewer small data center servers in West South Central and East North Central relative to number of commercial buildings. Overall, the similarity in spatial distributions underscores the prevalence of small data centers housed within commercial spaces across the U.S.

Contrary to our findings for small data centers, the spatial distribution of midsize data centers differs significantly from that of commercial buildings. Midsize data centers are significantly overrepresented in the Mid-Atlantic and Mountain relative to the number of commercial buildings in these regions. Given that midsize data centers are found less frequently than small data centers (as shown in Table 1), midsize data centers may only be utilized by certain industries that require significant computing power and do not necessarily track the geographic distribution of all CBECs buildings.

Servers by Principle Building Activity

In this section we investigate how servers are distributed by CBECS building activity. CBECS provides a principal building activity code and a more specific building activity code. In our analysis, we analyzed results by both PBA and specific PBA. For the results presented in this section, we focus our attention on results by PBA as little meaningful information is gained by the finer gradation provided by the specific building activity code. However, when noteworthy, we discuss results by specific building activity.

Table 5 shows the percentage of servers by PBA for each data center type. Although small data centers are found in a diverse variety of settings, the plurality of servers associated with small data centers are found in office buildings. This is unsurprising given the utility that servers provide within office settings such as file storage across a network, access to databases, and running shared enterprise applications. Looking at specific PBAs within office buildings, we find that 26% of servers in small data centers are found in administrative offices.

Similar to small data centers, servers in midsize data centers are primarily found in office buildings, specifically within administrative offices (38%). Medical buildings also house a significant number of servers within large data centers, with most associated with Inpatient Care (12%).

Table 5: Percentage of servers by building activity for each considered data center type

Building Activity	Small Data Centers	Midsize Data Centers
Education	9.8%	7.4%
Food Sales	1.8%	0.0%
Food Service	3.0%	0.0%
Lodging	1.2%	0.9%
Medical	6.9%	22%
Office	43%	57%
Public Assembly	3.3%	5.4%
Public Order	2.1%	1.7%
Religious Worship	2.0%	0.0%
Retail	13%	0.1%
Service	4.4%	0.2%
Warehouse	8.2%	5.4%
Vacant	0.71%	0.0%
Other	1.4%	0.3%
Total	**100%**	**100%**

Another way of investigating the prevalence of data centers is by looking at the market saturation of data centers in each PBA. For a given building activity, the data center saturation is defined as the ratio of the number of buildings of that activity with a data center to the total number of buildings of that activity.

Table 6 shows saturation rates of small and midsize data centers across PBA. For small data centers, saturation rates range from 14% for religious worship up to 59% for medical care facilities (not including administrative medical offices) with typical values between 20-30%. These results show that small data centers are relatively common in a wide range of industries. Again, we find that small data centers are especially prevalent in office settings.

Note that we find high saturation rates for medical (56%), courthouses (94%), and government buildings (55%), which house activities where federal privacy laws may impede adoption of off-site colocation, highlighting the need to customize efficiency strategies for these small data centers. For example, privacy law may prevent medical companies from moving their in-house data center to a cloud-based system operating from a larger, more efficient hyperscale data center. In such cases, there are potentially methods of leveraging the computational power of hyperscale data centers that interact with on-site protected data, which could yield significant energy savings. By contrast, high saturation rates for private businesses in office and retail spaces may provide an opportunity for substantial energy savings via cloud-based solutions without having to address as many obstacles regarding privacy.

Table 6: Server saturation by building activity for each considered data center type

Building Activity	Small Data Centers	Midsize Data Centers
Education	38%	0.54%
Food Sales	31%	0.0%
Food Service	22%	0.0%
Lodging	22%	0.21%
Medical	59%	2.2%
Office	56%	1.1%
Public Assembly	20%	0.21%
Public Order	28%	0.55%
Religious Worship	14%	0.0%
Retail	40%	0.0%
Service	19%	0.0%
Warehouse	21%	0.24%
Vacant	3.0%	0.0%
Other	32%	0.0%

Space Cooling in Data centers

The CBSA survey allows us to analyze HVAC equipment as a function of space type and number of server racks. Although these data are weighted to be representative of the Pacific Northwest, we note that the data may not reflect space conditioning across other geographic regions. Different geographic regions will have different space cooling requirements when determining HVAC needs for the building. The Pacific Northwest covers 'Marine' and 'Cold' climate zones as defined by the Building America program (Pacific Northwest National Laboratory, 2015), sponsored by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE). Buildings in these zones generally have lower cooling loads compared to higher temperature climate zones, which will be factored into HVAC system designs. This could potentially impact space conditioning for data center sites, particularly those that utilize economizers for cooling.

