Data Centers and Energy: Reaching Sustainability

The vital role of heat reuse

This paper is part diagnosis, part road map, and part inspiration to meet the sustainability test, and it provides a robust framework for developing best practices for data center design and management.

Foreword

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The information age started in the middle of the last century with the emergence of transistors, followed by a move from analog to digital technology. Miniaturization and the connection of computers and computer networks set the stage for the fast-evolving digital economy that we witness today. The term "information and communications technology" (ICT) captures both the digital and interconnected aspects of this economy.

Viewed from the vantage point of the United Nations' sustainable development agenda, the emergence of a digital economy is both a blessing in terms of the systemic efficiency improvements it offers and a source of concern in terms of the resources it consumes.

This white paper, *Data Centers and Energy: Reaching Sustainability, The vital role of heat reuse*, prepared by Danfoss outlines the challenges the world faces in addressing the resource concerns while securing the manifest benefits that the ICT revolution is bringing.

Monitoring, tracking, analyzing, managing, connecting, anticipating, – in each of these areas the progress has been astonishing. Writ large, ICT encompasses technology that measures and observes, records, communicates, and responds. Artificial intelligence is the new buzz word, though to date it is less about "intelligence" and more about hyper fast and diligent data management and analysis. At each step in all of the processes of ICT a vast trove of data is generated. The data can be used to discern opportunity – improvements in health, better operation and maintenance of mechanical systems, market monitoring, consumer preferences, real time inventory management, and so forth. The new world of data is opening pathways to a more prosperous, healthy, equitable and inclusive global order.

Progress, however, comes with a price. The digital economy is fast, ever growing, ever evolving, and ever more complex and energy intensive. Progress translates into data management being a source of a growing percentage of growing total greenhouse gas emissions. With global atmospheric temperatures already breaching the 1.5°C target and no clear peak in sight, such a potent and significant source of new emissions cannot be ignored.

The adverse impacts of data management for sustainability are concentrated in data centers. Important segments of the business community are focused on that fact and take it seriously. As the Danfoss report makes clear, the critical variable in the sustainability impact of data centers is the excess heat they generate. As data management technology becomes more sophisticated and powerful, the excess heat challenge is growing in step with the growth in the digitial economy.

Advances in artificial intelligence are expected to ramp up the volume of data produced and stored exponentially. Unfortunately, the volume of true data is dwarfed by the amount of data noise that is stored on servers and in data centers around the world. The electricity that data centers will need in the future will stress the ability of electricity markets to meet that demand with green supply.

The Danfoss report highlights the potential to reuse the heat that is created by data storage, processing and the rest. Properly harnessed, the otherwise waste heat it produces can provide an array of energy services such as hot water or heating for homes and offices. Data center design and their integration into residential/commercial and industrial ecosystems will be a critical dimensions of their sustainability.

The overarching point that emerges from the following pages, however, is that all of the sustainability challenges embedded in ICT developments are evolving rapidly. Prospective solutions will need to evolve as well. This paper is part diagnosis, part road map, and part inspiration to meet the sustainability test, and it provides a robust framework for developing best practices for data center design and management.

Executive Summary

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Danfoss is pleased to make available this white paper on one of the most important issues on the business and policy landscape, data centers. It is our first paper on a subject that promises to occupy leaders in industry, technology and regulation well into the future.

We are committed to helping meet the critical challenges posed by developments in data, data systems, and the tools available to store, process and analyze the vast quantities of electronic information now being created. The present paper is but a point of departure, but one that sheds light on the path ahead.

When the Information Age was launched several decades ago, few grasped how radical the impact of electronic information would be. It has transformed the conditions of work and productivity itself. It transformed research, product design, production and distribution systems, finance and payment systems – and became a major element of everyday life. Few innovations have been so powerful.

Data centers are the vital hubs of the global electronic information network that is now the nervous system of the global economy. And many of the benefits but also the challenges of electronic information are crystalized there. Central is the tension between data services and sustainability. And while the evolution of computing helps bring sustainability more within reach, the vast amount of electricity it requires is a significant challenge.

The core of the equation is that data centers generate heat that must be cooled or reused. Cooling without reuse is resource intensive, increasingly expensive, and undercuts decarbonization. So heat reuse is vital to a sustainable future for data centers. How to reuse data center heat effectively – and cost effectively – is the key question in securing the future of the vital services data and data centers provide. And it is the issue to which the present white paper provides a well-informed portal.

Central is the tension between data services and sustainability. And while the evolution of computing helps bring sustainability more within reach, the vast amount of electricity it requires is a significant challenge.

Only got 2 minutes?

