Going green @ the edge: Cost modelling of edge compute

Mats Eriksson, TietoEVRY / Arctos Labs Scandinavia AB

This document has not been peer-reviewed

I. Abstract

Data is increasingly fuelling the world to become increasingly digital, through technologies related to video, 5G, artificial intelligence, VR/AR etc being explored. To support all these new services, edge compute is promoted.

Edge compute introduce cost issues, that needs to be considered as input for business decisions to build or use a distributed set of clouds. As described in [10[1], 14[2]] the economy-of-scale aspects may make smaller data centres less efficient. It is also well known that green-gas emissions from data centres are significant, and on the rise, whereby efficiency becomes increasingly important.

Also, as shown in [13[3], 16[4]] the cost of data transport is already significant and today contributing to double-digit figures of global electricity consumption. Those figures can only be expected to increase as the world becomes more dependent on data.

These two trends raise the question on whether it is more efficient to move around data or whether less data transfer would justify a potentially less efficient data centre closer to the user.

There are two aspects related to cost and the edge-to-cloud continuum. The first one is related to the decision of investment into (edge) data centres and the overall costs related to building and operating such environments.

The second issue is how to optimally utilize the computing assets available at any given time. This issue represents the marginal cost of producing an additional service in a certain environment and its related optimization.

This paper introduces a model for such marginal costs and the savings that can be achieved across an edge-to-cloud continuum. We can view the question such that if these edge data centres would be built for other reasons – say 5G – and we have additional workloads to be deployed.

Where is then the most cost-efficient or environmentally friendly location to place those workloads?

II. Intro

a. Edge compute – device-to-cloud continuum

When considering Edge compute, it is obvious that location matters. The whole concept is to be able to control where applications are deployed along a continuum from the source /

[1] [10] "United States Data Center Energy Usage Report", June 2016

[2] [14] "The economics of the cloud", Rolf Harms; Michael Yamartino, Microsoft

[3] [13] "Evaluating Sustainable Interaction Design of Digital Services: The Case of YouTube", Schien et al, University of Bristol

[4] [16] "On Global Electricity Usage of Communication Technology: Trends to 2030", Andrae, Edler

consumer of data (device) to the (maybe unknown place of) the cloud. The reason for doing so is to be able to achieve certain benefits, such as lower latency, data transport off-loads or lower costs.

The potential places for compute resources along that continuum are interconnected through a data transport fabric, with a certain topology and characteristics.

A concept and terminology to describe Edge & Fog compute is introduced in [9][5], that outlines Devices, Mist & Fog computing, and centralized clouds. Alternative concepts and terminology have arisen, giving confusion into the term of edge compute.

a. *Placement – Constraints vs optimization*

There are basically two reasons for deciding placement. It is either due to constraints – i.e. the application will not fulfil its purpose if it is located too far away from devices. Examples here are machine control in industry environments. We refer to these criteria's as `constraints`.

The other reason is that it is more optimal to select a certain location over another. This may be so that application performance (in the eye of the user) improves, or cost of producing the service is reduced. The latter means that more efficient resource usage, or service quality can be achieved. We refer to this as `optimal`, i.e. a result of `optimization`

b. *Cost of compute*

In [3][6], Walker introduces a basic model for calculating the cost of a CPU hour, that is applied in many papers. The model captures both OPEX and CAPEX aspects of delivering compute capacity and uses a net-present-value of the CPU's and the net-present-capacity of the DC. The model considers amortization as well as decreasing relative value of CPU's derived from Moore's law.

$$NPV\ (cost) = \sum_{T=1}^{Y} \frac{(-L_T)}{(1+k)^T} - A$$

Where L_T is the pre-tax cash cost required to operate the asset at year T; k is the cost of capital; Y is the expected lifetime; A is the cash purchase price of the asset.

Walker's model is used, and additional software execution models introduced in [2][7].

A cost analysis for edge compute off-load based on Walker's model is outlined in [1][8]. As Walker's model is targeting a build vs "rent-in-cloud" decision any derivative from Walker do the same.

As outlined in [14][9], the economy of scale effects is huge for operating data centres, coming from both server procurement costs as a function of volume, energy costs negotiated, cooling system efficiency as well as staffing efficiencies. Furthermore, the economy of scale is improved through the ability to better multiplex workloads thereby increase the DC utilization.

Energy consumed by servers do not scale linear with the workload / performance applied. This effect is reported in [7][10] and as servers can draw somewhere between 25-60% of their maximum power when idle, utilization should be kept high to operate efficiently.