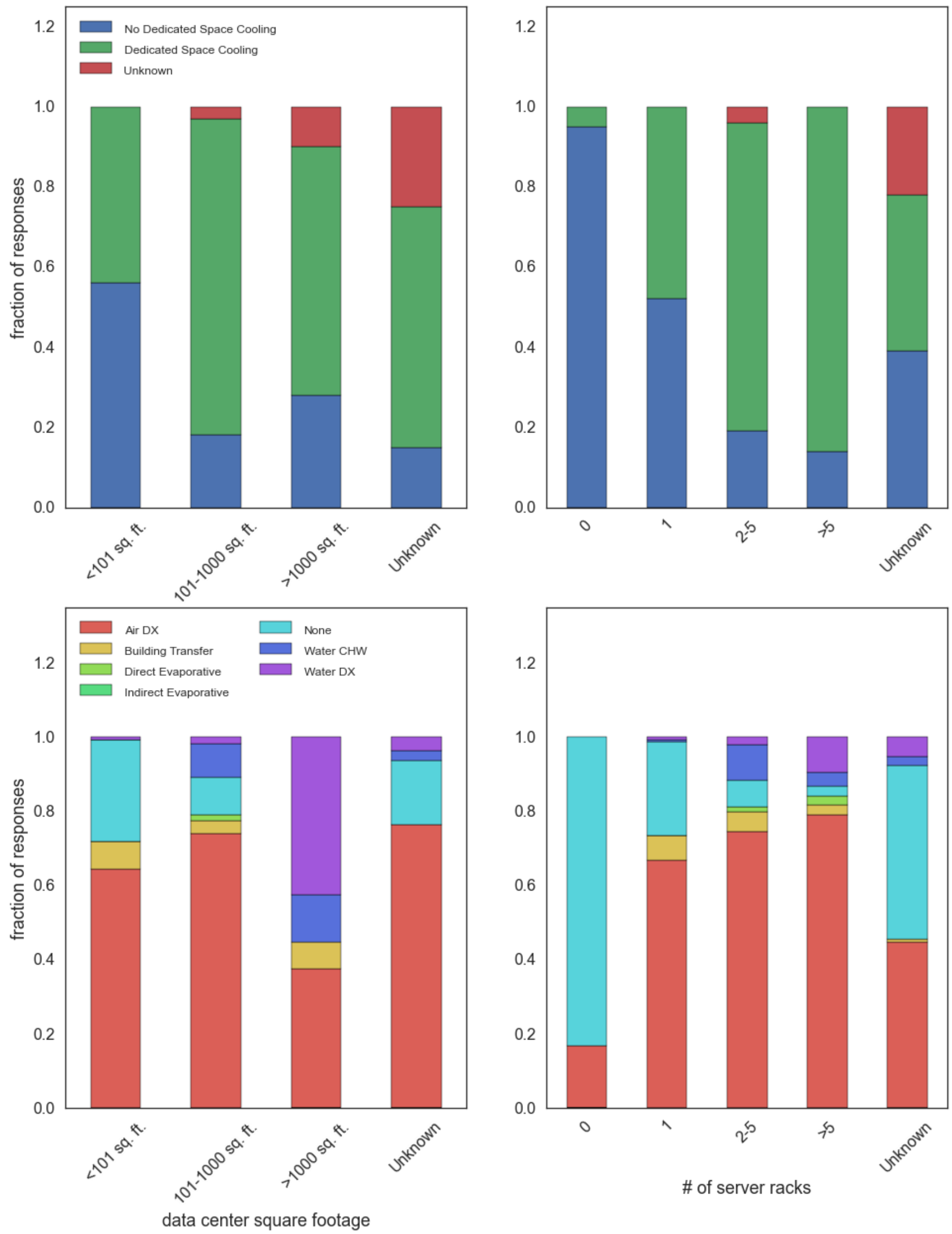

Figure 4: Space cooling characteristics of data centers in the CBSA

The top panels of Figure 4 display results for data centers with dedicated air conditioning. When categorizing data centers by square footage (left panel), we find that a majority of data centers less than 101 square feet do not have dedicated space conditioning, relying on cooling systems that service a larger part of the building or no cooling system. Surprisingly, data centers in the 101-1000 square foot range have a larger proportion of dedicated cooling (79%) compared to data centers larger than 1000 square feet (62%), although we note that there are only 13 records of data centers larger than 1000 square feet with no dedicated cooling. Further investigation finds that only one record of the 13 reports having no type of HVAC system. In the top, right panel, we find that the proportion of data centers without dedicated cooling decreases as the number of operational server racks increases.

