Novel Strategies for Data Centre Waste Heat Use

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Abstract. Data centres – warehouses where thousands of computers drive our online activities as well as an increasing amount of data computation and storage – are heavy electricity users. This paper proposes reusing the energy after the computers have transformed the electricity into waste heat. Two novel strategies are presented, commodity dehydration and increased work efficiency for ocean thermal energy conversion (OTEC) technology. We argue that data centre waste heat use is possible both in cold and warm nations, but that strategies to use the heat efficiently must be case-dependent. With the prospects of saving billions of dollars and many tons of carbon emissions, as well as bringing societal gains globally, it is concluded that few, if any, other energy savings can be this advantageous for the data centre industry.

Keywords: Data centre, sustainability, renewable energy, energy efficiency, waste heat, commodity dehydration, ocean thermal energy conversion, OTEC

INTRODUCTION

Our modern lifestyle, from listening to Spotify to filling out our income tax declarations, is to a constantly higher degree supported by and dependent on information and communications technology (ICT). Data centres – warehouses with thousands of computers and owned by the likes of Amazon and Google, smaller enterprises, authorities and individual, “co-location“ providers – enable this technology. Thus, whenever we use services “in the cloud“ we are simply shifting computation workloads or long-time storage from our own computers or smartphones to computers in such warehouses.

Consuming about 1% of world electricity [1], these heavy electricity users come with high carbon footprints and with severe strains on national energy grids. For the last decade, this electricity consumption has been problematic for the data centre industry. The underlying premise of this paper is that it is possible to use this energy twice, thus partially alleviate the electricity consumption problem. Two novel strategies are presented to show how.

METHOD

Finding new use cases for energy reuse calls for cross-disciplinary thinking, and paving new ground makes validation challenging. To verify our findings, we use “triangulation“, which gives a multi-faceted perspective on one specific issue [2]. In this case, the research problem has been approached through an extensive and cross-disciplinary literature review, ethnographic research, interviews, and participation in data centre industry hearings.

The literature review consists of papers, books and reports relating to data centres, energy, commodity production, OTEC technology and local suitability, drivers for commercialisation, statistics for countries’ societal progress, and environmental sustainability. The reading deepened the understanding for the computer science and engineering facets of the project, and gave insights into opportunities and barriers for implementation of the ideas.

Ethnographic research has involved a research trip to Luleå and Boden in northern Sweden, 26-29 October 2020, Falun in mid-Sweden, 23 August 2021 and 17 August 2022, and Kuala Lumpur, Johor Bahru, Port Dickson and Cameron Highlands in Malaysia, 30 April-2 June 2022. The visits to Luleå and Falun showed practical use cases for data centre waste heat use. Exploring Kuala Lumpur and the more rural areas of Peninsular Malaysia’s west coast mainly by foot and using public transport provided many insights in everyday life, legislation, cultural factors, commodity access and available land in these areas.

The project has meant taking active part in many industry hearings – mainly webinars – on data centre sustainability, data centre future design and OTEC technology prospects. In a few of these hearings, we have put forward the possibility of waste heat use around the Globe.

DATA CENTRES AND WASTE HEAT

Data centres' high power need is mainly due to processor intense computations on the computers (called "servers"). Additional electricity is needed to cool the servers; how much depends primarily on location and computational task. For cold and temperate regions, this typically results in 15-100% overhead, where the very large ("hyperscale") data centres achieve the lowest overhead [3]. In the tropics, the figure is higher; in our estimate roughly doubling these values. Supplied electricity ultimately transforms into waste heat, which is typically vented out [4], to keep the facility at a degree where servers can function well. Before reaching the servers, the airflow has been filtered and often dehumidified, to prolong the lifespan of the electrical components.

Industrial waste heat temperatures often exceed 100°C, but a data centre's airflow is much lower, generally 30-40°C (high-performance data centres may approach 45°C [5]). This makes turning heat into electricity a non-viable option, as energy conversion losses would be massive. Hence, in order to use the waste heat – that is, 1% of world electricity – we focus on secondary uses for dry, clean, lukewarm air.

In some instances, the waste heat has already been put to good use, and profitably so. For example, the Swedish capital Stockholm heats tens of thousands of homes using data centre waste heat by leading the waste heat airflow to the district heating network [5-7]. Reversing the process, district cooling is potentially obtainable. Still, cooling and heating techniques both rely on temperature differentials: the bigger the difference between waste heat temperature and desired indoor climate, the better – and data centre waste heat is not radically different from room temperature.

The problem space of data centre waste heat begs the question: How can the waste heat be used in temperate regions typically not relying on district heating networks? And how – if at all – can the heat be used in the tropics? This paper explores two novel strategies: commodity dehydration and increasing work efficiency of renewable energy technologies based on thermal principles.

