A Survey of Enabling Techniques and Technologies for Sustainable Cloud Data Centers

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Abstract

Cloud computing services have gained tremendous popularity and widespread adoption due to their flexible and on-demand nature. Cloud data centers serving as a backbone to host variety of applications are growing exponentially in numbers and size. Cloud data centers host thousands of computation, storage, and communication devices that consume enormous amount of energy that results in carbon emissions. Renewable energy resources replace fossil fuels based grid energy to effectively reduce carbon emissions of cloud data centers. Moreover, the waste heat generated from electronic components can be utilized in absorption based cooling systems to offset cooling costs of data centers. However, data centers need to be located at ideal geographical locations to reap benefits of sustainability options. Modular data centers are highly suited to application of renewable energy and waste heat utilization techniques due to their shippable nature. Moreover, workload can be transferred between intelligently placed geo-dispersed data centers to utilize renewable energy available elsewhere with virtual machine migration techniques. However, adoption of aforementioned techniques and technologies opens new challenges, such as, intermittency of power supply from renewable resources and higher capital costs. Lack of a comprehensive survey that considers enabling techniques and technologies for sustainable cloud data centers, such as, renewable energy, waste heat utilization, modular data centers, and VM migration motivated this study. In this paper, we examine sustainable cloud data centers from various aspects to survey the enabling techniques and technologies. Moreover, we discuss state-of-the-art research in sustainable cloud data centers. Furthermore, we debate the integration challenges and open research issues to sustainable cloud computing techniques and technologies.

Keywords: Cloud data centers, energy efficiency, renewable energy, waste heat utilization, modular data centers, VM migration.

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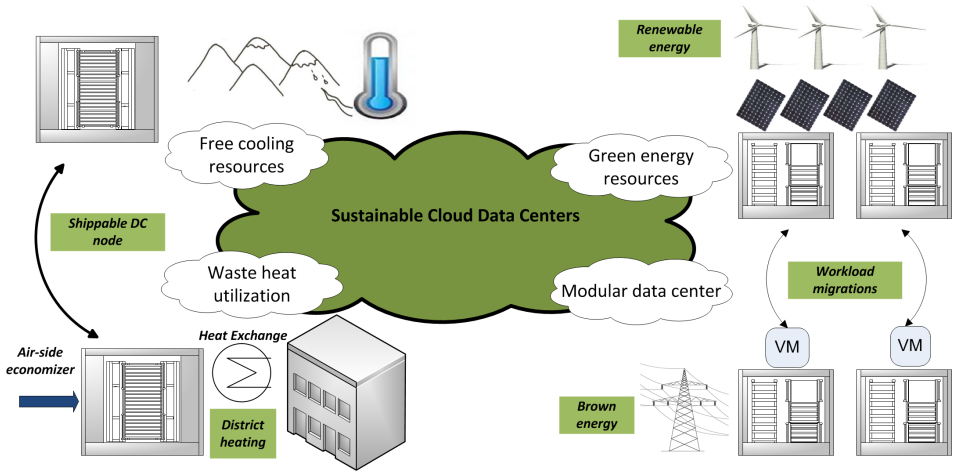

