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How can a green cloud benefit business?

A strategic analysis

Master's Thesis submitted by
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Master Thesis

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Foreword

Due to my previous career as an industrial engineer in the automotive industry, the proposed topic of the green economy immediately excited me. After a period of discovery and several discussions, the subject changed to green cloud transformation due to its urgency and future potential. Furthermore, the choice was supported by the fact that I`m going to start to work in the field of cloud transformation after my studies. During the writing process, it was a great help for me to start with a rough outline of the specific content. On the basis of this outline, it was possible to follow a central theme and thus create clarity, despite several restructurings and revisions.

I would like to thank Professor Paul Belleflamme, my first supervisor, for providing me with this interesting topic. In addition, through his always motivating and helpful support, he has ensured that I have felt encouraged in every phase of my work, which in turn is recognizable in the result of this thesis. Furthermore, he allowed my topic as well as my work to develop freely and supported the scientific approach of my work with his always constructive feedback.

Thanks also go to my second supervisor, Dr. Louis Strang. Through his approach, ways of thinking, with topics that were initially foreign to me, he increased the contribution and level of my work many times over. Through our exchanges and discussions, my own perspective was rightly often challenged and thus broadened.

I would also like to thank Mr. Lettmayer (Senior Manager Cloud Strategy, Deloitte Germany) and Mr. Matthias Farwick (CEO, Txture) for the enriching and exciting discussions on the topic of green cloud transformation. The frequent exchanges with these professionals were important in that they generated further possibilities as well as new ways of thinking outside the current scientific status of this field.

Finally, on a more personal level, I would like to thank my wife Dr. Ann-Katrin Röttger for her encouragement, the never-ending evening discussions, and her extensive support throughout my whole studies.

Abstract

Cloud computing represents on-demand network access to shared information technology resources. Thereby, the cloud model can be provided with minimal management effort by the service provider and is composed of several characteristics, delivery models, and deployment models. Furthermore, the cloud is the enabling technology for the accelerated digitization of tomorrow's applications and their datafication. The demand for this technology is expected to increase six times by 2030 which increases the energy consumption of its data center hosts. However, in the climate change debate, cloud computing is two sided. It can be either seen as one of the causes of environmental problems or as part of the solution in addressing them. In the latter case green cloud computing is particularly relevant. But a rethink of how we use our resources in information technology is urgently needed, as there is no alternative to establishing a sustainable cloud.

This work examines the scientific knowledge of green cloud computing through a semi-systematic literature review. The main contribution is the identification of a necessary change within a second wave of optimization initiatives. This must consider all stakeholder perspectives to make the technology sustainable and applicable in the long term. Over the past decade, the first wave of scientific efforts focused on optimizing the hardware and software of data centers as hosts of clouds. But due to the scarcity of fossil fuels and rare resources, these efforts will not sufficiently meet the future demand for cloud services. Therefore, environmental friendliness and profitability are inextricably linked in the cloud industry. In the following discourse, the missing perspective of consumers and their incentives for a green cloud is integrated into the discussion. This is done by examining internal as well as external incentives as innovation drivers to accelerate the green transformation. Finally, this paper discusses further research approaches and opportunities to advance the needed and inevitable green cloud transformation.

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Table of Abbreviations

AI	Artificial Intelligence	IEA	International Energy Agency
CPU	Central Processing Unit	MIT	Massachusetts Institute of Technology
CS	Cloud Service	PaaS	Platform as a Service
CSC	Cloud Service Consumer	PPA	Power Purchase Agreement
CSP	Cloud Service Provider	REC	Renewable Energy Certificates
CSR	Corporate Social Responsibility	RQ	Research Question
EU	European Union	SaaS	Software as a Service
ETS	Emission Trading System	SDG	Sustainable Development Goal
GHG	Greenhouse Gas	SLA	Service Level Agreement
QoS	Quality of Service	TCO	Total Cost of Ownership
IaaS	Infrastructure as a Service	USA	United States of America
ICT	Information/ Communication Technology	UN	United Nation
IoT	Internet of Things	VM	Virtual Machine
IT	Information Technology	WoS	Web of Science

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1. Introduction

Due to climate change, today's global society is facing pressing environmental challenges. The climate change is linked to the continuing increase of greenhouse gases (GHG) and associated carbon dioxide (CO_2) emissions (UN, 2015b). Following the International Energy Agency (IEA), the Information and Communications Technology (ICT) sector emitted 4% of global CO_2 emissions in 2020 (IEA, 2020b). This share will increase further. A conservative estimate is that it will be around 14% of the global CO_2 footprint by 2040 (Belkhir & Elmeligi, 2018). While data centers form the backbone of the ICT sector, the demand for its cloud based services has grown by a factor of seven and a half in the last decade (IEA, 2020a). Recent estimates of global data center electricity consumption are highly controversial due to data uncertainty, ranging from 1% (Masanet et al., 2020) to 4% (R. Mandal et al., 2020) of global electricity consumption in 2020. This is the same as the total yearly consumption of highly developed countries such as UK or France (IEA, 2020b). The datafication in computing intensive technologies will drive the demand for cloud services to unprecedented heights (Cukier & Mayer, 2013). These technologies include, for instance, smart and connected systems, Artificial Intelligence (AI), Internet of Things (IoT), Big Data Analytics, and autonomous vehicles. Consequently the electricity consumption of data centers is estimated to grow about six times by 2030 (Andrae & Edler, 2015; IEA, 2017; Masanet et al., 2020). This translates into high carbon emissions, as more than 63% of electrical energy comes from fossil fuel or coal (BP Global, 2020). Furthermore, because carbon-neutral renewable energy is intermittent, it is not suitable for the temporal variation in the energy demand of cloud computing.

To address the challenges and environmental pressures, the established economic approaches such as improvement, optimization, and expansion, have not yet provided a satisfactory solution. Additionally, the attractiveness of cloud computing technology has so far led to the neglect of environmental issues by both providers and consumers. The business world, in particular, bears a great responsibility in encouraging a behavioral change, as it is crucial to the prosperity of the population. In addition to this role model function, companies face the challenge of increasing globalization and digitization, accelerated by the COVID-19 pandemic.

Due to the exploding demand for cloud service, a new attitude from businesses towards environmental impacts as well as a green transformation of the cloud computing sector is needed. Here, the emerging paradigm of a green cloud is becoming increasingly important (Radu, 2017). It includes on the one hand the area of further optimization in the hardware and software of data centers and network operators. On the other hand, data centers consume a steadily growing share of global energy and are completely dependent on the energy mix in the local grid. This leads to increasing emissions, while the ongoing trend toward renewable sources for the total energy generation (including electricity, heat, transport) is still evolving with a global share of 15.7% in 2020 (for pure electricity generation around 35%) (BP Global, 2020; Statista, 2021). Therefore, the paradigm of a green cloud including the sustainable management as well as placement of data centers to increase energy efficiency, cool them naturally, or use 100% renewable energy at the point of origin are promising approaches.

The purpose of the present work is to map the increasingly important research area of cloud computing and synthesize its business impact as well as the current scientific status through a semi-systematic literature review. This qualitative approach seeks to outline the overarching impacts of different research traditions including fields like computer, business, and environmental science. While green cloud strategies focus on technical and environmental aspects, the economic impact they can bring to consumers is rarely addressed. The specific contribution of this work is the inclusion of the incentives and impacts of green clouds on the consumers of services from the cloud. Because of this consideration, the following two research questions arise in the context of "How can a green cloud benefit business?":

- Does profitability conflict with environmental friendliness in cloud computing?
- What are the impacts and incentives for the consumer in using a green cloud?

This work is structured in the following way. Chapter 1 identifies the basic concepts of cloud computing including its terminology, models, and main characteristics. Chapter 2 is a review of existing research literature from which three key findings are formulated. These are: the missing industrial standard, the challenge of implementation, and a missing conceptual link. Chapter 3 examines the current state of green cloud computing, the influencing factors, the use of renewable energy, and its purchase. Furthermore, to answer the first research question, the three key findings, mentioned above, are discussed in detail. The second question is answered through a discourse in Chapter 4, which focuses on the incentives for green cloud consumers. This includes a discussion of the advantages and disadvantages of, as well as the external and internal drivers for, green transformation. The findings of this work can be used as steppingstones for further research. To this end, limitations, needed steps, and other ideas are outlined in Chapter 5, together with an overall summary and conclusion in Chapter 6.

1.1. Cloud Computing Origins

In this chapter, the historical development of the cloud computing industry, as well as different prediction scenarios for the future, are investigated. Subsequently, basic terminology and specific models are examined to provide an overview of the technology. Finally, both characteristics and the virtual machine approach of cloud computing are outlined to enable the reader to follow the course of this work.

The term "cloud" refers to different platforms that are used as distributed computing resources. These are formed by servers, networks, interfaces, or software. The term "computing" includes the provision of the cloud package as a service, which can be purchased and deployed by consumers (Attaran & Woods, 2018). The outsourcing of ICT infrastructure into a cloud enables consumers to use ICT provided and managed by third-party providers. It allows them to access information online around the clock from multiple locations and devices such as desktop, laptop, tablet, and smartphone. This saves time and resources that would otherwise be required to build individual infrastructure and maintain data processes. Consumers can thus focus on their core competencies and critical business activities (Erl et al., 2013).

Cloud computing is not new and has its origins in the concept of utility computing. John McCarthy, a computer scientist at Stanford University, first coined the term utility computing in 1961 in a speech at the centennial of the Massachusetts Institute of Technology (MIT) (McCarthy, 1963). Since the mid-1990s, various forms of Internet-based computer services have been developed: search engines (Google, Yahoo!); email services (Gmail, Hotmail); and social media platforms (YouTube, Facebook, Twitter). But the business community did not pay much attention to the proposed concept of computing as a public utility until 2006. Then cloud computing emerged into the commercial area; Amazon launched its Elastic Compute Cloud services called EC2(AWS, 2006), and Google started its browser-based enterprise application, which led, three years later, to Google App Engine (Google, 2008). Nowadays, accelerated by the COVID-19 pandemic, video conferencing and streaming services (Zoom, MS Teams, Netflix) have joined the ranks of provided services. Due to their strong consumer centric development, these services have become popularized and thus form the basis of modern cloud computing (Erl et al., 2013).

In the past decade, the workload demand of data centers, as hosts of services from the cloud, has increased by a factor of seven and a half (Masanet et al., 2020), while nowadays companies have embraced cloud computing and have started to collect the rewards (F. Yang & Chien, 2018). The technology enables them to enjoy advantages such as reduced investment and proportional costs as well as increased scalability, availability, and reliability (Erl et al., 2013). Due to the growing demand, around 1% of the world's electricity is consumed by data centers (Masanet et al., 2020), a figure that has remained constant since 2010 despite the above mentioned increase in demand. This plateau can be explained mainly by an optimization of hardware and software as well as by a shift from traditional on-premises ICT to cloud and data centers from hyperscaler, as shown in Figure 1 (Andrae & Edler, 2015). While traditional on-premises ICT provided 79% of computing capacity in 2010, the trend changed, and ten years later 89% of computing capacity was provided by energy-efficient cloud and hyperscaler data centers. This upward trend is expected to continue (IEA, 2020a).

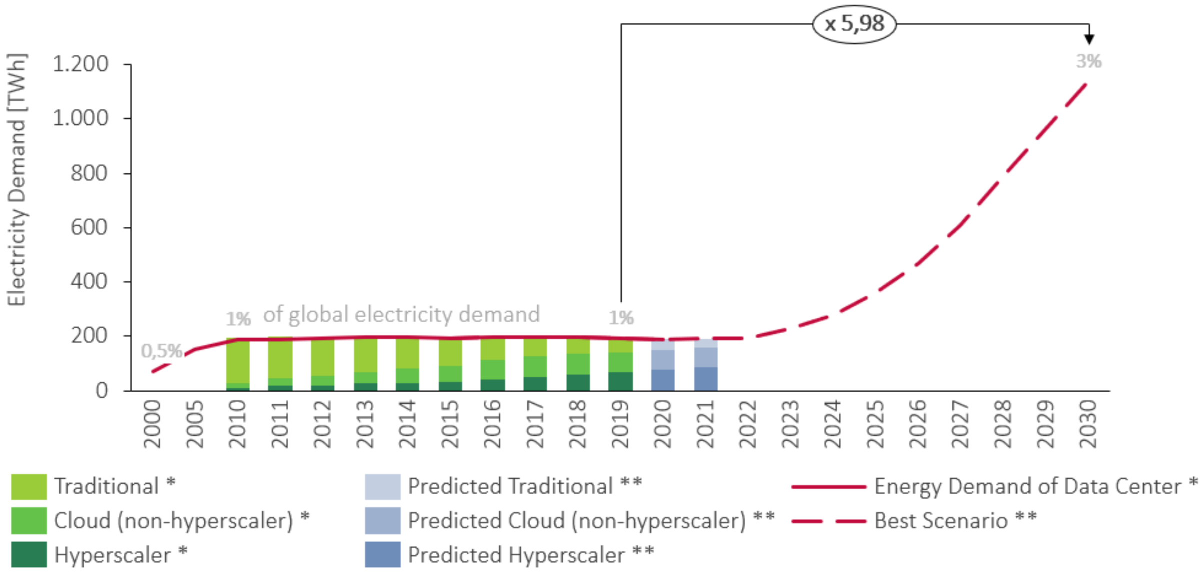

*Figure 1 - Data Center Electricity Demand (based on *IEA, 2020 and **Andrae A., Edler T., 2015)*

To meet future demands, organizing ICT resources in clouds as a public utility is already state of the art, much like the telephone network in recent decades (Attaran & Woods, 2018). However, the question arises as to how long the growing demand for services from the cloud can continue to be served with the established approaches (Masanet et al., 2020). This is accompanied in the scientific world, by a commonly agreed upon, but conservatively projected, six times increase in global data center electricity consumption by 2030: an increase from 1% in 2020 to 3% in 2030 (Andrae & Edler, 2015). This trend has been driven by the digitization and through datafication of emerging technologies like IoT, autonomous vehicles, smart and connected systems, and applications like video conferencing, streaming, AI, cryptocurrencies, and Big Data Analytics.

1.2. Terms, Delivery, and Deployment Models

In the cloud computing environment, organizations as well as humans can take on different roles depending on their interaction within the cloud or its Information Technology (IT) resources. An IT resource can be represented by a physical or virtual IT artifact. This can be either hardware-based, like a physical server or a network device, or software-based, like a virtual server or a software program. Cloud computing enables the provision and use of an IT resource via the cloud, this is referred to as Cloud Service (CS). The main parties are the Cloud Service Provider (CSP) and the Cloud Service Consumer (CSC). Therefore, the organization that provides the cloud-based service is the CSP. It is responsible for making CS available and usable for its consumers. This includes provision, management, and administration of duties to ensure the smooth operation of IT resources. The CSC has a contractual agreement with the CSP to use its CS (Erl et al., 2013). Data centers house the IT resources in a physical infrastructure network, where data storage and application take place. If these data centers are operated by independent third parties, the CSP leases the IT resources from the data center operator, organizes them and resells them to the CSC (Popoola & Pranggono, 2018). All agreed services are contractually defined by Service Level Agreement (SLA) which consist of different Quality of Service (QoS) parameters (Jeffery, 2012). The SLAs ensure compliance with the agreed scope of services (Guérout et al., 2014).

Due to its agile infrastructure, cloud computing provides different services, privatization, and payment options. Different service options describe the scope that is delivered to the CSC given by the cloud delivery models. Payment options include methods such as pay-per-use or subscription-based pricing. Cloud deployment models offers the degree of privatization while dealing with the different possibilities of accessibility and boundaries (Alfonso et al., 2013).

Three cloud delivery models have become widely accepted: Infrastructure-as-a-Service (IaaS); Platform-as-a-Service (PaaS); and Software-as-a-Service (SaaS) (Erl et al., 2013). IaaS includes the provision of physical IT resources by the CSP and represents an environment that is administrated by the CSC. The provided IT resources are not pre-configured to provide a high level of control and a high degree of responsibility, in terms of security and management, for the consumer (Attaran & Woods, 2018). The PaaS delivery model constitute a defined and ready to use software framework which is built with pre-configured IT resources. CSC can use libraries, tools, or services which are supported by the CSP. This enables the CSC to customize applications following its own IT requirements, while the CSP is still responsible for the security and policy (Jing et al., 2013). The SaaS model offers software which is accessible as a public utility including web applications and multimedia services. However, the CSC has limited control over the offered applications (Attaran & Woods, 2018). The provisioned services, responsibilities, and key providers of the three cloud delivery models compared to the traditional on-premises solution are shown in Figure 2.

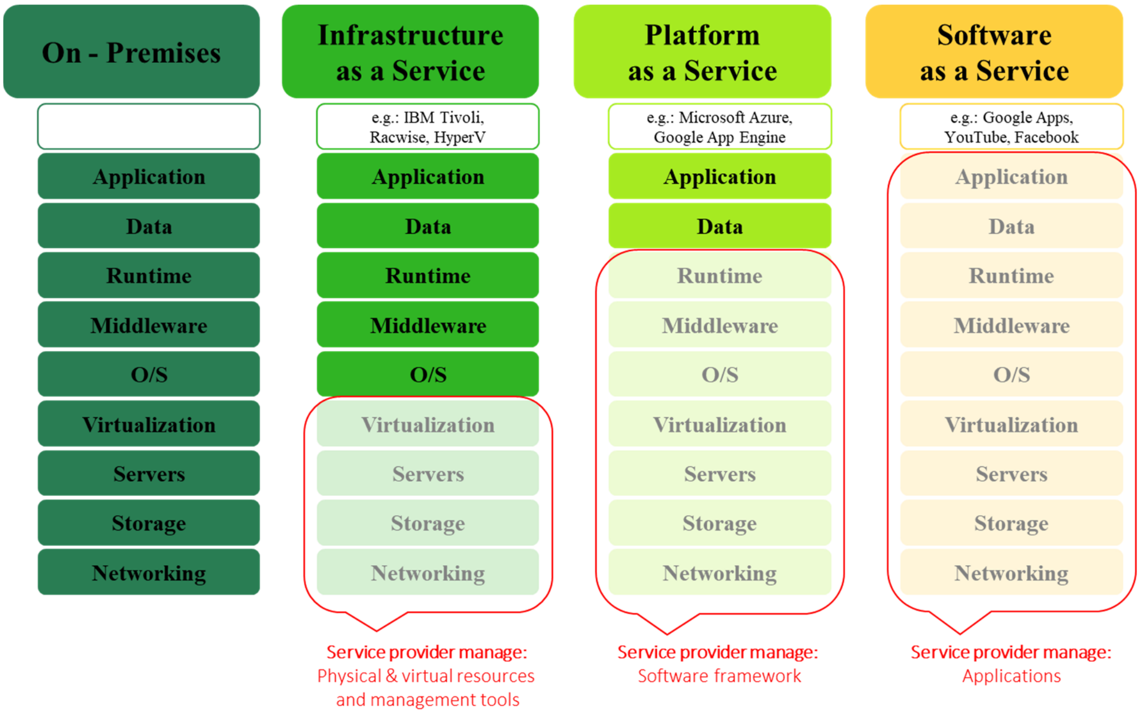

Figure 2 - Cloud Delivery Models (based on Jing et al., 2013)

Cloud deployment models represent an environment that can vary widely in ownership, size, and access rights. The primary models are public cloud, community cloud, private cloud and hybrid cloud, which are available through the different stages of cloud delivery models (Erl et al., 2013). The public cloud is owned by a provider, and the CSC does not have to bear the administration of the cloud. The CSP is responsible for the provision and maintenance of the cloud and enables the CSC to outsource their IT resources. The requested IT resources can be nimbly adapted to the needs of the CSC. This leads to an agile and efficient IT resource management (Bianchini et al., 2017). The nature of a community cloud is like a public cloud, except that access is restricted to a community of CSCs. This cloud can be owned by community members or a third party providing a public cloud with exclusive access (Erl et al., 2013). The environment of a private cloud is provided for an exclusive consumer. The physical IT resources can exist either on-premises at the company or at a provider or third-party. This cloud offers more control and security over the environment and enables the CSC to centralize their own ICT while using PaaS or IaaS as delivery models. Reasons for a private cloud include the frequent exchange of confidential information, greater operational control, or the demands of governmental regulations (Erl et al., 2013). Finally, the hybrid cloud is a network of public and private clouds. The public cloud is used for non-critical exchange of information and workload peaks, while sensitive information is processed via a private cloud (Bianchini et al., 2017). Leading public cloud providers are AWS, Microsoft Azure, Google Compute Engine, or Alibaba Cloud, while private clouds are assigned to the consumers (Attaran & Woods, 2018).

1.3. Characteristics and Virtual Machines

Certain characteristics are needed in an IT environment to effectively deliver scalable IT resources remotely. A general distinction is made between six specific characteristics in a cloud (Attaran & Woods, 2018): on-demand usage, broad network access, multitenancy, rapid elasticity, measured usage, and resiliency (Arora & Bala, 2020). These characteristics enable the effective virtualization of IT resources. They are described in the following paragraph.

The on-demand usage is the ability to access IT resources unilaterally and gives the CSC the freedom to utilize them independently. After a one-time configuration, the provided IT resources can be accessed without further human interaction. This enables an on-demand environment, while the usage is measured automatically (Erl et al., 2013). The characteristic of a broad and ubiquitous access is achieved through a network coupled to multiple devices (e.g., laptops, cell phone, or workstations). Providing such access requires the need of a range of interfaces and security technologies. Therefore, depending on the desired cloud delivery and deployment model, the architecture must be tailored to the specific requirements of the CSC (Attaran & Woods, 2018). The provider attaches IT resources by means of resource-pooling, using virtualization technologies, to serve many CSCs. Multitenancy assigns an instance of the program to different consumers simultaneously but independently. By coupling pooling and multitenancy, physical and virtual IT resources can be allocated based on the CSC demand profile (Erl et al., 2013). This ability to scale resources automatically according to runtime conditions is called elasticity. This characteristic is seen as the main reason for switching to the cloud, because low capital expenditure and the proportional cost advantage have a positive effect on business (Jing et al., 2013). The measured usage characteristic provides the ability to track and accurately calculate usage. The direct link between usage and costs enables the CSP to charge for the resources actually used. However, in addition to billing, it also enables the tracking of utilization and application. This makes it possible to develop efficient systems to act optimally in correspondingly high or low times. Therefore, this characteristic is linked to the on-demand usage (Marotta et al., 2018). Resilient computing is used for failover and to increase efficiency. Redundant virtual migrations of IT resources are distributed across physical locations. In the event of a failure, the resources are configured in such a way that the computing task is directly transferred to a redundant version within the same or across multiple clouds. The resilient characteristic assures CSCs of both the availability and reliability of their applications (Erl et al., 2013). The value, and therefore the cost of a cloud, depends on the varying degrees of these characteristics. Accordingly, the more the characteristics are supported and provided in the cloud, the greater the resulting value and costs for the CSC.

The Virtual Machine (VM) is enabled by these cloud characteristics and is an abstraction of physical IT resources. Through resource pooling, IT resources are virtualized and divided into VMs, while the hosting data center can be either centralized or distributed across the globe. This technique allows the CSP to provide and deploy a dynamic infrastructure. The main objective is to utilize the temporal distribution of VMs to achieve consistent performance, minimize active physical servers, and increase reliability as well as availability through pooling and multitenancy. This enables efficient control of an energy aware resources management. For example, uniform and energy-efficient performance can be achieved by shifting secondary tasks to periods when little or no computing power is needed (Hamdi & Chainbi, 2019). Other methods consolidate and migrate VMs between different physical machines. In this approach, VMs from underutilized servers are migrated to other servers to switch the underutilized into power-saving mode or to shut them down (Bhattacherjee et al., 2020). VMs can only operate within the given IT resource capacity, which may lead to a violation of the SLAs if the agreed service cannot be provided due to a lack of capacity. Thus, overloaded servers need to migrate their VMs to moderately loaded servers during their compute task. This process is called live migration because the VMs are kept alive during the migration process to maintain uninterrupted service (R. Mandal et al., 2020). However, too many migrations can drive up electricity consumption, network utilization, and operational costs. Therefore, various energy efficient VM consolidation and migration approaches exist and are outlined in Chapter 3.1.2.

2. Methodology

The production of knowledge in the field of business research is accelerating at a tremendous rate, while remaining fragmented and interdisciplinary. This makes it difficult to keep up with the latest developments and stay at the forefront of research. Therefore, reviewing existing literature as a research method is more relevant than ever before. Baumeister and Leary (1997) describe the literature review as a more or less systematic way of collecting and synthesizing previous research as a foundation for all types of future research and theory. The systematic literature review can be divided into four distinct phases (Snyder, 2019). The first, the design phase, includes the search strategy, while the second phase, the conduct, includes the review process. The analysis – the third phase – consists of the abstraction of data or information, the identification of their characteristics and their analysis. During the fourth phase, the structuring and writing phase, the main findings, the summary as well as the discussion take place (Snyder, 2019; Wong et al., 2013). Following this guideline, the development and design of the search strategy is discussed in Chapter 2.1 of this paper. Chapter 2.2 outlines the conduct of the review process. The third phase, the analysis and information abstraction of the identified documents, is described in Chapter 2.3. In Chapter 3, as the last phase starts with the examination of the findings and influences of green cloud computing and the purchasing of renewable energy. This is concluded by a discussion of the key findings and an answer to the first research question.

2.1. Design of Search Strategy

The aimed contribution of this literature review, within the topic "How can a green cloud benefit business?", is to map and summarize the different research areas and synthesize the most recent developments of green cloud computing. From this, the opportunities for the consumer of green clouds are discussed, and an agenda for further research will be established. Following a recently published guideline in the Journal of Business Research (Snyder, 2019) as well as the RAMSES publication standard (Wong et al., 2013), a semi-systematic literature review was selected for this work. The semi-systematic literature review was developed for areas that are conceptualized differently and studied by different research disciplines. It aims to identify and understand the different perspectives and synthesize them using narratives rather than measuring effective size. In the case of green cloud computing, many different research areas and perspectives need to be included. The research areas start with computer science, and include telecommunication, environmental science, engineering science, business and economics, as well as management science. The different perspectives include the data center owner, the cloud service provider and consumer, the end-user, governments, the power generation sector, the network provider, as well as the environmental sector. This diversity of perspectives necessitated the application of a semi-systematic review in the scope in this work (Wong et al., 2013). The first phase of this review includes the development of an appropriate search strategy with the selection of search terms, databases, inclusion, and exclusion criteria. Additionally, necessary changes in the process are described.

The review began with an initial brainstorming phase, which was conducted to identify the relevant search terms related to the topic and research questions. In this initial session, the terms “green economy”, “sustainable”, “IT resources”, “cloud computing”, “data center”, and “cloud service” were defined. To get an overview of the time horizon under consideration and to determine the relevance of the search terms and their dependencies, the identified terms were entered into the Google Scholar search engine as well as into the Digital University Catalogue. This initial search using the combination “green” and “cloud computing” proved promising 4,376 results, of which 2,156 had been published in scientific journals. The documents found in this initial search had all been published in the last 20 years, which shows that the research field of cloud computing is quite young. If the term green cloud was included in the search, the period of published documents was limited to only the last 10 years. The time horizon as well, as the number of documents subsequently identified as relevant, are shown in Figure 3. The entire search process was completed by the end of February 2021 and the relevance of the documents was evaluated based on their relevance for the purpose of this work. The resulting exclusion framework was developed as well as the process of identifying the relevant documents is described below.