Data centers are a leading focus for Paris Agreement stakeholders and the world's sustainability community. They provide critical data services including storage, processing, analysis, applications and distribution, but they also produce a large amount of heat and require intensive cooling – a major challenge to their sustainability.

New social and policy priorities in the US and abroad are adding powerful drivers to the shift on performance of buildings and especially data centers. Their role and the challenge they present is growing more urgent. Growing volumes of data are pushing the data center market to expand rapidly – the worldwide data center cooling market will reach 26.07 billion USD by 2031.

The costs of *not* investing in data center sustainability far exceed the cost of making them sustainable.

The Inflation Reduction Act is an important source of capital for data center transformation.

The excess heat produced by data centers can be harnessed for a wide variety of energy services – if the right infrastructure is in place. Planning for data centers near power generation sources AND production or facilities that can reuse that excess heat is vital to reach sustainability goals.

Data centers represent a unique business opportunity. Public and private sectors are collaborating, critical technologies are on the shelf, knowhow and financing is available to fuel progress.

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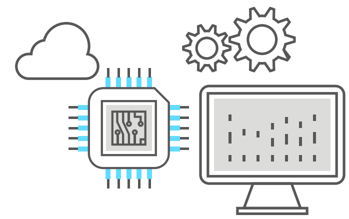


Since the Paris Climate Agreement was signed in 2016, the heat has been on to cut greenhouse gas emissions, especially carbon dioxide. Though progress has been made, leaders in the global climate community are signaling that the world is falling below target with what are feared will be catastrophic consequences. After experiencing what NASA, NOAA and others reported to be the hottest summer on record, along with worldwide extreme climate-related events, leaders are again calling for action.[1, 2]

Data centers are vital hubs of the digital economy. But they are energy intensive, consuming between 10 and 50 times more energy than a typical commercial building and 2% of the total electricity generated in the US.[3] As a result, they are a major source of indirect greenhouse emissions produced by generation of the electricity they consume – emitting as much CO_2, for example, as the entire US airline industry. They can also consume vast quantities of water, with potentially deep ecological impacts. Data centers are also expected, according to the 2023 Global Data Center Outlook, to grow in energy use and number due to increasing use of Artificial Intelligence (AI). The global colocation data center market size is forecast to grow with a 5-year CAGR of 11.3% from 2021-2026, and the hyperscale market is expected to grow even faster, at approximately a 20% CAGR.

Data center computer racks are also evolving quickly and, to increase capacity and capability, CPU chip power levels are increasing from 1,000 watts to as much as 4,000 watts, increasing energy use and indirect emissions of data centers.

It is unsurprising, then, that data centers have become a leading focus for many Paris Agreement stakeholders and the world's sustainability community. Growing in both number and resource consumption, data centers are emerging as critical to any serious effort to meet the Paris targets. Industry is being looked to for the knowledge and technology to meet that challenge – which is creating major new business and ESG opportunities.

Today's strategic dialogue on buildings, and data centers in particular, too often relies on an assumption from an earlier era – that the only options are to spend profit margins on environmental correctives or risk systemic disasters. For businesses with demanding financial targets and accountability, that can seem as if there are no good options.

But since that view was plausible, much has changed – in buildings data centers, communities, and policy at multiple levels; corporate priorities have also changed.

The culture of business has shifted and ESGs are now widely seen as vital priorities. Many major companies have committed to carbon reduction goals and it has become a focus of the investment community.

Communities too are prioritizing climate and resilience action, with major population centers establishing well-researched long-term plans for achieving sustainability and resilience to extreme weather and related events. Growing awareness of the link between climate change and extreme weather events is also impacting popular attitudes.

New regulations coming into force in the European Union (EU) are, or will soon be, adding powerful drivers to the shift in thinking about the performance of buildings and especially data centers. The regulations make ESG reporting a rigorous fact of business life for large companies, and they make large companies responsible for the conduct of suppliers and customers alike. The impact is being felt not only in Europe, but also in companies with European subsidiaries or that do business with the EU public or private sector.

Importantly, technology and best practices have emerged that are simultaneously good for the climate and good for business, from building design strategies and components to innovations specific to, or especially applicable to, data centers. The tool kit has evolved.

To see into that new reality for data centers, it is helpful to ask four key questions:

- Why are data centers important?
- What is the purpose of investment in performance?
- What does energy inefficiency in data centers cost?
- What does energy efficiency in data centers return?

The economics of sustainable data centers is ripe for progress. Optimization will certainly require investment and know-how. But that is not novel to data centers – it is a fact of basic business life. And *investment* is not *spending*. It is a path to financial and other returns – like risk reduction, brand enhancement, and goodwill – that exceed the present value of the funds required. Sustainability is increasingly *just business* – new paths to superior returns on balance sheet valued outcomes through capital investments. With the right information, innovation, and business instinct, creating such paths to growth and sustainability is today's reality for data centers.

