Mid-Term Evaluation of the Cloudberry Datacenter Project

1. Executive Summary

Scientific Impact

The “Cloudberry Datacenters” project is an ambitious effort to “develop new knowledge about energy and resource-efficient data centers by conducting high-quality research [5].”

The Cloudberry Datacenter has an exceptional production of high-quality journal papers and conference contributions in highly respected channels, e.g., by IEEE and ACM [17]. The center has succeeded in involving very experienced senior researchers in combination with very talented and motivated Ph.D. candidates.

The evaluator recommends updating the concept of the “Cloudberry Days” for more interaction of the audience with presenters, and especially the invited, high profile, international guests.

Industry and Society Impact

Several of the subprojects had very good interactions with industry, e.g., Ericsson, Luleå Energy, and Optima AB. These companies gave very positive feedback about relevance of the results.

Project representatives contributed to local events, e.g., by Business Region Liuleå [21] and national events hosted, e.g., “Energi- och resurseffektiva datacenter” by Energimyndigheten, and “Branschutveckling och innovation inom svensk datacenterindustri” in Stockholm.

The evaluator recommends reviewing and strengthening the relationship with Facebook’s Data Center in Luleå.

Project Implementation

The excellent results indicate that the project runs smoothly and according to plan. Researchers are positive about the center and its activities. Communication is efficient and the Cloudberry Datacenter home page is up to date with relevant news, events, and publications.

The evaluator recommends creating more cooperation between the 12 subprojects.

Final Statement

The “Cloudberry Datacenters” project is of national relevance as it studies sustainable solutions for a future information society in which the need for increased information processing requires new expertise in preserving energy at the same time.

Prof. Frank Reichert, University of Agder, Norway, May 16, 2021

2. Evaluation Approach

“Cloud Datacenters” is a research center hosted by the University of Luleå in cooperation with RISE SICS North. The center consists of 12 subprojects and has a budget of about 60 MSEK for a duration of 4 years [1-3] provided by public and industrial funding. The center started April 1, 2018, and this review will comment on the first half of the project.

The center’s purpose is to “develop new knowledge about energy and resource-efficient data centers by conducting high-quality research [4].” Topics address energy use in data centers, reduction of global carbon dioxide emissions and to contribute to a more efficient energy system as a whole [5].

This evaluation follows three main criteria that are typical for research projects [7]:

- Scientific Excellence
- Impact
- Project Implementation

The result of the evaluation is based on zoom interviews with lead scientists, project management, and provided project documents.

3. Scientific Excellence

3.1. Summary

The research projects are of outstanding scientific quality. The results are a combination of highly motivated and very experienced senior researchers with long years of successful international research and very talented Ph.D. candidates who succeed in publishing articles in relevant, peer-reviewed channels. The projects analyze and model real-world configurations to arrive at new models and energy-efficient control strategies. Many of the results have been communicated in workshops and direct meetings with the industry.

3.2. Comments on the reviewed subprojects.

The zoom interviews addressed six subprojects DP4, DP8-12 of the following twelve Cloudberry subprojects:

DP1 Datacenter's interaction with the national energy system
DP2 Multifunctional data centers
DP3 Quality and credibility when simulating cooling in data centers
DP4 Transient simulations of thermodynamic connections in data centers (Jon Summers)
DP5 Evaluation of energy recovery solutions for data centers
DP6 Design of distribution networks for energy-efficient data center operations
DP7 The impact of data centers on the electricity market with an increased share of renewable electricity generation
DP8 Flexible and large-scale simulation of interaction between district heating and remote cooling networks and data centers (Wolfgang Birk)
DP9 Liquid cooling in data centers for direct heat recovery (Jon Summers)
DP10 Automated maintenance of energy-efficient data centers (Chen-Wei Yang)
DP11 Resource efficiency in software processes and communication in data clouds and data centers (Olov Schelén)
DP12 Resource efficiency in distributed ledgers and smart contracts (Olov Schelén)