Figure 1: Elements of Sustainable Cloud Data Centers

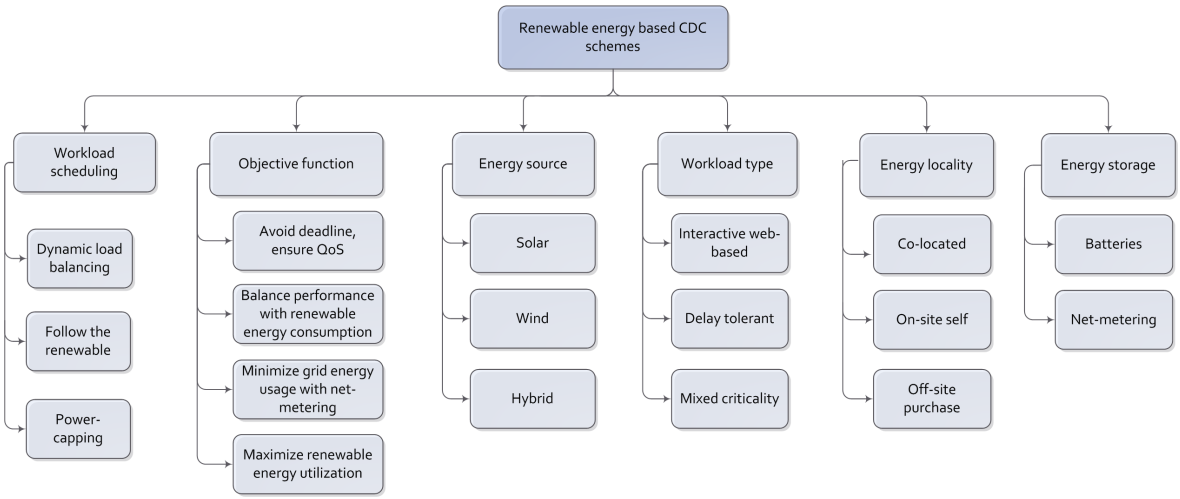

Figure 2: Taxonomy of renewable energy based Cloud Data Centers

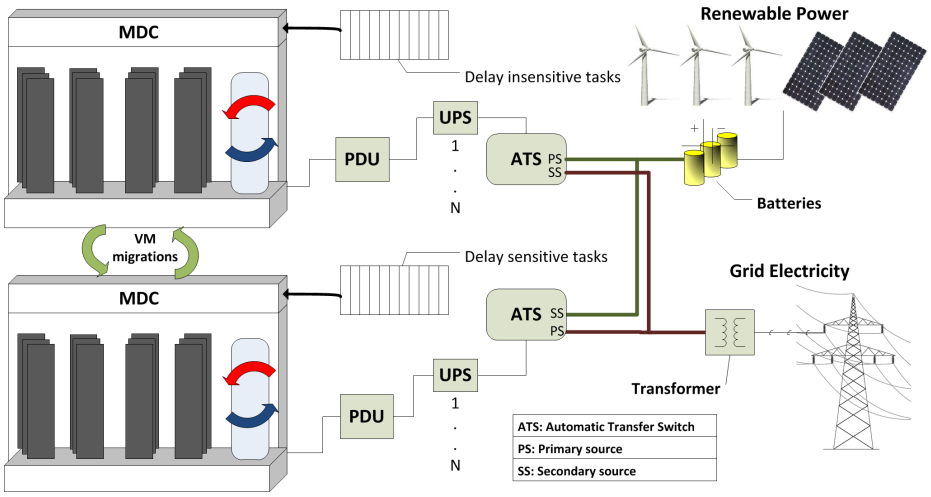

Figure 3: Sustainable Cloud Data Centers based on hybrid energy sources

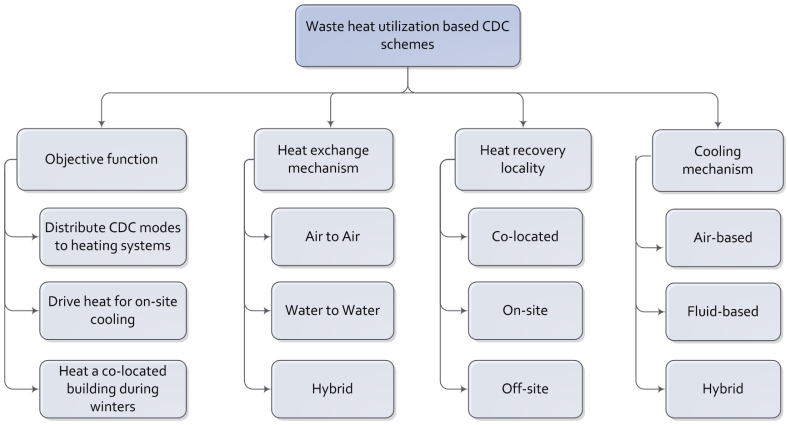