Why Are Data Centers Important: Services & Risks

Three reasons stand out for the importance of data centers and they outline the challenge of making them sustainable. Data centers:

1. Provide critical data services – storage, processing, analysis, applications and distribution.
2. Produce a large amount of heat, and so require intensive cooling, which has very challenging consequences for sustainability.
3. Are both indispensable to a digital economy and unsustainable in their present form, with a rapidly growing number of centers requiring vast amounts of electricity.

Growth in the size and number of centers will only intensify the problem. The interplay between criticality, thermogenesis, and sustainability is the defining and ever more amplified feature of data centers in the digital age.

Stored data is not inert, but other data services create substantial friction and heat sufficient to cause equipment to malfunction. Traditional cooling for a data center requires electricity to cool and move air, or (sometimes cool and) move liquids such as water, depending on the technology deployed. In a world of carbon-based electricity, either approach to cooling translates into added carbon emissions.

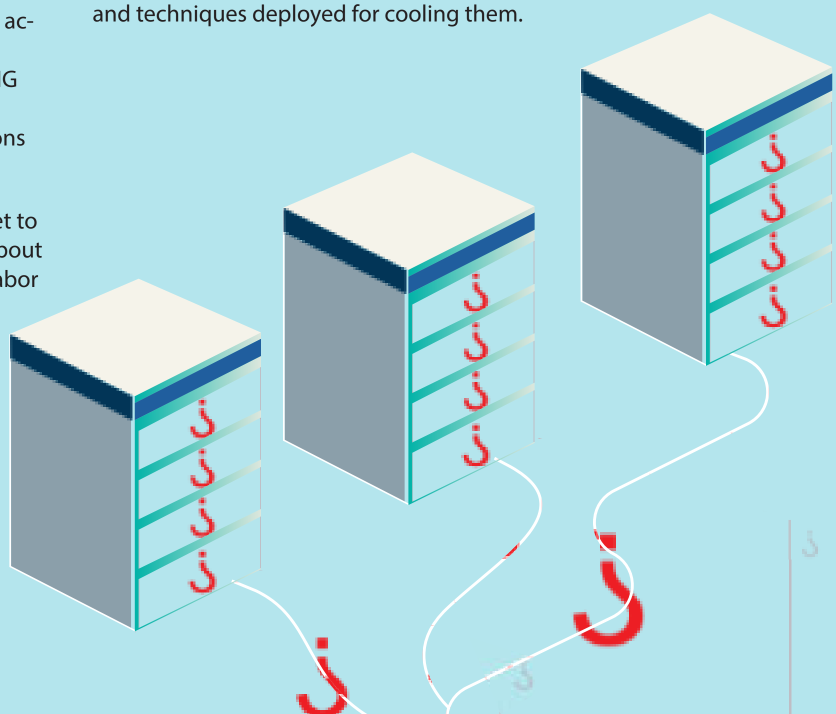
The International Energy Agency indicates that data centers accounted for 300 metric tons of CO_2e in 2020, equivalent to 0.6 % of overall GHG emissions or 0.9% of energy related GHG emissions. Globally, according to a 2018 study, data centers could be expected to account for 14% of the world's emissions by 2040.[3]

Growing volumes of data are pushing the data center market to grow rapidly in an overall economy that will likely grow at about 2.3% on average annually, according to the U.S. Bureau of Labor Statistics.[4] The C&C Technology Group observes that "[d]ata centers usually. . .consume about 1,000 kWh per square meter. . . [or] about ten times the power consumption of a typical American home."[5] The IEA, on the other hand, estimated average energy consumption for the full array of larger buildings (e.g., universities, schools, offices, food, lodging, public assembly and the rest) is 14.6 kWh/ft2 or 157.15 kWh/m. And on a worldwide scale, it's estimated that the transmission of data can consume anywhere from *260 to 340 TWh*.[6]

Though the number of internet users has more than doubled since 2010, global internet traffic has grown "20-fold." And while energy efficiency improvements, renewable energy, and decarbonization of electricity grids have kept emissions growth modest, the IEA believes that "*to get on track with the Net Zero Scenario, emissions must drop by half by 2030*.[5] Data center growth will likely make that target challenging to reach.

In a similar vein, *The Washington Post* reported that while air cooling is expensive and requires electricity and emissions, the cheaper option, water cooling, "sucks up millions of gallons of water. A large data center, researchers say, can gobble up anywhere between 1 million and 5 million gallons of water a day — as much as a town of 10,000 to 50,000 people."[4]

The interplay between data center criticality, thermogenesis and sustainability, then, depends largely on the specific technology and techniques deployed for cooling them.