3.3. DP4 and DP9 (Jon Summers, April 21, 2021)

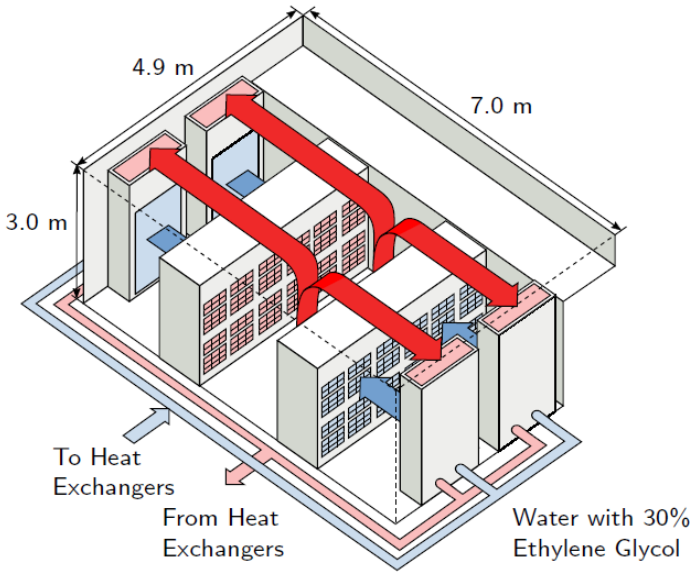
Prof. Jon Summers [8] is an international researcher at Luleå University and RISE SICS with over 25 years of experience in High-Performance Computing (Leeds University), thermal management, and energy flow projects within Data Centres, Heating Ventilation and Air Conditioning, and industrial sectors. Google Scholar lists over 110 publications, e.g., in highly respected IEEE and ACM journals and conferences.

DP4 Transient simulations of thermodynamic connections in data centers (Jon Summers)

“The project aims to develop a simulation tool to capture the dynamics of thermo fluidics for the

cooling of large-scale distributed IT systems, commonly found in modern data centers. A validated, quick, simulation tool will be able to analyze the benefits of different layouts at data centers and heat dissipation methods in case of alternating loads as well as disturbances and errors. [4]”

In the presentation “Lattice Boltzmann Method comparison for Data Center Thermal Conditions,” Johannes Sjölund” modeled the heat flow in data center. The model tried to evaluate a more detailed analytical model. However, results show that “D3Q27 MRT model yields no better results than D3Q19 SRT model.” The next steps propose using simulation as training input to reinforcement learning cooling control software.

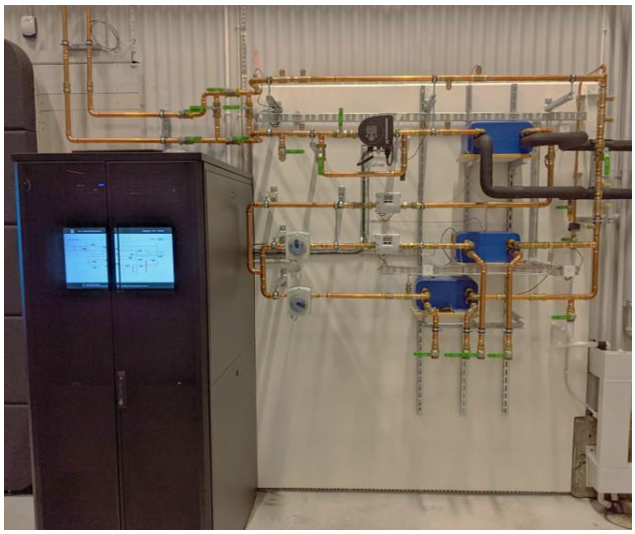


The results are highly relevant for better understanding and planning real systems.

DP9 Liquid cooling in data centers for direct heat recovery (Jon Summers)

The project aims at “Theoretical and experimental analysis of liquid-cooled IT systems for direct heat recovery.[4]”

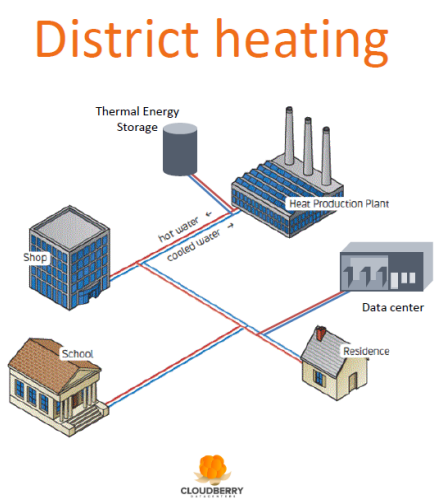
Jon Summers presented the results by Sebastian Fredriksson to develop a solution to “design system and controller so that IT hardware operate within safe temperatures, and also, strive towards an operating system that yields highest possible outlet temperatures delivered to heat exchanger”



The project is an excellent project of creating models and understanding of the cooling process with later prototyping to develop new practical cooling strategies.