---

5 [9] "Fog Computing Conceptual Model", NIST

6 [3] "The Real Cost of a CPU Hour", E. Walker

7 [2] "Cost effectiveness of commercial computing clouds", S. Brumec and N. Vrcek,

8 [1] "How beneficial are intermediate layer Data Centers in Mobile Edge Networks?", Mehta, Amardeep; Tärneberg, William; Klein, Cristian; Tordsson, Johan; Kihl, Maria; Elmroth, Erik

9 [14] "The economics of the cloud", Rolf Harms; Michael Yamartino, Microsoft

10 [7] "Analysis of the Influences on Server Power Consumption and Energy Efficiency for CPU-Intensive Workloads", Kistowski, Joakim; Block, Hansfried; Beckett, John; Lange, Klaus-Dieter; Arnold, Jeremy; Kounev, Samuel

The above also implies that the marginal energy consumed when adding workloads are quite limited. As outlined in [15][11], power usage effectiveness (PUE) varies between smaller and larger DC's. Smaller DC's can be as high as double that of larger, but there is clear trend that overall figures are going down. It is worth mentioning that some of these reports compare older small data centres with newer modern large size facilities.

c. Cost of transport

In [4][12], an elaboration on real costs for data transport is introduced, emerging from Bell figures made public. These figures depend on a range of variables, such as the technology used, the topology of the network, utilization, labour costs, lifetime just to name a few.

In [1][3], the model from Bell have been applied to a topology tree with three types of links; OC3, OC12 & OC48 and costs were calculated using the method from [4] [7].

It outlines costs as follows:

	OC3 (155)	OC12 (622)	OC48 (2500)
Cost ($ / GB)	0,30	0,10	0,08
Relative cost ratio	4,06	1,29	1

Table 1: Data Transfer Costs from [1]

Figures are also consistent with [5][13]. In [6][14], a similar cost ratio is outlined with normalized annual costs for a 2Mb/s connection per km.

Connection distance	Normalized annual cost / km
50 km	0,08
200 km	0,03
400 km	0,02
800 km	0,01

Table 2: Data Transfer Costs from [6]

It is consistent in the opinion that last mile access & first aggregation is more costly. Probably due to two issues; firstly, the utilization is lower, and secondly economy of scale. I.e. the labour costs become an increasing part of the cost structure compared to high capacity links.

Energy consumption for data transport has been studied in several papers. In [11][15] an LCA analysis was made on Telia's (Sweden) core network arriving at a consumption of 0,08 kWh/GB. In [12][16] a larger variety of reports are assessed with an upper-bound of 0,2 kWh/GB down to 0,02 kWh/GB (and even further).

Figures reported depends heavily on which part of the data transport network that is covered. The access parts of networks consume more than the core & transit parts as outlined by [13][17].

In [16][18], contribution from data transport technologies is expected to reach a stunning 10% of global electricity consumption in 2030.

III. PROBLEM STATEMENT AND MODEL APPROACH

As stated previously, this paper focus on the aspect of deploying new services across an

[11] [15] "Energy Efficiency Policy Options for Australian and New Zealand Data Centres", Consumer Research Associates, April 2014

[12] [4] "Canada's Usage Based Billing Controversy: How to address the Wholesale and Retail Issues,"

[13] [5] "Don't worry- Mobile broadband is profitable, Ericsson"

[14] [6] "Cost analysis of the transmission backbone", M. Naldi, Università di Roma "Tor Vergata", Italy – P. Pelusi, Wind Telecomunicazioni, Italy

[15] [11] "LCA of data transmission and IP core networks", Malmodin et. al.

[16] [12] "The Energy Intensity of the Internet:Home and Access Networks", Coroama, Schien et. al.

[17] [13] "Evaluating Sustainable Interaction Design of Digital Services: The Case of YouTube", Schien et al, University of Bristol

[18] [16] "On Global Electricity Usage of Communication Technology: Trends to 2030", Andrae, Edler

existing device-mist-fog-cloud continuum in a cost optimal way.

Optimal is here defined as minimal marginal cost (i.e. the added cost of producing an additional service) in an existing production environment consisting of data centres across a data transport topology.

We have made the following simplifications:

- There are no additional operational staff costs for adding a single new service
- Resources are available at the considered data centres – i.e. no additional installations needed
- Bandwidth is available at the needed data transport links – i.e. no additional installations required

The above assumptions imply that this paper and the conclusions do not consider the problem of resource management. I.e. the algorithms needed to determine if a request can be served by the existing capacity or not, i.e. aspects of statistical multiplexing. This is a separate problem.