Ongoing advances in traditional cooling strategies have not produced good marginal returns on added investment. In search of better performance, designers and operators have turned, in addition to immersion cooling, to AI applications for modeling, prediction and even recognition of heating patterns that may not be linear. Sensors deployed through the IT space support such AI analysis.

Efforts have been made to increase allowable temperatures in data centers to reduce the cooling load and to allow for free cooling when the ambient is cooler. But the heat rejected by chips in severs is increasing and new approaches like direct chip cooling with refrigerant, water and immersion of severs is developing.

For the cooling of data centers, the approach has been to use large chilled water systems. These can be water-cooled or air-cooled but the recent trend has been to use air-cooled to reduce the use of water. These have also been combined with dry cooling coils to allow for free cooling.

But the need for cooling will not go away in mild to warm climates, and in some cases, the increased load will exceed the available space on the roof of a data center for equipment. One alternative, that has been used in some applications, is to replace the chillers with heat pumps which can convert the low-grade rejected heat to higher-grade heat that can be used to heat other buildings through district heat and cooling plants and processes, including food growing facilities, desalination plants and industry drying processes. Excess heat can be used in a variety of ways, depending on location and other factors.

Whether the technologies used to cool a data center involve straightforward evacuation of heat, evaporation, or some other heat transfer mechanism, the heat has tended to end up in the outer atmosphere. Because the vented heat is essentially lost or wasted energy, attention has turned to how the heat be reused or put to work, which can add to both financial and ESG performance.

Such approaches can include providing district heating and cooling services to adjacent communities (air or water) – to heat conditioned spaces such as homes and offices, or to provide some other service. In one location, hot water was used to help farm lobsters. The heat can also be stored – in building material, in water, ice, elevation or other devices, albeit at varying levels of efficiency – to be recovered for use when, for example, renewables such as wind and solar are less plentiful or unavailable. By storing the heat as energy until it can be used, the data center cooling strategy can be made more comprehensively efficient through integration with other systems within the center or in the surrounding community.

The approaches available for heat reuse vary in efficiency, cost and applicability to the several types of data centers. When properly fitted to circumstances they are both effective and, with energy storage, a source of ongoing value to be monetized.

In summary, traditional data center cooling, made necessary by the physics of IT, achieved something of a Max-Tech level of performance in which the additional dollar invested did not provide a comparable return in performance. AI offered new avenues for investment that did indeed return value – in greater cooling and reduced cost. Storage and systems integration then offered new paths to recapture waste heat and return it to the utility. Taken together, these approaches have proven capable of making increased investment in efficient cooling a sound decision.

Data centers are vital hubs of the digital economy. But they are resource intensive, consuming between 10 and 50 times more energy than a typical commercial building.

What does energy inefficiency in data centers cost?

To see the true costs of energy *inefficient* data centers it is necessary to look not only at how they are cooled but also how they are housed. As noted above, data centers vary in size. There are also varied types of structures, varied locations, alternative materials and the like. A typology of data centers is needed. The criteria involved, however, are complex and the terms to describe them are to some degree new and still evolving. As the colocation data center leader Equinix has indicated:

> *Infrastructure is everywhere and the data center is evolving. Digital Leaders need to evolve their vision and their data centers – leveraging hybrid cloud-based platforms, as-a-service offerings, digital ecosystems and partners to ensure positive business outcomes and secure their business for the future*[7]…

Types of Data Centers

It is important, though, to create an outline of the options and their leading characteristics. Centers are often broken into four common types: onsite, colocation facilities, hyperscale, and edge centers. More descriptively, enterprise centers are specific to an organization – say, a corporation – and are housed in corporate facilities. Others are managed by leasing services and are off-site, supplied and managed sometimes by the lessor, perhaps for multiple clients, and sometimes with equipment supplied or managed by the lessee. These can include edge centers – built at the edge of the facilities of an end user. Others are cloud services provided by the big players – Amazon, Microsoft, IBM or others – sometimes termed *hypercenters or hyperscale* – which can house millions of servers.

An important, more recent development in data centers is the *modular* center, which offers significant advantages over traditional centers. Modular centers deploy individual modules that are designed and built separately and assembled at the site to form a complete structure. More flexible and scalable, modular centers can expand and contract with the addition or subtraction of modules. Their highly efficient cooling systems and other innovations make them usually much more energy efficient. And their flexibility and scalability are especially useful for edge centers with demand for center services that can shift rapidly.[8]

Costs of Data Centers

The various types of centers provide a variety of ways that the sustainability challenges of data centers are configured and costs assessed. To get a sense of the "big picture" direct financial costs involved, Astute Analytica projects that the worldwide data center cooling market will reach 26.07 billion USD by 2031.[9]