Figure 3 - Time Horizon of Identified Documents

In order not to exclude relevant insights no time limit was introduced as an exclusion criterion. However, due to the speed of development in the ICT field and the associated necessity of researching documents reflecting the current status, the last five years was given the most attention. Language was introduced as the first exclusion criterion with only English and German publications being included. The next step was to introduce an exclusion criterion so that only scientifically relevant and recognized sources, journals, or conference papers would be used. Therefore, only sources relevant for this work with a Scientific Journal Ranking (SJR) of Q1 or Q2 within their scientific area and an h-index above 50 were considered. These criteria built the exclusion framework of the applied literature review. After the development of this exclusion framework, the selection of appropriate multiple scientific databases followed. The Web of Science (WoS) was the first reference point in the search for a scientific cross-field insight. This overview was followed by a search assignment into disciplinary databases to include the different research traditions. For the computer science discipline, databases such as Association for Computing Machinery (ACM) Digital Library and IEEE Computer Science were selected. For the business discipline, databases such as Business and Academic Source Complete were chosen. These multi-scientific as well as disciplinary databases provided access to leading computer science and business journals as well as high-quality, peer-reviewed publications and science conference publications. In addition, non-scientific sources were used, such as government, non-governmental organization, or company websites and articles from other qualified sources. This was done to obtain a comprehensive overview and up to date figures. Nevertheless, the information from non-scientific sources were only included in the discussion and not into the literature review in order to clearly separate the areas.

2.2. Conduct of Review Process

The following description of the review process is illustrated at the end of this chapter in Figure 4. The initial search term "green" and "cloud computing" in the WoS resulted in 586 documents. This was reduced to 394 documents after the exclusion of all languages, other than English and German, and inappropriate science areas. The latter was necessary because the term "cloud" includes, for instance, weather-related research (such as meteorology and atmospheric sciences, geography, forestry, or astrophysics).

Following the exclusion framework discussed above, all lower ranked journals were then excluded. This second step left 226 documents. After reviewing the headlines, the key words, and the abstracts it became clear that the focus of the identified articles was mainly on the technical computing and programming part of green cloud. The economic and environmental impact for cloud consumers had not been comprehensively considered. Nevertheless, after this third exclusion 64 documents (28%) remained as directly relevant to the purpose of this work. A further set of 72 documents were identified as linked but were not of significant relevance. Their focus was, for instance, on the development and description of additional technical optimization features or efficiency algorithms without further contribution to this work. They were, therefore, excluded. Finally, 90 documents were identified as being not linked to the research direction in any way and were accordingly excluded. The 64 documents identified as relevant provide an overview of the technical development of cloud computing and an overview of the green cloud paradigm. In addition, they illustrate the relevance of green sustainable cloud computing, as well as providing the recent state-of-the-art developments in hardware and software.

However, as previously mentioned, the cloud consumer perspective – the main goal of this work – was missing. Therefore, a more targeted review process was utilized. After further research in the Digital University Library, a new search term was defined. In addition to the terms "green" and "cloud computing", the term "economic*" was added to the search process, which led to 1,945 documents. A second search in the WoS, including this new term, resulted in 125 documents. The three exclusion steps were once again applied. The first exclusion step, excluding all languages other than English and German and all inappropriate research areas, left 83 documents. The second step, the application of journal rankings, left 69 documents and in last step – the title and abstract review– another 52 documents were excluded. Both review process loops in the WoS identified 81 documents as relevant. To include the disciplinary databases in the review process, the identified databases were queried. As a result of this procedure, 38 additional documents from the computer science discipline and 17 additional documents from the business discipline were identified as relevant. The three exclusion steps were applied again, followed by the exclusion of duplications. This left 10 documents from both disciplinary databases and led in total to 101 documents being identified as relevant.

However, an ongoing scan for information published during this work was conducted to ensure accuracy. Therefore, documents published after February 2021 were used to bring numbers up to date, but they were not included in the initial literature review. A list of all identified, grouped, and clustered documents consisting of the 350 documents that entered the third exclusion phase can be found in Appendix I. The third exclusion step as well as the process of grouping and clustering is described in more detail in Chapter 2.3. In addition, Figure 4 visualizes the search process as described above, including the number of relevant documents per exclusion step.

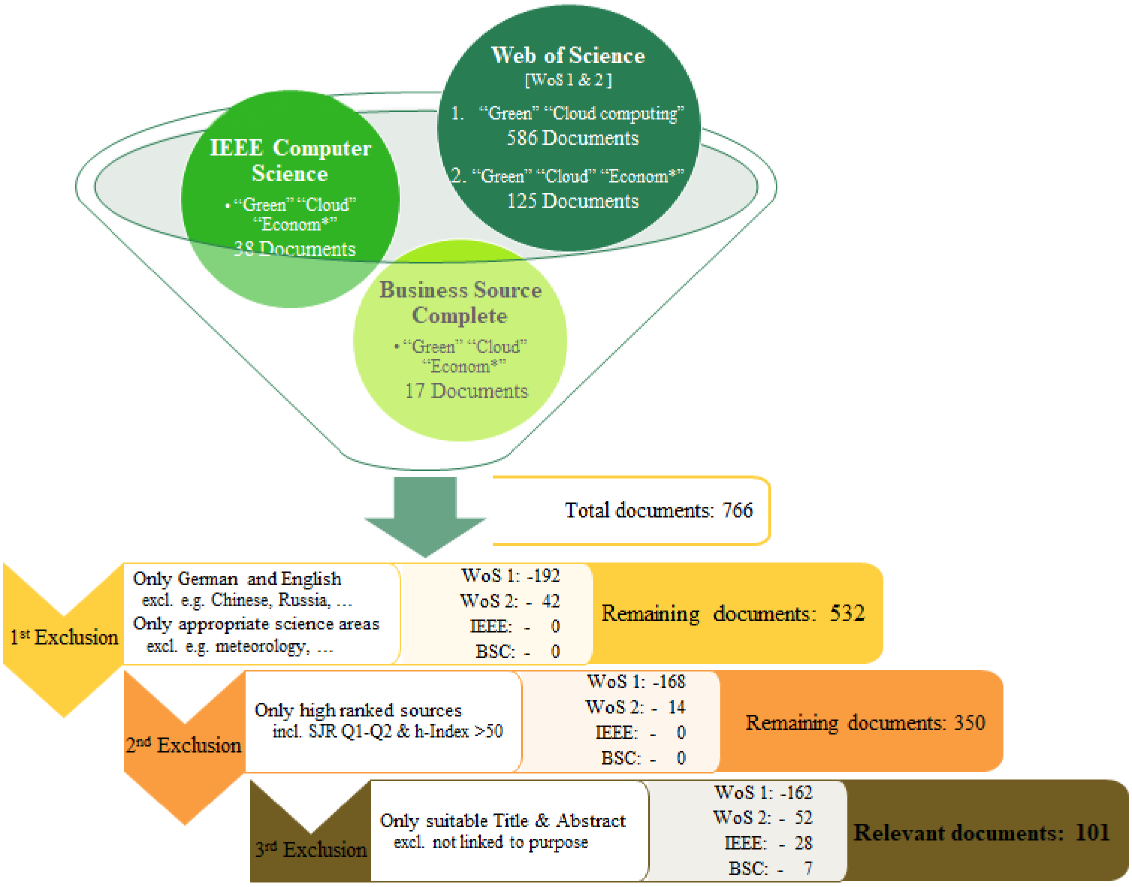

Figure 4 - Flow Diagram of Search Process

2.3. Information Abstraction and Analysis

To answer the first research question, the 101 documents identified as relevant were studied for the historical development of green cloud computing, its profitability and sustainability, as well as its different scientific traditions. To conduct an appropriate and target oriented analysis, the characteristics of interest from these documents were classified by their descriptive information as well as their target group within the historical context. To structure this approach and to ensure the quality and reliability of this semi-systematic literature review, the titles and abstracts of the 350 documents which entered the third exclusion phase were scanned first. The information considered as important was then identified, logged, and ranked from one to three. Number one indicated that the information provided by the document was considered as important for this work, number two indicated that the information was linked but had no significant new impact on the proposed direction of this work, and number three meant that the information was not linked to the topic of this work. During this ranking, the already mentioned 101 documents were identified as relevant. The entire texts of each of the 101 documents were studied. Subsequentially, they were divided into four target groups to identify their audience as well as the different streams of research traditions. The target groups consist of Cloud Service Consumer, Cloud Service Provider, Hardware & Data Centers, and Software & Optimization. In addition to this grouping, the documents were further classified and divided into six different dimensions, depending on the purpose of their research and descriptive information. The six dimensions are Allocation, Application, Architecture, Economy, Green Economy, and Virtual Machine. To enable the documents to be assigned to the four groups and six dimensions according to their purpose, the logged notes, as well as the ranking, were considered. In addition, the applied methods of the identified documents are logged. The notes which led to the ranking, the applied methods as well as the ranking itself are listed in a table in Appendix I. The resulting distribution of the dimensions on the respective groups can be seen in Figure 5.

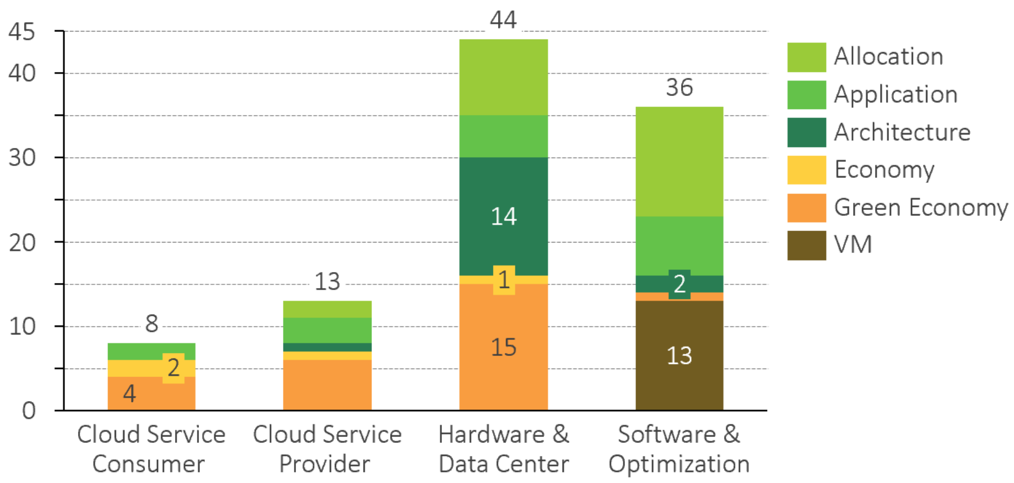

Figure 5 - Groups and Dimensions Allocation

The grouping provides an overview of the research traditions of the documents and the target groups on which previous research has focused. The majority of documents provided clear information about the affiliation to their target group. The Software & Optimization group deals with approaches of allocation models, the improvement of applications for more efficient energy management, or are directed towards the management of VMs. The documents in the group of Hardware & Data Center deal with the architecture and green economy – due to the fact, that data centers impact on both areas. The group of Cloud Service Providers is more difficult to distinguish, as some providers are also data center operators. Therefore, there is some blurring when separating these two groups. However, the last group, Cloud Service Consumer, can be clearly distinguished from the other groups. It can be seen in Figure 5 that the research focus was on Hardware & Data Centers and Software & Optimization, and that the Green Economy was mainly discussed in the target groups CSP and Data Centers.

The division into the six dimensions provides a cluster of the descriptive information of the documents. This clustering allows an understanding of the focus of different research traditions as well as their historical evolution. The Allocation dimension contains different rescheduling technics to improve energy and resource management regarding the software, hardware and the implications for the provider or consumer of CS. It is, therefore, consistent across the different target groups. The Application dimension contains documents describing different areas of green CS. Most topics within this dimension deal with service, quality, the cloud delivery models, and network security. The respective subject-specific areas are discussed in more detail in Chapter 3.1.2. The Architecture dimension deals with improved processors and memory, new cooling systems, waste heat regulation, and the network connections and its physical security. This dimension mainly directly addresses the target group of data centers or their on-premises IT resources. The dimension of Economy handles the economic influence on the business. The target group of this dimension consists of the Cloud Service Provider, its Consumer, and Data Centers, due to their specific business models. Here, it is remarkable that of the 101 identified documents, only four considered the influence on business. The low number of identified documents within this dimension could not be further increased despite adapting specific searches in the overall scientific as well as disciplinary databases. The dimension of Green Economy includes the environmental impact of cloud computing technology. It is separated from the Economic dimension due to its significance to the purpose of this work. This dimension deals with the sustainable and efficient use of resources and the use of renewable energies. The focus of the research within this dimension is on the target groups of the Cloud Service Provider and the Data Centers. Which makes sense insofar as these groups can exert the primary influence on the sustainability of the data centers, while the CSC has received little attention. The last dimension, the Virtual Machine, is closely related to the Allocation dimension in the Software & Optimization group, which makes it difficult to distinguish between the two. Nevertheless, the dimension is separate due to the high number of documents that deal with the VM approach. This dimension considers the temporal distribution of demand on computational capacities to achieve a consistent and energy efficient performance in data centers. The technical application and procedure will be further described in Chapter 3.1. Figure 6 illustrates the historical distribution of dimensions. It shows that the green cloud paradigm started in 2012 when the number of documents started to increase. The small number in 2021 is because only documents up to March were included.

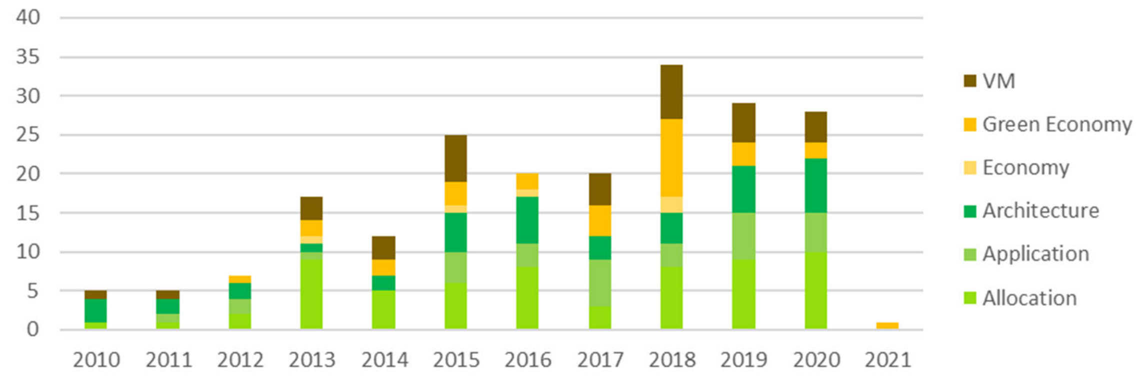

Figure 6 - Historical Distribution of Dimensions

Looking at the distribution of applied methods in the documents, the area in which new models are developed consists of the largest share with 45 documents. The implementation of simulations and experiments (22) as well as the survey and taxonomy approach (21) also account for a correspondingly large proportion. Eleven documents were identified as reviews, which were focused on during the reconstruction of the historical development. The allocation was always based on the largest proportion, although mixed variants in the procedures are common. For a detailed enumeration of the identified documents, please see Appendix I. The described grouping and clustering process of the identified documents make it possible to map green cloud research and to synthesize the current state of this research, as explained in the next chapter.

2.4. Key Findings

To summarize and discuss the relevant identified documents from the literature review in a structured manner and subsequently answer the first research question, the following three key findings were formulated. These were all developed in the context of the literature review process, as the review was a necessary first step in drawing a holistic picture. These findings enable the structuring of the discussion throughout Chapter 3.

At first, it appeared that most of the identified documents understood the innovative concepts developed in their work differently and viewed them from different perspectives. In the course of the review process, it became clear that the various approaches had some overlap, were divergent, and even counterproductive. This may have been due to the lack of a cornerstone providing a common starting point and a uniform understanding of the green cloud paradigm. Therefore, the following key finding was formulated first:

I. There exists no clear definition of a green cloud, due to the lack of an industry standard.

A second factor that contributed uncertainty and vagueness to the research was the fact that predictions of computation demand are highly controversial. A further possible factor of uncertainty is the problem of implementing energy that is 100% renewable. Both factors may be due to inaccurate data and insufficient information from the local power grids in each region of the world. These factors, in addition to the lack of an industry standard, distorted the focus of research efforts. Therefore, the second key finding out of the review was formulated:

II. There is a distortion of focus due to controversial demand predictions and uncertain renewable energy implementation.

The last key finding has to do with the very one-sided view of the identified literature. This picture could not be expanded despite further and broader search efforts. It can therefore be assumed that there is a conceptual lack of linkage between the technical, the economical, and environmental perspectives in the consideration of the optimization potential of cloud computing. For this reason, the following final key finding was formulated:

III. Future demand for cloud capacity will only be met by combining technical optimization with sustainable economic approaches.

3. Results: Profitable against Green?

In the following chapter, the first research question – "Does profitability conflict with environmental friendliness in cloud computing?" – will be answered based on the preceding literature review. The described grouping and clustering process of the identified documents enables the mapping and synthetization of information within the green cloud environment. At first, the current state of the emerging green cloud paradigm will be examined, including its technological and economic approaches driven by the influences of different scientific fields. Then, different influencing and shaping factors will be weighed against each other, including opportunities and limitations, the renewable electricity supply, and its purchase for data centers. Here, the different density of data centers, the corresponding local electricity mix, the issue of unstable availability, and the greening approach through power purchase agreements from market participants will be examined. Subsequently, the three key findings will guide the discussion, and finally are summarized to answer the first research question.

3.1. Green Cloud Paradigm

The growing demand for CS has been accompanied by rising CO_2 emissions due to both the increasing energy and resource requirements of data centers hosting CS, and the fact that most of the electricity has been generated by fossil fuel or coal (IRENA, 2019). Due to increasing pressure, the computing industry is becoming aware of the importance of sustainability to protect the environment (Mashayekhy et al., 2015). This growing public environmental awareness has led to the development of technological solutions which enable more sustainable operation. To meet the requirements for precise time and resource management at data centers, automated electricity aware methods are needed, because the human ability to intervene is no longer sufficient. The term "green" has been used a lot lately in the context of cloud computing, but the concept is decades old. The starting point of green IT can be found back in 1991, when the Environmental Protection Agency started their Green Light IT program (EPA, 1991). Beloglazov et al. (2012) combined the cloud approach with environmental friendly IT, and thus initiated the concept of green cloud computing. They created a vision in which the goal was not only to reduce electricity consumption and increase efficiency, but also to ensure the sustainable distribution and use of resources. Green economy initiatives place the proportionate and efficient use of resources at the heart of the industry. Factors such as reduced resource consumption leading to lower emissions, economic benefits due to cost and tax savings, and increased environmental awareness all support the greening of the industry. This has resulted in the incentive for, and potential of, the green cloud paradigm (Schniederjans & Hales, 2016).

All identified documents from the semi-systematic literature review deal in some way with green data center operations hosting cloud technology. They focus on either physical or virtual optimization (Shuja et al., 2017). Physical optimization involves increasing hardware efficiency, including component and cooling optimization, geographical placement, and data center network architecture. Virtual optimization includes the VM approaches, which handle management and scheduling algorithms as the key to ensuring consolidation and reducing energy waste (Han et al., 2020). To structure the vast amount of abstracted information from the identified documents, the four target groups and six dimensions developed in Chapter 2.3. will be used within the following subchapters. The content of the documents in the Hardware & Data Center group relate to the dimensions of Architecture and partly Allocation. Documents in the Software & Optimization group relate to the dimensions of Application, Virtual Machines and partly Allocation. Finally, documents relating to the dimensions of Economy and Green Economy, because they are overarching, are examined at the end of this chapter.

3.1.1. Hardware & Data Centers

As a result of information abstracted from the identified literature, the drivers of electricity consumption and efficiency in data centers can be separated into two dimensions, namely Allocation and Architecture. The dimension of Allocation within the Hardware Level includes the tasks of allocation and scheduling as well as resource management between geo distributed data centers. Architecture includes the cooling, waste heat regulation, and network connections.

IT resources allocation in geographically distributed data centers is used by multiple applications simultaneously to provide CS globally, reliably, and cost-effectively (X. Lu et al., 2018). For data centers a critical economic factor is to minimize the total cost of ownership (TCO), by considering bandwidth and electricity prices, as well as the availability of renewable electricity depending on the geographical location (Khalil et al., 2019). In this context, scientific approaches have pursued methods to optimize geographically distributed IT resources. This involves planning tasks so that the overall costs of the data center are efficient, as well as that the CO_2 footprint and the environmental impact are minimized (Haitao Yuan et al., 2019). Uddin et al. (2015) highlight the importance of including the location of data centers and the climatic conditions into schedule algorithms because power consumption and CO_2 emissions are directly related to these conditions. For instance, the amount of electricity required for cooling of data centers is directly related to the climatic environment of its location.

Another research stream in the dimension of Allocation relates to the use of renewable energy in workload distribution across geographically distributed data centers. This is achieved by taking advantages of dynamic electricity prices and increasing the use of renewable energy – depending on its availability in different locations (Khalil et al., 2019). To make data centers more sustainable, CSPs try to implement the use of renewable energy sources such as wind or solar power. However, the intermittent and variable nature of this energy sources poses additional challenges (Deng et al., 2014). Therefore, VM consolidation and migration is a promising approach to solve this problem. It is applied to shift workload, and thus energy demand, using flexible allocation techniques (U. Mandal et al., 2013). To manage the intermittent nature of renewable energy, Cheng et al. (2019) developed a management approach which aims to maximize its use. The system adaptively consolidates workload, allocates available resources to workloads, and migrates tasks between data centers, based on green power availability. In order to distribute the workload to different data centers, Kessaci et al. (2013) developed an algorithm for workload scheduling and mass data transfer. Although research efforts are moving in the direction of harnessing renewable energy as much and as efficiently as possible through mass or bulk data transfers between geo-distributed data centers, the objective of a sustainable and green data center has not yet been achieved. X. Lu et al. (2018) points to the resulting problem of increased power consumption due to internal data transfers between distributed data centers, resulting from the effort to integrate renewable energy. Zhou et al. (2020) developed an auction model which offers financial incentives to the CSP for taking over computational tasks that would otherwise have to wait due to utilization rate or green energy supply in cloud network. This model allows CSPs to submit financial bids for providing corresponding amounts of computing capacity depending on the demand. In this context, Pittl et al. (2017) developed a taxation model that calculates taxes for the use of VMs. The energy efficiency of the underlying server is considered as the decisive factor for the tax, which includes a tax reduction in the case of efficient application. Evaluations show that the developed model is a win-win mechanism for both the geo-distributed cloud and a smart grid.

Regarding dimension of Architecture, data center cooling contributes up to 40% of the total energy consumption. Therefore, efficient cooling is an essential component in making data centers sustainable and rentable (Zhang et al., 2017) and thus many scientific approaches aim to minimize the energy consumption of cooling systems from data centers. Among them are: virtualization and thermal benchmarking approaches (Chaudhry et al., 2020); thermally aware automatic heat and air circulation models (Viswanathan et al., 2011); air conditioning systems dependent on environmental influences (Liu et al., 2016); VMs migration models to control heat and cooling transfer (Witkowski et al., 2010); and models to decrease energy waste from overheating network nodes (Xu et al., 2019). A holistic approach was developed by Guan et al. (2018) combining cooling, heating, and energy management approaches. The simulation was conducted at a cloud data center operating in Chongqing, China, where they efficiently used steam-powered cooling to achieve economic and environmental benefits. Almost all approaches conclude that the economic and environmental advantage of optimized data center cooling is significant. The simulations show that most of the designed systems can contribute to a reduction in energy consumption without compromising cooling performance.

Another aspect in the dimension of Architecture is the operation of data center network, which is another cause of energy consumption in data centers. Interestingly, novel innovations are not always necessary to lower the consumption. As Popoola and Pranggono (2018) noted, simply implementing a commodity switch can reduce the cost, energy consumption, and heat dissipation in many data centers. Marotta et al. (2018) highlighted in their work the increasing problem of rescheduling workload and the effect this has on the energy consumption of the network. To relieve the network of the internal data exchange, T. Yang et al. (2017) created a workload aware VM scheduling approach to reduce the electricity consumption of highly utilized networks while not violating SLAs. For this purpose, they proposed a consolidation model that considers the energy efficiency of both switches that forward the traffic and servers that host VMs. But due to the opposing forces of growing demand for cloud computing on the one hand, and the efforts of rescheduling the tasks to decrease the energy consumption on the other, this issue will significantly increase in the future.

3.1.2. Software & Optimization

The content of the identified documents in the Software & Optimization group can be divided into three dimensions: Application, Virtual Machines, and Allocation. Application includes the energy efficiency of cloud delivery models, prediction models for service, quality, and security, as well as related emerging technologies. The dimensions VM and Allocation are closely connected, as mentioned in Chapter 2.3, because both include scheduling techniques and handle corresponding problems with SLA violation. In the dimension Application, cloud computing provides web-based IT resources for advanced technologies and applications. It is becoming essential in our daily lives and will become increasingly indispensable in future-oriented areas, such as video and conference streaming, the healthcare sector, Big Data Analytics, and AI (Hang Yuan et al., 2010). Arora and Bala (2020) compared different energy efficiency techniques for cloud computing. They identified the Big Data Analytics technique as optimal because it handles the trade-off between optimizing energy efficiency without violating SLA parameters. However, emissions and TCO are largely ignored compared to data center efficiency. To sharpen this imprecision, Shaikh et al. (2020) developed a calculator capable of a more comprehensive evaluation. It combines the power efficiency, CO_2 emissions, and total annual cost to create awareness of the resource requirements of data centers. Their calculator is already in application in data centers in Malaysia and the results demonstrate its effectiveness, regarding energy awareness. Other approaches considered the future utilization of IT resources within VMs (Subirats & Guitart, 2015). These use a regression-based approach to estimate the future Central Processing Unit (CPU) and memory utilization of physical and virtual servers. Because of this, pre-planned allocation task redistribution can be minimized or even avoided. This results in energy savings, fewer VM migrations, and fewer SLA violations (Farahnakian et al., 2019).

The use of CS in IoT applications is a growing field including the accelerated datafication of applications. The term IoT was coined by Ashton (1990) and has attracted much interest in the fields of research and industry. Today, it encompasses a variety of architectures, standards, and applications in several areas including housing, agriculture, retail, transportation, infrastructure, and healthcare. Autonomous and smart devices are being used to collect data and transfer it to the Internet. The limitations of the IoT- connected IT resources in terms of storage, accessibility, scalability, and networking & computation can be solved by leveraging the cloud infrastructure (Ismail & Materwala, 2018). Dupont et al. (2018) studied the economic, social and environmental impact of the IoT application while using sustainable energy provision in West Africa. They built an open IoT platform on the base of a sustainable development including the environmental impact as well as local economic and social aspect. They highlighted both the potential and the need to develop environmentally friendly cloud computing technology, not only in emerging countries.

Another approach for computation capacity optimization in green cloud computing is volunteer computing. The contribution here is that workloads are distributed to free computing resources using voluntarily participating devices. This approach enables low-costs, a high use of renewable energy, and a green computing infrastructure which can relieve expensive data centers (Mengistu & Che, 2019). However, issues such as security, task allocation, resource management, and incentive schemes for volunteers need to be further explored. In their paper, Khalid et al. (2018) developed an energy-efficient approach to solve the resource management and security problems in a smart volunteer-based IT network. They simulated three components: a community of 100 smartly connected households; the secure workload transfer; and the utilization of the network. The proposed approach reduced the data center's consumed electricity by up to 55% and its energy costs by 67% while the security of the data was ensured by encryption techniques.