COMMODITY DEHYDRATION

One theme we currently explore, and first presented to the research community in 2020 [8], involves commodity dehydration. This previously uncharted territory would not decrease energy use, but give an ability to repurpose heat to the benefit of high-, mid- and low-income countries around the Globe. Furthermore, using the heat as-is avoids the need for heat exchangers and their associated energy conversion losses. This section discusses the use of data centre waste heat for large-scale and small-scale commodity dehydration, and the production of heat storage units.

Large-scale commodity dehydration

One commodity used for large-scale dehydration is wooden pellets. Such dehydration is carried out during summer in the Swedish town Falun. Here, waste heat from EcoDataCenter dries pellets for heating (in winter, the waste heat is routed to the district heating network).

Many other commodities can potentially be dehydrated using data centre waste heat, such as fruit, fish or tea leaves for human consumption, fodder for cattle, and seaweed for biofuel production. In so doing, data centres would substitute massive amounts of electricity and fossil fuel used for dehydration today.

It is true that in the tropics, many of these commodities are sun-dried. However, the strategy bears merit also there: industrial dehydration in warehouses increases food security since the air is clean and rodents, insects and birds cannot access the commodity. Moreover, the produce can be dehydrated in a controllable fashion and more evenly than through sun-drying, and the humidity of outside air can make sun-drying infeasible anyhow.

What to dry is very site-specific. Ultimately, a plenitude of factors decides: available commodities, heat and humidity, road infrastructure, government policy and several others. The principles of large-scale commodity dehydration are found in Fig. 1a). Here, through a network of actors and activities, farmers or other commodity suppliers become both producers (of data and the commodity at hand) and consumers (again, of data, but also of conserves or other things).

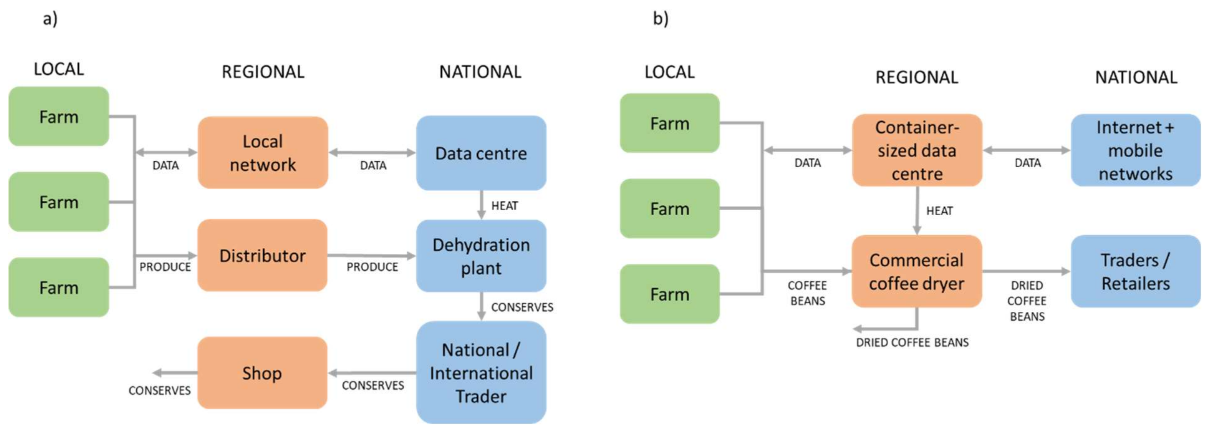

FIGURE 1. a) LARGE-SCALE COMMODITY DEHYDRATION. b) SMALL-SCALE COMMODITY DEHYDRATION.

One suitable large-scale commodity is wood, which usually requires industrial drying to obtain the desired moisture content. In their experiment from a 76 kW data centre, Vesterlund et al. [9] showed that data centre waste heat can dry leftovers from the Nordic forestry industry. Scaling up to a 10 MW data centre and comparing the setup with coal-based dehydration, we find that the approximate annual environmental savings would equal 13 000 tons of coal, that is, 30 000 tons of CO_2 emissions. Moreover, we estimate annual financial earnings of circa 5M euros, again based on [9]. Vesterlund et al. note that outside cold air mixing with the hot airflow hampered the efficiency considerably. In an enclosed building, or in hotter climates, therefore, much higher efficiency may be achievable.

Further research is needed to maximise the benefit in other geographical settings. For example, Malaysia and Indonesia are major forestry producers, and the wood industry is an important socio-economic sector [10], but the humidity in those countries is exceptionally high. Here, the semi-dry heat from a data centre would be quite beneficial, both for drying forestry leftovers and for lumber. Moreover, with lower temperature fluctuations than the Nordics' – where annual differences exceed 50°C – means it is easier to optimise dehydration efficiency.