Assetspire in the UK estimates the cost of running a data center to be between 10 and 25 million USD per year – or "anything up to $30,000 a year per rack in the US."[10]

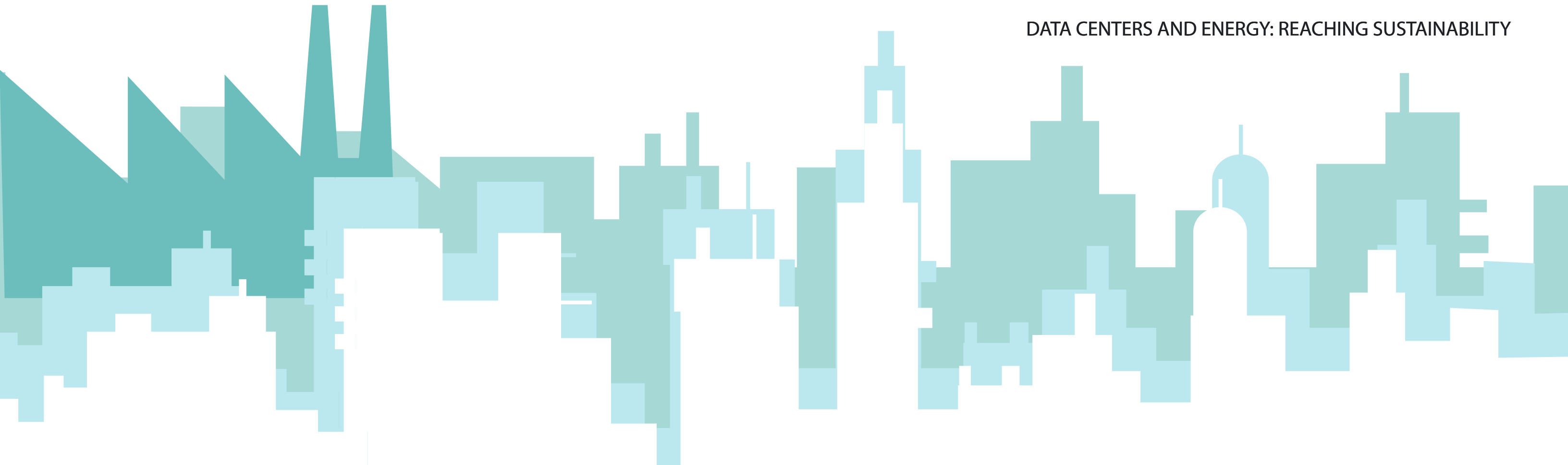
Those numbers do not capture the impact of AI on the demand for IT and associated scale and cost issues, though there is little controversy that it will be vast. But even today's numbers highlight the incremental financial cost of inefficiency generally and in data center cooling specifically. The numbers are large, and any failure of efficiency will reflect that order of magnitude in both cost incurred and revenue forgone, or opportunity cost.

There are several important metrics for evaluating the performance of the types of centers:

- *Power usage effectiveness* is a ratio that describes how efficiently a computer data center uses energy – specifically, how much energy is used by the computing equipment. PUE is the ratio of the total amount of energy used by a computer data center facility to the energy delivered to computing equipment.[10]
- *Carbon usage effectiveness* (CUE) is a metric developed by The Green Grid to measure data center sustainability in terms of carbon emissions. CUE is the ratio of the total CO_2 emissions caused by total data center energy consumption to the energy consumption of IT equipment.[11]
- *Water Use Effectiveness* (WUE) is the ratio between the use of water in data center systems (water loops, adiabatic towers, humidification, etc.) and the energy consumption of the IT equipment. The lower a data center's WUE ratio is, the more efficient its use of water resources is. The average data center has a WUE of 1.8L per 1kWh.[12]
- *Energy Reuse Effectiveness* (ERE) is the ratio of energy being reused divided by the sum of all energy consumed in a data centre. The ERF reflects the efficiency of the reuse process, which is not itself part of a data center.[13]

Each of these metrics can be applied to the performance evaluation of a type or actual data center, through modeling or real-time performance evaluation, to help determine both financial costs and ESG impacts (and impact improvements) of a center.

There are, however, other important ways to assess cost. Regions in the U.S. and abroad have been increasingly hesitant to accept the construction of new data centers especially for the demand they put on electricity generation and transmission capacity. Cen-



ters can strain supplies and the grid, requiring new infrastructural investment that may exceed the value of the data center to the region. And they can involve greater regional risk – like brown outs and worse during peak loads.

The benefits of data centers to communities appears to be great enough that moratoria and other obstructions are often eventually overcome. But delays have a price – both in forgone revenue and in the intangible but sometimes invaluable good will of the community and customers or clients.