The bottom panels show the proportion of data centers that use different types of HVAC systems. Note that these systems do not necessarily correspond to dedicated conditioning for only the server space and may also be used for conditioning other parts of the building. The left panel shows the fraction of responses by square footage and the right panel by number of operational server racks. A majority of data centers less than 1000 square feet use air-cooled computer room air conditioners (CRACs), which are labeled 'Air DX' in the figure. A sizable fraction of data centers less than 1000 square feet rely on building air-handling units (labeled 'Building Transfer'). Data centers less than 101 square feet have the largest fraction of respondents that use no conditioning (27%). Data centers larger than 1000 square feet data centers rely mostly on water-cooled direct expansion systems (42%). The bottom, right panel shows similar results by number of operational server racks. Over 80% of data centers with 0 racks replied they have no HVAC system.

Curiously, we find 67 records for data centers that report having either an air-cooled or water-cooled CRAC, but also report either having 'unknown' or no dedicated air conditioning. This is surprising given that CRACs are designed specifically for use in data centers and would be ill suited for general building cooling. It is unclear whether respondents answered the questions incorrectly including other types of cooling systems with CRACs or if there are offices where CRACs are also used more generally in a building.

Server Virtualization

Server virtualization allows a single physical server to act as multiple virtual machines running independent tasks and applications, rather than dedicate individual servers for each application. By creating virtual machines, data center operators can consolidate hardware and more fully utilize sever processing power. However, previous research on small business data center practices indicates that server virtualization is not heavily practiced. Bennett and Delforge (2012) found only 37% of small businesses practice server virtualization in a survey performed in 2011. The authors note that many small businesses had never heard of server virtualization or did not think the investment in virtualization would be cost-effective. A survey of large-scale enterprises in 2011 found that approximately 92% of businesses utilized virtualization (Vanson Bourne, 2011) and a more recent survey in 2016 found that 75% of businesses of all sizes utilized virtualization (Spiceworks, n.d.).

The CBSA study recorded the degree of virtualization undertaken by IT staff for each data center. Unfortunately, it is unclear whether the degree of virtualization refers to the number of servers that are virtual servers or the number of physical servers that contain virtualization software. Notably, most sites did not provide a response. Given the lack of virtualization in small businesses with virtualization knowledge (Bennett and Delforge, 2012), it is likely that most of these sites do not make use of data virtualization. However, there may be some sites where the respondent may not have been an IT professional capable of properly answering the question. Given the uncertainty, unknown responses are separately identified in our reporting.

In Figure 5, we show results for the reported degree of virtualization by square footage. Data centers less than 1000 square feet show a high proportion of unknown and no virtualization responses. Only 8% of data centers less than 101 square feet have any degree of virtualization, with 7% reporting more than 50% virtualization. Approximately 15% of data centers operate with server virtualization. Data centers larger than 1000 square feet operate with the highest proportion of server virtualization with 31%. We would expect that larger centers have more opportunity to consolidate, since they would be running a larger number of applications, and would benefit the most from virtualization.