In the dimensions of VMs and Allocation, one of the most important objectives of green cloud computing is to reduce electricity consumption. This is mainly achieved by maximizing server utilization and shutting down unused servers through two types of algorithms: VM consolidation algorithms and VM migration algorithms. Due to the urgency and the public awareness of environmental issues, schedule techniques comprised a major part (52 of the identified documents) of research efforts in the field of data center optimization. Consolidation and migration algorithms have been used to increase server utilization and energy efficiency, as well as to reduce data center energy demand and thus emissions (Cappiello et al., 2016; Y.

Lu & Sun, 2019). Although many research efforts have investigated the optimization of VMs consolidation and migration algorithms, they have all used different approaches. For instance, Mashayekhy et al. (2015) explored possible algorithms for physical and virtual resource management. Ullah et al. (2020) developed a system consisting of a resource monitor, a resource estimator, and a consolidation mechanism to automatically allocate the workload. J. Yang et al. (2019) introduced an AI consolidation approach, which increased utilization and reduced the number of physical servers through an intelligent schedule control engine. Abdessamia et al. (2020) included a gravitational algorithm for the VM consolidation, while Mishra et al. (2018) focused their consolidation algorithm on the execution rate. Regarding hybrid clouds, the problem of different trust boundaries needs to be considered in consolidation approaches (Vilaplana et al., 2015). In their migration approach Bhattacherjee et al. (2020) included a prediction-based algorithm to minimize the active physical server and VMs. Alarifi et al. (2020) developed a hybrid framework, which combined task consolidation and server migration, to offload overloaded servers by migrating their VMs to underloaded servers. Qie et al. (2019) combined an asynchronous multi-sleep mode and an adaptive task-migration scheme. It consists of two modules: the first is always ready for use, the second will independently go to sleep, if possible. This separation enables safe computing power for the data center without violating SLAs. Pierson et al. (2019) focused on renewable energy management. They developed a trade-off solution which negotiates the optimal balance of energy generated by renewable and fossil sources in a loop process. This ensures high availability and avoids unnecessary redundancy, caused by both the intermittent nature of green electricity and cloud service flow (H. Wang & Tianfield, 2018). The numerous studies listed above show that there has been rapid progress in the field of cloud computing research within the last decade.

With increased VM consolidation and migration, there is a need to balance energy consumption on the one hand and performance of the system and the network on the other so that SLA requirements are met (Marotta & Avallone, 2015). VM allocation requires, therefore, a continuous and careful balancing of conflicting requirements like performance, service level, operational cost, and energy efficiency (Mann, 2015). The ongoing optimization of energy consumption has a serious impact on all other parameters. The power-on and -off routines reduce energy, but they also affect the lifetime of physical servers (Shuja et al., 2017). Furthermore, the routines are difficult to implement without affecting delivery performance to the consumer. Many works have highlighted the issue of SLA violation when consolidating and migrating the workload between servers. They have focused on the importance of SLA compliance and have integrated this variable in their schedule algorithms (Guérout et al., 2014; Iturriaga et al., 2016; Mustafa et al., 2019; Ouyang et al., 2014). Malekloo et al. (2018) developed an energy- and SLA-aware VM consolidation and migration approach. It aims to achieve a trade-off between the conflicting requirements. In another approach, Hedwig et al. (2012) designed a risk-aware SLA for cost-effective decision making. Their model seeks to help IT decision makers understand the relationship between operational costs, SLA, and sustainability. This allows them to make more comprehensive long-term decisions. Stavrinides and Karatza (2019) focused on SLA compliance, cost-, and energy-efficient application for both the CSP and CSC. The proposed algorithm leverages power saving technologies with its core parameters – frequency, utilization and power consumption – on the underlying processors to detect and fill gaps in the schedule (Cotes-Ruiz et al., 2017).

An overarching approach combines energy and efficiency parameters with economic incentives. Agustí-Torra et al. (2015) developed this model which shifts the workloads of data center to less utilized times or data centers, while providing financial incentives for all participants. The approach is based on two assumptions, firstly, that there is a high level of flexibility regarding the SLA between the parties, and secondly, that the collaboration between the parties is dynamic. The energy provider benefits from rescheduling as it can smooth energy demand peaks due to performance reduction at data centers. The data center reduces their performance and therefore their energy consumption, which violates the SLAs. This, however, is not a problem if all parties are offered a financial incentive, based on rewards or discounts. However, this can have an impact on businesses, here the collaboration of all stakeholders is decisive. In times of high energy demand in one local grid, the workload can be relocated to data centers in another local grid with less demand, which ensures the performance (Renugadevi et al., 2020).

3.1.3. Overarching Dimensions

Finally, the dimensions Economy as well Green Economy are considered together in the following chapter. In the identified documents, these two dimensions appeared in all target groups. As a result, profitability, energy efficiency, renewable energy, and green SLAs are the main aspects considered below.

A few scientific works investigated the economic impact of cloud computing regarding profitability and TCO in the identified documents (Attaran & Woods, 2018; Bianchini et al., 2017; Ismail & Abed, 2019; F. Yang & Chien, 2018). Alfonso et al. (2013) compared the TCO of using own IT resources with outsourced cloud approaches. Their initial finding was that it is economically preferable for large industrial companies to host their own physical servers on-premises if they show a high and constant utilization rate of their cloud applications. For start-ups or companies with a high degree of uncertainty, as far as their computational requirements are concerned, clouds provided by CSP are a more economically and environmentally promising option (Schniederjans & Hales, 2016). Furthermore, a modeling tool was developed to compare energy consumption. It calculates the energy savings resulting from moving local IT resources to a data center. The simulations show that in the United States of America (USA), up to 87% of ICT energy consumption could be saved if all businesses in the USA migrated their email, productivity and customer relationship management from their own premises into the cloud (Radu, 2017). Similarly, Accenture (2020b), one of the major cloud providers, calculated that the potential savings for a company in moving into the cloud amount to a 30 – 40% reduction of their TCO. Khattar et al. (2019) investigated the state-of-the art optimization of energy efficiency in green cloud computing by classifying different optimization and dynamic management methods for data centers. They concluded that schedule algorithms are the most used techniques for reducing energy consumption. They also pointed out that common indicators for efficiency consideration are resource utilization, number of cores, node utilization, number of servers, and CPU utilization. An important indicator of a green cloud, on the other hand, is CO_2 emissions, which give an indication of the environmental friendliness of a data center.

Renewable energy sources play an important role in making IT environments more sustainable and greener, as well as generating electricity at a cheaper cost. To overcome the problem of intermittent availability of renewable energy, geo distributed task migration and volunteer cloud computing can play, according to Pierson et al. (2019), a significant role by distributing and managing computationally intensive tasks. F. Yang and Chien (2018) calculated that if data centers only used renewable energy instead of energy generated by fossil fuel, they would achieve a long-term cost saving of about 50%. However, exclusive use of renewable energy is, due to its intermittent nature, not yet realizable (Patchell & Hayter, 2021). With solar energy, the intermittency problem of a renewable electricity supply is obvious: it increases gradually during the morning; reaches its peak at noon; and progressively slows down according to the sun’s position, while the demand for computing capacity runs in the opposite direction and peaks in the evening hours. Capizzi et al. (2018) developed a management solution that models the behavior of a solar energy system and consumption device to determine the optimal energy distribution between both instances. Courchelle et al. (2019) studied the efficient use and storage of solar energy in data centers. They developed an algorithm that uses solar energy to plan and make decisions during renewable energy supply. This allow VMs to prepare a schedule using the smallest amount of energy from fossil fuel as possible. Their simulation, based on Google data, examines the dependencies between the components for storage (batteries) and renewable energy production (solar panels). Gu et al. (2018) investigated how data centers can be powered by self-generated wind energy. Thereby, they highlighted the possibility of energy trading with the power grid. This means, if overproduced energy cannot be used or stored, it is sold to refinance part of the energy expenditure of data centers.

An approach to green energy management is based on “Green SLAs.” Hasan et al. (2017) highlighted both the intermittent nature of renewable energy sources and the fact that the best location for producing renewable energy was not always the best location for building a data center. Therefore, they introduced the possibility of virtualizing green renewable energy, which increases the greenness, rather than the amount of green energy. This is done by summing up the interval of overproduction as a surplus interval and cancelling it with degraded intervals of renewable energy production. Such green energy balancing enables the grid operator to cover the electricity demand, which in turn enables the CSP and the CSC to always use the full potential of computing capacity, and this ensures QoS compliance agreed in the SLA. A further Green SLA-based scheduling framework for executing independent jobs was elaborated by Kumar and Vidyarthi (2017). Their "Green SLA" scheme automatically negotiates, along predefined boundaries, the use of renewable energy in terms of time span, efficiency, and cost between the CSP and the CSC. It also integrates a strategy to consolidate and migrate green IT resources to ensure cost efficiency without impacting performance or violating the SLA.

Another green approach concerns the supply chain of the cloud computing industry. Its objective is to lower the ICT carbon footprint of all involved stakeholders. For instance, K.-Q. Wang et al. (2017) assessed the green performance of energy providers, data center owners, CSP as well as CSC using economic and environmental criteria. They developed a multi-criteria decision-making model as a guideline for selecting the most suitable green supplier (in this case, CSP).

3.2. Magnitudes of Influence

From the previously identified technical insights it can be concluded that research efforts have tackled a vast number of different optimization approaches all consisting of different strengths and weaknesses. Several research efforts have focused on the various opportunities and limitations of cloud computing for stakeholders. The opportunities consist of benefits, while the limitations consider the different risks and challenges of cloud computing. Both, the opportunities and limitations of green cloud computing will be discussed from now on. This will be followed by a discussion about the renewable energy supply as well as its purchase.

3.2.1. Opportunities and Limitations

The opportunities can be summarized as reduced investment and proportional costs and an increased scalability, availability, and reliability (Erl et al., 2013), which can be derived from the six initial cloud characteristics described in Chapter 1.3. While most of the research community agree in general about the core benefits of cloud computing, the details are very diverse. A detailed overview of the benefits on the software level includes: on-demand computing resources for optimizing workload schedules (Attaran & Woods, 2018); nearly infinite scalable computing capacity (Cotes-Ruiz et al., 2017); and increased reliability through multiple protection of physical and virtual servers in globally distributed data centers (Ullah et al., 2020). On the hardware level, the benefits consist of: the elimination of investment and maintenance expense due to the outsourcing and leasing of IT resources (Garg et al., 2011); operating costs tailored to requirements due to elastic scaling and pay-as-you-go business model (Ismail & Abed, 2019); as well as speed up development cycles (Jing et al., 2013). For consumers, the cloud environment provides massively scalable service and cost savings. It enables them to plan their future capacity needs and adapt them on demand, to reduce their operational cost as well as to increase their agility (Xiong et al., 2012). Another great benefit for young or smaller companies without their own IT infrastructure is that they do not have to invest enormous costs in the hardware installation. They can lease the needed computing capacities and scale them depending on their demands (Bianchini et al., 2017). A few of the identified documents investigated the economic impact and benefits of cloud computing on consumers (Xiong et al., 2012). Here the data centers' TCO, as well as the effects of the inclusion of renewable energy, are important fields which are increasingly coming into focus. However, the amount of savings cannot be generalized and must be evaluated on a case-by-case basis, as many factors of the consumer have an impact (cloud readiness, existing IT infrastructure, available budget, governmental regulations, carbon emissions, and subsidies).

The potential limitations of cloud computing can be summarized as, performance inefficiency, security vulnerabilities, limited operational governance, lock in effects, and multi-regional legal issues, all in context with energy efficiency and SLA compliance (Dupont et al., 2018). Performance inefficiency is a result of the tremendous increase in demand for cloud computing and is caused by the increasing amount of data and information that needs to be transmitted and processed. This creates the significantly growing problem of energy consumption and heat waste, which are accompanied by serious environmental impacts: the exploitation of rare earth elements and resources; electronic hardware waste; the CO_2 as well as the superordinate GHG emissions; and environmental pollution. To meet this challenge, research efforts have investigated the various physical and virtual optimization and efficiency strategies for data centers, described in Chapter 3.1 (Lykou et al., 2018). As far as the security issue is concerned, the risks of cloud computing are increased by the fact that the responsibility for data no longer lies solely with the consumer. In a private cloud, this is not tragic, because the CSP and the CSC can agree on a compatible security framework. However, a private cloud with its own on-premises data center is not common, not always available, and in other cloud deployments models (public, hybrid, or community cloud) a compatible security framework is not possible. Here the CSC uploads his data to a third-party public cloud and releases the data from his trust boundary. A consequence of overlapping trust boundary is that that the CSP can access the data. This means, that the data security is now subject to the processes of both the CSP and the CSC. This increases the risk of cyber-attacks involving theft or corruption of business data (Erl et al., 2013). To address this challenge, Kiran et al. (2011) presented a framework for a risk assessment in cloud environments that includes risk identification, migration and monitoring. Their framework works with their VM migration strategy to ensure technical security and reliable service delivery. Another challenge arises as a result of the CSC having less control of the IT resources compared to on-premises solutions. Because an external connection is required for communication with the third party cloud operator, this poses a risk (Shojafar et al., 2020). The corresponding governance system for the cloud is established by SLAs between the parties. However, the level of governance varies significantly according to the cloud delivery models; these all have different capabilities, degrees of freedom, and authorization areas. Whereby IaaS has the highest degree of governance control and SaaS the lowest (K.-Q. Wang et al., 2017). Due to the lack of industry standards in the cloud computing industry, public clouds can be free or not free: the so-called ‘proprietary environments’ can vary considerably. For customized solutions, this can lead to significant challenges if the CSC wants to switch the provider of the proprietary environment. Additionally, the interconnections between different CS applications within a company can lead to a lock-in effect, similar to the business models of some social media providers (Patchell & Hayter, 2021). The final limitation outlined here concerns the data center location. The data center operator can place data centers at any location in the world. Decisive factors determining location can be accessibility to renewable energy, cooling resources, network connectivity, low operating costs, regulations, and subsidies. The resulting multi-regional locations can create compliance and security issues for the CSC. Furthermore, the geographical location of data can establish legal problems with the industry or government regulations concerning the privacy, security, or storage policies of data. For instance, a European CSC´s data located in the U.S. can be more easily accessed by government agencies (through the U.S. Patriot Act) than data located in many European Union (EU) countries (Erl et al., 2013). In other countries, such as China and Russia, government regulations are even more obscure and difficult to understand.

3.2.2. Renewable Energy and Purchase

The global power consumption of data centers creates a massive carbon footprint. Data centers are located all over the world and are connected to the local power grid. They are operated by several different operators, as well as regulated according to different industry and government specifications. Furthermore, data centers are highly dependent on the local grid's electricity mix which makes an accurate estimate of the carbon footprint nearly impossible (Malmodin & Lundén, 2018). The ongoing trend toward renewable energy sources for energy generation (including electricity, heat, and transport) is still evolving, with a global share of 15.6% in 2020 (about 36,7% for pure electricity generation), see Figure 7. However, this increase has been insufficient in the last decade. Furthermore, it is foreseeable that the share of renewable energy will increase steadily because the price of renewable energy is in some areas already competitive compared to energy from fossil fuels or coal (IRENA, 2019).

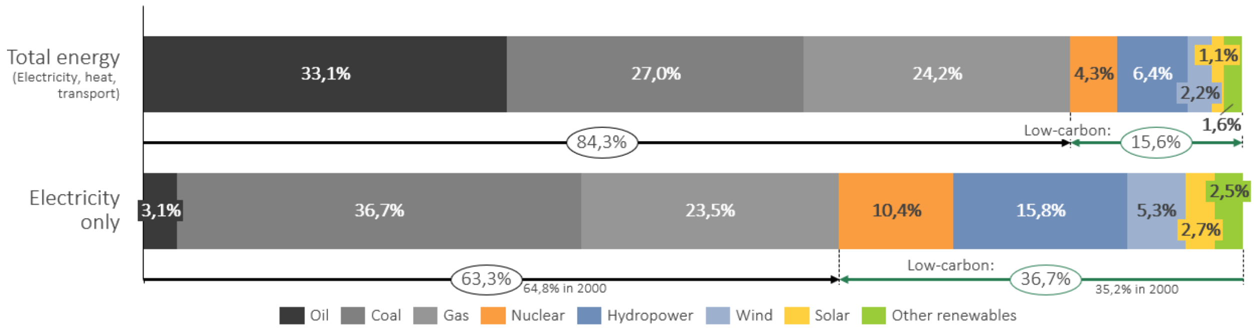

Figure 7 - Global Energy Production by Sources 2020 (BP Global, 2020)

As previously mentioned, the operators' geographic location choice for data center placement can be influenced by a variety of factors. These include, among others, country of origin, governmental regulations, climate conditions, geological and geographic constraints, costs and subsidies, quality of infrastructure, and renewable energy availability (Khalil et al., 2019). The regions with the highest data center density are the USA, European Union (EU), and China, followed by the United Kingdom. Emerging countries such as India, Singapore, Brazil, Japan and Australia are not as well represented compared to the major regions, but their market share is steadily rising due to the decisive factors mentioned above (DataCenters, 2021; IEA, 2020a). Figure 8 shows the most important regions and the corresponding local electricity mixes. It is important to note that there can be immense local differences in the regional power grid. For example, the power grid in California, USA, consists of nearly 95% renewable energy, while the power mix in Virginia, USA, is nearly 90% fossil fuel (BP Global, 2020). The magnitude of this local difference is increased significantly by the fact that the density of data centers in Virginia is extremely high (Patchell & Hayter, 2021). Hence a specific community of counties in Virginia is known as Data Center Valley where almost 70% of the world's internet traffic is handled daily (DataCenters, 2021).

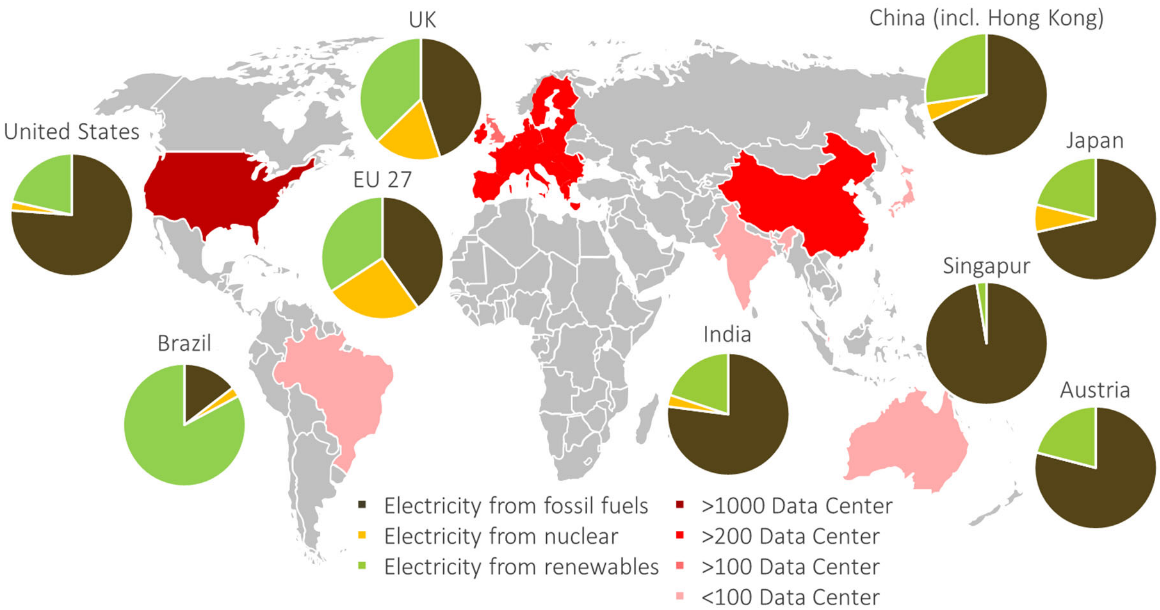

Figure 8 - Global Distribution of Data Centers and Energy Mix (Based on BP Global, 2020; DataCenters, 2021)

One frequently highlighted issue concerning energy generated by renewable sources is its intermittent nature (Deng et al., 2014). This is especially important in green cloud computing since the demand for computing capacity and the associated energy and resource consumption of the data centers is constant and needs to be met securely and reliably (Malmodin & Lundén, 2018). This is particularly the case with wind or solar energy, because the latter on is dependent on the sun cycle and private demand (for streaming, video calling, online shopping) is usually highest in the evening, i.e. after sunset where almost no local solar energy is available (Danilak, 2017). To handle this issue, approaches have focused on storage as well as scheduling and distribution of tasks, which were described in depth in Chapter 3.1.1.

Regarding power purchase, data center owners, as well as the CSPs, have come under pressure due to their increasing energy demand and the impact this has had on global electricity consumption. The three major providers in the cloud service industry in 2020, with a total market share of 63%, are Amazon Web Services (32%), Microsoft Azure (20%), and Google Cloud (9%) (Statista, 2021). Due to increasing public environmental awareness, these global IT companies have been forced to greening their data centers as well as their businesses. In 2011, Facebook became the first IT company to commit powering its data centers with 100% renewable energy in the long term. Both Apple and Google followed with the same commitment a year later, and AWS and Microsoft in 2014. This pioneering role by the major internet companies has motivated several other companies to implement targets of 100% renewable energy usage (Patchell & Hayter, 2021). The key drivers for this adaptation have been renewable energy competitiveness, brand reputation, and the growing number of energy-conscious business customers (Mayer & Gereffi, 2010). In addition, many governments are setting climate and energy targets to motivate companies operating in the marketplace to being more transparent and committed to reducing their energy footprint (Greenpeace, 2019). However, the green power supply in many countries is regulated and strictly limited. Therefore, it is often not possible to respond adequately to the accelerated renewable energy requests of the cloud industry. The solution of building and operating data centers directly next to renewable energy power plants is not always suitable for the CSP, due to climate or geological conditions or grid regulations (Malmodin & Lundén, 2018). Therefore, they have to invest huge amounts of money into third-party development of the renewable energy grid at their operating regions. This has been done, for example, through Power Purchase Agreements (PPAs), Renewable Energy Certificates (REC), or Emission Trading Systems (Accenture, 2020a). PPAs and REC are long-term bilateral electricity supply contracts, between a power generator and an electricity consumer (in this case the data center owner). The PPAs defines the terms of the agreement, such as the amount and type of electricity to be supplied (guarantees of origin), and negotiates prices, billing, and penalties for non-compliance. They are becoming increasingly important, especially for the renewable energy sector, as many government subsidies have expired in the EU (EU, 2021b). Here, PPAs provide long-term opportunities to continue the operation of green power generation facilities (wind or solar farms) competitively. Therefore, the purchase of green PPAs makes sense both economically and because it is good for public relations. It allows the consumer to control the future of their energy procurement and to support the local grid in a sustainable and carbon neutral development. However, electricity generation is only one side of the coin. To get a complete picture of the energy position of a sector, it is equally important to maintain an overview of consumption. A holistic view of the energy supply and demand portfolio, segmented by region, time, and resource type, is essential for sustainable development. This type of information is critical for assessing gaps, identifying new opportunities, and transitioning to less reliance on conventional generation to balance the renewable portfolio (Patchell & Hayter, 2021).

3.3.Discussion of Key Findings

The following discussion is based on the already derived key findings in Chapter 2.4. As described, these were formulated as a result of the semi-systematic literature review process and are as follows:

I. There exists no clear definition of a green cloud, due to the lack of an industry standard.
II. There is a distortion of focus due to controversial demand predictions and uncertain renewable energy implementation.
III. Future demand for cloud capacity will only be met by combining technical optimization with sustainable economic approaches.

The review was a necessary first step in drawing a holistic picture and the key findings were necessary to structure the discussion as well as the findings. The presented state of research on the green cloud computing was conducted to generate an overview of the research efforts to date and their impact on the technology. From now on, the three key findings form the basis of the following discussion. They guide the economic and environmental implications of the current situation and identify missing gaps in the following chapters. Which leads to the summary and answer of the first research question in Chapter 3.4.

3.3.1. Missing Industrial Standard

The identified documents and research efforts for greening the cloud environment support the green agenda only up to a point. The majority of scientific research has focused on energy consumption reduction in data centers and has dubbed this a “green cloud”. The main focus of research has been on efficient resource management: the implementation of VM consolidation and corresponding migration approaches to optimize the use of server capacities as well as to decrease the number of active servers; and the optimization of architecture, hardware, and thermal efficiency (reuse of heat, efficient automated cooling). However, it takes more than just increasing technological efficiency to develop a sustainable green cloud and make it competitive in the long run. One reason for this gap could be that there is no standard definition of cloud computing, let alone one for green cloud computing. As a result, all research efforts have different assumptions and understandings of what is meant by “green” and what goals should be pursued when implementing sustainability strategies. In a sustainable green cloud, the pursued optimization approaches are of course all a part of, but are not the essential key for, a sustainable green economy. In order to create a framework for an industrial standard, global Key Performance Indicators (KPIs) should be considered and developed. These could be used as benchmarks and should be published by the CSP to enable the CSC to select providers according to environmental standards. Examples of these KPIs could be the power utilization effectiveness of data centers, the CSP's investment in renewable energy (in relation to actual emissions), or individual indicators such as server, network, storage, and air conditioning utilization and efficiency. If a sufficient industrial standard including KPIs were defined, compliance with regulatory requirements and benchmarks could take place. In addition, certifications by independent environmental associations would support this. An example of this is the ecolabel of Blue Angel, which was introduced by the federal government of Germany in 1978. The label sets standards for an environmentally friendly IT product design and a more sustainable consumption. In the context of the cloud industry, an already developed certificate of the blue angels is the "energy-efficient data center operation" (DE-UZ-161) label, where the interdisciplinary focus is on the energy efficiency of the entire facility as well as on environmentally conscious management (Blauer Engel, 2021). If such a certification framework were developed and established globally, the monitoring and benchmarking would be accelerated and supported. Furthermore, public awareness of the energy problem of the cloud industry would be increased which in turn would exert pressure for transformation.

The sustainable green economy should aim to preserve the environment as well as serving the needs of all stakeholders in line with the Sustainable Development Goals (SDGs) introduced by the United Nations (UN) in 2016 (UN, 2016). These integrate, among other things, the perspectives of social welfare, long-term economic and operational benefits, as well as environmental longevity into the concept of developing sustainability. The SDGs invite companies to support climate protection and clean energy. In doing so, sustainable development emphasizes the need to balance environmental, economic, and social development. But to implement this, or similar models, the governments, in cooperation with experts from all related scientific areas, need to set guidelines. These should include incentives, restrictions, and subsidies. For instance, the frequently discussed carbon tax or emission limits could be one measure (EU, 2021a). Furthermore, a deeper collaboration of, and an exchange between, the CSPs needs to be implemented. For example, nowadays a CSC can have several CSPs. An example of this is a hybrid cloud in which the CSC could have different providers: one for the private and another for the public cloud; a further CSP for SaaS applications, like the IoT integration; and another for PaaS applications including self-made accounting and salary software. This forces the consumer to migrate, manage, and bill all their CS requirements with various providers in a huge bureaucratic effort. However, for the CSC it would be much easier to get a single bill for all their communication consumptions rather than a separate one from each provider. This administrative optimization could be done through a superordinated and regulated billing center including even governmental regulations.

However, as a first step, a clear definition of green cloud computing is necessary to focus the perspective and concentrate research efforts so that similar assumptions and guidelines are used. In the context of an industrial standard, global performance indicators should be considered to enable the government as well as the consumers to benchmark the CSP. This is necessary to achieve a more focused outcome towards sustainability. Dupont et al. (2018) highlighted that, to shape this emerging technology, a sustainable and truly green definition needs to be introduced and become state of the art globally and not only for emerging regions like Afrika or Asia.