Costs, too, come through regulations – sometimes even remote ones. The new EU regulatory regime seeks to tighten the grip on carbon in its several climate relevant forms – embedded, leaked, and emitted more and less directly. As already noted, the impact of the regulations will be felt massively and well beyond EU borders.

There are now many regulatory authorities interested in cutting GHG emissions, and the energy use profile of data centers makes them a leading target. The definition of emissions is likewise growing more expansive and sophisticated.

Defining Emissions in the New Race to Zero

Emissions are now typically categorized as Scope 1, Scope 2, or Scope 3 – a vernacular that is coming to dominate the discussion of emissions, their regulation, and building or data center performance assessment.

The Scopes all focus, as the National Grid outlines, on where emissions are originally *sourced*. The three Scopes are ways of categorizing the various kinds of emissions that are sourced both in direct operations and elsewhere in the "value chain" of suppliers and customers.

The term Scopes originated with the Greenhouse Gas Protocol, the world's most widely used greenhouse gas accounting standard. And their purpose is to provide for "a full [greenhouse gas] emissions inventory – incorporating Scope 1, Scope 2 and Scope 3 emissions" enabling "companies to understand their full value chain emissions and focus their efforts on the greatest reduction opportunities".

The Scopes typography comprises:

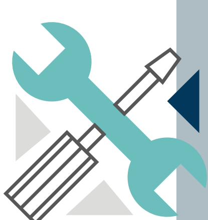
SCOPE 1: emissions from sources that an organization owns or controls directly.

SCOPE 2: emissions that a company causes indirectly and come from where the energy it purchases and uses is produced.

SCOPE 3: emissions that are not produced by the company itself and are not the result of activities from assets owned or controlled by them, but by those that it's indirectly responsible for within its value chain. Scope 3 emissions include all sources not within the definitions of Scopes 1 and 2.[14]

The new EU regulations take aim at all three types of emissions, and they will impact anyone trading directly or indirectly with the EU – in other words, the world.

So, whether the cost of inefficiency is directly monetary – cash out of pocket – or in delayed or foregone revenue, or in loss of opportunity to compete and consequent loss of market share, the *costs of energy inefficiency are substantial*. They are driven by the performance properties of the data center structure – building or modules – as well as and especially by the cooling strategies deployed. In a world ever more pressured by climate sensitivity and strained resources and infrastructure, those costs will play a major role in determining who is successful in the marketplace.



The US Inflation Reduction Act (IRA) targets not only the acquisition of clean energy, but also its storage, energy efficiency and electrification. The Act comprises a $430 billion stimulus package with $369 billion for energy and climate change.

What does energy efficiency in data centers return?

Data centers are profitable – and added energy efficiency can make them substantially more profitable. Given the role energy costs play in center operations, it is not just cooling that can be a source of returns on investment, but the building itself is a significant factor. The other very real risks and costs of data centers already outlined can each be a source of "return" in the form of successful cost or bad outcome avoidance.

But more, the current U.S. push for emissions reductions and energy efficiency is an important part of the data center cost/reward equation. *The Inflation Reduction Act (IRA) commits substantial sums to support the investment that top data center energy performance will require.* When financial targets hover over investment decisions, the IRA can make a decisive difference and help create a viable path to ongoing energy and financial performance.

Data Centers are Profitable

In 2021, McKinsey reports, there were 209 data center deals. Their collective value was $48 billion, up 40% from the prior year. The attraction to investors more than suggests an impressive price-to-earning ratio.[15]

Total data center revenue in the U.S. in 2023 is expected by Statistica to be about $326 billion. With a growth rate of 6.12%, that translates to $438.70 by 2028.[16] As a basis for judging final returns, Equinix, which "owns and operates a network of 250 International Business Exchange data centers located in 71 major metros around the world," had a 49% EBITDA in 2018. NAREIT, another leading data center owner, posted an October 2022 dividend of 3.14% on top of a total 202 return of 25.47%.

However profitable data centers may already be, there is still money being left on the table. Biggins, Lacey & Shapiro, specialists in site selection and economic development, estimate the cost of electrical power as 60-70% of the total operating cost of a data center.[17] Those are margin making numbers, and every kW saved adds something.

There are other major returns to be considered, as well. First, ESG benefits – the positive sides of the risks and costs already outlined, including regulatory compliance, community receptivity, ease and speed of development, and ongoing goodwill. In some regions, even power reliability can be an issue. Each of those items hit the bottom line, balance sheet, or both, directly and indirectly.

With energy such a major factor in data center operational costs, facility cooling is obviously a leading concern. But the energy of performance of the center structure is, as well, since it also contributes substantially to direct energy cost and the emissions profile of the data center.