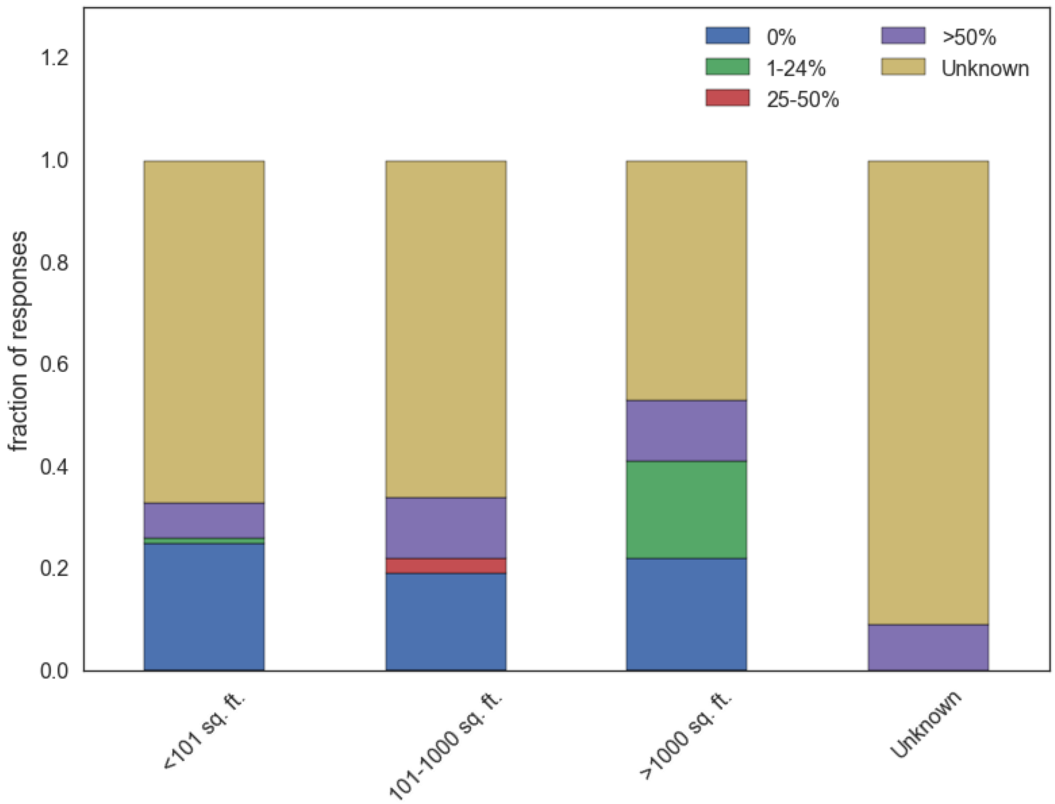

Figure 5: Degree of server virtualization by data center space type

4. Discussion

Spatial Distribution of Servers

In this section we combine data from CBECS and OES to construct spatial maps of server intensity (i.e., servers per unit area). As discussed in Section 2, occupation statistics at the zip code level are used as a proxy to estimate the spatial distribution of servers. Figure 6 shows the combined geographic server intensity for both small and midsize data centers. Server intensity closely tracks population centers with high intensities in urban areas. This is unsurprising given that most jobs that would utilize a server are found in cities.

Maps of CO_2 emission intensities displayed a very similar distribution to what we find for server intensity. They are not included here because differences between the server intensity and CO_2 emission maps were hard to discern. However, it is worth mentioning that there are subtle differences between the geographic distribution for server and carbon dioxide emission intensity. For example, the Pacific Northwest has lower emissions per server due to the region's reliance on hydropower. The Denver metropolitan region in Colorado has higher emissions per server due to the region's reliance on coal.

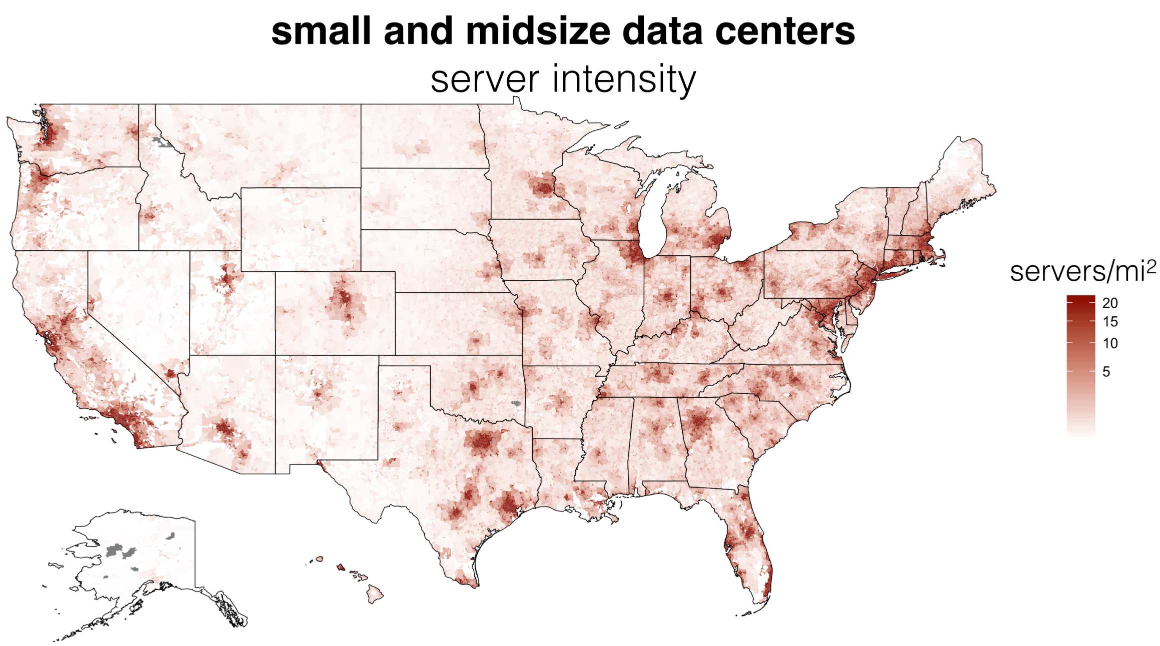

Figure 6: Geographic distribution of servers

In the next section, we will combine our derived spatial distribution of servers with typical power consumption values and geographic-specific with carbon emission factors from eGrid to estimate regional carbon dioxide emissions.