3.3.2. Challenges of Implementation

The demand forecast for cloud computing capacity, and therefore the corresponding electricity consumption of data centers, is disputed and therefore uncertain. Even the current consumption of data centers leaves room for interpretation. Electricity demand estimates for global data centers are currently at 1%, using conservative estimations, and are projected to increase to 3% of global electricity consumption in a best-case scenario (the lowest increase) for the year 2030 (Andrae & Edler, 2015; Jones, 2018; Malmodin & Lundén, 2018). However, frequently cited forecasts estimate the increase to be 7% in the best case and 20% in the worst-case by 2030. Other estimations range from 0,8% (Masanet et al., 2020) up to even 10% (Belkhir & Elmeligi, 2018) in a best-case scenario for 2030 (Accenture, 2020a). Regardless of the actual amount, however, all forecasts agree that demand, and correspondingly the electricity consumption, will increase. This work follows the estimates of Andrae's and Edler's (2015) best-case scenario, as this forecast most realistically predicts the course of events up to the present year. They weighed the strengths and opportunities, as well as the threats and risks very precisely and transparently against each other. In addition, they looked at the past decade of the entire ICT sector and used this to derive their future forecasts, with different scenarios for various cases. All these factors indicate acceptable precision and reliability for the context and objective of this work.

To answer the increased electricity and computing demand for services from the cloud industry, vast amounts of rare resource and electricity generation are necessary when considering the actual technical state. According to Masanet et al. (2020), the current ongoing optimization efforts will not be enough to meet the exponential demand increase. Additionally, rare resources as well as electricity generation from fossil fuels, coal, and gas will come to an end due to limited availability and conservation projects. Therefore new, innovative, and "out of the box" approaches must be developed. The pure rescheduling of workload or virtualization of green electricity, as currently pursued, does not achieve a sustainable electricity demand. The innovative approach must consider a 100% use of renewable electricity to supply reliably and economically the exponentially increasing demand in the future without further destroying and exploiting our planet. In this context, Hasan et al. (2017) highlight the dependence of weak green power generation phases on the power supply from fossil fuels for data center operation. A potential first step towards a green energy supply has already been undertaken by the cloud industry. Mayer and Gereffi (2010) highlighted, other industrial organizations such as oil and automotive companies, which are directly affected by the impact of climate change but are not initiating the strongest response. In contrast, cloud companies have introduced a way to manage the commercialization of electricity efficiency through the PPAs. Cloud firms initiated this trend because electricity is their major expense, and it can be measured and reduced through commercialization. Additionally, they were pushed to respond because their global reputation was at stake. This approach created the opportunity for companies to enter foreign markets and to innovate the local electricity grid by integrating the innovations of renewable energy generation and supply. Thus, it enabled the cloud computing industry to improve both, their financial and reputational risk parameters. In this context, cloud companies have been particularly attracted to countries that have already established open and competitive energy markets. This is particularly evident in the Nordic countries (Norway, Sweden, Denmark), Chile, and Australia, where the prior establishment of competitive energy markets and corporate access to green PPAs and REC has facilitated the coupling of data centers and renewable energy. But PPAs do not guarantee that the owner's data center is powered with renewable energy. Therefore, the countries where the PPA is valid and where the data center is operated from are important considerations. Green PPAs, depending on their contractual agreements, only ensure the development of the renewable energy infrastructure (like power plants, grid, storage) and the share within the local grid. The data center operator, however, has neither short-term possibility to control and track this development nor to determine the green supply. Therefore, it remains to be mentioned that although major participants invest vast sums of money in PPAs, this does not make their data centers "green". This can be seen in the example of Virginia's Data Center Valley in the USA. According to Greenpeace (2019) estimations, this county handles as much as 70% of the world's internet traffic on a daily basis, but the supply using renewable electricity in this county is below 3% (BP Global, 2020). It becomes clear that the Data Center Valley is not as green as is sometimes propagated by marketing campaign. Another example is China. As one of the fastest growing markets, it has a renewable energy share of 25%. This share includes 80% of energy mainly from the hydroelectric power plant at the Yangtze river known as the Three Gorges Dam, Yichang, China (State Council P.R.C., 2020). But the greenness of this project, as well as other hydroelectric dam projects, is controversial due to the environmental and social impacts caused by the damming of the immense water masses and the ensuing, and sometimes harsh, resettlement of the population. These examples make it clear that switching to, and sourcing, renewable energy sometimes requires drastic action and thinking outside the box (regardless of whether its source is wind, solar, or hydroelectric plants). However, a change in the status quo will always be necessary to face future challenges appropriately.

One innovative architectural approach has come from a company in Germany called the "Green IT Cloud". They have pursued the approach of operating data centers in the towers of wind turbines. This means that up to 90% of IT resources can be supplied using renewable energy directly at its place of origin. This could make the Green IT Cloud a zero-emission solution, as transport routes are eliminated, resulting in sustainable and economical cloud computing. Another advantage is that wind turbines offer plenty of space in their existing architecture for installation. Furthermore, integration into towers promise protection against natural or technical interferences like fire, disturbances, or access by illegal third parties. The cloud is connected to two independent network operators, a wind and a fossil operator, thus solving the problem of intermittent supply and ensuring up to 99.98% reliability (GREEN IT, 2021).

3.3.3. Missing Conceptual Link

The business world bears a great responsibility for the required change in social behavior because it is crucial for the prosperity of the population. In addition to the role model function, companies face the challenge of increasing globalization and digitization, accelerated by the current COVID-19 pandemic. To meet corporate and environmental challenges and to keep pace with the digitization, the paradigm of green cloud computing is becoming increasingly attractive. However, in most research efforts the focus has been primarily on technical improvement neglecting environmental and social impacts. While 79% of the identified documents deal with the target groups of hardware and software, only 21% of the research documents deal with, to some extent, the influence on CSPs and CSCs. Furthermore, the research tradition of computer science with 76% is strongly reflected in the field of green cloud: 67% of the identified documents are concerned with sustainability and environmental science and a further 42% deal with engineering science. However, only 20% refer to the field of business administration and 1% with the economic impact on the consumer. Clearly, some authors presented their work in the light of more issues and dimensions, e.g., allocation and virtual machine, or application and green economy, falling into two or more scientific fields and overlapping accordingly. However, all the identified approaches were very biased toward technology, and did not consider the economic sustainability of data centers and the cloud environment holistically. This lack of any combined economic, environmental, and social incentive approach will not sustainably lead down an efficient path. More innovative concepts are needed to stimulate an urgency and a willingness to change among all stakeholders. Therefore, environmental and social capacities need to be truly coupled to enable the ongoing expansion of cloud computing technology (including the indigenous data centers). Here, the stand points of all stakeholders (for instance, the energy provider, data center owner, CSP, CSC, and end-consumer) need to be considered in developing an innovative green cloud approach. All participants need to have an intrinsic motivation to implement, use, and highlight the green aspect of cloud computing instead of simply being attracted to a state-of-the-art cloud environment. In this context, the SDGs call for companies to support climate protection and clean energy. In doing so, sustainable development emphasizes the need to balance environmental, economic, and social development (Dupont et al., 2018). Similarly Lykou et al. (2018) highlighted, that the use of renewable energy, the optimization of energy efficiency, the minimization of resource waste, and also a social contribution towards the environment will contribute to the creation of real sustainable clouds in the long run. Therefore, the current wave of research must look beyond the end of its nose and, in addition to hardware and software optimization efforts, also include the social and economic aspects in any subsequent research wave. This includes the SDGs and makes sense not only environmentally, but also economically and socially. Agile and appropriate action is necessary to tackle the upcoming problems of increasing computing demand, limited resources, and climate change.

3.4. Results of the first Research Question

As a result of the semi-systematic literature review, the current state of research of the green cloud computing technology was presented. This enabled an understanding of the research traditions and their historical development. Furthermore, three key findings were discussed to structure the research approaches and gaps. The contribution of this current paper is to compile the technical, social, and economic issues of the broad field of green cloud computing, which has not until now been done. Finally, the acquired knowledge is used to answer the first research question:

Does profitability conflict with environmental friendliness in cloud computing?

As previously stated, scientific attention has been focused less on business or environmental than on technical improvements. However, the economic, environmental, and social science directions are becoming increasingly important in the context of green cloud computing, see Figure 6. But they are wide ranging and not bundled due to the lack of an industrial standard. This could be optimized by introducing a standardized definition for green cloud computing, which should be aligned with KPIs, the SDGs and the green economy.

Based on the findings, it can be summarized that profitability and environmental friendliness in cloud computing are not only not mutually exclusive, but a green transformation of the whole industry is necessary to make it sustainable and economically efficient in long term. This is supported by the fact that the demand for resources and energy is expected to increase immensely and that, in addition to the climatic impact this will entail, the supply of fossil fuels is coming to an end. Moreover, the power consumption plateau of the last decade can be mainly explained by workload shifts towards efficient cloud or hyperscaler data centers. The potential for further improvement in this area, however, is now limited. Current research efforts in green cloud computing strive to achieve efficient resource management primarily through the implementation of VM consolidation and corresponding migration approaches to optimized use of server capacities, or through the optimization of hardware and thermal efficiency (reuse of heat, efficient cooling). This optimized resource management in turn has a direct impact on energy consumption, resource usage, as well as the carbon footprint and thus on the economic sustainability of the entire cloud industry. These approaches towards handling the computing environment are good and necessary, but a combination of economic, environment, and social aspects along the guidelines of the SDGs in the development of this emerging field is urgently needed. Some promising innovative approaches which combine the SDGs and their aspects have been addressed in this work: a100% use of renewable energy, the strategic placement of data centers, incentives, auctions, and taxation models. However, all these approaches raise new questions as well as problems and still need to be proven and established in the market.

Finally, the documents identified conclude in different ways, that more efficient resource use consistently leads to a greener cloud environment and sustainably reduces the economic expenditure of both the providers and consumers. But with the environmental challenges and the climate change ahead, the main goal of green cloud computing should not only be to increase the performance, revenue, and competitiveness for its stakeholders. Only a corporate environment that combines the cloud transformation and green sustainability along the guidelines of the SDGs will be competitive in the long run. Therefore, sustainability should be included into the transformation as a pillar for prosperity and social well-being to shape the future with foresight.

4. Discourse: Entrepreneurial Incentive for Green Cloud?

Based on the previous investigation of the state of the art in green cloud computing and on the results of the first research question, the following chapter goes one step further. As discussed, the majority of research efforts have focused on improving data center hardware and software to optimize the cloud environment and make it environmentally friendly. This can be classified as “technology push innovation” because providers push these innovations into the market to reduce their costs. However, far less attention has been paid to understanding the strategic benefits of a more sustainable cloud and its infrastructure. This lack of attention is also particularly evident in the priorities of the consumer and society as a whole. Addressing the challenges of climate change requires a change in the behavior and attitude of all participants. Various tools have been discussed, or are under development, to force a change in thinking and acting. These include so-called “regulatory push innovations” such as taxes, regulations, and subsidies for sustainable projects. In addition to these policy instruments that act externally on a company, other internal factors can be added to the list of innovative instruments. These are voluntary processes carried out by organizations themselves. To some extent, these can be understood as internal driven innovations as well as external "market-pull innovations" due to public environmental awareness and the desire to secure the company's reputation. Therefore, the following chapter takes the already outlined missing economic, environmental, and social perspective of the CSC into account. For this purpose, the advantages and disadvantages of green cloud computing for the consumer of cloud services are discussed. In addition, possible external regulatory concepts such as the carbon dioxide emission standard, or internal concepts driven by market demand like corporate social responsibility, are included in the discussion. Based on this, the second research question – "What are the impacts and incentives for the consumer in using a green cloud?" – will be answered. Here, the focus is on the sustainable economic incentives for the consumer.

4.1. Advantages and Disadvantages for Consumers

The fundamental advantages for the consumer in green cloud computing are similar to the advantages of cloud computing generally. These are reduced investments or proportional costs as well as an increased scalability, availability, and reliability of IT services, as described in Chapter 3.2.1. The conceptual difference of green cloud computing, however, lies in its sustainability and resource aware interaction with the environment. This can be achieved first by establishing a definition of green cloud as a standard. Based on this, the research and development efforts can unfold in a focused manner along specified guidelines to pursue a primary goal, namely the sustainable and careful utilization of the given resources of our earth. This benefits not only the provider in the long term, but all parties involved, from the network operator to the data center operator, provider, consumer, and end user, no matter which delivery or deployment model is used. Nevertheless, the greatest economic, environmental, and social advantage is currently being realized in the public cloud and SaaS. This is mainly due to the maximum possible energy-aware utilization of its IT resources. Here the CSP can develop all applications optimally for use in the cloud and coordinate their global deployment in the best possible way to reach as many consumers as possible efficiently and simultaneously. However, to achieve a green cloud, large sums of financial up-front investments need to be made by the network operators, the data center operators, and the providers. These must be used to change the entire infrastructure. This change begins with the significantly accelerated expansion of renewable energies, including grid expansion, followed by further optimization of software programs and hardware components, and ends with sustainable and socially acceptable migration of cloud application in the established IT infrastructure and our daily lives in general. The resulting costs will be reflected in the operating costs of the providers, which in turn will primarily be passed on to the consumers. For the consumer of its services, however, the sustainable transformation of the cloud environment allows long-term application and increasing usage options without harming the environment, while still exploiting the full potential of cloud technology. This is not guaranteed in the cloud environment as we know it today, as resource scarcity and advancing climate change limit provision of computing capacity. But, due to the additional short-term costs, green cloud computing has not been financially attractive for consumers recently. However, in the long term, this approach can ensure the economical and sustainable availability of computing capacity through the cloud. Furthermore, this leaves room for the further spread of technology into everyday life, for example in the establishment of autonomous driving technology.

In this context, an emerging important approach that was not considered in the identified literature is the increasing development and implementation of "cloud native applications". This aims to utilize the full potential of the IT resources in the data center and can reduce CO_2 emissions by up to 98%, compared to individual on-premises solutions (Accenture, 2020b). Cloud native means that applications are developed, configurated, and operated directly in the cloud and thus usage is optimized within the cloud. Only in this way can all the advantages and innovations of technology be fully exploited. However, one of the major hurdles is the established, inefficient, and expensive legacy software systems of companies. These still control many of the core processes in most companies and are highly integrated into existing processes. In most cases, removing these is, in the short term, very expensive and time-consuming. Therefore, a paradigm shift in the entire IT world is necessary to enable companies to master the path to cloud native IT infrastructure. According to Herrmann (2020), the editorial manager of a recently published study in cooperation with Deloitte, such a paradigm shift must not only include technical aspects, but must also entail sustainable and resource-saving aspects. In the long term, such a paradigm shift must and will lead to a green cloud, because current evidence shows that "business as usual" is no longer tenable.

4.2. Emission Certificates and Trade

To provide further incentives and accelerate the sustainable adaptation of a green cloud for all stakeholders, different approaches can be pursued to reduce the GHG and therefore the associated CO_2 emissions. A regulatory push approach are the emission certificates. These are standard certificates that specify emission limits, broken down to individual sectors and participants. It can encourage parties to decrease CO_2 emissions. In the context of cloud computing, such an emission standard gives the external incentive for consuming companies to implement a green cloud by reducing their own carbon footprint. For instance, a new study by Accenture shows that a significant reduction in CO_2 emissions can be achieved by migrating on-premises ICT to a public cloud. The total emission savings are estimated to be 5.9% or 60 million tons of CO_2 worldwide per year. This equates to 22 million cars disappearing from the roads (Accenture, 2020b).

The first global agreement to implement an incentive scheme based on the mechanism of emission certificates was reached in Kyoto in the Kyoto Protocol and adopted in December 1997 (UN, 1997), it was further anchored in the Paris Agreement (UN, 2015b). In line with these agreements, certificates are issued in the EU to the emitting sectors and companies stating the amount of permitted emission levels. One certificate entitles the holder to emit one ton of CO_2 or a comparable quantity of GHG. If the actual emissions by the cut-off date (April 1st of each year) exceed those allowed by the certificates, the companies concerned must pay penalties – recently 100 euros per missing certificate – and subsequently submit a valid certificate. The issued certificates are allocated and can be partly traded according to the cap & trade principle (EU, 2021a). Article 6 of the Paris Agreement allows parties to trade their emission certificates globally (UN, 2015a). Therefore, trading certificates has become a widely accepted and conducted business method, resulting in the development of complete emissions exchanges in the EU and worldwide. These platforms are for instance the European Climate Exchange in London, the European Energy Exchange in Leipzig, or the Energy Exchange Austria in Vienna. As a global trading platform, the Blue Next environmental exchange at the New York Stock Exchange is in high demand (EEX, 2021). The EU developed the Emissions Trading System (EU ETS) scheme and introduced it in 2005 (Convery, 2009). The EU ETS is planned in four different phases up to 2030. Because the total number of certificates decline each year, companies have a great incentive to decrease their emitted emissions. In the fourth phase, starting in 2021 and lasting until 2030, the reduction of certificates will be increased from 1,74% to 2,2% per year to reach the climate targets of the EU in 2030. Due to the scarcity of emission allowance certificates and driven by the penalty and reduction method, additional costs are incurred by the targeted industries. The emitters shift the additional costs to their opportunity costs and, depending on the market situation, pass them on to customers. This in turn increases the price but also the incentive for the customer and for the producer to become emission neutral. Supply and demand on the trading exchanges determine the price of each certificate. After the introduction in 2005, the electricity price in the EU increased by 22€/MWh in one year, which indicates that the certificate and electricity price are correlated. It is often concluded that this is indicative of the functioning of the EU ETS (EU, 2021a). However, a common criticism of the EU emissions trading system is that too many certificates were issued at the beginning (over-allocation) and therefore no incentive for the industry was given to lower their emissions (Hintermann, 2010). A total of around 2,150 million certificates were issued in 2005, but only 2,012 million (2005), 2,034 million (2006) and 2,050 million (2007) certificates were required (EU, 2013). But according to environmental economists from the MIT, this unexpected under demand was a result of industries optimizing processes to reduce emissions incentivized by the announcement of the emission certificates (Ellerman & Buchner, 2008). According to the Catholic University of Leuven, emissions caused by electricity production in EU from 2005 to 2006 were reduced by 35% (Delarue et al., 2008).

Linking the EU ETS to the green cloud paradigm is essential to its economic durability. As Alfonso et al. (2013) pointed out, migrating corporate IT to a cloud environment, and thus uninstalling the individual inefficient on-premises solutions, leads to a much more efficient, environmentally friendly, and thus sustainable application of a company's IT infrastructure. For instance, Accenture (2020b) estimated a CO_2 reduction of up to 84% and an energy reduction of up to 65% of their IT infrastructure when companies with average on-premises IT implement a green cloud environment. This enables CSCs to save expenditure on emission certificates, trade their residual certificates and thus increase their competitiveness. Moreover, all CSP marketing materials suggest that moving to the cloud will reduce the environmental footprint of the IT environment. And in fact, the major providers of cloud applications are large promoters (through PPAs) and consumers of renewable energy due to the nature of data centers. They also have the lowest energy waste scores and are continually developing innovative and more efficient equipment (Patchell & Hayter, 2021). However, the CSPs keep their real emission data under wraps, which is why the traceability of their environmental friendliness remains questionable. Given this secrecy, confirmation of emissions savings claims with real data is, therefore, not possible. Microsoft was the first provider who published a sustainability calculator in January 2020. This enables customers to calculate the CO_2 and overarching GHG emissions of their applications. However, only a fraction of customers have access to this calculator (Microsoft, 2020). Due to the increasing public attention of environmental issues, the pressure on CSP is growing. In 2021, Google published an overview of which data centers are operated with which electricity mix (Google Cloud Blog, 2021). This shows that the CSPs are trying to create the transparency, which is necessary to evaluate the environmental footprint of a product or service. But the current lack of data makes it impossible for CSC to calculate and thus meet the CO_2 reduction requirements itself which would be a necessary step. As Mytton (2020) points out, to ensure that the environmental impact of the green cloud application is not just a marketing tactic and to increase credibility, providers must either release the required data or perform the calculations on behalf of their CSC. This could allow consumers to include these emission savings in their company's carbon footprint reduction. In the context of carbon certificates, this in turn provides a significant incentive for consumers to migrate their IT to a green cloud, choosing the best possible sustainable option that makes the most long-term economic sense. To create more transparency, the Austrian company Txture has developed a benchmark platform to make the costs, technical features, and compliance regulations between the different CSPs comparable for the consumer. According to Txture's CEO, Dr. Matthias Farwick, a next step towards green transformation could be to integrate data center carbon emissions into their benchmark platform. This would allow CSCs to select their providers based on financial, technical, and environmental considerations. However, this would require all providers of CS to publish the emissions of their corresponding data centers (Txture, 2021).

4.3.Corporate Social Responsibility

In addition to the emission certificate and taxation instruments outlined in the previous chapter, further tools for accelerating the transformation of the IT environment need to be considered. This is where Corporate Social Responsibility (CSR) comes in, driven by external market demand and the intrinsic motivation of the actors. However, in the context of this work, a link between CSR and scientific cloud research could not be found, and certainly not with the green cloud. None of the available databases and scientific search engines yielded a result. CSR, however, could be another powerful driver for companies to create real sustainable value for humanity as they transform their often inefficient on-premises IT into a green cloud. Currently, companies often get rid of their increasing digitization, datafication, and the associated rising energy consumption by outsourcing to the cloud. This is done by using the outsourced CS and handing the correlated emissions from the energy consumption over to the providers. But blaming these emissions on the CSP balance sheet neither improves the situation, nor does it demonstrate responsible behavior towards the environment by the CSC. Therefore, companies should develop sustainable policies not only for themselves or their marketing departments, but also to incorporate their entire network of suppliers into their strategies. This is in line with the already mentioned green supply chain in Chapter 3.1.3.

The concept of CSR reflects a form of corporate self-regulation which is integrated into the business model of a company. This goes beyond compliance or statutory requirements and engages actions that offer social good, including philanthropy and volunteering initiatives (Wood, 1991). This sense of responsibility toward the community and environment can be expressed, for instance, through environmental protection actions, contributing to educational programs, or promoting supporting social initiatives (EU, 2001). The efforts of large cloud companies like AWS, Google, or Accenture with their PPAs can be seen as being as CSR compliant. However, this is currently very controversial. The PPAs still have to demonstrate their true benefit to the environment in order not to be considered as merely a "green washing" marketing campaign. Green washing is not a new phenomenon, it means that a company or organization engages in activities designed to give the impression that they value the environment, even if the actual business is harmful for it (Laufer, 2003).

However, not only the CSP bears responsibility. It is also the responsibility of the consumer as well as the end user to demand, support, and promote a more sustainable use of the resources we have left. To achieve this, all stakeholders must to an extent bear the costs of change, be open to innovations, and accept the possible destruction of established habits. It is precisely this that underpins the concept of corporate or organizational social responsibility, as both the public and the shareholder are already beginning to demand more corporate sustainability and clearer regulations. For example, an article published in the Guardian stated that a group of influential investors from the United Kingdom urged that a climate risk report should be mandatory for the biggest companies and that it needed to be included in the annual report. This could have a great impact on the sustainable and environmental behavior of larger companies, as well as being a performance indicator for shareholders independent of the stock exchange market (Makortoff, 2020). In addition to the corporate and consumer perspective, the effect of environmental and social corporate measures on a company's employees must not be neglected. Meynhardt et al. (2020) investigated the effect of creating organizational public value on employees' life satisfaction as well as on their commitment, performance and identification with the company. Their results show that the indirect effects of organizational public value on employees' life satisfaction via work engagement and organizational citizenship behavior are significantly increased when more CSR is adopted by the company.

But the link of CSR with the cloud or the CSC has been not done until now. Due to the lack of CSR investigation in the context of the cloud environment, this work relies on a few existing studies of CSR in the context of a general green ICT environment taking all three perspectives into account (corporate, consumer, employees). Here, recently published studies have developed a framework for the connection of CSR and green ICT, from which recommendations for the green cloud can be made in the next step.

For instance, McWilliams and Siegel (2000) separate two different types of CSR within a company. These are strategic CSR and responsive CSR. The first is anchored in the strategic vision of a company and thus aims at a long-term competitive advantage. In contrast, the latter one, the responsive CSR, shows a limited integration in long-term strategy. In this context, Bocquet et al. (2014) as well as Bohas and Poussing (2016) emphasized the correlation between strategic and reactive CSR with different technological innovations. Thus, a more strategic CSR drives the more long-term product innovations, whereas a reactive CSR tends to drive the sometimes short-term and necessity-driven process innovations. In the end both are necessary for a holistic transformation. In the green cloud environment, the sustainable extent and direction of an CSR integration into the company's vision and strategy needs to be investigated in more depth in further research. But a strategic CSR could be implemented to create a sustainable vision and to direct a long-term strategy of a company, which is intrinsically motivated to transform its IT infrastructure into a sustainable and resource-aware future. Reactive CSR is necessary to be able to respond to unforeseen problems or situations at short notice. This shorter-term reactive CSR can be realigned spontaneously and on demand along the corporate guidelines or a code of conduct which is set by strategic CSR. The results presented by the studies suggest that both CSR schemes and the successful adoption of more sustainable green IT are highly correlated. This is consistent with other studies that emphasize the importance of corporate voluntary actions as drivers of environmental innovation, corporate reputation, and employee engagement (Le Bas & Poussing, 2013; Veugelers, 2012). This again shows that an environmentally conscious corporate commitment is influenced by economic factors (cost savings), the desire for social acceptance (corporate image), and also by their core values (an element of CSR).

4.4. Results of the second Research Question

In the previous discourse, current potential impacts and incentives for consumers to accelerate the green cloud transformation were outlined. The scientific gap of these topics was identified through the previously conducted literature review and key finding discussion. During the documentation of the discussion, it quickly became clear that the identified gap has many different approaches, advantages, and disadvantages. Based on this, the second research question can be answered, within the limits of the current state of knowledge:

What are the impacts and incentives for the consumer in using a green cloud?

The advantages of a cloud are reduced investment and proportional costs as well as increased scalability, availability, and reliability. In addition, the use of a green cloud brings sustainable and long-term serviceability to increasing demand. By implementing a green cloud, the full potential of the technology can be realized without harming the environment. This enables sustainable use and offers even greater application possibilities. A disadvantage is the large up-front investment necessary for infrastructure, accessing renewable energy, and hardware and software optimization.

As motivators for all participants, external and internal incentives have been discussed. The drivers can be distinguished between technology pushed, regulatory pushed, and market pulled innovations. Technology pushed innovations were described in Chapter 3.1 and are currently the main component of efforts. In the context of regulatory pushed innovations, the issuing and trading of emission certificates were discussed. One problem here is that simply shifting emissions from the consumers' environmental footprint to the provider does not represent a reduction or improve our environment. Additionally, the true emissions of the large CSPs and their data centers have been kept secret for a long time, which is currently in a state of flux. This is where the intrinsic motivation concept of CSR comes in, driven by internal corporate values but also by external market demand. However, the CSR concept in the cloud sector has not yet been studied. Therefore, it remains to be concluded that the spread of the green cloud paradigm should not be driven solely by extrinsic incentives such as direct or indirect taxes or subsidies. Rather, targeted political incentives and measures should be used to increase companies' environmental awareness. Additionally, the business community should commit to green clouds through an industry standard or defined code of conduct including the SDGs and targeting CSR. This can strengthen its intrinsic and voluntary environmental protection awareness and efforts and can accelerate the green transformation of the whole industry.

This discourse was carried out to examine the current consumer perspective and to highlight related economic, environmental, and social incentives. Only the collaboration of all stakeholders has the power to accelerate the greening of the cloud computing industry in an acceptable accelerated manner. In conclusion, the scientific community agrees that nowadays the regulatory framework is the primary extrinsic driver of environmental innovation and that intrinsically motivating incentives are lacking in the transformation process.

