Survey on Energy Consumption Optimization Approach in Container Based Cloud Environments

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Abstract
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Contents

1 Introduction

Cloud computing evolved to support scalable platform usage, moving from single-file applications to client/server architectures with monolithic backends, then to microservices with containers, and now transitioning to micro-frontends. Containers run directly on the host using Linux CGroups, bypassing the hypervisor overhead inherent in VMs (e.g., Proxmox, VMWare), which allows for full utilization of host CPU resources and simplifies telemetry monitoring. This lightweight nature is evident in Docker files that simply copy files and run builds, making containers easier to integrate into CI/CD pipelines.

However, this increased reliance on cloud-based infrastructures has led to a significant rise in energy consumption. In 2006, the electricity costs for IT infrastructures in the United States alone were estimated at $ 4.5 billion, with projections to double by 2011[4]. Energy consumption optimization has since become a critical concern, especially as cloud data centers now account for approximately 1-1.5% of global electricity use[11]. Despite efficiency improvements, the demand for digital services continues to grow, pushing the need for more sustainable solutions.

Early research focused on heuristic-based approaches to optimize virtual machine (VM) placement, achieving energy savings of up to 83% while maintaining only a 1.1% service level agreement (SLA) violation rate[4]. More recently, research has shifted from VM-based allocation towards containerized environments, where energy efficiency is influenced by scheduling strategies, workload distribution, and infrastructure optimizations. Studies indicate that modern cloud providers, including Amazon, Microsoft, Google, and Meta, have doubled their energy consumption between 2017 and 2021, reaching 72 TWh in 2021[14;9;11].

Recent research has begun to explore renewable energy-aware strategies to further optimize cloud infrastructures. A notable study proposed a renewable energy-based multi-indexed job classification and scheduling scheme using containers for sustainability in cloud data centers[12]. The scheme focuses on transferring workloads to data centers with sufficient renewable energy, incorporating energy-efficient server selection and container consolidation. The results showed that the proposed method achieved 15%, 28%, and 10.55% higher energy savings compared to existing approaches, demonstrating the potential for significantly reducing energy consumption while enhancing sustainability.

The paper "Survey on Energy Consumption Optimization Approach in Container Based Cloud Environments" further highlights that containerization not only drives scalability and reproducibility but also plays a crucial role in optimizing energy consumption. It explores strategies for efficient resource allocation, reducing power overhead, and ensuring that the benefits of container-based deployments extend beyond performance to sustainability in cloud infrastructures.

In this work, we present a state-of-the-art review on Energy Consumption Optimization Approaches in Container-Based Cloud Environments. Our survey of the available literature—predominantly spanning from 2010 to 2020—reveals that foundational research primarily focused on energy measurement, basic optimization strategies, and energy visualization techniques[4].

Early contributions, such as those by Beloglazov and Buyya[4], as well as Piraghaj et al.[15], laid the groundwork for dynamic resource allocation and energy-efficient container consolidation. Later advancements introduced more sophisticated container scheduling mechanisms, including availability-aware scheduling[1], concurrent scheduling in heterogeneous clusters[10], and hybrid AI-driven resource allocation[17].

In parallel, energy-efficient resource management techniques gained prominence, incorporating renewable energy-aware scheduling[12], optimization-based consolidation methods[16;15], and brownout-based scheduling strategies[18]. Several studies further explored predictive optimization and SLA-aware provisioning frameworks to enhance energy efficiency[7;8;13;5;6].

Beyond optimization techniques, researchers have also examined broader energy consumption trends and policy implications[2], reflecting the increasing emphasis on sustainability in cloud computing. Additionally, efforts in DevOps-driven elastic container management have contributed to improving the adaptability and efficiency of containerized cloud applications[3].

Although these prior works have significantly advanced the field, our review highlights an evolving trend toward more integrated and user-centric energy management strategies, as reflected in recent data on energy consumption in cloud environments[14;9;11]. This synthesis not only underscores the robust foundation established by past research but also identifies critical areas for achieving digital sufficiency and sustainable cloud infrastructures.

2 Methodology

Systematic Procedure to Identify Papers

The research process started with the defintion of the topic together with our supervisor Professor Pierson, together we decided to settle on creating a state fo the art review on the topic of Container and Cloud Computing, with a particular emphasis on energy consumption optimization. To begin with we defined a "Search Pipeline"

Figure 1: Search Pipeline Flowchart

This procedures allowed us to organize the work and have a standardized method of acceptance for navigating the papers. We also defined a search string with which we would start the search: ((energy OR resource) AND container). We decided to expand the search also to resource since we noticed that many times better resource utilization leads to better dynamic power handling, hence lowering the amount of energy required to carry out a task. Before starting with the research we also defined some acceptance criteria that would define whether a paper was going to be included in our survey or not. We defined the criteria as follows:

Direct Exclusion of Paper If
Work is not in English
Work is not a scientific paper
Work has less than 10 citations
Work is not about containers/cloud

Table 1: Exclusion Rules

Hence we proceeded with our search and we identified a total of 34 papers. That are divided as follows through the various publishers

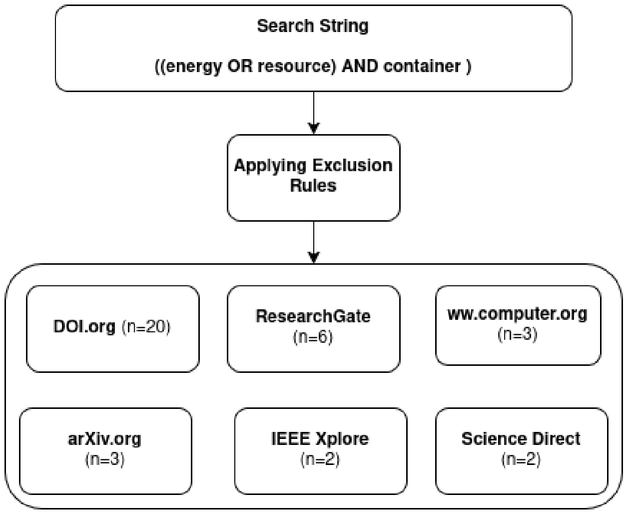

Figure 2: Exported Papers

To have an insight on the publication dates for the filtered papers, we can clearly visualize how the period between 2017 and 2019 was the most important for research in this field.