National Energy Use and Carbon Dioxide Emissions

In this section, we aggregate our results to estimate the annual energy use due only to servers, total site energy use including energy used to maintain and operate the data center, and total CO_2 emissions including gross grid losses for the considered data centers. Results for small and midsize data centers can be found in Table 7.

Table 7: Aggregate annual energy consumption and CO2 emissions by data center type

Data Center Type	Number of Servers (millions)	Server Energy Use (billion kWh)	Total Energy Use (billion kWh)	Total CO_2 Emissions (MMT)
Small	3.70	5.83	12.9	6.71
Midsize	1.47	2.32	6.34	3.29
Total	**5.17**	**8.15**	**19.2**	**10.0**

In aggregate, small and midsize data centers use approximately 20 billion kWh and emit 10 million metric tons of CO_2 per year, equivalent to the annual electricity use of 1.5 million homes.[5]

The average server in a small data center is responsible for 1.81 metric tons of CO_2 per year and in a midsize data center the average server is responsible for 2.23 metric tons of CO_2 per year.

Comparison to IDC Market Report

Market research firm IDC authored a 2014 study analyzing the state of the data center industry (IDC, 2014b). The study provides a census of US data centers based on in-depth interviews with IT buyers and suppliers including vendors that manufacture power, cooling, server, storage, and networking equipment. The study presents historical data and projections of the data center market based on underlying industry trends. We use data presented in the IDC study to compare to the estimates derived from CBECS.

IDC reports the number of data centers by space type using a taxonomy that captures the relatively broad definition of data center. From smallest to largest, their taxonomy includes closet, room, localized internal, mid-tier internal, and high-end internal data centers. As described in Section 2, the taxonomy used in this work combines closet and room data centers into "small" and localized internal and mid-tier internal into "midsize".

In Table 8, we compare the number of data centers reported by IDC and our estimates from CBECS. There are large discrepancies between the two data sets. IDC reports nearly one million more small data centers compared to the number of buildings classified as a small data center in CBECS. For midsize data centers, CBECS reports roughly a quarter of data centers found by IDC.

Table 4: Summary of comparison in data center counts between IDC and this work

IDC Taxonomy	IDC Data Center Count	Taxonomy (this work)	IDC Data Center Count	CBECS (this work)
Closet	1,512,829	**Small**	2,846,125	1,724,783
Room	1,333,296			
Localized	70,419	**Midsize**	80,383	21,203
Mid-tier	9,964			
High-end	8,283	**Not Analyzed**	8,283	Not Analyzed

Within small data centers, IDC reports a roughly even split between closet and room data centers. However, assuming buildings in CBECS with fewer than 5 servers correspond to a closet data center, we find that 91% of small data centers are closets. The skew towards

[5] Using EPA's greenhouse gas equivalency calculator: https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

closet data centers can be seen in the bottom left panel of Figure 1 which shows the vast majority of small data centers have only 1 server. If we apply the IDC definition of closet data center to CBECS buildings (i.e., a data center with less than 5 servers), we estimate 1.56 million closet data centers. This value is very close to IDC's reported estimate of 1.51 million data centers. However, as in the case of midsize and high-end data centers, CBECS reports significantly fewer room data centers by approximately a factor of 8.

IDC's range in the number of servers is intended as a rough guide to categorize data centers and not as a strict definition. However, it is difficult to see how misaligned classifications of data centers in CBECS could potentially explain the difference for large and high-end data centers between the two data sets. For these data centers, CBECS reports roughly a quarter fewer data centers.

One possible explanation for the difference is CBECS gives a count by building, whereas IDC is estimating the number of data centers. That is, a building in CBECS with multiple data centers would be aggregated and recorded as a single record. As CBECS gives estimates of the total number of servers in each building, we have no way of inferring the true number of data centers in buildings with multiple separate data centers.

The systematic differences could potentially be related to differences in survey methodology between IDC and CBECS. IDC relies on information from the IT industry to develop estimates of data centers, whereas CBECS respondents are commercial building owners and operators. However, note that since our energy use and CO_2 calculations rely on the number of servers, our estimates are not sensitive to this discrepancy in the number of data centers.