Therefore, we make the conclusion that the marginal cost of adding a service consists only of the additional energy consumption because of such service being produced.

It also implies that criteria for cost and environmental impact coincides.

d. The marginal cost for compute

To determine the marginal cost for compute, we need to understand to what extent servers comply to `energy proportionality` (i.e. when running at *N* % load, it consumes *N* % of maximum power).

In [7][19] this has been analysed by using Standard Performance Evaluation Corporation' server efficiency rating tool benchmarks [8][20]. It shows that even the proportionality property has improved, it is still some 25% power consumed at 10% load. From that point the load consumption is different for different benchmarks within the tool (depending on the internal SW architecture of individual benchmarks).

We calculated an average over the various benchmarks of the tool, concluding in the following profile.

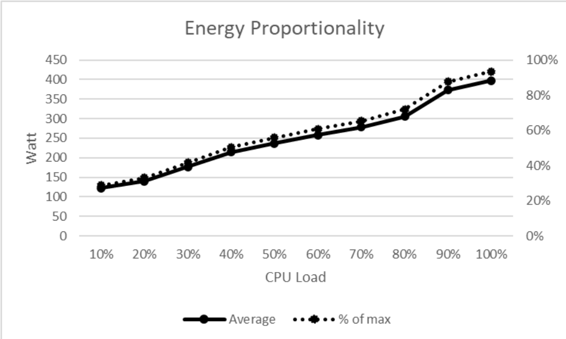

Figure 1: Energy proportionality average for SPEC energy benchmark

If we simplify this to a linear dependency from P_{idle} to P_{max}, we can express the power consumed at a certain utilization (U) as:

$$P = P_{idle} + P_{max} * \left(1 - \frac{P_{idle}}{P_{max}}\right) * U$$

The server used for the above benchmark had a max power (P_{max}) of 450 W, running over 16 cores. This means it can produce 16 CPU-h per hour of operation.

So, adding an additional CPU-h corresponds to increasing the utilization by 6%. Applying the formula above arrives in an increase of 21 W for an additional CPU-h.

But as outlined in [15][21] ,PUE may vary between DC sizes, so an increase in server power must

[19] [7] "Analysis of the Influences on Server Power Consumption and Energy Efficiency for CPU-Intensive Workloads", Kistowski, Joakim; Block, Hansfried; Beckett, John; Lange, Klaus-Dieter; Arnold, Jeremy; Kounev, Samuel

[20] [8] Standard Performance Evaluation Corporation, http://spec.org

[21] [15] "Energy Efficiency Policy Options for Australian and New Zealand Data Centres", Consumer Research Associates, April 2014

also be multiplied with the PUE corresponding to the size of DC.

We can then multiply the result with the price of energy arriving in the following formula for calculating the delta-cost imposed by an additional CPU-hour.

$$\Delta COST_{CPUh} = \frac{1}{C_{server}} * \frac{(P_{max} - P_{idle})}{1000} * PUE * COST_{energy}$$

Where C_{server} is the total no of CPU-h/h delivered by the server

e. The marginal cost for data transport

As outlined previously, there are numerous investigations on the energy consumed by transmitting a GB through a network.

We can assume there to be a similar non-proportional property of networks, although we have not found any such data.

So, in our modelling we have therefore applied the energy consumption from [11][22] – 0,08 kWh/GB.

This energy consumption has been applied both in access-, aggregation- and core networks. We can then view it as a best case as it is reasonable to consider real costs for the access layer to be higher than for core networks.

f. Price of energy

In our calculations we have applied a cost of energy of 0,1 $/kWh. As the optimization criteria is the same for cost and energy, all conclusions in this paper is independent of the price of energy.

g. Topology analysed

We have applied the topology from [1][23] in our modelling. This means that we have three layers of DC's interconnected in a tree structure. It is a simplification as some interconnections east-west as well as ring structures will typically be used in real networks.

Furthermore, this simple topology does not cater for the energy consumption effects of multiple hops used for moving data on the links in the topology. We also assume that the DC's are located on the route between the device and the top-level DC.