The Inflation Reduction Act

In addition, there is now financial support for taking action to make data centers more energy efficient and energy effective for decarbonization.

The U.S. Inflation Reduction Act targets not only the acquisition of clean energy, but also its storage, energy efficiency and electrification. The Act consists of a $430 billion stimulus package with $369 billion for energy and climate change. Much of the money is earmarked for existing programs, so there is not a mountainous learning curve.

The rewards for centers can be especially substantial for integrated systems approaches to decarbonization of the building and data services – including both systems within the center structure and in the broader community. The IRA is expected to be a major driver in the shift to high energy performance in buildings, and data centers should be a high-priority beneficiary.

First, the Investment Tax Credit (ITC) provisions target clean energy and energy storage. There is now a 30% ITC for stand-alone clean energy storage (up from 24%) – which includes captured waste heat. And the stored energy can provide not only potential revenue streams from internal use and external sales, but also energy resilience for the data center itself.

Most outages, according to the Data Knowledge Center, cost at least $100,000, with 25% costing $1 million or more. If battery storage is used, or other technologies that are green power adaptable, it has the additional advantage that they can be recharged from either waste heat conversion or other green energy – for which there are additional incentives in the IRA. So the return on investment is not only in terms of cost offsets and ESGs, but also in invaluable center resilience.

The Act's provisions reach to solar, heat pumps, combined heat and power, battery storage and thermal storage. So building and data systems can mutually leverage the IRA across the building's design and management to optimize performance.

The IRA also targets energy efficiency and electrification through a 179D tax deduction by lowering the percentage improvement via new investment that is required to qualify – from 50% down to 25%. Credits for storage equipment can be combined with credits for energy efficiency retrofits in HVAC, hot water, lighting, building envelope, and controls. Renewable low-carbon energy use, and low-carbon energy generation (including from waste heat) can be included. With such a breadth of provisions, the IRA can easily be seen as the biggest collection of supports and incentives in modern history to offset the cost of the advanced greening of data centers.

Taking Action – Data Centers' Excess Heat in Integrated Community Level Systems

The data center market, growing already at extraordinary rates, is on the threshold of a new era with the emergence of AI. The growth trajectory ahead is historic. Innovation, acumen and creativity will be required. But major new business and community design needs and pathways are opening as a result.

The goal is not decarbonization alone, but also economic growth and potentially vast improvements in quality of life – with reliance on carbon energy peeled away. Data centers themselves can be important to that effort in many ways. From a broader, community level perspective, the data center challenge may well offer a particularly valuable opportunity.

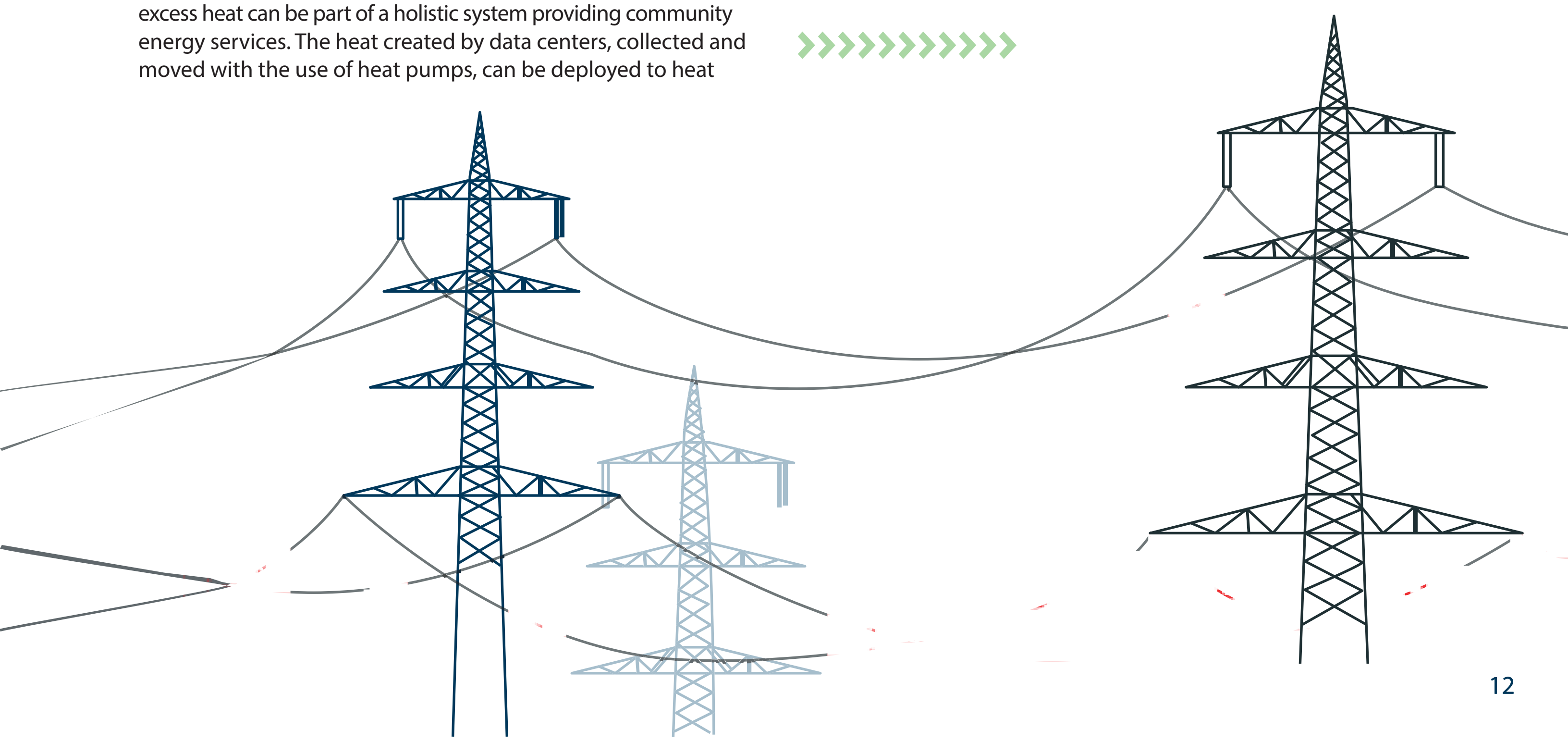
A major shift is already in motion toward a green grid. Decarbonizing the grid implies reliance on distributed non-carbon sources of electricity, as well as a "smarter" grid that can integrate non-carbon based electrical power from multiple sources with activities of a vast array of "consumers" – i.e. buildings, with their electrified systems and subsystems. As the grid becomes more green, the energy will likely come from wind, solar, hydro and other renewable energy sources. But such sources are not always aligned with consumption patterns. Integration of data centers with a smart grid will open up new opportunities for demand shifting and smarter use of energy consumption as well as storage.