In addition to the IDC data center report, we also obtained data on installed server stock (IDC, 2014a). IDC estimates approximately 13.4 million servers in 2012. From CBECS data, we estimate 5.17 million servers installed in small and midsize data centers implying these embedded data center space types account for approximately 40% of server stock. The large fraction of servers in small and midsize data centers again underscores the need to better understand these types of data centers to achieve energy savings potential.

Energy Saving Opportunities

Server Virtualization

Results from the CBSA 2014 show that server virtualization remains mostly underutilized in small and midsize data centers. Similarly, Bennett and Delforge (2012) report 26% server virtualization saturation in small businesses surveyed in 2011. Our analysis of CBSA data in Section 3 found approximately 10% of data centers utilized some level of server virtualization. These low estimates of virtualization indicate there is significant available energy savings potential from increasing saturation.

Bennett and Delforge (2012) estimate that data centers with 10 or more servers would benefit from virtualization. As a scenario, we assume that 50% of data centers with 10 or more servers in CBECS are able to reach virtualization ratio of 5 to 1, reported as an "average" use case by WSP and the National Resource Defense Council (2012). In this scenario, we estimate annual site energy savings of 3.8 billion kWh, corresponding to 2 million metric tons of CO_2 emissions.

There are many barriers to the adoption of virtualized servers in small businesses. In many cases, businesses pay a flat fee for energy services eliminating energy costs as an incentive to reduce energy demand. Organization barriers may include lack of capital to upgrade and lack of IT knowledge. Additionally, virtualization will not benefit small data centers that operate few servers with little room to eliminate excess hardware.

Cloud Computing

The rise of cloud computing over the past decade has provided a new means for businesses to meet IT needs. The availability of Software as a Service (SaaS), Infrastructure as a Service (IaaS), and Platform as a Service (PaaS) cloud solutions has moved computing demand away from small, on-premise data centers into highly optimized cloud-computing data centers. In a small data center, individual servers are often used for running individual applications or tasks. This leads to servers that, on average, operate at very low utilization levels. In large, hyper-scale datacenters, applications and tasks are distributed across a huge number of servers and operationalized to run at utilization levels closer to 50% (Shehabi et al., 2016).

Cloud-computing data centers benefit from economies of scale and are able to make upfront infrastructure investments to support efficient data center operations (WSP Environment & Energy and Natural Resources Defense Council, 2012). Given the large cost of operating thousands of servers, even small improvements in efficiency can lead to significant operating cost savings. The Uptime Institute (2014) estimated an average PUE of 1.7 for data centers that self-reported the PUE for their largest data center. Some cloud computing data centers have achieved even lower PUEs. For example, Google has reached a fleet-wide average PUE of 1.12 (Google, 2016). Pushing the limits even further, Gao (2014) presents a framework for applying machine-learning artificial intelligence to operational data to potentially decrease Google data center PUEs below 1.10. For comparison, small data centers have typical PUEs closer to 2.0 (Cheung et al., 2014; Shehabi et al., 2016).

Here we perform a simple analysis to approximate the potential savings from moving computing needs away from a small data center to a cloud-computing data center. We assume that server loads from private-run office and retail stores can be easily shifted from in-house data centers to cloud computing data centers. Shehabi et al. (2016) estimate a cloud-computing server running under typical conditions consumes approximately 360 W. However, moving an application or task from a small data center to a cloud-computing server will only consume a marginal fraction of the server's computing power. Previous studies estimate that the load of a small data center server is approximately equivalent to 1/5 the load of high-end cloud server (Masanet, 2014; Shehabi et al., 2016). If we assume conservatively a 10% reduction in servers from industries other than financial, health, and government related fields, we estimate a potential 1.2 billion kWh reduction in energy consumption and 0.85 MMT of CO_2 emissions per year.

A survey of business owners with small data centers found that for many owners, a main barrier to cloud adoption stems from privacy and security concerns (Bennett and Delforge, 2012). However, these are concerns that are not necessarily rooted in reality. Cloud computing data centers often take more measures to ensure customer data is maintained securely and dedicate staff resources for this purpose. Additionally, many cloud computing operators offer private cloud solutions for companies that wish to silo their data from public cloud resources. Increasing penetration of cloud deployment within smaller data centers will take a concerted effort to educate IT professionals.