5. Limitations and Further Research

Although this work covers a large area and has highlighted important issues, it is also subject to limitations. One limitation is that due to the nature of a master's thesis, the literature review was conducted by only one person. According to Snyder's (2019, p. 337) guidelines, the selection and review of articles should be conducted by at least two reviewers to ensure the quality and reliability of the selected documents. Furthermore, the ideas and models in the whole work were developed based on the current state of knowledge and need to be substantiated or refuted by further research approaches.

This work points out that the scientific and technological discipline of green cloud computing is a young field that is only in its infancy. However, the potential applicability of the cloud becomes apparent when considering the datafication of everyday life and the digitization of industry. Technologies such as smart and connected systems (-home, -city, -industry), autonomous driving, or even the prediction-based control of processes via IoT, AI, or Big Data Analytics, are becoming increasingly important in this new era. Their ascent requires more data processing and is very computing capacity intensive; this is where the possibilities of the cloud computing industry come into its own. The full potential becomes obvious when considering all the possibilities which are offered through the cloud environment. Therefore, it is not surprising that initial research efforts have increasingly focused on the obvious problems and potentials of this young technology. Over the last decade, this first wave of sustainable research initiatives considered mainly the optimization and efficiency increases of data centers. However, to continue the development and utilization of the cloud environment to its full potential, more diverse research efforts are needed. Because the first wave has dealt with the obvious tasks, this optimization potential is already at a very high level. A second wave of sustainability-oriented research efforts must therefore focus on the difficult underlying tasks. These underlying tasks relate primarily to indirect influences on the technology. These include environmental impact and footprint, social impact and acceptance, government-driven regulations, and corporate responsibility in addressing company core values.

Initially, the previously discussed definition of an industrial standard for the green cloud industry is necessary to guide and focus further research approaches. In the context of a standard definition, the outlined KPIs as a measurement and benchmark tool should be included along with the SDGs. This would increase transparency while improving reporting and accelerating sustainable development. For further research, it would be interesting to examine the end consumer's awareness and willingness to transform the cloud. This could be investigated through a survey where firstly the awareness of the cloud industry's energy and related demand issues, and secondly the willingness to financially support the going green efforts, are the main components of the questionnaire. Here it is important not only to evaluate the answers but also to observe real behavior of the consumers, due to the ambivalent nature of human beings.

To maintain the efforts of the first research wave, the technical optimization needs to be further improved. This includes software optimization, like VM schedule approaches, energy efficient tools for evaluation of applications, and server utilization, as well as hardware optimization, such as cooling efficiency, component improvement, or energy aware placement decisions. This needs to be followed by further investigation and in-depth development of the 24-hour usability of renewable energy within the green cloud environment. These steps are already being advanced by current research efforts, as highlighted in Chapter 3.3.2. It seems that scientific efforts are on the right track, judging by the number of recently developed models. In the upcoming second wave of research, outlined in Chapter 4, the underlying connections, impacts, and desires of the green cloud environment need to be considered. Here the consumer, whether business or private, needs to be centric in the development of the technology. An example of a consumer centric achievement is a superordinated billing center as outlined in Chapter 3.3.1. Here the business CSC gets a single bill for all communication consumption and not a different one from every CSP. This could be implemented via state regulations.

To strengthen the external regulatory as well as internal environmental innovations the world community should develop an overarching governmental incentive scheme. This could be achieved at the external level, for example, by the unification and strict enforcement of the different emissions trading schemes. The aim being to make all existing emissions certificate systems comparable so that they can be off set against each other or traded under certain conditions. In this context, the footprint of technologies such as cloud computing needs to be transparent and publicly available to allow comparison and inclusion in the carbon footprint of the enterprise. Among other things, this can be encouraged or even enforced by government authorities through the discussed approach of carbon certificates and carbon tax or price. For future research, the question of how far the established certificates on a continental level (e.g., EU ETS) have contributed to an improvement in emission levels is of decisive importance. Furthermore, research efforts should focus on investigating the exact impact of emission limitation in the cloud industry as well as simulating a global emission trading and limitation system. At the internal level, the persistent neglect of CSR in connection with a green cloud needs to be investigated in more depth. The impact CSR could have on the green cloud transformation should be examined. This could mean finding out to what extent the providers and consumers of cloud computing want to improve their environment or whether their efforts are only green-washing campaigns. Another interesting possibility would be to look into the relationship between consumer, business, and societal values of the green cloud. Here research could examine how sustainable strategies can impact the underlying values of stakeholders. But further research is needed to understand the impact of a sustainable IT strategy on the market.

Further questions could be whether there are other benefits of sustainability-oriented cloud strategies for the CSC, apart the cost-saving incentive, in turning their IT infrastructure green. Here, it is important not to neglect the consumer or employee perspective. In other words, how willing are consumers to pay for the additional expense involved in green transformation efforts? Or what impact has a sustainable long-term corporate vision on its employees? It would also be interesting to investigate whether a green cloud can achieve an economic short-term competitive advantage for the CSP. After all, in our western capitalist society, an economic model for the development and implementation of green cloud must demonstrate profitability. This model will therefore likely need to integrate sustainability initiatives within the IT organization, at the enterprise level, and across the enterprise ecosystem.

6. Conclusion

The demand for computing capacity from the cloud has grown enormously to date and is expected to increase six times over the next decade. This is leading to an enormous increase in energy demand as well as GHG and CO_2 emissions, contributing to climate change. Because of its impact on the environment, cloud sustainability is a growing concern for all stakeholders, whereby its impact can be discussed from two perspectives. It can be seen either as one of the causes of environmental problems or as part of the solutions to address them. Green cloud computing comes into play in the latter. This work investigates – "How can a green cloud benefit business?" – and demonstrates its contribution by exploring the extent to which a green cloud can be of sustainable benefit to both providers and consumers. The main advantage of a green cloud is that it is the only way to meet future demand for cloud computing capacity. This is due to the increasingly limited availability of resources, the accelerated progress of climate change, and the sustainability of the nature of a green cloud. In addition, this work makes the unprecedented contribution of identifying the scientific gap in the consumer perspective and filling it with initial ideas to engage and benefit all stakeholders involved.

During the last decade, the first wave of sustainability research in the cloud environment aimed to combine profitability with environmental friendliness and to minimize the problems this caused. This is explored in the context of the first research question of this work. As a result, scientific research focused on reducing energy consumption by shifting workloads to energy efficient hyperscaler or optimizing hardware and software performance. This includes power utilization, infrastructure, thermal and workload management, virtualization, and product design. However, the advances that had been made have caused new problems. By increasing efficiency and reducing costs, companies can offer their services more cheaply. As a result, the technology has been introduced into new areas and caused an exponential increase in demand, which in turn has led to higher energy consumption. Therefore, the lack of an industry standard, the challenge of implementing 100% renewable energy due to its intermittent nature, and the biased research perspective were discussed. From these insights, it can be concluded that environmental friendliness and economic viability are not only mutually exclusive in the cloud industry, but a green transformation of the technology is necessary to establish it sustainably and economically in long term. This implies that any discussion about the relevance of a green cloud is obsolete; its importance has been proven in many ways.

The upcoming second wave of initiatives should be focused on establishing green cloud computing as part of the solution to environmental problems. Critical to this are the impacts and incentives for the consumer, which have been identified as missing in previous considerations and are discussed in the discourse of this work. However, it is more difficult to investigate these underlying interrelations, as it requires a shift in thinking involving an environmentally conscious enterprise IT strategy. This includes defining fundamental metrics, redesigning business processes, encouraging participation, and adapting organizational culture to new ways of acting and thinking. To accelerate implementation, this work addresses both internal and external innovation drivers. External drivers of innovation include incentive and regulatory schemes such as limited emission certificates or trading legislation, which have been to date insufficiently associated with the green cloud. Furthermore, corporate social responsibility was identified as an internal innovation driver, which is to some extend externally created due to public awareness and the importance of reputation and image for companies. Here, scientific investigation is completely missing. However, both innovation drivers are necessary to achieve the green transformation of the cloud environment One recommendation for the consumers of cloud services is to choose providers that operate resource-efficient data centers according to their CSR along the SDGs. These can be compared and identified via benchmarking applications. Factors which need to be implemented are the purchase of green energy and traceability through KPI benchmarks including independent environmental labels.

The continuing scientific task now is to create interventions and overarching measures based on the already existing approaches to develop a truly sustainable as well as economic green cloud based on the SDGs. The attitudes of the population towards the cloud could also be an interesting area for further research as it would encourage more accurate, efficient, and easily adaptable methods. In addition, governments should further intervene and incentivize green transformation through targeted programs and regulations.

In the context of this work, it can be stated that the topic of green cloud will become increasingly important in the future. Therefore, significantly more attention and pronounced research efforts must be made to meet the upcoming challenges. These do not only refer to the obvious optimizations but must additionally focus on the underlying issues identified in this paper.

References

Abdessamia, F., Zhang, W.-Z., & Tian, Y.-C. (2020). Energy-efficiency virtual machine placement based on binary gravitational search algorithm. *Cluster Computing*, *23*(3), 1577–1588. https://doi.org/10.1007/s10586-019-03021-0

Accenture (2020a, September 22). The green behind the cloud. *Accenture*. https://www.accenture.com/de-de/insights/strategy/green-behind-cloud

Accenture (2020b, October 15). Cloud Migrations Can Reduce CO2 Emissions: by Nearly 60 Million Tons a Year. *Accenture*. https://newsroom.accenture.com/news/cloud-migrations-can-reduce-co2-emissions-by-nearly-60-million-tons-a-year-according-to-new-research-from-accenture.htm

Agustí-Torra, A., Raspall, F., Remondo, D., Rincón, D., & Giuliani, G. (2015). On the feasibility of collaborative green data center ecosystems. *Ad Hoc Networks*, *25*, 565–580. https://doi.org/10.1016/j.adhoc.2014.11.004

Alarifi, A., Dubey, K., Amoon, M., Altameem, T., El-Samie, F. E. A., Altameem, A., Sharma, S. C., & Nasr, A. A. (2020). Energy-Efficient Hybrid Framework for Green Cloud Computing. *IEEE Access*, *8*, 115356–115369. https://doi.org/10.1109/ACCESS.2020.3002184

Alfonso, C. de, Caballer, M., Alvarruiz, F., & Moltó, G. (2013). An economic and energy-aware analysis of the viability of outsourcing cluster computing to a cloud. *Future Generation Computer Systems*, *29*(3), 704–712. https://doi.org/10.1016/j.future.2012.08.014

Andrae, A., & Edler, T. (2015). On Global Electricity Usage of Communication Technology: Trends to 2030. *Challenges*, *6*(1), 117–157. https://doi.org/10.3390/challe6010117

Arora, S., & Bala, A. (2020). A survey: ICT enabled energy efficiency techniques for big data applications. *Cluster Computing*, *23*(2), 775–796. https://doi.org/10.1007/s10586-019-02958-6

Ashton, K. (1990). *That 'internet of things' thing*. RFID journal. http://www.itrco.jp/libraries/rfidjournal-that%20internet%20of%20things%20thing.pdf

Attaran, M., & Woods, J. (2018). *Cloud Computing Technology: A viable Option for Small and Medium-Sized Businesses* (Vol. 13).

https://www.researchgate.net/publication/327756016_Cloud_Computing_Technology_A_viable_Option_for_Small_and_Medium-Sized_Businesses

AWS. (2006). *Amazon EC2 Beta | Amazon Web Services.* Amazon Web Service. https://aws.amazon.com/de/blogs/aws/amazon_ec2_beta/

Baumeister, R. F., & Leary, M. R. (1997). Writing Narrative Literature Reviews. *Review of General Psychology*, *1*(3), 311–320. https://doi.org/10.1037/1089-2680.1.3.311

Belkhir, L., & Elmeligi, A. (2018). Assessing ICT global emissions footprint: Trends to 2040 & recommendations. *Journal of Cleaner Production*, *177*, 448–463. https://doi.org/10.1016/j.jclepro.2017.12.239

Beloglazov, A., Abawajy, J., & Buyya, R. (2012). Energy-aware resource allocation heuristics for efficient management of data centers for Cloud computing. *Future Generation Computer Systems*, *28*(5), 755–768. https://doi.org/10.1016/j.future.2011.04.017

Bhattacherjee, S., Das, R., Khatua, S., & Roy, S. (2020). Energy-efficient migration techniques for cloud environment: a step toward green computing. *The Journal of Supercomputing*, *76*(7), 5192–5220. https://doi.org/10.1007/s11227-019-02801-0

Bianchini, R., Khan, S. U., & Mastroianni, C. (2017). Guest Editors' Introduction: Special Issue on Green and Energy-Efficient Cloud Computing Part II. *IEEE Transactions on Cloud Computing*, *5*(2), 152–154. https://doi.org/10.1109/TCC.2016.2641618

Blauer Engel. (2021). *Klimaschonende Colocation-Rechenzentren.* Blauer Engel - Das Umweltzeichen. https://www.blauer-engel.de/de/produktwelt/elektrogeraete/klimaschonende-colocation-rechenzentren

Bocquet, R., Le Bas, C., Mothe, C., & Poussing, N. (2014). *CSR, Innovation, and Firm Performance in a Sluggish Growth Context: A Firm-Level Empirical Analysis.* https://doi.org/10.2139/ssrn.2616304

Bohas, A., & Poussing, N. (2016). An empirical exploration of the role of strategic and responsive corporate social responsibility in the adoption of different Green IT strategies. *Journal of Cleaner Production*, *122*, 240–251. https://doi.org/10.1016/j.jclepro.2016.02.029

BP Global. (2020). *Statistical Review of World Energy 2020: Energy economics*. https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html

Capizzi, G., Lo Sciuto, G., Napoli, C., & Tramontana, E. (2018). An advanced neural network based solution to enforce dispatch continuity in smart grids. *Applied Soft Computing*, *62*, 768–775. https://doi.org/10.1016/j.asoc.2017.08.057

Cappiello, C., Ho, N. T. T., Pernici, B., Plebani, P., & Vitali, M. (2016). CO 2 -Aware Adaptation Strategies for Cloud Applications. *IEEE Transactions on Cloud Computing*, *4*(2), 152–165. https://doi.org/10.1109/TCC.2015.2464796

Chaudhry, M. T., Jamal, M. H., Gillani, Z., Anwar, W., & Khan, M. S. (2020). Thermal-benchmarking for cloud hosting green data centers. *Sustainable Computing: Informatics and Systems*, *25*, 100357. https://doi.org/10.1016/j.suscom.2019.100357

Cheng, D., Zhou, X., Ding, Z., Wang, Y., & Ji, M. (2019). Heterogeneity Aware Workload Management in Distributed Sustainable Datacenters. *IEEE Transactions on Parallel and Distributed Systems*, *30*(2), 375–387. https://doi.org/10.1109/TPDS.2018.2865927

Convery, F. J. (2009). Origins and Development of the EU ETS. *Environmental and Resource Economics*, *43*(3), 391–412. https://doi.org/10.1007/s10640-009-9275-7

Cotes-Ruiz, I. T., Prado, R. P., García-Galán, S., Muñoz-Expósito, J. E., & Ruiz-Reyes, N. (2017). Dynamic Voltage Frequency Scaling Simulator for Real Workflows Energy-Aware Management in Green Cloud Computing. *PloS One*, *12*(1), e0169803. https://doi.org/10.1371/journal.pone.0169803

Courchelle, I. de, Guérout, T., Da Costa, G., Monteil, T., & Labit, Y. (2019). Green energy efficient scheduling management. *Simulation Modelling Practice and Theory*, *93*, 208–232. https://doi.org/10.1016/j.simpat.2018.09.011

Cukier, K. N., & Mayer, V. -Schoenberger (2013, January 5). The Rise of Big Data. *Foreign Affairs Magazine*. https://www.foreignaffairs.com/articles/2013-04-03/rise-big-data

Danilak, R. (2017). Why Energy Is A Big And Rapidly Growing Problem For Data Centers. *Forbes*. https://www.forbes.com/sites/forbestechcouncil/2017/12/15/why-energy-is-a-big-and-rapidly-growing-problem-for-data-centers/?sh=547726cf5a30

DataCenters. (2021). *Data Center Locations:: Top Cities, States, Countries and Regions.* DataCenter.com. https://www.datacenters.com/locations

Delarue, E., Voorspools, K., & D'haeseleer, W. (2008). Fuel Switching in the Electricity Sector under the EU ETS: Review and Prospective. *Journal of Energy Engineering*, *134*(2), 40–46. https://doi.org/10.1061/(ASCE)0733-9402(2008)134:2(40)

Deng, W., Liu, F., Jin, H., Li, B., & Li, D. (2014). Harnessing renewable energy in cloud datacenters: opportunities and challenges. *IEEE Network*, *28*(1), 48–55. https://doi.org/10.1109/MNET.2014.6724106

Dupont, C [Corentin], Vecchio, M., Pham, C., Diop, B., Dupont, C [Charlotte], & Koffi, S. (2018). An Open IoT Platform to Promote Eco-Sustainable Innovation in Western Africa: Real Urban and Rural Testbeds. *Wireless Communications and Mobile Computing*, *2018*, 1–17. https://doi.org/10.1155/2018/1028578

EEX. (2021). *European Energy Exchange.* European Energy Exchange. https://www.eex.com/de/

Ellerman, A. D., & Buchner, B. K. (2008). Over-Allocation or Abatement? A Preliminary Analysis of the EU ETS Based on the 2005–06 Emissions Data. *Environmental and Resource Economics*, *41*(2), 267–287. https://doi.org/10.1007/s10640-008-9191-2

EPA. (1991). *Green Lights Program, History and Major Milestones*. https://www.energystar.gov/about/history/major-milestones

Erl, T., Mahmood, Z., & Puttini, R. (2013). *Cloud Computing: Concepts, Technology & Architecture*. ServiceTech Press.

EU. (2001, July 19). *Promoting a European framework for Corporate Social Responsibility* [Press release]. https://ec.europa.eu/commission/presscorner/detail/en/DOC_01_9

EU. (2013). *Phases 1 and 2 (2005-2012): - Climate Action.* European Commission. https://ec.europa.eu/clima/policies/ets/pre2013_en

EU. (2021a). *EU Emissions Trading System (EU ETS): - Climate Action.* European Commission. https://ec.europa.eu/clima/policies/ets_en

EU. (2021b). *Renewable energy | Energy: Fundings.* European Commission. https://ec.europa.eu/energy/topics/renewable-energy_en

Farahnakian, F., Pahikkala, T., Liljeberg, P., Plosila, J., Hieu, N. T., & Tenhunen, H. (2019). Energy-Aware VM Consolidation in Cloud Data Centers Using Utilization Prediction Model. *IEEE Transactions on Cloud Computing*, *7*(2), 524–536. https://doi.org/10.1109/TCC.2016.2617374

Garg, S. K., Yeo, C. S., Anandasivam, A., & Buyya, R. (2011). Environment-conscious scheduling of HPC applications on distributed Cloud-oriented data centers. *Journal of Parallel and Distributed Computing*, *71*(6), 732–749. https://doi.org/10.1016/j.jpdc.2010.04.004

Google. (2008). *Google App Engine Blog:: Introducing Google App Engine + our new blog.* Google. https://googleappengine.blogspot.com/2008/04/introducing-google-app-engine-our-new.html

Google Cloud Blog. (2021). *Sharing Carbon-Free Energy percentage for Google Cloud regions.* Google. https://cloud.google.com/blog/topics/sustainability/sharing-carbon-free-energy-percentage-for-google-cloud-regions

GREEN IT. (2021, February 16). *GREEN IT Cloud*. https://www.greenit.systems/portfolio/green-it-cloud/

Greenpeace. (2019). *Clicking Clean Virginia: The Dirty Energy Powering Data Center Alley.*

Gu, C., Fan, L., Wu, W., Huang, H., & Jia, X. (2018). Greening cloud data centers in an economical way by energy trading with power grid. *Future Generation Computer Systems*, *78*, 89–101. https://doi.org/10.1016/j.future.2016.12.029

Guan, X., Zhang, H., & Xue, C. (2018). A method of selecting cold and heat sources for enterprises in an industrial park with combined cooling, heating, and power. *Journal of Cleaner Production*, *190*, 608–617. https://doi.org/10.1016/j.jclepro.2018.04.099

Guérout, T., Medjiah, S., Da Costa, G., & Monteil, T. (2014). Quality of service modeling for green scheduling in Clouds. *Sustainable Computing: Informatics and Systems*, *4*(4), 225–240. https://doi.org/10.1016/j.suscom.2014.08.006

Hamdi, N., & Chainbi, W. (2019). A survey on energy aware VM consolidation strategies. *Sustainable Computing: Informatics and Systems*, *23*, 80–87. https://doi.org/10.1016/j.suscom.2019.06.003

Han, G., Jia, G., Lloret, J., & Bi, Y. (2020). IEEE Access Special Section Editorial: Emerging Trends, Issues, and Challanges in Energy-Efficient Cloud Computing. *IEEE Access*, *8*, 108847–108856. https://doi.org/10.1109/ACCESS.2020.3001770

Hasan, M. S., Kouki, Y., Ledoux, T., & Pazat, J.-L. (2017). Exploiting Renewable Sources: When Green SLA Becomes a Possible Reality in Cloud Computing. *IEEE Transactions on Cloud Computing*, *5*(2), 249–262. https://doi.org/10.1109/TCC.2015.2459710

Hedwig, M., Malkowski, S., & Neumann, D. (2012). Risk-Aware Service Level Agreement Design for Enterprise Information Systems. In R. H. Sprague (Ed.), *2012 45th Hawaii International Conference on System Sciences: (HICSS 2012) ; Maui, Hawaii, USA, 4 - 7 January 2012* (pp. 4552–4561). IEEE. https://doi.org/10.1109/HICSS.2012.509

Herrmann, W. (2020). *Studie Cloud Native 2020*. IDG Bunisess Media GmbH. https://www2.deloitte.com/de/de/pages/industry-operations/articles/cloud-native-studie-2020.html

Hintermann, B. (2010). Allowance price drivers in the first phase of the EU ETS. *Journal of Environmental Economics and Management*, *59*(1), 43–56. https://doi.org/10.1016/j.jeem.2009.07.002

IEA. (2017). *Digitalization and Energy – Analysis - IEA*. https://www.iea.org/reports/digitalisation-and-energy

IEA. (2020a). *Data Centres and Data Transmission Networks: Analysis.* International Energy Agency. https://www.iea.org/reports/data-centres-and-data-transmission-networks

IEA. (2020b). *Global Energy Review 2020.* International Energy Agency. https://www.iea.org/reports/global-energy-review-2020

IRENA. (2019). *Renewable Power Generation Costs in 2019.* International Renewable Energy Agency.

Ismail, L., & Abed, E. H. (2019). Linear Power Modeling for Cloud Data Centers: Taxonomy, Locally Corrected Linear Regression, Simulation Framework and Evaluation. *IEEE Access*, *7*, 175003–175019. https://doi.org/10.1109/ACCESS.2019.2956881

Ismail, L., & Materwala, H. (2018). Energy-Aware VM Placement and Task Scheduling in Cloud-IoT Computing: Classification and Performance Evaluation. *IEEE Internet of Things Journal*, *5*(6), 5166–5176. https://doi.org/10.1109/JIOT.2018.2865612

Iturriaga, S., Nesmachnow, S., Tchernykh, A., & Dorronsoro, B. (2016). Multiobjective Workflow Scheduling in a Federation of Heterogeneous Green-Powered Data Centers. In *Ccgrid 2016: 2016 16th IEEE/ACM International Symposium on Cluster, Cloud, and Grid Computing : 16-19 May 2016, Cartagena, Colombia : Proceedings* (pp. 596–599). IEEE. https://doi.org/10.1109/CCGrid.2016.34

Jeffery, K. G. (2012). Quality Aspects in CLOUD Computing. *4673-2345*, 4–9. https://doi.org/10.1109/QUATIC.2012.47

Jing, S.-Y., Ali, S., She, K., & Zhong, Y. (2013). State-of-the-art research study for green cloud computing. *The Journal of Supercomputing*, *65*(1), 445–468. https://doi.org/10.1007/s11227-011-0722-1

Jones, N. (2018). How to stop data centres from gobbling up the world's electricity. *Nature*, *561*(7722), 163–166. https://doi.org/10.1038/d41586-018-06610-y

Kessaci, Y., Melab, N., & Talbi, E.-G. (2013). A Pareto-based metaheuristic for scheduling HPC applications on a geographically distributed cloud federation. *Cluster Computing*, *16*(3), 451–468. https://doi.org/10.1007/s10586-012-0210-2

Khalid, A., Aslam, S., Aurangzeb, K., Haider, S., Ashraf, M., & Javaid, N. (2018). An Efficient Energy Management Approach Using Fog-as-a-Service for Sharing Economy in a Smart Grid. *Energies*, *11*(12), 3500. https://doi.org/10.3390/en11123500

Khalil, M. I. K., Ahmad, I [Iftikhar], & Almazroi, A. A. (2019). Energy Efficient Indivisible Workload Distribution in Geographically Distributed Data Centers. *IEEE Access*, *7*, 82672–82680. https://doi.org/10.1109/ACCESS.2019.2924085

Khattar, N., Sidhu, J., & Singh, J. (2019). Toward energy-efficient cloud computing: a survey of dynamic power management and heuristics-based optimization techniques. *The Journal of Supercomputing*, *75*(8), 4750–4810. https://doi.org/10.1007/s11227-019-02764-2

Kiran, M., Jiang, M., Armstrong, D. J., & Djemame, K. (2011). Towards a Service Lifecycle Based Methodology for Risk Assessment in Cloud Computing. In *2011 IEEE Ninth International Conference on Dependable, Autonomic and Secure Computing* (pp. 449–456). IEEE. https://doi.org/10.1109/DASC.2011.89

Kumar, N., & Vidyarthi, D. P. (2017). An Energy Aware Cost Effective Scheduling Framework for Heterogeneous Cluster System. *Future Generation Computer Systems*, *71*, 73–88. https://doi.org/10.1016/j.future.2017.01.015

Laufer, W. S. (2003). Social Accountability and Corporate Greenwashing. *Journal of Business Ethics*, *43*(3), 253–261. https://doi.org/10.1023/A:1022962719299

Le Bas, C., & Poussing, N. (2013). *Firm Voluntary Measures for Environmental Changes, Eco-Innovations and CSR: Empirical Analyses Based on Data Surveys.* https://doi.org/10.2139/ssrn.2616343

Liu, Q., Ma, Y., Alhussein, M., Zhang, Y., & Peng, L. (2016). Green data center with IoT sensing and cloud-assisted smart temperature control system. *Computer Networks*, *101*, 104–112. https://doi.org/10.1016/j.comnet.2015.11.024

Lu, X., Jiang, D., He, G., & Yu, H. (2018). GreenBDT: Renewable-aware scheduling of bulk data transfers for geo-distributed sustainable datacenters. *Sustainable Computing: Informatics and Systems*, *20*, 120–129. https://doi.org/10.1016/j.suscom.2018.07.004

Lu, Y., & Sun, N. (2019). An effective task scheduling algorithm based on dynamic energy management and efficient resource utilization in green cloud computing environment. *Cluster Computing*, *22*(S1), 513–520. https://doi.org/10.1007/s10586-017-1272-y

Lykou, G., Mentzelioti, D., & Gritzalis, D. (2018). A new methodology toward effectively assessing data center sustainability. *Computers & Security*, *76*, 327–340. https://doi.org/10.1016/j.cose.2017.12.008

Makortoff, K. (2020, October 19). Make climate risk reports mandatory: for 480 FTSE firms, say investors. *The Guardian*. https://www.theguardian.com/environment/2020/oct/19/call-climate-risk-reports-mandatory-ftse-listed-firms