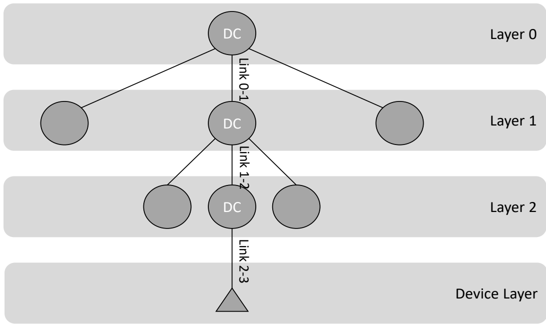

Figure 2: Topology analysed

In our analysis, we have varied the number of servers on each layer to be 1, 15, 150, 1 500 or 15 000 servers.

PUE's are from [15][24], selecting the closest DC size and assuming a PUE for the nano DC size.

Slogan	no of Servers	Cost ($/CPH-h) - marginal	PUE
nano	1	0,0053	*2,5*
micro	15	0,0048	2,27
mini	150	0,0045	2,11
small	1 500	0,0039	1,85
regular	15 000	0,0033	1,57

Table 1: Data centre types and no of servers used

a. Workloads used for the model

We can classify workloads with respect to their needs for compute and data transport. A general trend is that workloads tend to increase their need for both data transport and compute.

---

22 [11] "LCA of data transmission and IP core networks", Malmodin et. al.

23 [1] "How beneficial are intermediate layer Data Centers in Mobile Edge Networks?", Mehta, Amardeep; Tärneberg, William; Klein, Cristian; Tordsson, Johan; Kihl, Maria; Elmroth, Erik

24 [15] "Energy Efficiency Policy Options for Australian and New Zealand Data Centres", Consumer Research Associates, April 2014

	Low amount of compute	**High amount of compute**
Low amount of data	Low cost so placement is less sensitive	Compute cost dominate – central location
High amount of data	Data transport cost dominate, placement – closer to edge	Need for more detailed modelling

Table 2: Different types of workloads

We have used the following three workloads to find examples that can be placed in all three interesting categories (they are used merely as examples of effects of placement).

Webserver

Based on Apache bench, we have captured the amount of data transferred for rendering of an example webpage as well as the compute consumed for doing so. We are only interested in the relation between data and compute, to analyse where in the topology that work should be best placed. In this case, it is also clear that data for the webpage needs to be available. This aspect has been omitted in the analysis assuming that all data needed are available at all locations and no additional transfer need to take place.

This is a workload that is quite data intense in relation to the compute work needed to render the webpage.

Video compression

Here we have used a benchmark from SPEC [8][25], that compresses a YUV file into an MPEG-4 file. In this analysis we assume that the YUV file emerges from the device and sent upstream for compression. The compressed result is then sent further upstream to Layer 0.

So, we have a data transport input, a compute workload, and a data transport output to take into consideration.

This workload is both data and compute hungry.

[25] [8] Standard Performance Evaluation Corporation, http://spec.org

Image manipulation

This is another workload in the SPEC benchmark series. It operates on a 2068x1380 pixel image as input and manipulates the image in a series of operations, resulting in a 3299x5002 pixel image that we assume is sent upstream towards layer 0.

This workload is very compute intensive at a moderate need for data transport.

Summary of the workloads

Application	CPU/h	GB (in)	GB (out)	Slogan
1	0,001	0,0059	0	web
2	0,43	0,07	0,009	video compression
3	1,350	0,009	0,050	Image manipulation

Table 3: Summary of the workloads

Note: The needed compute and data relates to very different work and cannot be compared between each other. It is the ratio between compute and data transport that is interesting.

IV. Modelling Results

Firstly, we analyse a configuration where:

- Layer 0 is size regular (15 000 servers)
- Layer 1 is size small (1 500 servers)
- Layer 2 is size micro (15 servers)

We capture cost savings of decentralizing each of the applications from Layer 0, to either Layer 1 or Layer 2, expressed as savings compared to running the workload at Layer 0.

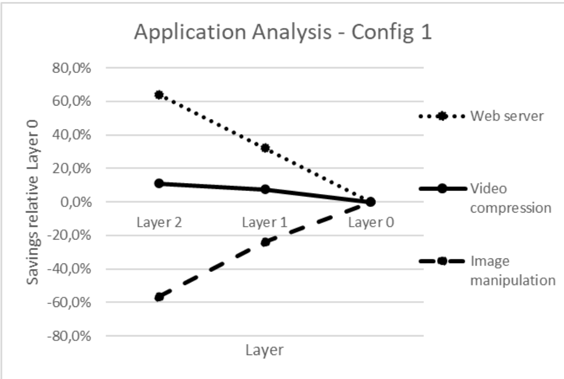

Figure 3: Application savings

The Web server application, being quite data hungry exposes savings above 60% when being distributed, whilst the video compression have more modest savings of slightly over 10% and the image manipulation experience an increased cost of almost 60% and should be kept centralized.