Viewed from a *community energy* standpoint, then, data center excess heat can be part of a holistic system providing community energy services. The heat created by data centers, collected and moved with the use of heat pumps, can be deployed to heat buildings, heat water, and provide heat to other processes needing it. Data center heat energy can be stored in a variety of ways and used as needed to offset targeted electricity applications, especially during peak load hours, or to reduce the power load consistently throughout the day by replacing the need for electricity at a discrete location.

Conclusion

In the overall energy equation of data centers, centers first need to be housed in truly sustainable structures. That is already happening on a substantial scale, though there is ample room for progress. Beyond that, they need to be cooled efficiently. As component power grows, however, the electricity required for centers is growing exponentially. Well-tailored applications for data center heat reuse, with centers sited with such goals especially in mind, can help address centers' cooling needs and offer pathways to much improved net or systemic community scale energy efficiency.

Ultimately, data centers can be important elements in community energy systems. The discrete application of excess heat to specific locations can be articulated within a smart system of grid and energy management and support the IT systems of communities large and small. To realize such a holistic vision is the next great challenge in community design and infrastructure know-how.



Postscript

Thomas Santucci
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The importance of data and data centers to public service and the economy cannot be overstated. Danfoss is to be commended for their effects to help all of us understand the challenges of data centers better, as well as the possible responses to those challenges.

Readers will judge for themselves the observations and arguments outlined in this report. Three things are suggested by it, though, that are incontrovertible: the importance of the issues raised, the necessity of a collaborative approach across sectors and professions in addressing those issues, and the value of more opportunities for the public and their civic leaders to inform themselves about those issues.

Data centers are here to stay. They are essential, rapidly growing in number and resource intensity, and a major challenge to our sustainability goals, which are every bit as essential. Responsible officials across the public and private sectors are confronting that dilemma, and a lot will depend on the soundness of their responses.

Data centers are also complex. The buildings that house them have special demands placed on them, the technology they use is intricate and changing rapidly, and the viewpoints and knowledge of all of the stakeholders and professions that are needed in their design, siting, construction, management, maintenance, equipment and retirement need to be integrated to make them both optimally effective and sustainable.

Our data centers are relatively new, along with the underlying infrastructure challenges. Nowhere is there a body of experience to which to turn for authoritative answers. So it is critical that we work globally so communities and their leaders be afforded ready access to what is known, what is understood, and what are both the risks and the opportunities.

I am very hopeful about the opportunities, but respectful of the risks. We really need to get this right. Through this report, and efforts like this, has made a serious effort to help everyone judge the better paths available. I hope they will continue that important work.

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