Small-scale commodity dehydration

In addition to addressing the world's electricity use, data access and commodity dehydration are enablers for building local sustainable communities. One particularly suitable commodity for dehydration is coffee, the world's most traded agricultural commodity in need of dehydration. Coffee beans need drying to achieve moisture levels low enough for extended storage, and to avoid taste deficiencies, the airflow should preferably not exceed 45°C [11]. Moreover, coffee is often produced in humid areas, where sun-drying for partial dehydration is not possible. Therefore, drying is commonly (partly or wholly) carried out using diesel-, wood- or electricity-powered machinery.

For Costa Rica, a substantial coffee producer, about 275 kWh of electricity and 1.5 cubic metres of burned wood are used for every ton of dried coffee [12, 13]. With an annual export of 90 000 tons [14], Costa Rica needs 25 000 MWh and 140 000 m^3 of wood to dry their coffee. The electricity can, in theory, be substituted with a 10 MW data centre running at a typical 30% capacity. (Matters are complicated by the fact that coffee has a limited harvest season. This does not mean the waste heat is useless the rest of the year, though, as other commodities can be dried at those times; leather work comes to mind.)

For an agricultural community away from major cities, the prospects of using data centre waste heat to dry commodities are appealing. Conversely, suppose an existing drying facility in a community may be powered by data centre waste heat. That may attract international data centre builders for both financial and CSR (corporate social responsibility) reasons, in turn increasing ICT availability locally or regionally.

Our vision is illustrated in Fig. 1b). Here, many farms (in this case, coffee plantations) need dehydration, so they already need to transport their undried coffee to a drying facility. In our vision, a small data centre, consisting of servers in a standard freight container, supplies the dryer with heat. This approach – much elaborated upon in [15] – gives more power to local coffee producers: drying coffee beans close to source and then playing a more active role in supply chains may substantially increase profits for local farmers or collective efforts. Bridging political ecology and engineering, this strategy can be used in many countries.

OCEAN THERMAL ENERGY CONVERSION (OTEC) INTEGRATION

Both large and small actors are currently expressing interest in placing data centres near the coastline, or even as floating or submerged facilities, to take advantage of seawater for server cooling. However, even though these maritime data centres have minimal need for electrical server cooling, the waste heat – in this case, the heated seawater – is not used. One option we put forward in 2021 [16] is running a working fluid such as ammonia or seawater between a data centre and a dedicated heat exchanger in an ocean thermal energy conversion (OTEC) plant. This section provides an overview of our proposed idea.

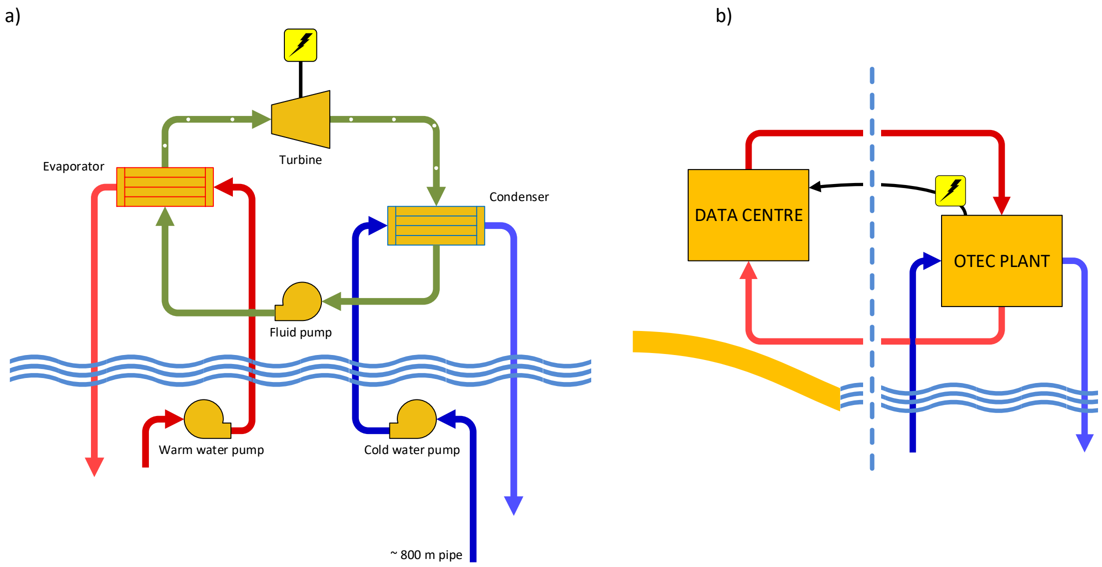

FIGURE 2. a) THE WORKING PRINCIPLE OF CC-OTEC. b) A SHORE-BASED DATA CENTRE AND OTEC.