Malekloo, M.-H., Kara, N., & El Barachi, M. (2018). An energy efficient and SLA compliant approach for resource allocation and consolidation in cloud computing environments. *Sustainable Computing: Informatics and Systems*, *17*, 9–24. https://doi.org/10.1016/j.suscom.2018.02.001

Malmodin, J., & Lundén, D. (2018). The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015. *Sustainability*, *10*(9), 3027. https://doi.org/10.3390/su10093027

Mandal, R., Mondal, M., Banerjee, S., & Biswas, U. (2020). An approach toward design and development of an energy-aware VM selection policy with improved SLA violation in the domain of green cloud computing. *The Journal of Supercomputing*, *76*(9), 7374–7393. https://doi.org/10.1007/s11227-020-03165-6

Mandal, U., Habib, M., Zhang, S., Mukherjee, B., & Tornatore, M. (2013). Greening the cloud using renewable-energy-aware service migration. *IEEE Network*, *27*(6), 36–43. https://doi.org/10.1109/MNET.2013.6678925

Mann, Z. Á. (2015). Allocation of Virtual Machines in Cloud Data Centers—A Survey of Problem Models and Optimization Algorithms. *ACM Computing Surveys*, *48*(1), 1–34. https://doi.org/10.1145/2797211

Marotta, A., & Avallone, S. (2015). A Simulated Annealing Based Approach for Power Efficient Virtual Machines Consolidation. In C. Pu (Ed.), *2015 IEEE 8th International Conference on Cloud Computing (CLOUD 2015): New York City, New York, USA, 27 June - 2 July 2015* (pp. 445–452). IEEE. https://doi.org/10.1109/CLOUD.2015.66

Marotta, A., Avallone, S., & Kassler, A. (2018). A Joint Power Efficient Server and Network Consolidation approach for virtualized data centers. *Computer Networks*, *130*, 65–80. https://doi.org/10.1016/j.comnet.2017.11.003

Masanet, E., Shehabi, A., Lei, N., Smith, S., & Koomey, J. (2020). Recalibrating global data center energy-use estimates. *Science (New York, N.Y.)*, *367*(6481), 984–986. https://doi.org/10.1126/science.aba3758

Mashayekhy, L., Nejad, M. M., & Grosu, D. (2015). Physical Machine Resource Management in Clouds: A Mechanism Design Approach. *IEEE Transactions on Cloud Computing*, *3*(3), 247–260. https://doi.org/10.1109/TCC.2014.2369419

Mayer, F., & Gereffi, G. (2010). Regulation and Economic Globalization: Prospects and Limits of Private Governance. *Business and Politics*, *12*(3), 1–25. https://doi.org/10.2202/1469-3569.1325

McCarthy, J. (1963). A Basis for a Mathematical Theory of Computation). In D. Hirschberg & P. Braffort (Eds.), *Studies in Logic and the Foundations of Mathematics. Computer programming and formal systems* (Vol. 35, pp. 33–70). North-Holland Pub. Co. https://doi.org/10.1016/S0049-237X(08)72018-4

McWilliams, A., & Siegel, D. (2000). Corporate social responsibility and financial performance: Correlation or misspecification? *Strategic Management Journal*, *21*(5), 603–609. https://doi.org/10.1002/(SICI)1097-0266(200005)21:5<603::AID-SMJ101>3.0.CO;2-3

Mengistu, T. M., & Che, D. (2019). Survey and Taxonomy of Volunteer Computing. *ACM Computing Surveys*, *52*(3), 1–35. https://doi.org/10.1145/3320073

Meynhardt, T., Brieger, S. A., & Hermann, C. (2020). Organizational public value and employee life satisfaction: the mediating roles of work engagement and organizational citizenship behavior. *The International Journal of Human Resource Management*, *31*(12), 1560–1593. https://doi.org/10.1080/09585192.2017.1416653

Microsoft. (2020). *Sustainability Calculator:: Analyse der CO2-Emission der IT-Infrastruktur von Unternehmen.* Microsoft Azure. https://azure.microsoft.com/de-de/blog/microsoft-sustainability-calculator-helps-enterprises-analyze-the-carbon-emissions-of-their-it-infrastructure/

Mishra, S. K., Puthal, D., Sahoo, B., Jena, S. K., & Obaidat, M. S. (2018). An adaptive task allocation technique for green cloud computing. *The Journal of Supercomputing*, *74*(1), 370–385. https://doi.org/10.1007/s11227-017-2133-4

Mustafa, S., Sattar, K., Shuja, J., Sarwar, S., Maqsood, T., Madani, S. A., & Guizani, S. (2019). SLA-Aware Best Fit Decreasing Techniques for Workload Consolidation in Clouds. *IEEE Access*, *7*, 135256–135267. https://doi.org/10.1109/ACCESS.2019.2941145

Mytton, D. (2020). Assessing the suitability of the Greenhouse Gas Protocol for calculation of emissions from public cloud computing workloads. *Journal of Cloud Computing*, *9*(1). https://doi.org/10.1186/s13677-020-00185-8

Ouyang, Y.-C., Chiang, Y.-J., Hsu, C.-H., & Yi, G. (2014). An optimal control policy to realize green cloud systems with SLA-awareness. *The Journal of Supercomputing*, *69*(3), 1284–1310. https://doi.org/10.1007/s11227-014-1190-1

Patchell, J., & Hayter, R. (2021). The Cloud's fearsome five renewable energy strategies: Coupling sustainable development goals with firm specific advantages. *Journal of Cleaner Production*, *288*, 125501. https://doi.org/10.1016/j.jclepro.2020.125501

Pierson, J.-M., Baudic, G., Caux, S., Celik, B., Da Costa, G., Grange, L., Haddad, M., Lecuivre, J., Nicod, J.-M., Philippe, L., Rehn-Sonigo, V., Roche, R., Rostirolla, G., Sayah, A., Stolf, P., Thi, M.-T., & Varnier, C. (2019). DATAZERO: Datacenter With Zero Emission and Robust Management Using Renewable Energy. *IEEE Access*, *7*, 103209–103230. https://doi.org/10.1109/ACCESS.2019.2930368

Pittl, B., Mach, W., & Schikuta, E. (2017). Greencloudtax: A Flexible IaaS Tax Approach as Stimulus for Green Cloud Computing. In M. Younas, M. Aleksy, & J. Bentahar (Eds.), *2017 IEEE 5th International Conference on Future Internet of Things and Cloud: Ficloud 2017 : Prague, Czech Republic, 21-23 August 2017 : Proceedings* (pp. 112–119). IEEE. https://doi.org/10.1109/FiCloud.2017.45

Popoola, O., & Pranggono, B. (2018). On energy consumption of switch-centric data center networks. *The Journal of Supercomputing*, *74*(1), 334–369. https://doi.org/10.1007/s11227-017-2132-5

Qie, X., Jin, S., & Yue, W. (2019). An Energy-Efficient Strategy for Virtual Machine Allocation over Cloud Data Centers. *Journal of Network and Systems Management*, *27*(4), 860–882. https://doi.org/10.1007/s10922-019-09489-w

Radu, L.-D. (2017). Green Cloud Computing: A Literature Survey. *Symmetry*, *9*(12), 295. https://doi.org/10.3390/sym9120295

Renugadevi, T., Geetha, K., Muthukumar, K., & Geem, Z. W. (2020). Optimized Energy Cost and Carbon Emission-Aware Virtual Machine Allocation in Sustainable Data Centers. *Sustainability*, *12*(16), 6383. https://doi.org/10.3390/su12166383

Schniederjans, D. G., & Hales, D. N. (2016). Cloud computing and its impact on economic and environmental performance: A transaction cost economics perspective. *Decision Support Systems*, *86*, 73–82. https://doi.org/10.1016/j.dss.2016.03.009

Shaikh, A., Uddin, M., Elmagzoub, M. A., & Alghamdi, A. (2020). PEMC: Power Efficiency Measurement Calculator to Compute Power Efficiency and CO_2 Emissions in Cloud Data Centers. *IEEE Access*, *8*, 195216–195228. https://doi.org/10.1109/ACCESS.2020.3033791

Shojafar, M., Canali, C., Lancellotti, R., & Abawajy, J. (2020). Adaptive Computing-Plus-Communication Optimization Framework for Multimedia Processing in Cloud Systems. *IEEE Transactions on Cloud Computing*, *8*(4), 1162–1175. https://doi.org/10.1109/TCC.2016.2617367

Shuja, J., Ahmad, R. W., Gani, A., Abdalla Ahmed, A. I., Siddiqa, A., Nisar, K., Khan, S. U., & Zomaya, A. Y. (2017). Greening emerging IT technologies: techniques and practices. *Journal of Internet Services and Applications*, *8*(1). https://doi.org/10.1186/s13174-017-0060-5

Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

State Council P.R.C. (2020). *Three Gorges Dam Annual Power Output.* The State Council Information Office P.R.C. http://en.sasac.gov.cn/2020/11/20/c_6065.htm

Statista (2021). Amazon Leads $130-Billion Cloud Market. *Statista*. https://www.statista.com/chart/18819/worldwide-market-share-of-leading-cloud-infrastructure-service-providers/

Stavrinides, G. L., & Karatza, H. D. (2019). An energy-efficient, QoS-aware and cost-effective scheduling approach for real-time workflow applications in cloud computing systems utilizing DVFS and approximate computations. *Future Generation Computer Systems*, *96*, 216–226. https://doi.org/10.1016/j.future.2019.02.019

Subirats, J., & Guitart, J. (2015). Assessing and forecasting energy efficiency on Cloud computing platforms. *Future Generation Computer Systems*, *45*, 70–94. https://doi.org/10.1016/j.future.2014.11.008

Txture. (2021). *Calculating Cloud Migration Total Cost of Ownership.* txture.io. https://www.txture.io/en/blog/cloud-tco

Uddin, M., Darabidarabkhani, Y., Shah, A., & Memon, J. (2015). Evaluating power efficient algorithms for efficiency and carbon emissions in cloud data centers: A review. *Renewable and Sustainable Energy Reviews*, *51*, 1553–1563. https://doi.org/10.1016/j.rser.2015.07.061

Ullah, Q. Z., Khan, G. M., & Hassan, S. (2020). Cloud Infrastructure Estimation and Auto-Scaling Using Recurrent Cartesian Genetic Programming-Based ANN. *IEEE Access*, *8*, 17965–17985. https://doi.org/10.1109/ACCESS.2020.2966678

UN. (1997). *Kyoto Protocol | UNFCCC.* United Nations Framework Convention on Climate Change.

UN. (2015a). *Key aspects of the Paris Agreement.* United Nations Framework Convention on Climate Change. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement/key-aspects-of-the-paris-agreement

UN. (2015b). *The Paris Agreement | UNFCCC.* United Nations Framework Convention on Climate Change. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

UN. (2016). *Sustainable Development: Take Action for the Sustainable Development Goals.* United Nations. https://www.un.org/sustainabledevelopment/sustainable-development-goals/

Veugelers, R. (2012). Which policy instruments to induce clean innovating? *Research Policy*, *41*(10), 1770–1778. https://doi.org/10.1016/j.respol.2012.06.012

Vilaplana, J., Mateo, J., Teixidó, I., Solsona, F., Giné, F., & Roig, C. (2015). An SLA and power-saving scheduling consolidation strategy for shared and heterogeneous clouds. *The Journal of Supercomputing*, *71*(5), 1817–1832. https://doi.org/10.1007/s11227-014-1351-2

Viswanathan, H., Lee, E., & Pompili, D. (2011). Self-organizing sensing infrastructure for autonomic management of green datacenters. *IEEE Network*, *25*(4), 34–40. https://doi.org/10.1109/MNET.2011.5958006

Wang, H., & Tianfield, H. (2018). Energy-Aware Dynamic Virtual Machine Consolidation for Cloud Datacenters. *IEEE Access*, *6*, 15259–15273. https://doi.org/10.1109/ACCESS.2018.2813541

Wang, K.-Q., Liu, H.-C., Liu, L., & Huang, J. (2017). Green Supplier Evaluation and Selection Using Cloud Model Theory and the QUALIFLEX Method. *Sustainability*, *9*(5), 688. https://doi.org/10.3390/su9050688

Witkowski, M., Brenner, P., Jansen, R., Go, D. B., & Ward, E. (2010). Enabling Sustainable Clouds via Environmentally Opportunistic Computing. In *2010 IEEE Second International Conference on Cloud Computing Technology and Science* (pp. 587–592). IEEE. https://doi.org/10.1109/CloudCom.2010.111

Wong, G., Greenhalgh, T., Westhorp, G., Buckingham, J., & Pawson, R. (2013). Rameses publication standards: Meta-narrative reviews. *Journal of Advanced Nursing*, *69*(5), 987–1004. https://doi.org/10.1111/jan.12092

Wood, D. J. (1991). Corporate Social Performance Revisited. *Academy of Management Review*, *16*(4), 691–718. https://doi.org/10.5465/amr.1991.4279616

Xiong, N., Vandenberg, A., & Han, W. (2012). Green cloud computing schemes based on networks: a survey. *IET Communications*, *6*(18), 3294–3300. https://doi.org/10.1049/iet-com.2011.0293

Xu, X., Zhang, Q., Maneas, S., Sotiriadis, S., Gavan, C., & Bessis, N. (2019). VMSAGE: A virtual machine scheduling algorithm based on the gravitational effect for green Cloud computing. *Simulation Modelling Practice and Theory*, *93*, 87–103. https://doi.org/10.1016/j.simpat.2018.10.006

Yang, F., & Chien, A. A. (2018). Large-Scale and Extreme-Scale Computing with Stranded Green Power: Opportunities and Costs. *IEEE Transactions on Parallel and Distributed Systems*, *29*(5), 1103–1116. https://doi.org/10.1109/TPDS.2017.2782677

Yang, J., Xiao, W., Jiang, C., Hossain, M. S., Muhammad, G., & Amin, S. U. (2019). AI-Powered Green Cloud and Data Center. *IEEE Access*, *7*, 4195–4203. https://doi.org/10.1109/ACCESS.2018.2888976

Yang, T., Pen, H., Li, W., & Zomaya, A. Y. (2017). An energy-efficient virtual machine placement and route scheduling scheme in data center networks. *Future Generation Computer Systems*, *77*, 1–11. https://doi.org/10.1016/j.future.2017.05.047

Yuan, H [Haitao], Bi, J., & Zhou, M. (2019). Spatial Task Scheduling for Cost Minimization in Distributed Green Cloud Data Centers. *IEEE Transactions on Automation Science and Engineering*, *16*(2), 729–740. https://doi.org/10.1109/TASE.2018.2857206

Yuan, H [Hang], Kuo, C.-C. J., & Ahmad, I [Ishfaq] (2010). Energy efficiency in data centers and cloud-based multimedia services: An overview and future directions. In *International Conference on Green Computing* (pp. 375–382). IEEE. https://doi.org/10.1109/GREENCOMP.2010.5598292

Zhang, X., Lindberg, T., Xiong, N., Vyatkin, V., & Mousavi, A. (2017). Cooling Energy Consumption Investigation of Data Center IT Room with Vertical Placed Server. *Energy Procedia*, *105*, 2047–2052. https://doi.org/10.1016/j.egypro.2017.03.581

Zhou, Z., Liu, F., Chen, S., & Li, Z. (2020). A Truthful and Efficient Incentive Mechanism for Demand Response in Green Datacenters. *IEEE Transactions on Parallel and Distributed Systems*, *31*(1), 1–15. https://doi.org/10.1109/TPDS.2018.2882174

Statutory Declaration

I hereby formally declare that I have drawn up the submitted dissertation on my own and without using other than the allowed means. All parts which are taken out directly or indirectly from other published or unpublished works are quoted and recognizable as such.

I clearly marked and separately listed all of the literature and all of the other sources which I employed when producing this scientific work, either literally or in content.

Hiermit versichere ich, dass ich die vorliegende Arbeit selbstständig und ohne die Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe. Alle Stellen, die wörtlich oder sinngemäß aus veröffentlichten und nicht veröffentlichten Schriften entnommen wurden, sind als solche kenntlich gemacht.

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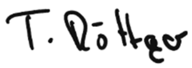
Louvain-la-Neuve, 25th of May 2021



Location, Date Signature

Appendix I

DataBase	No	relevant	Excl.	Dimension	Group	Method	Author Full Names	DOI	Article Title	Source Title	Year
1.WoS	1		3	Green Econ.	hardware &	model dev	Toha, Tarik Reza; Rizvi, A. S. M.; Noor, Jannatun; …	10.1109/TPDS.2020.3029724	Towards Greening MapReduce Clusters Considering Both Comp	IEEE TRANSACTIONS ON PARALLEL AND	2021
1.WoS	2		3	Application	hardware &	model dev	Bebortta, Sujit; Singh, Amit Kumar; Pati, Bibudhendu; …	10.1007/s10922-020-09572-7	A Robust Energy Optimization and Data Reduction Scheme for	JOURNAL OF NETWORK AND SYSTEMS	2021
1.WoS	3		3	Architecture	hardware &	simulation	Zhou, Zhenyu; Liao, Haijun; Wang, Xiaoyan; …	10.1109/MNET.001.1900527	When Vehicular Fog Computing Meets Autonomous Driving: Co	IEEE NETWORK	2020
1.WoS	4		3	Architecture	hardware &	model dev	Su, Yuhan; LiWang, Minghui; Huang, Lianfen; …	10.1109/MNET.011.2000105	Green Communications for Future Vehicular Networks: Data Co	IEEE NETWORK	2020
1.WoS	5		2	Allocation	software &	simulation	Hassan, Hadeer A.; Salem, Sameh A.; Saad, Elsayed M.	10.1016/j.future.2020.05.040	A smart energy and reliability aware scheduling algorithm for wo	FUTURE GENERATION COMPUTER SYST	2020
1.WoS	6		3	Allocation	hardware &	simulation	Gholipour, Niloofar; Arianyan, Ehsan; Buyya, Rajkumar	10.1016/j.simpat.2020.102127	A novel energy-aware resource management technique using joi	SIMULATION MODELLING PRACTICE AND	2020
1.WoS	7		2	Allocation	software &	simulation	Shojafar, Mohammad; Canali, Claudia; Lancellotti, Riccardo; …	10.1109/TCC.2016.2617367	Adaptive Computing-Plus-Communication Optimization Framew	IEEE TRANSACTIONS ON CLOUD COMPU	2020
1.WoS	8	1	1	VM	software &	model dev	Mandal, Riman; Mondal, Manash Kumar; Banerjee, Sourav; …	10.1007/s11227-020-03165-6	An approach toward design and development of an energy-aware	JOURNAL OF SUPERCOMPUTING	2020
1.WoS	9		3	Application	software &	model dev	Priya, Swarna R. M.; Bhattacharya, Sweta; …	10.1016/j.jpdc.2020.02.010	Load balancing of energy cloud using wind driven and firefly algo	JOURNAL OF PARALLEL AND DISTRIBUT	2020
1.WoS	10		3	Architecture	hardware &	simulation	Wu, Dapeng; Yan, Junjie; Wang, Honggang;…	10.1109/JSAC.2020.2986871	User-Centric Edge Sharing Mechanism in Software-Defined Ultra	IEEE JOURNAL ON SELECTED AREAS IN	2020
1.WoS	11	2	1	Allocation	hardware &	simulation	Bhattacherjee, Srimoyee; Das, Rituparna; Khatua, Sunirmal;…	10.1007/s11227-019-02801-0	Energy-efficient migration techniques for cloud environment: a st	JOURNAL OF SUPERCOMPUTING	2020
1.WoS	12	3	1	Application	hardware &	model dev	Ismail, Leila; Materwala, Huned	10.1145/3390605	Computing Server Power Modeling in a Data Center: Survey, Ta	ACM COMPUTING SURVEYS	2020
1.WoS	13	4	1	Green Econ.	software &	survey & t	Arora, Sumedha; Bala, Anju	10.1007/s10586-019-02958-6	A survey: ICT enabled energy efficiency techniques for big data a	CLUSTER COMPUTING-THE JOURNAL OF	2020
1.WoS	14		3	Application	software &	empirical	Kaur, Harkiran; Sood, Sandeep K.; Bhatia, Munish	10.1007/s10586-019-02981-7	Cloud-assisted green IoT-enabled comprehensive framework for	CLUSTER COMPUTING-THE JOURNAL OF	2020
1.WoS	15		3	Allocation	software &	empirical	Sharma, Mohan; Garg, Ritu	10.1016/j.suscom.2020.100373	An artificial neural network based approach for energy efficient t	SUSTAINABLE COMPUTING-INFORMATIC	2020
1.WoS	16		3	Application	software &	simulation	Kaur, Kuljeet; Garg, Sahil; Kaddoum, Georges; …	10.1109/JIOT.2019.2939534	KEIDS: Kubernetes-Based Energy and Interference Driven Sche	IEEE INTERNET OF THINGS JOURNAL	2020
1.WoS	17		3	Architecture	hardware &	model dev	Zhang, Deyu; Tan, Long; Ren, Ju;…	10.1109/TMC.2019.2901474	Near-Optimal and Truthful Online Auction for Computation Offloa	IEEE TRANSACTIONS ON MOBILE COMP	2020
1.WoS	18		3	Application	software &	empirical	Das, Jaydeep; Mukherjee, Anwesha; Ghosh, Soumya K.; …	10.1016/j.simpat.2019.102043	Spatio-Fog: A green and timeliness-oriented fog computing mod	SIMULATION MODELLING PRACTICE AND	2020
1.WoS	19	5	1	Architecture	hardware &	empirical	Chaudhry, Muhammad Tayyab; Jamal, M. Hasan; …	10.1016/j.suscom.2019.100357	Thermal-benchmarking for cloud hosting green data centers	SUSTAINABLE COMPUTING-INFORMATIC	2020
1.WoS	20		3	Application	software &	empirical	Kaur, Amandeep; Sood, Sandeep K.	10.1109/JIOT.2019.2951610	Cloud-Centric IoT-Based Green Framework for Smart Drought Pr	IEEE INTERNET OF THINGS JOURNAL	2020
1.WoS	21		3	Application	software &	simulation	Liu, Jialei; Wang, Shangguang; Zhou, Ao; …	10.1007/s11704-018-7172-3	SLA-driven container consolidation with usage prediction for gree	FRONTIERS OF COMPUTER SCIENCE	2020
1.WoS	22		3	Architecture	software &	empirical	Xu, Jianzhong; Zhai, Jiaqi; Li, Feng'en; ..	10.1109/ACCESS.2020.3045388	Research on Diffusion Mechanism of Green Innovation of Cloud	IEEE ACCESS	2020
1.WoS	23		3	Architecture	not target	empirical	Zhang, Qing; Lin, Xiaoyong; Hao, Yongsheng; …	10.1109/ACCESS.2020.3044932	Energy-Aware Scheduling in Edge Computing Based on Energy	IEEE ACCESS	2020
1.WoS	24	6	1	Allocation	hardware &	model dev	Shaikh, Asadullah; Uddin, Mueen; Elmagzoub, Mohamed A.; …	10.1109/ACCESS.2020.3033791	PEMC: Power Efficiency Measurement Calculator to Compute P	IEEE ACCESS	2020
1.WoS	25		3	Architecture	not target	survey & t	Mughees, Amna; Tahir, Mohammad; Sheikh, Aman;…	10.1109/ACCESS.2020.3029903	Towards Energy Efficient 5G Networks Using Machine Learning:	IEEE ACCESS	2020
1.WoS	26		3	Architecture	not target	survey & t	Etengu, Richard; Tan, Saw Chin; Kwang, Lee Ching; …	10.1109/ACCESS.2020.3022291	AI-Assisted Framework for Green-Routing and Load Balancing ir	IEEE ACCESS	2020
1.WoS	27		2	Allocation	CSC	simulation	Ghaemi, Sara; Khazaei, Hamzeh; Musilek, Petr	10.1109/ACCESS.2020.3010119	ChainFaaS: An Open Blockchain-Based Serverless Platform	IEEE ACCESS	2020
1.WoS	28	7	1	Application	hardware &	review	Han, Guangjie; Jia, Gangyong; Lloret, Jaime; …	10.1109/ACCESS.2020.3001770	IEEE Access Special Section Editorial: Emerging Trends, Issue	IEEE ACCESS	2020
1.WoS	29	8	1	Green Econ.	hardware &	model dev	Alarifi, Abdulaziz; Dubey, Kalka; Amoon, Mohammed; …	10.1109/ACCESS.2020.3002184	Energy-Efficient Hybrid Framework for Green Cloud Computing	IEEE ACCESS	2020
1.WoS	30		2	Allocation	software &	empirical	Li, Shaohui; Liu, Hong; Gong, Bin; …	10.1109/ACCESS.2020.3003304	An Algorithm Incarnating Deep Integration of Hardware-Software	IEEE ACCESS	2020
1.WoS	31		3	Architecture	not target	survey & t	Kumari, Adesh; Kumar, Vinod; Abbasi, M. Yahya; …	10.1109/ACCESS.2020.3001152	CSEF: Cloud-Based Secure and Efficient Framework for Smart	IEEE ACCESS	2020
1.WoS	32		3	Architecture	not target	simulation	Zahed, M. Ishtiaque A.; Ahmad, Iftekhar; Habibi, Daryoush;…	10.1109/ACCESS.2020.2982669	Green and Secure Computation Offloading for Cache-Enabled Io	IEEE ACCESS	2020
1.WoS	33		3	Architecture	not target	model dev	Qiao, Shuaiqing; Zhang, Qisheng; Zhang, Qimao; …	10.1109/ACCESS.2020.2966510	Hybrid Seismic-Electrical Data Acquisition Station Based on Cl	IEEE ACCESS	2020
1.WoS	34		2	Application	CSP	model dev	Liao, Yongjian; Zhang, Ganglin; Chen, Hongjie	10.1109/ACCESS.2020.2969223	Cost-Efficient Outsourced Decryption of Attribute-Based Encrypt	IEEE ACCESS	2020
1.WoS	35	9	1	Application	software &	model dev	Ullah, Qazi Zia; Khan, Gul Muhammad; Hassan, Shahzad	10.1109/ACCESS.2020.2966678	Cloud Infrastructure Estimation and Auto-Scaling Using Recurre	IEEE ACCESS	2020
1.WoS	36		2	Architecture	hardware &	model dev	Chin, Tai-Lin; Chen, Yeong-Sheng; Lyu, Kun-Yu	10.1109/ACCESS.2020.2979479	Queuing Model Based Edge Placement for Work Offloading in M	IEEE ACCESS	2020
1.WoS	37		3	Allocation	software &	model dev	Li, Chen; Huo, Lisu; Chen, Huangke	10.1109/ACCESS.2019.2955013	Real-Time Workflows Oriented Hybrid Scheduling Approach With	IEEE ACCESS	2020
1.WoS	38		3	Architecture	not target	model dev	Sun, Xiang; Ansari, Nirwan	10.1109/TCC.2017.2764463	Green Cloudlet Network: A Sustainable Platform for Mobile Clou	IEEE TRANSACTIONS ON CLOUD COMPU	2020
1.WoS	39		2	Architecture	hardware &	model dev	He, Zhiming; Zhang, Yin; Tak, Byungchul; …	10.1109/ACCESS.2019.2961952	Green Fog Planning for Optimal Internet-of-Thing Task Schedulir	IEEE ACCESS	2020
1.WoS	40		2	VM	software &	review	Masdari, Mohammad; Gharehpasha, Sasan; …	10.1007/s10586-019-03026-9	Bio-inspired virtual machine placement schemes in cloud compu	CLUSTER COMPUTING-THE JOURNAL OF	2020
1.WoS	41		3	Allocation	software &	model dev	Toor, Asfa; ul Islam, Saif; Sohail, Nimra; …	10.1016/j.future.2019.07.010	Energy and performance aware fog computing: A case of DVFS	FUTURE GENERATION COMPUTER SYST	2019
1.WoS	42	10	1	Allocation	software &	model dev	Abdessamia, Foudil; Zhang, Wei-Zhe; Tian, Yu-Chu	10.1007/s10586-019-03021-0	Energy-efficiency virtual machine placement based on binary gra	CLUSTER COMPUTING-THE JOURNAL OF	2020
1.WoS	43		3	Application	not target	model dev	Mukherjee, Anwesha; Deb, Priti; De, Debashis; …	10.1007/s11227-019-02928-0	IoT-F2N: An energy-efficient architectural model for IoT using Fe	JOURNAL OF SUPERCOMPUTING	2019
1.WoS	44	11	1	VM	software &	model dev	Qie, Xiuchen; Jin, Shunfu; Yue, Wuyi	10.1007/s10922-019-09489-w	An Energy-Efficient Strategy for Virtual Machine Allocation over	JOURNAL OF NETWORK AND SYSTEMS	2019
1.WoS	45		3	Architecture	not target	simulation	Chen, Weiwei; Wang, Dong; Li, Keqin	10.1109/TSC.2018.2826544	Multi-User Multi-Task Computation Offloading in Green Mobile E	IEEE TRANSACTIONS ON SERVICES CO	2019
1.WoS	46		3	VM	software &	model dev	Murana, Jonathan; Nesmachnow, Sergio; Armenta, Fermin; …	10.1007/s10586-018-2882-8	Characterization, modeling and scheduling of power consumptio	CLUSTER COMPUTING-THE JOURNAL OF	2019
1.WoS	47	12	1	VM	software &	survey & t	Hamdi, Najet; Chainbi, Walid	10.1016/j.suscom.2019.06.003	A survey on energy aware VM consolidation strategies	SUSTAINABLE COMPUTING-INFORMATIC	2019
1.WoS	48	13	1	Allocation	software &	survey & t	Khattar, Nagma; Sidhu, Jagpreet; Singh, Jaiteg	10.1007/s11227-019-02764-2	Toward energy-efficient cloud computing: a survey of dynamic po	JOURNAL OF SUPERCOMPUTING	2019
1.WoS	49	14	1	Architecture	software &	survey & t	Mengistu, Tessema M.; Che, Dunren	10.1145/3320073	Survey and Taxonomy of Volunteer Computing	ACM COMPUTING SURVEYS	2019
1.WoS	50	15	1	Application	hardware &	model dev	Stavrinides, Georgios L.; Karatza, Helen D.	10.1016/j.future.2019.02.019	An energy-efficient, QoS-aware and cost-effective scheduling ap	FUTURE GENERATION COMPUTER SYST	2019
1.WoS	51		3	Allocation	software &	model dev	Yu, Ye; Bu, Xiangyuan; Yang, Kai;…	10.1109/JIOT.2018.2875587	Green Large-Scale Fog Computing Resource Allocation Using J	IEEE INTERNET OF THINGS JOURNAL	2019
1.WoS	52		3	Architecture	not target	model dev	Ji, Luyue; Guo, Songtao	10.1109/JIOT.2018.2880812	Energy-Efficient Cooperative Resource Allocation in Wireless Po	IEEE INTERNET OF THINGS JOURNAL	2019
1.WoS	53		3	Architecture	not target	model dev	Zhang, Ximu; Jia, Min; Gu, Xuemai;…	10.1109/JIOT.2019.2894000	An Energy Efficient Resource Allocation Scheme Based on Clou	IEEE INTERNET OF THINGS JOURNAL	2019
1.WoS	54		2	Allocation	software &	simulation	Gu, Lin; Cai, Jingjing; Zeng, Deze;…	10.1016/j.future.2018.12.062	Energy efficient task allocation and energy scheduling in green e	FUTURE GENERATION COMPUTER SYST	2019
1.WoS	55		2	Allocation	software &	simulation	Meshkati, Jafar; Safi-Esfahani, Faramarz	10.1007/s11227-018-2626-9	Energy-aware resource utilization based on particle swarm optim	JOURNAL OF SUPERCOMPUTING	2019
1.WoS	56	16	1	VM	software &	simulation	Xu, Xiaolong; Zhang, Qitong; Maneas, Stathis;…	10.1016/j.simpat.2018.10.006	VMSAGE: A virtual machine scheduling algorithm based on the	SIMULATION MODELLING PRACTICE AND	2019
1.WoS	57	17	1	Green Econ.	hardware &	simulation	De Courchelle, Ines; Guerout, Tom; Da Costa, Georges;…	10.1016/j.simpat.2018.09.011	Green energy efficient scheduling management	SIMULATION MODELLING PRACTICE AND	2019
1.WoS	58		3	Architecture	not target	model dev	Sun, Yaohua; Peng, Mugen; Mao, Shiwen	10.1109/JIOT.2018.2871020	Deep Reinforcement Learning-Based Mode Selection and Resou	IEEE INTERNET OF THINGS JOURNAL	2019
1.WoS	59	18	1	Application	software &	simulation	Farahnakian, Fahimeh; Pahikkala, Tapio; Liljeberg, Pasi;…	10.1109/TCC.2016.2617374	Energy-Aware VM Consolidation in Cloud Data Centers Using U	IEEE TRANSACTIONS ON CLOUD COMPU	2019
1.WoS	60		2	Architecture	hardware &	model dev	de Alfonso, Carlos; Caballer, Miguel; Calatrava, Amanda;…	10.1007/s10723-018-9449-z	Multi-elastic Datacenters: Auto-scaled Virtual Clusters on Energ	JOURNAL OF GRID COMPUTING	2019
1.WoS	61		2	Allocation	hardware &	model dev	Amoon, Mohammed; El Tobely, Tarek E.	10.1007/s10586-018-2028-z	A Green energy-efficient scheduler for cloud data centers	CLUSTER COMPUTING-THE JOURNAL OF	2019
1.WoS	62		3	Architecture	not target	model dev	Boukerche, Azzedine; Guan, Shichao; De Grande, Robson E.	10.1145/3286688	Sustainable Offloading in Mobile Cloud Computing: Algorithmic	ACM COMPUTING SURVEYS	2019
1.WoS	63		3	Architecture	not target	review	Piao, Zhuying; Peng, Mugen; Liu, Yaqiong;…	10.1109/JIOT.2018.2866709	Recent Advances of Edge Cache in Radio Access Networks for	IEEE INTERNET OF THINGS JOURNAL	2019
1.WoS	64	19	1	Architecture	hardware &	model dev	Cheng, Dazhao; Zhou, Xiaobo; Ding, Zhijun;…	10.1109/TPDS.2018.2865927	Heterogeneity Aware Workload Management in Distributed Sust	IEEE TRANSACTIONS ON PARALLEL AND	2019
1.WoS	65	20	1	Application	software &	simulation	Mustafa, Saad; Sattar, Kinza; Shuja, Junaid;…	10.1109/ACCESS.2019.2941145	SLA-Aware Best Fit Decreasing Techniques for Workload Cons	IEEE ACCESS	2019
1.WoS	66	21	1	Allocation	hardware &	simulation	Ismail, Leila; Abed, Eyad H.	10.1109/ACCESS.2019.2956881	Linear Power Modeling for Cloud Data Centers	IEEE ACCESS	2019
1.WoS	67	22	1	Allocation	software &	simulation	Lu, Yong; Sun, Na	10.1007/s10586-017-1272-y	An effective task scheduling algorithm based on efficient resourc	CLUSTER COMPUTING-THE JOURNAL OF	2019