If we instead apply the same PUE across all DC sizes (1,57), the results will point even more in favour of distributed computing.

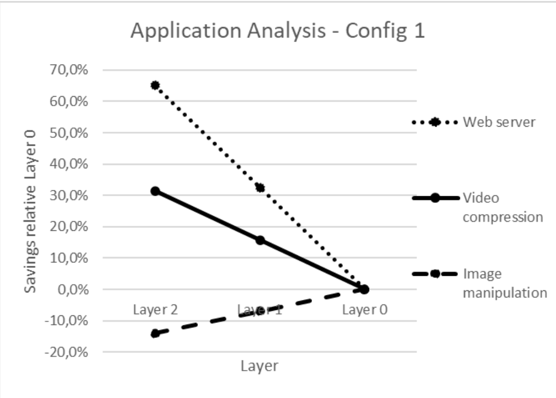

Figure 4: Sensitivity for size of Layer 2 DC

If we analyse the video compression workload and the sensitivity towards the size of the Layer 2 data centre (i.e. their PUE), the following results is achieved:

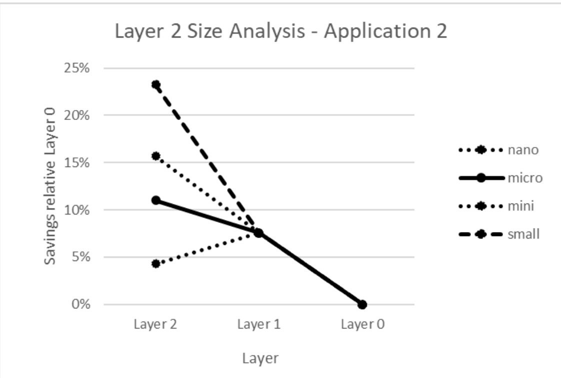

Figure 5: Sensitivity for size of Layer 2 DC

The solid line is the same as in figure 3, whilst the various dotted line represents savings that would appear with smaller or larger Layer 2 DC's. As can be expected, increasing the efficiency at layer 2, increases the savings possible.

Note: The efficiency in DC's in our model is entirely derived from PUE. So, achieving a good PUE for a small DC would be crucial to maximize savings for distributed computing.

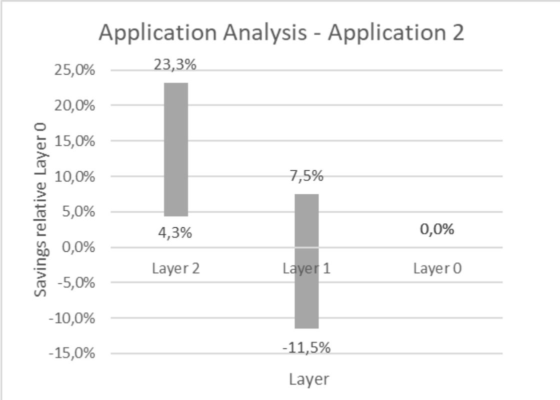

Figure 6: Sensitivity for size of Layer 2 DC

A similar effect is achieved also at Layer 1, with the difference that a small DC would yield an 11,5% cost increase depending on the size. This implies that smaller DC's needs to be utilized quite far out in the topology to harvest savings.

As been stated earlier, the marginal cost comes from the marginal increase in energy consumption from adding an instance of the workload.

It is quite clear that a substantial consumption comes from data transport, in different ways for different applications.

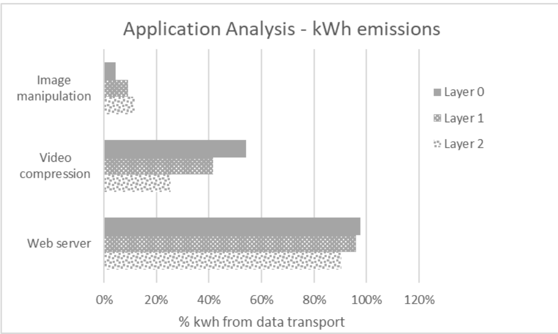

Figure 7: Portion of kWh coming from data transport depending on the placement

It is obviously so, that very compute intense workloads with little or limited need for data transport would be best optimized in highly efficient data centres, whereas other workloads that are more data intense would be best placed closer to the edge of the network.