Figure 4: Taxonomy of waste heat utilization techniques in Cloud Data Centers

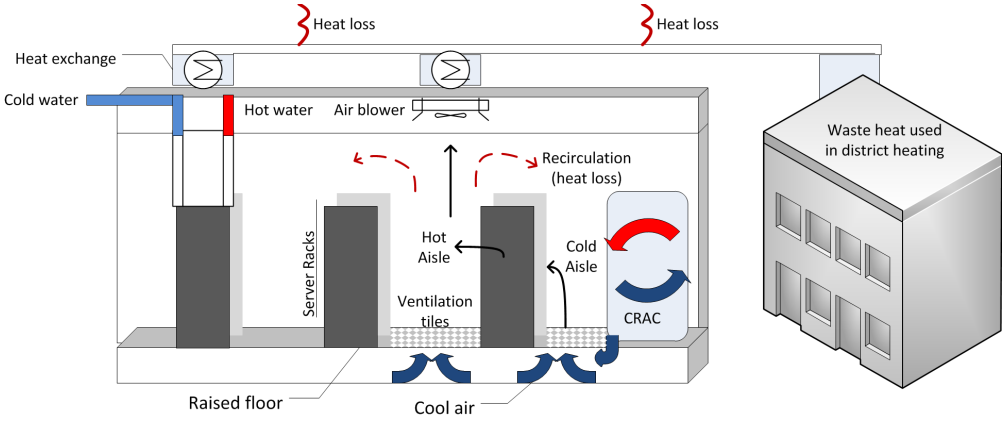

Figure 5: Hybrid Cooling with waste heat utilization in Cloud Data Centers

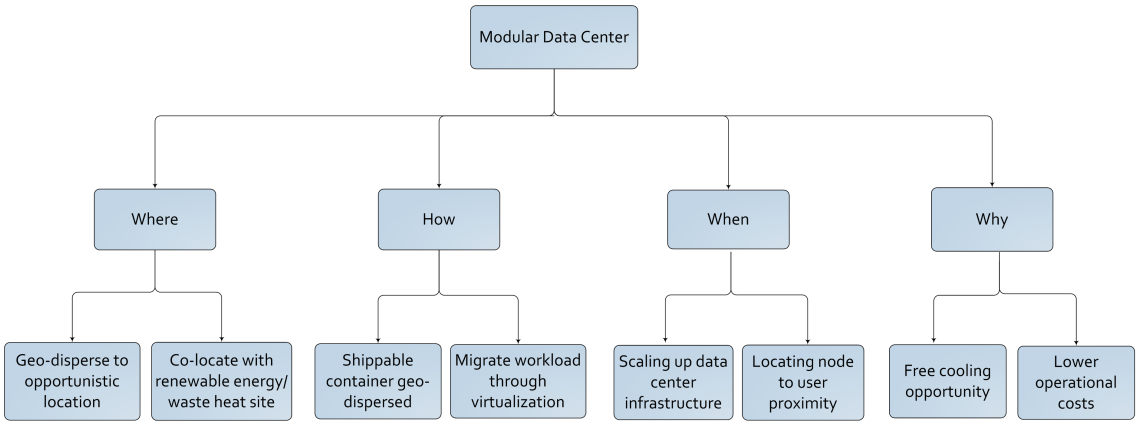

Figure 6: Modular Data Center decision tree for sustainability opportunities