3.4. DP8 Flexible and large-scale simulation of interaction between district heating and remote cooling networks and data centers (Wolfgang Birk, April 20, 2021)

Prof. Wolfgang Birk [9] is a professor of Automatic Control at Luleå University with a long experience in research and industry. He successfully completed a large number of research projects and won prestigious awards for his work like the “Henry Ford Technology Award” for innovation. Google Scholar lists about 130 publications in well-respected publications channels.



The SImberry subproject with Luleå Energy and Optimation AB addresses “Flexible and large scale simulation of interaction between district heating and remote cooling networks and data centers.[10]”

The project faces the challenge of creating meaningful, computable modeling of a municipal heat network using the waste energy of a data center and other industrial sites (e.g. a steel plant)..

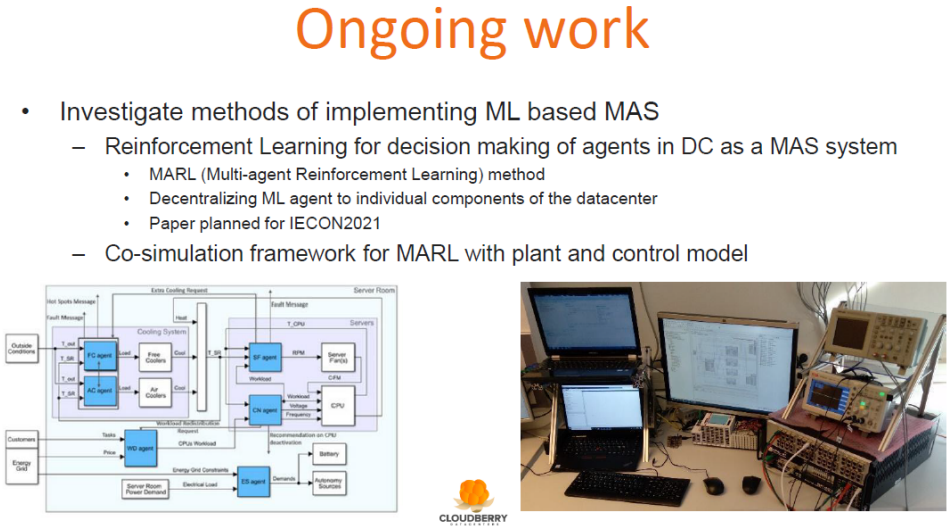
Current simulations are only about 4-5 time real-time and thereby much too slow. New methods involving “Gaussian Processes” look promising for the next phase of the project.

The project has good interaction with its local industrial partners and its international research network. The project is very productive with 4 high-quality, international publications already and an upcoming licentiate thesis in May 2021.

3.5. DP10 Automated maintenance of energy-efficient data centers (Chen-Wei Yang, April 19 2021)

DP 10 “Investigates appropriate methods for intelligent and automated server room maintenance systems and measure the impact on data center energy efficiency. [4]”

Dr. Chen-Wei Yang [11] is a Senior Lecturer at Luleå University since 2018 in Dependable Communication and Computation Systems with about 50 publications listed by Google Scholar, e.g. at prestigious IEEE conferences and in IEEE journals. DP10 has been very productive with six publications during the project duration.



The project models a multi-agent control system (MAS) to control, e.g., the CPU fans in server rooms with stacks of CPUs. The project is now looking at methods of implementing and validating a MAS using machine learning.

3.6. DP11 Resource efficiency in software processes and communication in data clouds and data centers (Olov Schelén, April 19, 2021)

Prof. Olov Schelén is a professor at the Pervasive and Mobile Computing Laboratory of Luleå University with a research interest in Cyber-Physical Systems. His most-cited journal paper in the ACM SIGMOBILE's "Mobile Computing and Communications Review" [14] has 2999 citations according to Google Scholar.