V. Discussion

This paper outlines significant savings both in costs as well as in environmental impact from better utilizing the opportunity of placing workloads closer to the devices in an edge setup. Based on [16][26], and a potential of substantial savings this paper introduces a model for saving maybe 2-5% of global electricity consumption by 2030.

Most analysis related to cost of operating an edge cloud is based on a comparison between a highly automated and efficient public (large) data centre and legacy enterprise operations. This is somewhat unfair as there are multiple ways to increase the efficiency also for smaller data centres. But even so, edge DC's are geographically dispersed, so some additional costs cannot be avoided.

In real commercial settings, a consumer needs to consider whether to build or buy from a public cloud provider. This question needs careful consideration and relates heavily on the variation of the expected workloads and resulting variation in utilization.

This paper analyses only the marginal costs incurred by additional workloads and therefore do not intend to capture a full life-cycle cost analysis. Both our analysis, as well as a full LCA needs also to consider the aspect of make-vs-buy. We have taken an optimization perspective on edge compute, assuming that premises are built for other reasons, e.g. to deploy 5G.

b. Workload constraints

All the above have assumed that there are no other criteria for placement than the cost & energy consumed of producing the extra work.

Normal workloads have a limit as to how far away they can be placed, whilst still serving the users in an acceptable way. Such constraints need to be considered for a placement decision.

c. Mobile workloads

This paper has not considered users moving in the geography, whose applications would then require compute at various locations over a period.

Such scenarios represent a very specific constraint and more advanced mechanisms to support moving of compute and the application context data in a way that comply with the optimization outlined by this paper.

d. Placement automation

It is obvious to the authors that the placement optimization needed to harvest the savings of this paper can hardly be a manual task. It needs cloud-scale automation across the entire network.

This topic needs further research to enable the scale and intelligence required to maximize the 2-5% electricity saving potential outlined by this paper.

[26] [16] "On Global Electricity Usage of Communication Technology: Trends to 2030", Andrae, Edler

VI. REFERENCES

[1] "How beneficial are intermediate layer Data Centers in Mobile Edge Networks?", Mehta, Amardeep; Tärneberg, William; Klein, Cristian; Tordsson, Johan; Kihl, Maria; Elmroth, Erik

[2] "Cost effectiveness of commercial computing clouds", S. Brumec and N. Vrcek,

[3] "The Real Cost of a CPU Hour", E. Walker

[4] "Canada's Usage Based Billing Controversy: How to address the Wholesale and Retail Issues," https://www.queensu.ca/lawjournal/sites/webpublish.queensu.ca.qljwww/files/files/issues/pastissues/Volume37a/6-Geist.pdf. Accessed 2020-05-14

[5] "Don't worry- Mobile broadband is profitable," http://www.ericsson.com/ericsson/corpinfo/publications/ericsson_business_review/pdf/209/209_BUSINESS_CASE_mobile_broadband.pdf

[6] "Cost analysis of the transmission backbone", M. Naldi, Università di Roma "Tor Vergata", Italy – P. Pelusi, Wind Telecomunicazioni, Italy

[7] "Analysis of the Influences on Server Power Consumption and Energy Efficiency for CPU-Intensive Workloads", Kistowski, Joakim; Block, Hansfried; Beckett, John; Lange, Klaus-Dieter; Arnold, Jeremy; Kounev, Samuel

[8] Standard Performance Evaluation Corporation, http://spec.org

[9] "Fog Computing Conceptual Model", NIST, https://doi.org/10.6028/NIST.SP.500-325

[10] "United States Data Center Energy Usage Report", June 2016

[11] "LCA of data transmission and IP core networks", Malmodin et. al. (available at https://www.ericsson.com/en/reports-and-papers/research-papers/lca-of-data-transmission-and-ip-core-networks, accessed May 2020)

[12] "The Energy Intensity of the Internet:Home and Access Networks", Coroama, Schien et. al.

[13] "Evaluating Sustainable Interaction Design of Digital Services: The Case of YouTube", Schien et al, University of Bristol

[14] "The economics of the cloud", Rolf Harms; Michael Yamartino, Microsoft

[15] "Energy Efficiency Policy Options for Australian and New Zealand Data Centres", Consumer Research Associates, April 2014

[16] "On Global Electricity Usage of Communication Technology: Trends to 2030", Andrae, Edler