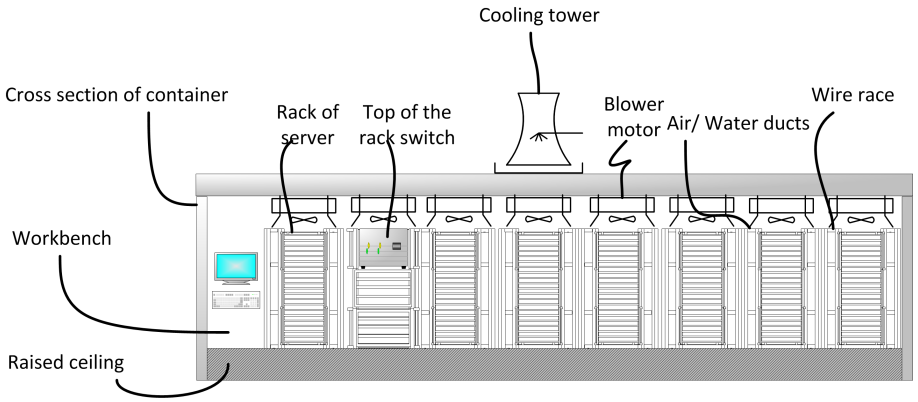

Figure 7: Container based Modular Data Center design

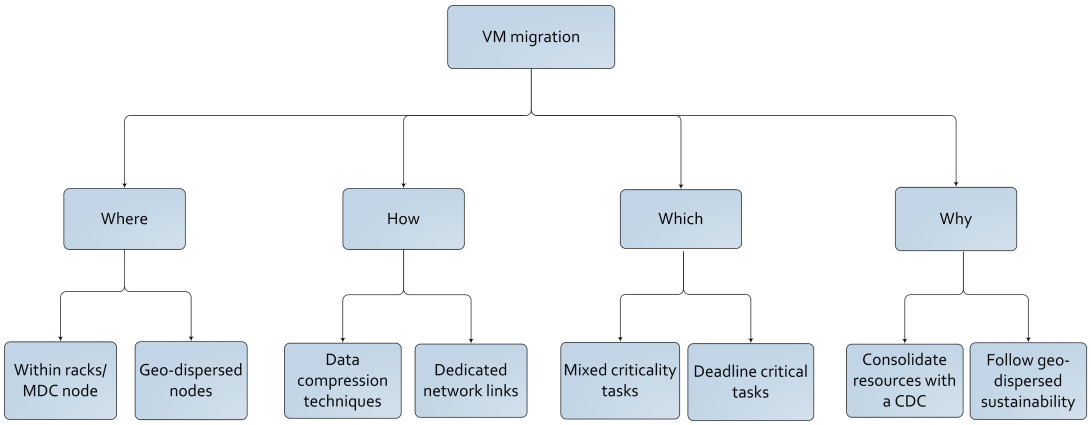

Figure 8: VM migrations decision tree for sustainable Cloud Data Centers

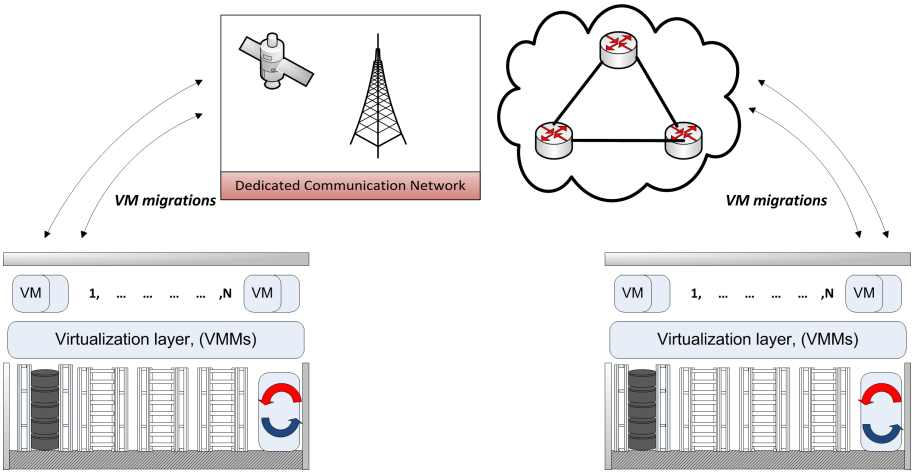

Figure 9: Sustainable Cloud Data Center based on workload migrations