DP11 studies a general software architecture that provides resource-efficient methods for virtualization of software processes and communication between them in a distributed environment. The results were recently published in IEEE Transactions on Cloud Computing in article titled "HYDRA: Decentralized Location-aware Orchestration of Containerized Applications." by Lara Lorna Jiménez and her Supervisor Olov Schelén. The proposed orchestrator provides "churn resistance, failure prevention, and recovery for the management of applications and the applications themselves." Ericsson regarded the results as very important for their future service and communication architectures.

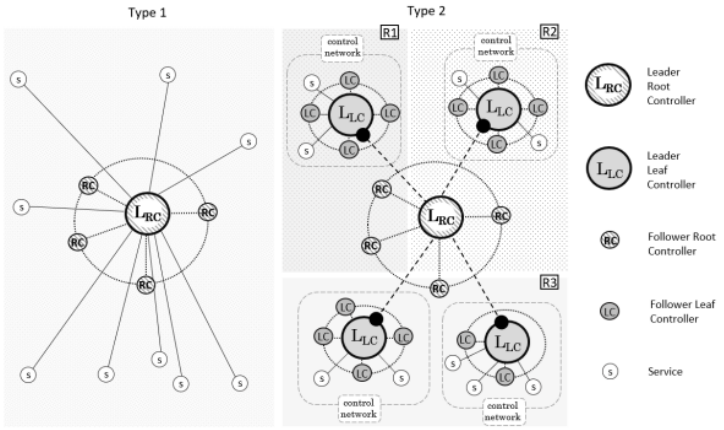


Fig. 1. This shows an example of application control through two control types. The application is composed of 9 services. In type 1 (on the left), the HYDRA orchestrator is not location-aware, and therefore, neither is the placement of services. There is a single management layer performed by the root controllers. HYDRA is location-aware in type 2 (on the right), and so is the deployment of services. The root controllers carry out global, lightweight management, and the leaf controller sets perform local, active management.

3.7. DP12 Resource efficiency in distributed ledgers and smart contracts (Olov Schelén, April 19, 2021)

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DP12 studies blockchain solutions for more flexible charging/re-selling of energy trading exemplified in the context of electric vehicles to replace existing centralized systems where

consumers have to have multiple subscriptions with different service providers while roaming. These new solutions enable, e.g. peer-to-peer transactions. Results are published in several articles, e.g.,in [16] A. A. Monrat, O. Schelén, and K. Andersson, “Blockchain Mobility Solution for Charging Transactions of Electrical Vehicles,” in 2020 IEEE/ACM 13th International Conference on Utility and Cloud Computing (UCC), 2020, pp. 348–253.

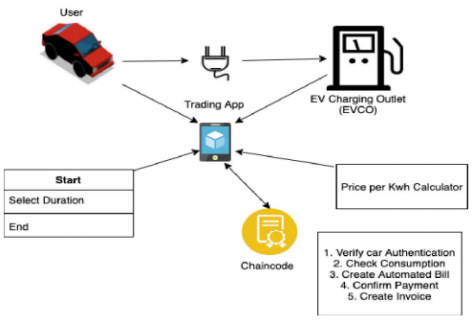

Fig. 2. System Architecture of the Blockchain based EV charging transaction system

The article presented the methodology, system architecture, and implementation of the solution. Future work will address scalability and privacy.

4. Scientific Impact

The Cloudberry Datacenter has an exceptional production of journal papers and conference contributions in highly respected channels, e.g., by IEEE and ACM [17].

The center has succeeded in involving very experienced senior researchers in combination with very talented and motivated Ph.D. candidates.

The center has reached out to a broader audience via yearly Cloudberry Days in 2019, 2020, and 2021. The 2021 workshop included presentations from internationally leading institutions and colleagues such as prof. Jos Keurentjes [18], director of University of Twente's Centre for Energy Innovation (CEI). Events like these prepare the ground for future EU projects.

The Cloudberry Days would benefit from a more strategic approach to discussions. During my attendance, I could hardly observe any interaction from Ph.D. candidates or other participants. Questions were few after a presentation with the exception of one very engaged colleague. My proposal would be to require that Ph.D. students prepare questions for at least two of the presentations. Especially an opportunity to interact with guest presenters should not be lost.

5. Industry and Society Impact

Several of the subprojects had very good interactions with industry, e.g., Ericsson, Luleå Energy, and Optima AB. These companies gave very good feedback about the results.