Although cloud computing offers energy savings potential by shifting loads away from small data centers to more efficient hyperscale data centers, easy access to cloud services could lead to increased demand for computing needs that were not needed previously. For example, businesses that previously relied on paper records that move to cloud services will add to overall energy demand or start providing services that require cloud-computing resources. These businesses will likely benefit from the efficiency of digitizing records and online management. For some new users, the cloud offers an ease of setup and maintenance in that it does not require a dedicated IT professional to install a new system.

5. Conclusion

Targeting smaller data centers remains challenging due to the *ad hoc* nature of small data centers, which are often situated in confined spaces within larger buildings. We make use of recently released data on servers and data centers in commercial buildings to characterize the small and midsize data center market and construct spatial maps of their locations across the United States.

We categorize buildings with less than 25 servers as small data centers and buildings with more than 25 but fewer than 500 data centers as midsize data centers. We find approximately 5 million servers (approximately 40% of installed stock) in small and midsize data centers, consistent with previous estimates (Bailey et al., 2007; Delforge and Whitney, 2014). The vast majority of servers in small & medium data centers are found in small data centers.

A majority of small data centers are found in offices and retail buildings. The highest saturations are in medical, retail, office, and education sectors. We find that approximately 26% of servers in small data centers are found in administrative offices.

Based on data from the CBSA conducted in the Pacific Northwest, a majority of small data centers with more than one operational rack make use of air-cooled direct expansion CRACs for space conditioning. The majority of data centers with one or less operational server rack did not report using any specialized cooling system and are likely relying on the building HVAC system. Sites with two or more operation racks tend to rely on dedicated space cooling with air-cooled CRACs being the most common. Water-cooled CRACs are mainly used in data centers that are larger than 1000 square feet, making up approximately 40% of cooling units in these sites.

In aggregate, we find that small and midsize data centers consume approximately 20 billion kWh of site energy. Using data from the Bureau of Labor of Statistics, we correlate the number of servers found in the CBECS data sets to employment data within occupational fields identified as using data centers. This allows us to disaggregate results by zip code to create detailed geospatial maps of server intensity across the US. Unsurprisingly, highest server intensities are located in dense metropolitan areas, with highest concentrations on the East and West Coasts. In total, small and midsize data centers emit over 10 MMT on CO_2 emissions annually.

Server virtualization provides a means for an individual server to act as multiple machines allowing for server consolidation. Although a practical means to decrease data center energy consumption, we find that it is not a common practice in small data centers. The vast majority of data centers responded that they did not employ virtualization or did not know the degree of virtualization within their datacenter. Only 15% of small data centers reported having any level of virtualization within their fleet. Modest consolidation of hardware through virtualization in data centers with more than 10 servers could save 3.8 billion kWh annually, corresponding to 2 million metric tons of CO_2. The most challenging barrier to adoption of virtualization is not technical. Most small businesses have either never heard of server virtualization or did not think the investment in virtualization would be cost-effective (Bennett and Delforge, 2012).

The era of cloud computing represents an opportunity to shift resources from inefficient small data centers to highly optimized hyper-scale data centers. Although, there are industries where privacy regulations may prevent the use of third party cloud data centers, such as in healthcare, many industries that currently rely on small data centers should be able to move computing to cloud centers. Assuming offices other than financial, healthcare, and government offices can shift 10% of their load to cloud-computing resources, we calculate approximate energy savings of 1.2 billion kWh per year.

Despite increasing consolidation of small data centers into larger ones, there remain a sizable number of small and midsize data centers. This report takes a first step towards identifying and characterizing how these centers operate. However, as discussed throughout this report, a main barrier impeding efficient operation is lack of education about best practices and opportunities. Future progress will be made by measures and policies that are able to directly target small data centers.

References

Bailey, M., Eastwood, M., Grieser, L., Turner, V., Gray, R.C., 2007. IDC Special Study: Data Center of the Future (No. IDC #06C4799). International Data Corporation (IDC).

Bennett, D., Delforge, P., 2012. Small Server Rooms, Big Energy Savings: Opportunities and Barriers to Energy Efficiency on the Small Server Room Market. Natural Resources Defense Council.

BLS, 2015. Occupational Employment Statistics Home Page [WWW Document]. URL https://www.bls.gov/oes/ (accessed 6.27.17).

Brown, R., Energy, A. to S., Incorporated, I.C.F., Incorporated, E.R.G., Agency, U.S.E.P., 2008. Report to Congress on Server and Data Center Energy Efficiency: Public Law 109-431. Lawrence Berkeley Natl. Lab.

