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# A systematic literature review on energy efficiency in cloud software architectures

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ABSTRACT

Cloud-based software architectures introduce more complexity and require new competences for migration, maintenance, and evolution. Although cloud computing is often considered as an energy-efficient technology, the implications of cloud-based software on energy efficiency lack scientific evidence. At the same time, energy efficiency is becoming a crucial requirement for cloud service provisioning, as energy costs significantly contribute to the Total Cost of Ownership (TCO) of a data center. In this paper, we present the results of a systematic literature review that investigates cloud software architectures addressing energy efficiency as a primary concern. The aim is to provide an analysis of the state-of-the-art in the field of energy-efficient software architectures.



## 1. Introduction

Information and Communication Technologies (ICT) energy demand is continuously increasing. Recent projections show that the fraction of commercial electricity consumed by ICT will be 10% of the total commercial electricity in the U.S. and almost 20% in Germany. In particular, projections for data centers in the U.S. indicate a growth in demand from 60 TWh/y in 2005 to 250 TWh/y in 2017 [1]. These figures show the need for more sustainable and energy efficient ICT technologies. Cloud computing is often regarded as to be one of those [2]. Indeed, one of the principles of cloud computing is on-demand provisioning of virtual resources, which can be aggregated on fewer physical machines. This allows to improve hardware utilization, thus increase energy efficiency.

Nowadays, energy efficiency is starting to be considered as a Service-Level Objective (SLO), i.e. a specific, measurable characteristic of a service, to be described as achievement values in Service-Level Agreement (SLA)[1]. An example would be: "The energy bill of the client should be reduced by 20% in one year". Cloud service providers could benefit from representing energy efficiency as a SLO.

However, in order to offer cloud services, providers rely on very complex software architectures. The impact of architecture characteristics on energy efficiency is yet unclear and possibly unexplored. Also, we still miss explicit or implicit reference architectures that can help in increasing energy efficiency.

The role of software in energy consumption is widely discussed among the scientific community, and a number of metrics for software energy efficiency have been proposed [3]. Our work tries to advance to the next step: whether it is possible to quantify the effects on energy consumption when adopting a certain software architecture, and what architectural solutions can be adopted to increase energy efficiency in cloud-based software. We performed a Systematic Literature Review (SLR) [4] to investigate the relationship between cloud-based software architectures and energy efficiency.

The preliminary results of our SLO were reported on an initial publication [5]. In this paper we extend our initial work, as follows: Section 2 describes our review protocol in detail. Section 3 presents the results of a demographic analysis conducted on our primary studies. Section 4 provides insights about the state-of-the-art of energy efficiency in cloud software architectures. Section 5 gives an overview of the stakeholders for energy efficiency we identified during our research. In Section 6 we discuss the threats to validity that might affect our study. Section 7 concludes the paper with future outlooks and follow-up studies.

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[1] http://www.greenbiz.com/news/2009/01/12/energy-efficiency-new-sla, last visited on June 12th, 2013.

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