Project representatives contributed to local events, e.g., by Business Region Liuleå [21] and national events hosted, e.g., “Energi- och resurseffektiva datacenter” by Energimyndigheten, and “Branschutveckling och innovation inom svensk datacenterindustri” in Stockholm.

Throughout the process, I tried to understand the interaction with Facebook’s Data Center in Luleå [22,23]. Based on the responses and web searches it remains unclear whether the university and the Cloudberry datacenter have established a productive relationship.

The town of Luleå is very fortunate to host the Luleå University of Technology, and that the university attracted a major expertise center in energy efficiency. It is unclear how the municipality’s “Luleå Vision 2050 [19,20]” is influenced by the university and the results of the center.

6. Project Implementation

The excellent results indicate that the project runs smoothly and according to plan. Researchers were positive about the center and its activities.

Communication is efficient and the Cloudberry Datacenter home page is up to date with relevant news, events, and publications.

The management is proactively preparing a number of follow-on projects for the future in cooperation with potential partners.

The project structure with 12 subprojects creates an internal communication and management challenge. For the evaluator it is evident that some of the subprojects would benefit from closer cooperation. This can be addressed, e.g., by defining a few “thematic areas”, a WP leader forum with very short briefs about current activities, or motivating PhD candidates to take a more active role in workshops.

The progress report in Appendix 1.1 [3] would benefit from a standard format for each subproject clearly stating achieved (!) results and ongoing activities.Some statements were rather short, e.g., DP7.

7. References

[1] Andersson, Karl, “Lägesrapporten - Forskningscentrum Cloudberry Datacenters.” Sep. 15, 2020.

[2] “Lägesrapport 2020-09-15, Forskningscentrum Cloudberry Datacenters. Bilaga 1.” Sep. 15, 2020.

[3] “Lägesrapport 2020-09-15, Forskningscentrum Cloudberry Datacenters. Underbilaga 1.1.” Sep. 15, 2020.

[4] “Cloudberry Datacenters - Powerpoint Presentation.” Feb. 19, 2021.

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[7] “Processing of grant applications.” https://www.forskningsradet.no/en/processing-grant-applications/processing-applications/processing-of-grant-applications/ (accessed May 16, 2021).

[8] “Jon Summers, Senior Forskare,” RISE. https://www.ri.se/en/person/jon-summers

[9] “Wolfgang Birk, Professor.” https://www.ltu.se/staff/w/wolfgang-1.10529?l=en

[10] “Simberry - Powerpoint Presentation.” Apr. 20, 2021.

[11] “Chen-Wei Yang, Senior Lecturer.” https://www.ltu.se/staff/c/cheyan-1.107291?l=en

[12] Y. Berezovskaya and Y. Chenb-Wei, “SubProject 10: Automated Maintenance of Energy Efficient Data Centers - Powerpoint Presentation.” Apr. 19, 2021.

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[14] A. Lindgren, A. Doria, and O. Schelén, “Probabilistic routing in intermittently connected networks,” ACM SIGMOBILE mobile computing and communications review, vol. 7, no. 3, pp. 19–20, 2003.

[15] L. L. Jimenez and O. Schelen, “HYDRA: Decentralized Location-aware Orchestration of Containerized Applications,” IEEE Transactions on Cloud Computing, 2020.

[16] A. A. Monrat, O. Schelén, and K. Andersson, “Blockchain Mobility Solution for Charging Transactions of Electrical Vehicles,” in 2020 IEEE/ACM 13th International Conference on Utility and Cloud Computing (UCC), 2020, pp. 348–253.

[17] “Publications.” https://www.cloudberry-datacenters.com/publications-43395508

[18] “prof.dr.ir. J.T.F. Keurentjes (Jos) | University of Twente.” https://people.utwente.nl/j.t.f.keurentjes

[19] “Vision Luleå 2050,” Luleå kommun. https://www.lulea.se/kommun--politik/hallbar-utveckling/vision-lulea-2050.html

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[22] “Inside Facebook’s Lulea Data Center,” Inside Facebook’s Lulea Data Center, Jun. 12, 2013. https://www.datacenterknowledge.com/inside-facebooks-lulea-data-center

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[24] “Karl Andersson, Professor, Executive Director.” https://www.ltu.se/staff/k/karand-1.12878?l=en