Center of Expertise for Energy Efficiency in Data Centers, n.d. Center of Expertise for Energy Efficiency in Data Centers [WWW Document]. URL https://datacenters.lbl.gov/ (accessed 3.27.17).

Cheung, I., Greenberg, S., Mahdavi, R., Brown, R., Tschudi, W., 2014. Energy Efficiency in Small Server Rooms: Field Surveys and Findings. Presented at the 2014 ACEEE Summer Study on Energy Efficiency in Buildings.

Delforge, P., Whitney, J., 2014. Data Center Efficiency Assessment - Scaling Up Energy Efficiency Across the Data Center Industry - Evaluating Key Drivers and Barriers. Natural Resources Defense Council.

EIA, 2015. Energy Information Administration (EIA)- Commercial Buildings Energy Consumption Survey (CBECS) Data [WWW Document]. URL https://www.eia.gov/consumption/commercial/data/2012/index.php?view=microdata (accessed 6.27.17).

EIA, n.d. Office buildings with data centers use significantly more electricity than other offices - Today in Energy - U.S. Energy Information Administration (EIA) [WWW Document]. URL https://www.eia.gov/todayinenergy/detail.php?id=28232 (accessed 5.8.17).

EPA, 2015. Power Profiler Zipcode Tool [WWW Document]. URL from http://www2.epa.gov/sites/production/files/2015-10/power_profiler_zipcode_tool_2012_v6-0.xlsx (accessed 10.21.16).

EPA, n.d. Emissions & Generation Resource Integrated Database (eGRID) [WWW Document]. URL https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid (accessed 5.8.17).

Gao, J., 2014. Machine Learning Applications for Data Center Optimization.

Google, 2016. Efficiency: How we do it – Data Centers – Google [WWW Document]. URL https://www.google.com/about/datacenters/efficiency/internal/ (accessed 9.1.16).

Google, 2011. Google's Green Data Centers: Network POP Case Study.

IDC, 2014a. IDC's Worldwide Quaterly Server Shipment Tracker, 2010-2018. International Data Corporation (IDC), Framingham, MA.

IDC, 2014b. U.S. Datacenter Census and Construction 2014–2018 Forecast: Realigning Workloads, Managing Obsolescence, and Leveraging Hyperscale (No. 252712).

Koomey, J., 2011. Growth in data center electricity use 2005 to 2010. Rep. Anal. Press Complet. Req. N. Y. Times 9.

Koomey, J., Taylor, J., 2015. New data supports finding that 30 percent of servers are "Comatose", indicating that nearly a third of capital in enterprise data centers is wasted.
Masanet, E., 2014. The Energy Efficiency Potential of Cloud-Based Software: A U.S. Case Study. eScholarship.
Masanet, E.R., Brown, R.E., Shehabi, A., Koomey, J.G., Nordman, B., 2011. Estimating the energy use and efficiency potential of US data centers. Proc. IEEE 99, 1440–1453.
Navigant Consulting, 2014. 2014 Commercial Building Stock Assessment: Final Report. Northwest Energy Efficiency Alliance.
Northwest Energy Efficiency Alliance, 2014. Northwest Energy Efficiency Alliance: 2014 CBSA Database [Dataset]. Portland,OR.
Pacific Northwest National Laboratory, 2015. Guide to Determining Climate Regions by County, Building America Best Practies.
Shehabi, A., Smith, S.J., Horner, N., Azevedo, I., Brown, R., Koomey, J., Masanet, E., Sartor, D., Herrlin, M., Lintner, W., 2016. United States Data Center Energy Usage Report (No. LBNL-1005775).
Spiceworks, n.d. 2016 Latest Trends in IT & Technology Adoption [WWW Document]. URL https://www.spiceworks.com/marketing/resources/reports/2016-state-of-it/ (accessed 5.8.17).
The Green Grid, 2012. PUE: A Comprehensive Examination of the Metric.
Uptime Institute, 2014. 2014 Data Center Industry Survey [WWW Document]. Uptime Inst. EJournal. URL https://journal.uptimeinstitute.com/2014-data-center-industry-survey/ (accessed 9.9.16).
Vanson Bourne, 2011. Veeam launches V-index to measure virtualization penetration rate [WWW Document]. Veeam Softw. URL https://www.veeam.com/news/veeam-launches-v-index-to-measure-virtualization-penetration-rate.html (accessed 9.8.16).
WSP Environment & Energy, Natural Resources Defense Council, 2012. The Carbon Emissions of Server Computing for Small- to Medium-Sized Organizations: A Performance Study of On-Premise vs. The Cloud. WSP Environment & Energy and Natural Resources Defense Council.