In OTEC, warm surface water and cold deep ocean water (DOW) interplay to either evaporate and condense a working fluid (closed cycle or CC-OTEC; Fig. 2a), or evaporate the incoming surface water, which produces drinking water as a by-product (open cycle or OC-OTEC). In both cases, the evaporated fluid drives a turbine and generates electricity. OTEC works well in tropical and subtropical regions at temperature differences around 20-25°C [17], which is a lower (better) differential than other heat recovery methods. One barrier to commercial success for OTEC plants is the low energy conversion potential. Albeit an ideal potential of 8%, in a real scenario it is difficult to exceed 4% [18]. Energy conversion is directly corresponding to the temperature differential, so if this can be increased, OTEC plants will become more profitable.

In our proposition, a working fluid (or a separate intake of seawater or river water) would cool the multi-megawatt data centre. The data centre's heat energy is then transferred via heat exchangers to the OTEC plant and the cycle is repeated (see Fig. 2b).

Much of the world's population and financial growth in the coming three decades will take place in Africa and Southeast Asia. Hence, this is where new data centres are needed, and the areas coincide with OTEC's most favourable locations. That being the case, with our method, the geographic area in which OTEC works may be significantly expanded. For example, in the Arabic Peninsula, the water temperature differential is too low for OTEC, but would possibly be big enough with introduced data centre waste heat. If so, OC-OTEC could deliver drinking water to the region. With this solution implemented, OTEC financials would improve and a market space for the technology be created.

OTEC plants can also be used to produce hydrogen gas through electrolysis of the sea water [17], and data centres can provide these plants with heat energy. Incidentally, it has been suggested that future data centres should rely on hydrogen fuel cells for backup power, to replace today's diesel backup solutions [19]. Thus, not only is there a symbiotic relationship regarding electricity between data centres and OTEC plants, but also a supply- and demand-relationship regarding auxiliary power.

CHALLENGES

For both main strategies, some challenges remain. Regarding *commodity dehydration*, the principle has been proven to work, and is used successfully in the Nordics today. Still, to make this strategy work in other contexts, not least in the tropics (or, for that matter, the Arizona desert, which hosts many of the world's biggest data centres), many factors must be taken into consideration. These include temperature, humidity, available commodities, commodity drying season length, political stability, road infrastructure, ICT needs and country financials.

The combination of *OTEC and data centres* is appetising, not least as it may provide a financial injection to the still small OTEC industry. However, the strategy comes with a few challenges. First, there is the question of the OTEC industry itself. The technology has been proven, but needs scaling up. Second, more research is needed to understand how to use the waste heat as efficiently as possible. This (planned) work involves finding the appropriate working fluid and discovering where in the OTEC process to inject it to achieve optimal results.

RELATED WORK

In the literature on energy-efficient or otherwise sustainable data centres, waste heat use is typically ignored, resulting in few writings related to our research. That said, concerning Europe, the possibility of data centre waste heat use has been explored in Britain [20], the Nordics [21, 22] and Europe overall [6, 7]. There are a number of works on industrial waste heat use, but data centre waste heat is often excluded [6] (likely due to its low temperature), even though the data centre industry is very big.

Using OTEC in conjunction with industrial waste heat is not an entirely new idea (though the symbiotic relationship put forward above has not previously been proposed). For example, researchers have investigated the use of heated water from nuclear power plants or gas plants [23, 24]. It was found that with elevated warm water temperatures, not only can the OTEC process be made more efficient, but also used in waters typically too cold for the technology to be financially feasible. The merits of OTEC in wider industrial contexts has been discussed in [25] and [17]. In both instances, OTEC is viewed as a societal enabler and a climate change mitigator for the tropics.

CONCLUSION

Despite the many industry reports on data centre energy savings, surprisingly few discuss waste heat use, and outside of the Nordics, it is not a widely used practice. However, the triangulation-based methodology points towards one single conclusion: data centre waste heat use is possible in both cold and warm climates and regardless of social structures and local financial situation. Evidently, there are several exciting uses for data centre waste heat.

The prospects of *commodity dehydration* with data centre waste heat are promising. The question is no longer whether the concept works, but what commodity to use in what context: one needs to match available commodities to technological advancements, ICT needs, local financial structures and enabling political incentives.

Data centres and OTEC make for an appetising combination. OTEC can deliver constant power and feed on the waste heat that the data centre produces. Moreover, OTEC would offer unlimited and free cooling to the data centre.

The apparent many-to-many relationship that these strategies offer also paves the way for future work regarding engineering design solutions and geography-based case studies.

We claim that for the data centre industry, few, if any, other energy savings can be so easily achieved, and bring the societal gains that data centre waste heat can. Our further work will shed more light on this issue.

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