[25] “Michael Nilsson, Project Manager.” https://www.ltu.se/staff/m/michael-1.10050?l=en

8. Appendix A - List of Interviews

April 19
Interview with Center Management with
Prof. Karl Andersson [24] and Michael Nilsson [25]

April 19
DP11 and DP12 with Prof. Olov Schelén [13]

April 19
DP10 with Chen-Wei Yang. Senior Lecturer [11]

April 20, 2021
DP8 with Prof. Wolfgang Birk [9]

April 21, 2021
DP4 and DP9 with Prof. Jon Summers [8]

9. Appendix B - “Cloudberry Day”

LULEÅ UNIVERSITY OF TECHNOLOGY

Responsible body | Date | Reg. No

Administrator

Day: Tuesday 4 May 2021
Time: 09:15-16:00 (The Zoom room will open at 9:00!)

09:15-09:25	Welcome and short introduction	Karl Andersson and Michael Nilsson, LTU
09:25-09:50	Study of data center energy flow in biding area one (SE1)	Simin Hajizadeh, LTU
09:50-10:05	Data center excess-heat: Kista and Luleå comparison	Marcus Sandberg & Cristina Ramos Cáceres, LTU
10:05-10:30	Lattice Boltzmann method comparison for simulating data center thermal conditions	Johannes Sjölund, RISE
SHORT BREAK		
10:45-11:10	Drying with data center excess heat	Hampus Markeby Ljungqvist, LTU
11:10-11:35	Reliability evaluation of the internal power supply system of datacenter	Kazi Main Uddin Ahmed, LTU
11:35-12:00	Study of probable power quality disturbances for a data center	Jil Sutaria, LTU
LUNCH BREAK		
13:00-13:30	An international outlook: Low-energy datacenter research programme	Jos Keurentjes and Judith Inberg, UTwente (NL)
13:30-13:55	Towards efficient simulation and modeling of district energy systems	Johan Simonsson, LTU
13:55-14:20	State space design control for wind tunnel Immersed liquid cooling with distributed pumps	Sebastian Fredriksson, RISE
SHORT BREAK		
14:35-15:00	Reinforcement learning approach to energy efficient control of server fans in data centres	Yulia Berezovskaya, LTU
15:00-15:25	Blockchain tradeoffs and challenges for emerging applications	Ahmed Afif Monrat, LTU
15:25-15:40	Short update from Datacenter Innovation Region	Jan-Olov Johansson and Annika Svensson, LTU
15:40-16:00	The future of Cloudberry Datacenters + Wrap-up of the day	Karl Andersson and Michael Nilsson, LTU

10. Appendix C - List of Cloudberry Publications

The publication list is taken from the Cloudberry Datacenters home page [5]

Subproject 1: Datacenter's interaction with the national energy system

Subproject 2: Multifunctional data centers

- C. Ramos Cáceres, (2019). "Data center and the city: A potential for urban synergies", AESOP 2019 Conference: Book of Papers, Università Iuav di Venezia
- C: Ramos Cáceres, (2020) "Analysis of urban scale factors for data center waste-heat use: Three case studies in Sweden", PLEA2020

Subproject 3: Quality and credibility when simulating cooling in data centers

Subproject 4: Transient simulations of data center dynamic thermal management arrangements

- J. Sjölund, M. Vesterlund, N. Delbosc, A. Khan, & J. Summers, (2018). "Validated thermal air management simulations of data centers using remote graphics processing units", IECON-18, Washington DC, USA

Subproject 5: Evaluation of energy recovery solutions for data centers

- H.M. Ljungqvist, L. Mattsson, M. Risberg, M. Vesterlund, "Data center heated greenhouses, a matter for enhanced food self-sufficiency in sub-arctic regions", Energy. 215 (2021)

Subproject 6: Design of distribution networks for energy efficient data center operations