DataBase	No	relevant	Excl.	Dim.	Group	Method	Author Full Names	DOI	Article Title	Source Title	Year
1.WoS	68		2	Application	CSP	survey & t	Kuppusamy, P.; Kalpana, R.; Rao, P. V. Venkateswara	10.1007/s10586-018-2172-5	Optimized traffic control and data processing using IoT	CLUSTER COMPUTING-THE JOURNAL OF	2019
1.WoS	69		2	Architecture	software &	simulation	Dong, Yunmeng; Xu, Gaochao; Ding, Yan;…	10.1109/ACCESS.2019.2928582	A 'Join Me' Task Deployment Strategy for Load Balancing in Edg	IEEE ACCESS	2019
1.WoS	70	23	1	Allocation	hardware (	simulation	Khalil, Muhammad Imran Khan; Ahmad, Iftikhar; Almazroi, Abdulv	10.1109/ACCESS.2019.2924085	Energy Efficient Indivisible Workload Distribution in Geographica	IEEE ACCESS	2019
1.WoS	71		3	Application	not target	model dev	Guo, Mian; Li, Lei; Guan, Quansheng	10.1109/ACCESS.2019.2922992	Energy-Efficient and Delay-Guaranteed Workload Allocation in Io	IEEE ACCESS	2019
1.WoS	72		3	Architecture	not target	model dev	Teng, Yinglei; Cheng, Kang; Zhang, Yong;…	10.1109/ACCESS.2019.2921317	Mixed-Timescale Joint Computational Offloading and Wireless R	IEEE ACCESS	2019
1.WoS	73		2	Application	software &	model dev	Qin, Baodong; Zheng, Dong	10.1109/ACCESS.2019.2907364	Generic Approach to Outsource the Decryption of Attribute-Base	IEEE ACCESS	2019
1.WoS	74		2	Application	hardware (	model dev	Ning, Zhaolong; Kong, Xiangjie; Xia, Feng;…	10.1109/MCOM.2018.1700895	Green and Sustainable Cloud of Things: Enabling Collaborative E	IEEE COMMUNICATIONS MAGAZINE	2019
1.WoS	75	24	1	Green Econ.	hardware (	survey & t	Gill, Sukhpal Singh; Buyya, Rajkumar	10.1145/3241038	A Taxonomy and Future Directions for Sustainable Cloud Compu	ACM COMPUTING SURVEYS	2019
1.WoS	76	25	1	Green Econ.	hardware (	model dev	Yang, Jun; Xiao, Wenjing; Jiang, Chun;…	10.1109/ACCESS.2018.2888976	AI-Powered Green Cloud and Data Center	IEEE ACCESS	2019
1.WoS	77		2	VM	not target	model dev	Mohiuddin, Irfan; Almogren, Ahmad	10.1016/j.jpdc.2018.09.011	Workload aware VM consolidation method in edge/cloud compu	JOURNAL OF PARALLEL AND DISTRIBUT	2019
1.WoS	78	26	1	VM	software &	simulation	Ismail, Leila; Materwala, Huned	10.1109/JIOT.2018.2865612	Energy-Aware VM Placement and Task Scheduling in Cloud-IoT	IEEE INTERNET OF THINGS JOURNAL	2018
1.WoS	79	27	1	Green Econ.	CSP	simulation	Lu, Xingjian; Jiang, Dongxu; He, Gaoqi;…	10.1016/j.suscom.2018.07.004	GreenBDT: Renewable-aware scheduling of bulk data transfers f	SUSTAINABLE COMPUTING-INFORMATIC	2018
1.WoS	80		2	Allocation	software &	simulation	Shojaei, Kiamars; Safi-Esfahani, Faramarz; Ayat, Saeed	10.1007/s11227-018-2508-1	VMDFS: virtual machine dynamic frequency scaling framework i	JOURNAL OF SUPERCOMPUTING	2018
1.WoS	81		2	VM	software &	simulation	Nasim, Robayet; Zola, Enrica; Kassler, Andreas J.	10.1007/s10586-018-2718-6	Robust optimization for energy-efficient virtual machine consolid	CLUSTER COMPUTING-THE JOURNAL OF	2018
1.WoS	82		3	Architecture	not target	model dev	Wen, Jinming; Ren, Chao; Sangaiah, Arun Kumar	10.1109/MCOM.2018.1701054	Energy-Efficient Device-to-Device Edge Computing Network: An	IEEE COMMUNICATIONS MAGAZINE	2018
1.WoS	83		3	Allocation	software &	simulation	Wang, Cong; Zink, Michael; Irwin, David	10.1016/j.suscom.2018.07.009	Energy-agile design for parallel HPC applications	SUSTAINABLE COMPUTING-INFORMATIC	2018
1.WoS	84		3	Green Econ.	not target	survey & t	Gupta, Brij B.; Agrawal, Dharma P.; Yamaguchi, Shingo	10.1016/j.suscom.2018.07.007	Introduction to special issue on recent advances on sustainabilit	SUSTAINABLE COMPUTING-INFORMATIC	2018
1.WoS	85		3	Application	hardware (	model dev	Stergiou, Christos; Psannis, Kostas E.; Gupta, Brij B.;…	10.1016/j.suscom.2018.06.003	Security, privacy & efficiency of sustainable Cloud Computing fo	SUSTAINABLE COMPUTING-INFORMATIC	2018
1.WoS	86		2	Allocation	software &	simulation	Mao, Li; Li, Yin; Peng, Gaofeng;…	10.1016/j.suscom.2018.05.003	A multi-resource task scheduling algorithm for energy-performan	SUSTAINABLE COMPUTING-INFORMATIC	2018
1.WoS	87		2	Allocation	software &	simulation	Safari, Monire; Khorsand, Reihaneh	10.1016/j.simpat.2018.07.006	Energy-aware scheduling algorithm for time-constrained workflov	SIMULATION MODELLING PRACTICE ANI	2018
1.WoS	88		3	VM	software &	model dev	Barkat, Amine; Kechadi, Mohand-Tahar; Verticale, Giacomo;…	10.1007/s10922-017-9441-0	Green Approach for Joint Management of Geo-Distributed Data (	JOURNAL OF NETWORK AND SYSTEMS	2018
1.WoS	89		3	Allocation	software &	empirical ı	Kansal, Nidhi Jain; Chana, Inderveer	10.1007/s10586-017-1166-z	An empirical evaluation of energy-aware load balancing techniqu	CLUSTER COMPUTING-THE JOURNAL OF	2018
1.WoS	90		3	Architecture	not target	model dev	You, Changsheng; Huang, Kaibin	10.1109/TWC.2018.2820077	Exploiting Non-Causal CPU-State Information for Energy-Efficien	IEEE TRANSACTIONS ON WIRELESS CO	2018
1.WoS	91		2	VM	software &	simulation	Callau-Zori, Mar; Samoila, Lavinia; Orgerie, Anne-Cecile;…	10.1016/j.suscom.2017.11.001	An experiment-driven energy consumption model for virtual mach	SUSTAINABLE COMPUTING-INFORMATIC	2018
1.WoS	92		3	VM	software &	simulation	Vasudevan, Meera; Tian, Yu-Chu; Tang, Maolin;…	10.1016/j.asoc.2018.03.016	Energy-efficient application assignment in profile-based data cer	APPLIED SOFT COMPUTING	2018
1.WoS	93		3	Architecture	software &	simulation	Rahman, Md. Abdur; Hossain, M. Shamim; Hassanain, Elham;…	10.1109/MCOM.2018.1700907	Semantic Multimedia Fog Computing and Lot Environment: Slist	IEEE COMMUNICATIONS MAGAZINE	2018
1.WoS	94		2	Green Econ.	CSP	review	Yang, Fan; Chien, Andrew A.	10.1109/TPDS.2017.2782677	Large-Scale and Extreme-Scale Computing with Stranded Greer	IEEE TRANSACTIONS ON PARALLEL ANI	2018
1.WoS	95		3	Application	software &	model dev	Plageras, Andreas P.; Psannis, Kostas E.; Stergiou, Christos;…	10.1016/j.future.2017.09.082	Efficient IoT-based sensor BIG Data collection-processing and a	FUTURE GENERATION COMPUTER SYST	2018
1.WoS	96		2	Architecture	hardware (	simulation	Lee, Eun Kyung; Viswanathan, Hariharasudhan; Pompili, Dario	10.1109/TCC.2015.2481423	Model-Based Thermal Anomaly Detection in Cloud Datacenters	IEEE TRANSACTIONS ON CLOUD COMPU	2018
1.WoS	97		3	Architecture	not target	review	Chang, Zheng; Zhou, Sheng; Ristaniemi, Tapani;…	10.1109/MWC.2017.1600170	COLLABORATIVE MOBILE CLOUDS: AN ENERGY EFFICIENT	IEEE WIRELESS COMMUNICATIONS	2018
1.WoS	98		3	Architecture	not target	model dev	Phuong Luong; Gagnon, Francois; Despins, Charles;…	10.1109/TWC.2018.2799859	Joint Virtual Computing and Radio Resource Allocation in Limite	IEEE TRANSACTIONS ON WIRELESS CO	2018
1.WoS	99		2	Allocation	hardware (	simulation	Niemi, Tapio; Nurminen, Jukka K.; Liukkonen, Juha-Matti;…	10.1016/j.future.2017.11.001	Towards Green Big Data at CERN	FUTURE GENERATION COMPUTER SYST	2018
1.WoS	100	28	1	VM	software &	simulation	Malekloo, Mohammad-Hossein; Kara, Nadjia; El Barachi, May	10.1016/j.suscom.2018.02.001	An energy efficient and SLA compliant approach for resource all	SUSTAINABLE COMPUTING-INFORMATIC	2018
1.WoS	101		3	Allocation	software &	empirical ı	Panneerselvam, John; Liu, Lu; Antonopoulos, Nick	10.1016/j.future.2017.05.022	InOt-RePCoN: Forecasting user behavioural trend in large-scale	FUTURE GENERATION COMPUTER SYST	2018
1.WoS	102	29	1	VM	software &	model dev	Marotta, Antonio; Avallone, Stefano; Kassler, Andreas	10.1016/j.comnet.2017.11.003	A Joint Power Efficient Server and Network Consolidation approa	COMPUTER NETWORKS	2018
1.WoS	103		2	Application	hardware (	survey & t	Atat, Rachad; Liu, Lingjia; Wu, Jinsong;…	10.1109/ACCESS.2018.2878681	Big Data Meet Cyber-Physical Systems: A Panoramic Survey	IEEE ACCESS	2018
1.WoS	104	30	1	VM	software &	simulation	Wang, Hui; Tianfield, Huaglory	10.1109/ACCESS.2018.2813541	Energy-Aware Dynamic Virtual Machine Consolidation for Cloud	IEEE ACCESS	2018
1.WoS	105		3	Architecture	not target	model dev	Darwish, Tansneem S. J.; Abu Bakar, Kamalrulnizam	10.1109/ACCESS.2018.2815989	Fog Based Intelligent Transportation Big Data Analytics in The Ir	IEEE ACCESS	2018
1.WoS	106		3	Architecture	not target	model dev	Guo, Pengze; Liu, Ming; Wu, Jun; …	10.1109/ACCESS.2018.2871821	Energy-Efficient Fault-Tolerant Scheduling Algorithm for Real-Tin	IEEE ACCESS	2018
1.WoS	107		3	Architecture	not target	model dev	Lyu, Xinchen; Tian, Hui; Jiang, Li; …	10.1109/MNET.2018.1700101	Selective Offloading in Mobile Edge Computing for the Green Int	IEEE NETWORK	2018
1.WoS	108	31	1	Application	software &	model dev	Yadav, Rahul; Zhang, Weizhe; Kaiwartya, Omprakash;…	10.1109/ACCESS.2018.2872750	Adaptive Energy-Aware Algorithms for Minimizing Energy Consu	IEEE ACCESS	2018
1.WoS	109		2	Allocation	software &	simulation	Kurdi, Heba A.; Alismail, Shaden M.; Hassan, Mohammad Mehe	10.1109/ACCESS.2018.2839028	LACE: A Locust-Inspired Scheduling Algorithm to Reduce Energ	IEEE ACCESS	2018
1.WoS	110		3	Green Econ.	not target	survey & t	Khan, Minhaj Ahmad; Umer, Tariq; Khan, Samee U.;…	10.1109/ACCESS.2018.2805543	IEEE ACCESS SPECIAL SECTION EDITORIAL: ENERGY EFF	IEEE ACCESS	2018
1.WoS	111	32	1	Green Econ.	hardware (	empirical ı	Popoola, Olusogo; Pranggono, Bernardi	10.1007/s11227-017-2132-5	On energy consumption of switch-centric data center networks	JOURNAL OF SUPERCOMPUTING	2018
1.WoS	112	33	1	Allocation	software &	simulation	Mishra, Sambit Kumar; Puthal, Deepak; Sahoo, Bibhudatta;…	10.1007/s11227-017-2133-4	An adaptive task allocation technique for green cloud computing	JOURNAL OF SUPERCOMPUTING	2018
1.WoS	113	34	1	Allocation	software &	simulation	Capizzi, Giacomo; Lo Sciuto, Grazia; Napoli, Christian;…	10.1016/j.asoc.2017.08.057	An advanced neural network based solution to enforce dispatch	APPLIED SOFT COMPUTING	2018
1.WoS	114		2	Allocation	software &	simulation	Juarez, Fredy; Ejarque, Jorge; Badia, Rosa M.	10.1016/j.future.2016.06.029	Dynamic energy-aware scheduling for parallel task-based applica	FUTURE GENERATION COMPUTER SYST	2018
1.WoS	115	35	1	VM	software &	simulation	Yang, Ting; Pen, Haibo; Li, Wei;…	10.1016/j.future.2017.05.047	An energy-efficient virtual machine placement and route schedul	FUTURE GENERATION COMPUTER SYST	2017
1.WoS	116		3	Application	hardware (	survey & t	Zhu, Chunsheng; Zhou, Huan; Leung, Victor C. M.;…	10.1109/MCOM.2017.1700142	Toward Big Data in Green City	IEEE COMMUNICATIONS MAGAZINE	2017
1.WoS	117		3	Architecture	not target	model dev	Tang, Jianhua; Wen, Ruihan; Quek, Tony Q. S.;…	10.1109/MCOM.2017.1600922	Fully Exploiting Cloud Computing to Achieve a Green and Flexib	IEEE COMMUNICATIONS MAGAZINE	2017
1.WoS	118		2	Allocation	software &	model dev	Casalicchio, Emiliano; Lundberg, Lars; Shirinbab, Sogand	10.1007/s10586-017-0912-6	Energy-aware auto-scaling algorithms for Cassandra virtual data	CLUSTER COMPUTING-THE JOURNAL OF	2017
1.WoS	119	36	1	Green Econ.	hardware (	review	Shuja, Junaid; Ahmad, Raja Wasim; Gani, Abdullah;…	10.1186/s13174-017-0060-5	Greening emerging IT technologies: techniques and practices	JOURNAL OF INTERNET SERVICES AND	2017
1.WoS	120	37	1	Application	CSC	simulation	Khasnabish, Jyotiska Nath; Mithani, Mohammad Firoj; Rao, Shris	10.1109/TCC.2015.2424888	Tier-Centric Resource Allocation in Multi-Tier Cloud Systems	IEEE TRANSACTIONS ON CLOUD COMPU	2017
1.WoS	121		2	Application	hardware (	model dev	Jin, Zhenjun; Xu, Gaochao; Li, Yang;…	10.1007/s10586-017-0870-z	A novel cloud scheduling algorithm optimization for energy cons	CLUSTER COMPUTING-THE JOURNAL OF	2017
1.WoS	122		2	Allocation	software &	model dev	Kumar, Neetesh; Vidyarthi, Deo Prakash	10.1016/j.future.2017.01.015	An Energy Aware Cost Effective Scheduling Framework for Hete	FUTURE GENERATION COMPUTER SYST	2017
1.WoS	123		3	Architecture	not target	model dev	Zhu, Chunsheng; Leung, Victor C. M.; Wang, Kun;…	10.1109/MCOM.2017.1600822	Multi-Method Data Delivery for Green Sensor-Cloud	IEEE COMMUNICATIONS MAGAZINE	2017
1.WoS	124	38	1	Green Econ.	hardware (	survey & t	Bianchini, Ricardo; Khan, Samee U.; Mastroianni, Carlo	10.1109/TCC.2016.2641618	Guest Editors' Introduction: Special Issue on Green and Energy-	IEEE TRANSACTIONS ON CLOUD COMPU	2017
1.WoS	125		2	VM	software &	model dev	Yang, Yang; Liu, Jiqiang; Li, Lin;…	10.1109/TCC.2015.2459704	Towards Robust Green Virtual Cloud Data Center Provisioning	IEEE TRANSACTIONS ON CLOUD COMPU	2017
1.WoS	126	39	1	Green Econ.	CSP	model dev	Hasan, Md Sabbir; Kouki, Yousri; Ledoux, Thomas;…	10.1109/TCC.2015.2459710	Exploiting Renewable Sources: When Green SLA Becomes a P	IEEE TRANSACTIONS ON CLOUD COMPU	2017
1.WoS	127		2	Allocation	software &	model dev	Vasudevan, Meera; Tian, Yu-Chu; Tang, Maolin;…	10.1016/j.future.2016.06.037	Profile-based application assignment for greener and more energ	FUTURE GENERATION COMPUTER SYST	2017
1.WoS	128		3	Allocation	software &	model dev	Kierzynka, Michal; Kosmann, Lars; vor dem Berge, Micha;…	10.1016/j.future.2016.05.006	Energy efficiency of sequence alignment tools-Software and harc	FUTURE GENERATION COMPUTER SYST	2017
1.WoS	129		2	VM	software &	simulation	Ghazisaeedi, Ebrahim; Huang, Changcheng	10.1016/j.comnet.2016.11.015	GreenMap: Green mapping of MapReduce-based virtual network	COMPUTER NETWORKS	2017
1.WoS	130		2	Application	software &	model dev	Nan, Yucen; Li, Wei; Bao, Wei;…	10.1109/ACCESS.2017.2766165	Adaptive Energy-Aware Computation Offloading for Cloud of Thin	IEEE ACCESS	2017
1.WoS	131		3	Architecture	not target	model dev	Siddiqui, Isma Farah; Lee, Scott Uk-Jin; Abbas, Asad;…	10.1109/ACCESS.2017.2752242	Optimizing Lifespan and Energy Consumption by Smart Meters	IEEE ACCESS	2017
1.WoS	132		3	Architecture	not target	simulation	Conti, Stefania; Faraci, Giuseppe; Nicolosi, Rosario;…	10.1109/ACCESS.2017.2755588	Battery Management in a Green Fog-Computing Node: a Reinfor	IEEE ACCESS	2017
1.WoS	133		3	Architecture	not target	model dev	Li, Ting; Liu, Yuxin; Gao, Longxiang;…	10.1109/ACCESS.2017.2756826	A Cooperative-Based Model for Smart-Sensing Tasks in Fog Co	IEEE ACCESS	2017
1.WoS	134		2	VM	software &	model dev	Wen, Yingyou; Li, Zhi; Jin, Shuyuan;…	10.1109/ACCESS.2017.2721548	Energy-Efficient Virtual Resource Dynamic Integration Method ir	IEEE ACCESS	2017