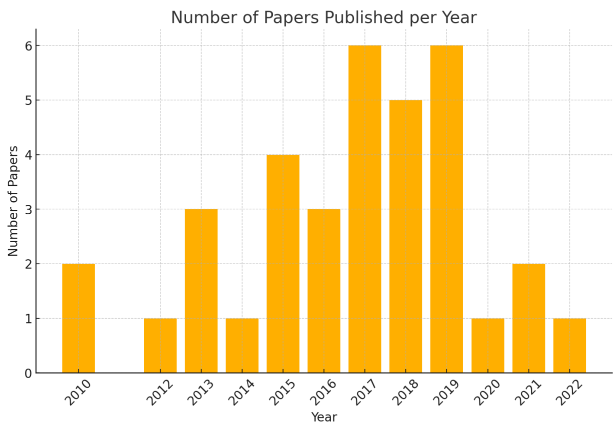

Figure 3: Papers per year

At this point we could move to the classification step of our workflow. We decided to define the following metrics

Direct Exclusion of Paper If
Work is not in English
Work is not a scientific paper
Work has less than 10 citations
Work is not about containers/cloud

Table 2: Exclusion Rules

3 "State of the art description"

Small description

3.1 Subsection

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Conclusion

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5 Conclusions

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References

[1] Yanal Alahmad, Tariq Daradkeh, and Anjali Agarwal. *Availability-Aware Container Scheduler for Application Services in Cloud.*

[2] Maria Avgerinou, Paolo Bertoldi, and Luca Castellazzi. Trends in data centre energy consumption under the european code of conduct for data centre energy efficiency. 10(10):1470.

[3] Cornel Barna, Hamzeh Khazaei, Marios Fokaefs, and Marin Litoiu. *Delivering Elastic Containerized Cloud Applications to Enable DevOps.*

[4] Anton Beloglazov and Rajkumar Buyya. Energy efficient allocation of virtual machines in cloud data centers. In *2010 10th IEEE/ACM International Conference on Cluster, Cloud and Grid Computing*, pages 577–578. IEEE.

[5] Dinh-Mao Bui, YongIk Yoon, Eui-Nam Huh, SungIk Jun, and Sungyoung Lee. Energy efficiency for cloud computing system based on predictive optimization. 102:103–114.

[6] Alessandro Carrega and Matteo Repetto. Energy-aware consolidation scheme for data center cloud applications. In *2017 29th International Teletraffic Congress (ITC 29)*, pages 24–29. IEEE.

[7] Mehiar Dabbagh, Bechir Hamdaoui, Mohsen Guizani, and Ammar Rayes. Energy-efficient resource allocation and provisioning framework for cloud data centers. 12(3):377–391.

[8] Abdul Hameed, Alireza Khoshkbarforoushha, Rajiv Ranjan, Prem Prakash Jayaraman, Joanna Kolodziej, Pavan Balaji, Sherali Zeadally, Qutaibah Marwan Malluhi, Nikos Tziritas, Abhinav Vishnu, Samee U. Khan, and Albert Zomaya. A survey and taxonomy on energy efficient resource allocation techniques for cloud computing systems. 98(7):751–774.

[9] Ralph Hintemann and Simon Hinterholzer. Cloud computing drives the growth of the data center industry and its energy consumption. *Data centers*, 2022.

[10] Yang Hu, Huan Zhou, Cees de Laat, and Zhiming Zhao. Concurrent container scheduling on heterogeneous clusters with multi-resource constraints. 102:562–573.

[11] IEA. Data centres & networks. `https://www.iea.org/energy-system/buildings/data-centres-and-data-transmission-networks`. Accessed: 2025-03-25.

[12] Neeraj Kumar, Gagangeet Singh Aujla, Sahil Garg, Kuljeet Kaur, Rajiv Ranjan, and Saurabh Kumar Garg. Renewable energy-based multi-indexed job classification and container management scheme. 15(5):2947–2957.

[13] Lianpeng Li, Jian Dong, Decheng Zuo, and JIaxi Liu. SLA-aware and energy-efficient VM consolidation in cloud data centers using host states naive bayesian prediction model. pages 80–87. IEEE Computer Society.

[14] Eric Masanet, Arman Shehabi, Nuoa Lei, Sarah Smith, and Jonathan Koomey. Recalibrating global data center energy-use estimates. *Science*, 367(6481):984–986, 2020.

[15] Sareh Fotuhi Piraghaj, Amir Vahid Dastjerdi, Rodrigo N. Calheiros, and Rajkumar Buyya. A framework and algorithm for energy efficient container consolidation in cloud data centers. In *2015 IEEE International Conference on Data Science and Data Intensive Systems*, pages 368–375. IEEE.

[16] Tao Shi, Hui Ma, and Gang Chen. *Energy-Aware Container Consolidation Based on PSO in Cloud Data Centers.*

[17] Boxiong Tan, Hui Ma, and Yi Mei. *A Hybrid Genetic Programming Hyper-Heuristic Approach for Online Two-level Resource Allocation in Container-based Clouds.*

[18] Minxian Xu, Amir Vahid Dastjerdi, and Rajkumar Buyya. Energy efficient scheduling of cloud application components with brownout. 1(2):40–53.