- K. M. U. Ahmed, J. Sutaria, M. H. J. Bollen & S. K. Rönnberg, (2019). “Electrical Energy Consumption Model of Internal Components in Data Centers”, IEEE PES Innovative smart grid technologies Europe (ISGT), Bucharest, September 2019
- J. Sutaria, K. M. U. Ahmed, M. H. J. Bollen & S. K. Rönnberg,(2019). “Propagation of Supraharmonics through EMI Filters with Varying Loads”, IEEE Cigré Norpie 2019, Narvik, September 2019
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- K. M. U. Ahmed, M. Alvarez, M. H. J. Bollen, (2021). “Reliability Analysis of Internal Power Supply Architecture of Data Centers in Terms of Power Losses." Electric Power Systems Research 193 (2021): 107025
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- K. M. U. Ahmed, M. Alvarez, M. H. J. Bollen, “A Novel Reliability Index to Assess the Computational Resource Adequacy in Data Centers”, IEEE Access
- K. M. U. Ahmed, R. A. Oliveira, Math H. J. Bollen, Manuel Alvarez. (2021). “Risk Assessment of Server Outages Due To Voltage Dips In The Internal Power Supply System of A Data Center”, CIRED 2021

Subproject 7: Data centers impact on the electricity market when the amount of renewable electricity augment

- M. Alvarez, P. De Oliveira, J. Zhong, ”Financial Incentives for Data Centers in Sweden”

Subproject 8: SimBerry - Flexible and large-scale simulation of interaction between district heating and remote cooling networks and data centers

- J. Simonsson, K. Atta, D. Zachariah, & W. Birk, (2019). "Heat load prediction for district heating using a latent variable approach", Proc.22nd Nordic Process Control Workshop, Copenhagen, Denmark
- G. Schweiger, H. Nilsson, J. P. Schöggl, W. Birk, & A. Posch. (2019). "Modeling and simulation of large-scale Systems: a systematic comparison of modeling paradigms", Applied Mathematics and Computation 365 (1-14)
- J. Simonsson, K. Atta & W. Birk. (2020). "Probabilistic Modeling of Thermal Grids using Gaussian Processes", 59th IEEE Conference on Decision and Control (CDC), IEEE
- J. Simonsson, K. Atta, G. Schweiger, & W. Birk. (2021). "Experiences from City-Scale Simulation of Thermal Grids", Resources, E-ISSN 2079-9276, Vol. 10, no 2

Subproject 9: Proximity liquid cooling inside data centers for direct heat recovery

- S. Fredriksson, J. Gustafsson, D. Olsson, J. Sarkinen, A. Beresford, M. Kaufeler, T.B. Minde, & J. Summers. (2019). "Integrated thermal management of a 150kW pilot Open Compute Project style data center", Proceedings of INDIN 2019, Helsinki, Finland

Subproject 10: Automated maintenance of energy-efficient data centers

- Y. Berezovskaya, A. Mousavi, V. Vyatkin, and X. Zhang. (2018). "Smart distribution of IT load in energy efficient data centers with focus on cooling systems", Proceedings of IEEE IECON, Washington D.C., USA.

- Y. Berezovskaya, V. Vyatkin, A. Mousavi, X. Zhang, C.-W. Yang. (2019). "A hybrid fault detection and diagnosis method in server rooms' cooling systems", Proceedings of INDIN, Helsinki, Finland
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Subproject 11: Resource efficiency in software processes and communication in data clouds and data centers

- Jiménez, L. L., & Schelén, O. (2019)." DOCMA: a Decentralized Orchestrator for Containerized Microservice Applications", IEEE Cloud Summit, Washington DC, USA
- Jiménez, L. L., & Schelén, O. (2019). "The DOCMA architecture and proof-of-Concept", The 3rd IEEE International Conference on Cloud and Fog Computing Technologies and Applications, IEEE Cloud Summit
- Jiménez, L. L., & Schelén, O. (2020). "HYDRA : Decentralized Location-aware Orchestration of Containerized Applications", IEEE Transactions on Cloud Computing
- Jimenez, L. L. (2020). "Decentralized Location-aware Orchestration of Containerized Microservice Applications : Enabling Distributed, Intelligence at the Edge", PhD dissertation, Luleå University of Technology

Subproject 12: Resource efficiency in distributed ledgers and smart contracts

- A. A. Monrat, O. Schelén, & K. Andersson. (2019). "A Survey of Blockchain From the Perspectives of Applications, Challenges, and Opportunities", IEEE Access 7(1):117134-117151
- A. A. Monrat, O. Schelén, & K. Andersson. (2020). "Blockchain Mobility Solution for Charging Transactions of Electrical Vehicles." IEEE/ACM 13th International Conference on Utility and Cloud Computing (UCC), pp. 348-253. IEEE
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