DataBase	No	relevant	Excl.	Dim.	Group	Method	Author Full Names	DOI	Article Title	Source Title	Year
1.WoS	135		3	Architecture	not target	simulation	Sun, Xiang; Ansari, Nirwan	10.1109/MNET.2017.1500293NM	Green Cloudlet Network: A Distributed Green Mobile Cloud Netw	IEEE NETWORK	2017
1.WoS	136		2	Application	hardware &	model dev	Singh, Sukhpal; Chana, Inderveer; Singh, Maninder;…	10.1007/s10586-016-0623-4	SOCCER: Self-Optimization of Energy-efficient Cloud Resources	CLUSTER COMPUTING-THE JOURNAL OF	2016
1.WoS	137		3	Allocation	not target	model dev	Mao, Yuyi; Zhang, Jun; Letaief, Khaled B.	10.1109/JSAC.2016.2611964	Dynamic Computation Offloading for Mobile-Edge Computing Wi	IEEE JOURNAL ON SELECTED AREAS IN	2016
1.WoS	138		3	Architecture	not target	model dev	Jin, A-Long; Song, Wei; Wang, Ping;…	10.1109/TSC.2015.2430315	Auction Mechanisms Toward Efficient Resource Sharing for Clou	IEEE TRANSACTIONS ON SERVICES CO	2016
1.WoS	139		3	Architecture	not target	review	Akyildiz, Ian F.; Nie, Shuai; Lin, Shih-Chun;…	10.1016/j.comnet.2016.06.010	5G roadmap: 10 key enabling technologies	COMPUTER NETWORKS	2016
1.WoS	140	40	1	Allocation	software &	review	Akhter, Nasrin; Othman, Mohamed	10.1007/s10586-016-0579-4	Energy aware resource allocation of cloud data center: review ar	CLUSTER COMPUTING-THE JOURNAL OF	2016
1.WoS	141	41	1	Application	hardware &	model dev	Liu, Qiang; Ma, Yujun; Alhussein, Musaed;…	10.1016/j.comnet.2015.11.024	Green data center with IoT sensing and cloud-assisted smart ter	COMPUTER NETWORKS	2016
1.WoS	142		2	Allocation	hardware &	survey & t	Kaur, Tarandeep; Chana, Inderveer	10.1007/s10586-016-0566-9	Energy aware scheduling of deadline-constrained tasks in cloud	CLUSTER COMPUTING-THE JOURNAL OF	2016
1.WoS	143		3	Architecture	not target	survey & t	Fan, Congmin; Zhang, Ying Jun (Angela); Yuan, Xiaojun		Advances and Challenges toward a Scalable Cloud Radio Acces	IEEE COMMUNICATIONS MAGAZINE	2016
1.WoS	144		2	Architecture	hardware &	model dev	Asad, Zakia; Chaudhry, Mohammad Asad Rehman; Malone, Davi	10.1109/JSAC.2016.2520245	Greener Data Exchange in the Cloud: A Coding-Based Optimiza	IEEE JOURNAL ON SELECTED AREAS IN	2016
1.WoS	145		3	Architecture	not target	simulation	Cao, Pan; Liu, Wenjia; Thompson, John S.;…	10.1109/JSAC.2016.2545478	Semidynamic Green Resource Management in Downlink Hetero	IEEE JOURNAL ON SELECTED AREAS IN	2016
1.WoS	146	42	1	Green Econ.	hardware &	survey & t	Bianchini, Ricardo; Khan, Samee U.; Mastroianni, Carlo	10.1109/TCC.2015.2506298	Guest Editors' Introduction: Special Issue on Green and Energy-	IEEE TRANSACTIONS ON CLOUD COMPU	2016
1.WoS	147	43	1	Architecture	hardware &	model dev	Cappiello, Cinzia; Nguyen Thi Thao Ho; Pernici, Barbara;…	10.1109/TCC.2015.2464796	CO2-Aware Adaptation Strategies for Cloud Applications	IEEE TRANSACTIONS ON CLOUD COMPU	2016
1.WoS	148		2	Architecture	hardware &	simulation	Lent, Ricardo	10.1016/j.future.2015.10.008	Evaluating the cooling and computing energy demand of a datac	FUTURE GENERATION COMPUTER SYST	2016
1.WoS	149	44	1	Green Econ.	hardware &	review	Dorronsoro, Bernabe; Kliazovich, Dzmitry; Bouvry, Pascal;…	10.1007/s10723-016-9365-z	Green Cloud Computing	JOURNAL OF GRID COMPUTING	2016
1.WoS	150		2	Allocation	software &	simulation	de Carvalho Junior, Osvaldo Adilson; Bruschi, Sarita Mazzini;…	10.1007/s10723-015-9333-z	Green Cloud Meta-Scheduling A Flexible and Automatic Approa	JOURNAL OF GRID COMPUTING	2016
1.WoS	151		2	Architecture	software &	model dev	Borylo, Piotr; Lason, Artur; Rzasa, Jacek;…	10.1007/s10723-015-9354-7	Green Cloud Provisioning Throughout Cooperation of a WDM Wi	JOURNAL OF GRID COMPUTING	2016
1.WoS	152		3	Architecture	not target	simulation	Mukherjee, Anwesha; De, Debashis	10.1016/j.simpat.2016.01.014	Femtolet: A novel fifth generation network device for green mobil	SIMULATION MODELLING PRACTICE AND	2016
1.WoS	153		2	Allocation	software &	model dev	Tang, Zhuo; Qi, Ling; Cheng, Zhenzhen;…	10.1007/s10723-015-9334-y	An Energy-Efficient Task Scheduling Algorithm in DVFS-enablec	JOURNAL OF GRID COMPUTING	2016
1.WoS	154		2	Allocation	software &	simulation	Cheng, Dazhao; Rao, Jia; Jiang, Changjun;…	10.1109/TC.2015.2428695	Elastic Power-Aware Resource Provisioning of Heterogeneous W	IEEE TRANSACTIONS ON COMPUTERS	2016
1.WoS	155		2	Application	hardware &	survey & t	Szymanski, Ted H.	10.1109/ACCESS.2016.2613512	Securing the Industrial-Tactile Internet of Things With Determinis	IEEE ACCESS	2016
1.WoS	156		2	Architecture	hardware &	model dev	Liu, Longjun; Sun, Hongbin; Li, Chao;…	10.1007/s11227-015-1529-2	RE-UPS: an adaptive distributed energy storage system for dyna	JOURNAL OF SUPERCOMPUTING	2016
1.WoS	157		3	Architecture	not target	survey & t	Gomes, Danielo G.; Tolosana-Calasanz, Rafael; Agoulmine, Nazi	10.1016/j.suscom.2015.11.002	Introduction to special issue on Green Mobile Cloud Computing	SUSTAINABLE COMPUTING-INFORMATIC	2015
1.WoS	158		3	Application	not target	simulation	Pan, Jianli; Jain, Raj; Paul, Subharthi;…	10.1109/JIOT.2015.2413397	An Internet of Things Framework for Smart Energy in Buildings:	IEEE INTERNET OF THINGS JOURNAL	2015
1.WoS	159		3	Allocation	hardware &	simulation	Qiu, Meikang; Ming, Zhong; Li, Jiayin;…	10.1109/TC.2015.2409857	Phase-Change Memory Optimization for Green Cloud with Gene	IEEE TRANSACTIONS ON COMPUTERS	2015
1.WoS	160		2	Allocation	software &	model dev	Bruneo, Dario; Lhoas, Audric; Longo, Francesco;…	10.1109/TPDS.2014.2364194	Modeling and Evaluation of Energy Policies in Green Clouds	IEEE TRANSACTIONS ON PARALLEL AND	2015
1.WoS	161		2	Architecture	software &	model dev	Chen, Xiaodao; Wang, Lizhe; Zomaya, Albert Y.;…	10.1109/TETC.2015.2443714	Cloud Computing for VLSI Floorplanning Considering Peak Temp	IEEE TRANSACTIONS ON EMERGING TO	2015
1.WoS	162		2	Application	software &	model dev	Lin, Suqing; Zhang, Rui; Ma, Hui;…	10.1109/TIFS.2015.2449264	Revisiting Attribute-Based Encryption With Verifiable Outsource	IEEE TRANSACTIONS ON INFORMATION	2015
1.WoS	163	45	1	Architecture	hardware &	review	Procaccianti, Giuseppe; Lago, Patricia; Bevini, Stefano;…	10.1016/j.suscom.2014.11.004	A systematic literature review on energy efficiency in cloud softw	SUSTAINABLE COMPUTING-INFORMATIC	2015
1.WoS	164		2	VM	software &	model dev	Pascual, J. A.; Lorido-Botran, T.; Miguel-Alonso, J.;…	10.1007/s10723-014-9312-9	Towards a Greener Cloud Infrastructure Management using Opti	JOURNAL OF GRID COMPUTING	2015
1.WoS	165		2	Allocation	software &	model dev	Arroba, Patricia; Risco-Martin, Jos L.; Zapater, Marina;…	10.1007/s10723-014-9313-8	Enhancing Regression Models for Complex Systems Using Evol	JOURNAL OF GRID COMPUTING	2015
1.WoS	166	46	1	VM	software &	survey & t	Mann, Zoltan Adam	10.1145/2797211	Allocation of Virtual Machines in Cloud Data Centers-A Survey o	ACM COMPUTING SURVEYS	2015
1.WoS	167	47	1	Architecture	hardware &	model dev	Mashayekhy, Lena; Nejad, Mahyar Movahed; Grosu, Daniel	10.1109/TCC.2014.2369419	Physical Machine Resource Management in Clouds: A Mechani	IEEE TRANSACTIONS ON CLOUD COMPU	2015
1.WoS	168		2	Architecture	software &	model dev	Itani, Wassim; Ghali, Cesar; Kayssi, Ayman;…	10.1007/s10586-015-0443-y	G-Route: an energy-aware service routing protocol for green clou	CLUSTER COMPUTING-THE JOURNAL OF	2015
1.WoS	169		3	Architecture	not target	simulation	Zhou, Jun; Dong, Xiaolei; Cao, Zhenfu;…	10.1109/TIFS.2015.2407326	Secure and Privacy Preserving Protocol for Cloud-Based Vehicu	IEEE TRANSACTIONS ON INFORMATION	2015
1.WoS	170		3	Application	hardware &	survey & t	Lyu, Michael R.; Zhang, Liang-Jie (LJ)	10.1109/TSC.2015.2428791	Guest Editorial: Recommendation Techniques for Services Comp	IEEE TRANSACTIONS ON SERVICES CO	2015
1.WoS	171		2	VM	software &	model dev	Kim Khoa Nguyen; Cheriet, Mohamed	10.1109/TSC.2014.2362544	Environment-Aware Virtual Slice Provisioning in Green Cloud En	IEEE TRANSACTIONS ON SERVICES CO	2015
1.WoS	172		3	Application	not target	survey & t	Bojanova, Irena; Voas, Jeffrey; Hurlburt, George	10.1109/MITP.2015.41	The Internet of Anything and Sustainability	IT PROFESSIONAL	2015
1.WoS	173	48	1	Allocation	hardware &	model dev	Vilaplana, Jordi; Mateo, Jordi; Teixido, Ivan;…	10.1007/s11227-014-1351-2	An SLA and power-saving scheduling consolidation strategy for s	JOURNAL OF SUPERCOMPUTING	2015
1.WoS	174	49	1	Allocation	software &	model dev	Chiang, Yi-Ju; Ouyang, Yen-Chieh; Hsu, Ching-Hsien (Robert)	10.1109/TCC.2014.2350492	An Efficient Green Control Algorithm in Cloud Computing for Cos	IEEE TRANSACTIONS ON CLOUD COMPU	2015
1.WoS	175		3	Allocation	not target	model dev	Vishwanath, Arun; Jalali, Fatemeh; Hinton, Kerry;…	10.1109/JSAC.2015.2393431	Energy Consumption Comparison of Interactive Cloud-Based and	IEEE JOURNAL ON SELECTED AREAS IN	2015
1.WoS	176	50	1	Application	hardware &	model dev	Subirats, Josep; Guitart, Jordi	10.1016/j.future.2014.11.008	Assessing and forecasting energy efficiency on Cloud computing	FUTURE GENERATION COMPUTER SYST	2015
1.WoS	177		2	VM	software &	model dev	Farahnakian, Fahimeh; Ashraf, Adnan; Pahikkala, Tapio;…	10.1109/TSC.2014.2382555	Using Ant Colony System to Consolidate VMs for Green Cloud (	IEEE TRANSACTIONS ON SERVICES CO	2015
1.WoS	178		2	Allocation	software &	model dev	Moghaddam, Fereydoun Farrahi; Moghaddam, Reza Farrahi; …	10.1007/s10586-014-0359-y	Carbon-aware distributed cloud: multi-level grouping genetic algo	CLUSTER COMPUTING-THE JOURNAL OF	2015
1.WoS	179		3	Architecture	not target	simulation	Nguyen Dinh Han; Chung, Yonghwa; Jo, Minho	10.1109/MNET.2015.7064906	Green Data Centers for Cloud-Assisted Mobile Ad Hoc Networks	IEEE NETWORK	2015
1.WoS	180		2	VM	software &	model dev	Gu, Chonglin; Shi, Pengzhou; Shi, Shuai;…	10.1109/ACCESS.2015.2430276	A Tree Regression-Based Approach for VM Power Metering	IEEE ACCESS	2015
1.WoS	181		3	Application	not target	review	Zhu, Chunsheng; Leung, Victor C. M.; Shu, Lei;…	10.1109/ACCESS.2015.2497312	Green Internet of Things for Smart World	IEEE ACCESS	2015
1.WoS	182		3	Architecture	not target	model dev	Luo, Shixin; Zhang, Rui; Lim, Teng Joon	10.1109/TWC.2014.2352619	Downlink and Uplink Energy Minimization Through User Associa	IEEE TRANSACTIONS ON WIRELESS CO	2015
1.WoS	183		3	Architecture	not target	simulation	Peng, Mugen; Li, Yuan; Jiang, Jiamo;…	10.1109/MWC.2014.7000980	HETEROGENEOUS CLOUD RADIO ACCESS NETWORKS: A	IEEE WIRELESS COMMUNICATIONS	2014
1.WoS	184	51	1	Allocation	software &	model dev	Deng, Zhigang; Zeng, Guosun; He, Qi;…	10.1007/s10586-014-0378-8	Using priced timed automaton to analyse the energy consumptio	CLUSTER COMPUTING-THE JOURNAL OF	2014
1.WoS	185	52	1	Allocation	hardware &	model dev	Guerout, Tom; Medjiah, Samir; Da Costa, Georges;…	10.1016/j.suscom.2014.08.006	Quality of service modeling for green scheduling in Clouds	SUSTAINABLE COMPUTING-INFORMATIC	2014
1.WoS	186		2	VM	software &	model dev	Song, Weijia; Xiao, Zhen; Chen, Qi;…	10.1109/TC.2013.148	Adaptive Resource Provisioning for the Cloud Using Online Bin F	IEEE TRANSACTIONS ON COMPUTERS	2014
1.WoS	187		2	Architecture	software &	model dev	Addis, Bernardetta; Ardagna, Danilo; Capone, Antonio;…	10.1016/j.comnet.2014.04.011	Energy-aware joint management of networks and Cloud infrastru	COMPUTER NETWORKS	2014
1.WoS	188	53	1	Green Econ.	hardware &	review	Yen, Neil Y.; Wang, Cho-Li; Hussain, Sajid;…	10.1007/s11227-014-1281-z	Computational awareness towards green environments	JOURNAL OF SUPERCOMPUTING	2014
1.WoS	189		2	VM	hardware &	simulation	Lee, Hwa Min; Jeong, Young-Sik; Jang, Haeng Jin	10.1007/s11227-013-1020-x	Performance analysis based resource allocation for green cloud	JOURNAL OF SUPERCOMPUTING	2014
1.WoS	190		3	Architecture	not target	model dev	Park, Jong Hyuk; Jeong, Hwa Young	10.1007/s11227-013-1007-7	Cloud computing-based jam management for a manufacturing sy	JOURNAL OF SUPERCOMPUTING	2014
1.WoS	191	54	1	Allocation	software &	model dev	Ouyang, Yen-Chieh; Chiang, Yi-Ju; Hsu, Ching-Hsien;…	10.1007/s11227-014-1190-1	An optimal control policy to realize green cloud systems with SL	JOURNAL OF SUPERCOMPUTING	2014
1.WoS	192		2	Allocation	software &	model dev	Horri, Abbas; Mozafari, Mohammad Sadegh; …	10.1007/s11227-014-1224-8	Novel resource allocation algorithms to performance and energy	JOURNAL OF SUPERCOMPUTING	2014
1.WoS	193		3	Architecture	CSC	simulation	Chuah, Seong-Ping; Yuen, Chau; Cheung, Ngai-Man	10.1109/MWC.2014.6882299	CLOUD GAMING: A GREEN SOLUTION TO MASSIVE MULTIP	IEEE WIRELESS COMMUNICATIONS	2014
1.WoS	194		3	VM	software &	model dev	Kim-Khoa Nguyen; Cheriet, Mohamed; Lemieux, Yves	10.1109/MIC.2014.42	Virtual Slice Assignment in Large-Scale Cloud Interconnects	IEEE INTERNET COMPUTING	2014
1.WoS	195		2	Allocation	software &	model dev	Wu, Chia-Ming; Chang, Ruay-Shiung; Chan, Hsin-Yu	10.1016/j.future.2013.06.009	A green energy-efficient scheduling algorithm using the DVFS te	FUTURE GENERATION COMPUTER SYST	2014
1.WoS	196		2	VM	software &	model dev	Xiao, Zhen; Chen, Qi; Luo, Haipeng	10.1109/TC.2012.284	Automatic Scaling of Internet Applications for Cloud Computing :	IEEE TRANSACTIONS ON COMPUTERS	2014
1.WoS	197		3	Architecture	not target	simulation	Zapater, Marina; Arroba, Patricia; Ayala, Jose L.;…	10.1016/j.future.2013.12.012	A novel energy-driven computing paradigm for e-health scenarios	FUTURE GENERATION COMPUTER SYST	2014
1.WoS	198	55	1	Green Econ.	CSP	survey & t	Deng, Wei; Liu, Fangming; Jin, Hai;…	10.1109/MNET.2014.6724106	Harnessing Renewable Energy in Cloud Datacenters: Opportunit	IEEE NETWORK	2014
1.WoS	199		2	Architecture	hardware &	model dev	Gattulli, Mirko; Tornatore, Massimo; Fiandra, Riccardo;…	10.1109/JSAC.2014.140104	Low-Emissions Routing for Cloud Computing in IP-over-WDM Ne	IEEE JOURNAL ON SELECTED AREAS IN	2014
1.WoS	200		2	VM	software &	model dev	Xu, Jielong; Tang, Jian; Kwiat, Kevin;…	10.1109/JSAC.2013.131203	Enhancing Survivability in Virtualized Data Centers: A Service-A	IEEE JOURNAL ON SELECTED AREAS IN	2013
1.WoS	201		2	Allocation	hardware &	model dev	Abu Sharkh, Mohamed; Jammal, Manar; Shami, Abdallah;…	10.1109/MCOM.2013.6658651	Resource Allocation in a Network-Based Cloud Computing Envir	IEEE COMMUNICATIONS MAGAZINE	2013

DataBase	No	relevant	Excl.	Dim.	Group	Method	Author Full Names	DOI	Article Title	Source Title	Year
1.WoS	202	56	1	VM	software &	simulation	Mandal, Uttam; Habib, M. Farhan; Zhang, Shuqiang;…	10.1109/MNET.2013.6678925	Greening the Cloud Using Renewable-Energy-Aware Service Mig	IEEE NETWORK	2013
1.WoS	203	57	1	Allocation	hardware {	model dev	Kessaci, Yacine; Melab, Nouredine; Talbi, El-Ghazali	10.1007/s10586-012-0210-2	A Pareto-based metaheuristic for scheduling HPC applications c	CLUSTER COMPUTING-THE JOURNAL OF	2013
1.WoS	204	58	1	Allocation	software &	model dev	Kolodziej, Joanna; Khan, Samee Ullah; Wang, Lizhe;…	10.1007/s10586-012-0226-7	Hierarchical genetic-based grid scheduling with energy optimizat	CLUSTER COMPUTING-THE JOURNAL OF	2013
1.WoS	205		3	Architecture	not target	review	Kachris, Christoforos; Tomkos, Ioannis	10.1007/s10586-012-0227-6	Power consumption evaluation of all-optical data center networks	CLUSTER COMPUTING-THE JOURNAL OF	2013
1.WoS	206		3	Application	CSP	model dev	Lai, Junzuo; Deng, Robert H.; Guan, Chaowen;…	10.1109/TIFS.2013.2271848	Attribute-Based Encryption With Verifiable Outsourced Decrypti	IEEE TRANSACTIONS ON INFORMATION	2013
1.WoS	207	59	1	Green Econ.	hardware {	review	Jing, Si-Yuan; Ali, Shahzad; She, Kun;…	10.1007/s11227-011-0722-1	State-of-the-art research study for green cloud computing	JOURNAL OF SUPERCOMPUTING	2013
1.WoS	208		2	Allocation	hardware {	model dev	Vrbsky, Susan V.; Galloway, Michael; Carr, Robert;…	10.1016/j.future.2012.12.016	Decreasing power consumption with energy efficient data aware	FUTURE GENERATION COMPUTER SYST	2013
1.WoS	209		2	VM	software &	model dev	Xiao, Zhen; Song, Weijia; Chen, Qi	10.1109/TPDS.2012.283	Dynamic Resource Allocation Using Virtual Machines for Cloud	IEEE TRANSACTIONS ON PARALLEL ANI	2013
1.WoS	210		2	Allocation	software &	model dev	Zhang, Luna Mingyi; Li, Keqin; Lo, Dan Chia-Tien;…	10.1016/j.suscom.2013.01.002	Energy-efficient task scheduling algorithms on heterogeneous cc	SUSTAINABLE COMPUTING-INFORMATIC	2013
1.WoS	211		2	Allocation	hardware {	model dev	Wu, Zhengkai; Giles, Christopher; Wang, Jun	10.1007/s10586-011-0173-8	Classified power capping by network distribution trees for green	CLUSTER COMPUTING-THE JOURNAL OF	2013
1.WoS	212	60	1	Allocation	software &	simulation	de Alfonso, Carlos; Caballer, Miguel; Alvarruiz, Fernando;…	10.1016/j.future.2012.08.014	An economic and energy-aware analysis of the viability of outsou	FUTURE GENERATION COMPUTER SYST	2013
1.WoS	213	61	1	Architecture	hardware {	survey & t	Chauhan, Nitin Singh; Saxena, Ashutosh	10.1109/MITP.2013.6	A Green Software Development Life Cycle for Cloud Computing	IT PROFESSIONAL	2013
1.WoS	214		3	Application	not target	simulation	Pau, Giovanni	10.1109/MIC.2013.13	Quickly Home Please How Connected Vehicles Are Revolutioniz	IEEE INTERNET COMPUTING	2013
1.WoS	215		2	Architecture	hardware {	survey & t	Kim Khoa Nguyen; Cheriet, Mohamed; Lemay, Mathieu;…	10.1016/j.comnet.2012.03.008	Environmental-aware virtual data center network	COMPUTER NETWORKS	2012
1.WoS	216	62	1	Allocation	CSP	survey & t	Beloglazov, Anton; Abawajy, Jemal; Buyya, Rajkumar	10.1016/j.future.2011.04.017	Energy-aware resource allocation heuristics for efficient manage	FUTURE GENERATION COMPUTER SYST	2012
1.WoS	217		3	Allocation	not target	survey & t	Mazzucco, Michele; Dyachuk, Dmytro	10.1016/j.suscom.2011.11.001	Optimizing Cloud providers revenues via energy efficient server a	SUSTAINABLE COMPUTING-INFORMATIC	2012
1.WoS	218		3	Architecture	hardware {	model dev	Steenhof, Paul; Weber, Chris; Brooks, Martin;…	10.1016/j.suscom.2012.01.001	A protocol for quantifying the carbon reductions achieved througl	SUSTAINABLE COMPUTING-INFORMATIC	2012
1.WoS	219		2	Allocation	hardware {	simulation	Dougherty, Brian; White, Jules; Schnlidt, Douglas C.	10.1016/j.future.2011.05.009	Model-driven auto-scaling of green cloud computing infrastructur	FUTURE GENERATION COMPUTER SYST	2012
1.WoS	220		3	Application	software &	model dev	Li, Jianxin; Li, Bo; Wo, Tianyu;…	10.1016/j.future.2011.04.012	CyberGuarder: A virtualization security assurance architecture fc	FUTURE GENERATION COMPUTER SYST	2012
1.WoS	221	63	1	Architecture	hardware {	model dev	Viswanathan, Hariharasudhan; Lee, Eun Kyung; Pompili, Dario	10.1109/MNET.2011.5958006	Self-Organizing Sensing Infrastructure for Autonomic Manageme	IEEE NETWORK	2011
1.WoS	222	64	1	Architecture	hardware {	simulation	Garg, Saurabh Kumar; Yeo, Chee Shin; Anandasivam, Arun;…	10.1016/j.jpdc.2010.04.004	Environment-conscious scheduling of HPC applications on distri	JOURNAL OF PARALLEL AND DISTRIBUT	2011
1.WoS	223		2	VM	software &	model dev	Liao, Xiaofei; Hu, Liting; Jin, Hai	10.1007/s10586-009-0110-2	Energy optimization schemes in cluster with virtual machines	CLUSTER COMPUTING-THE JOURNAL OF	2010
1.WoS	224		3	Architecture	not target	model dev	Cerf, Vinton G.; Singh, Munindar P.	10.1109/MIC.2010.11	Internet Predictions	IEEE INTERNET COMPUTING	2010
1.WoS	225		3	Architecture	not target	model dev	Estrin, Deborah	10.1109/MIC.2010.12	Participatory Sensing: Applications and Architecture	IEEE INTERNET COMPUTING	2010
1.WoS	226		3	Architecture	not target	review	Ruth, Stephen	10.1109/MIC.2009.82	Green IT - More Than a Three Percent Solution?	IEEE INTERNET COMPUTING	2009
2.WoS	227		3	Green Econ.	not target	review	Koondhar, Mansoor Ahmed; Shahbaz, Muhammad; Memon, Kan	10.1007/s11356-020-12199-5	A visualization review analysis of the last two decades for enviro	ENVIRONMENTAL SCIENCE AND POLLUT	2018
2.WoS	228		3	Green Econ.	not target	simulation	Colombo, Bianca; Pereira, Joana; Martins, Margarida;…	10.1016/j.seppur.2020.117521	Recovering PHA from mixed microbial biomass: Using non-ionic	SEPARATION AND PURIFICATION TECHN	2020
2.WoS	229		2	VM	software &	model dev	Ganesan, Madhubala; Kor, Ah-Lian; Pattinson, Colin;…	10.3390/su12219255	Green Cloud Software Engineering for Big Data Processing	SUSTAINABILITY	2020
2.WoS	230		3	Green Econ.	not target	model dev	Leite, Rodrigo Vieira; Silva, Carlos Alberto; Mohan, Midhun;…	10.3390/rs12213599	Individual Tree Attribute Estimation and Uniformity Assessment	REMOTE SENSING	2020
2.WoS	231		2	Architecture	software &	model dev	Li, Ye; Chen, Yiyan; Li, Qun	10.1016/j.rser.2020.110245	Assessment analysis of green development level based on S-typ	RENEWABLE & SUSTAINABLE ENERGY	2020
2.WoS	232		3	Architecture	not target	model dev	Sun, Guolin; Ayepah-Mensah, Daniel; Xu, Rong;…	10.1016/j.jnca.2020.102757	End-to-end CNN-based dueling deep Q-Network for autonomous	JOURNAL OF NETWORK AND COMPUTE	2020
2.WoS	233		3	Green Econ.	not target	simulation	Olsson, Johanna Alkan; Brunner, Jonas; Nordin, Amanda;…	10.1016/j.envsci.2020.06.025	A just urban ecosystem service governance at the neighbourhoo	ENVIRONMENTAL SCIENCE & POLICY	2020
2.WoS	234	65	1	Application	software &	model dev	Shojafar, Mohammad; Canali, Claudia; Lancellotti, Riccardo;…	10.1109/TCC.2016.2617367	Adaptive Computing-Plus-Communication Optimization Framewc	IEEE TRANSACTIONS ON CLOUD COMPU	2020
2.WoS	235		3	Application	not target	review	Demestichas, Konstantinos; Daskalakis, Emmanouil	10.3390/su12187272	Information and Communication Technology Solutions for the Cir	SUSTAINABILITY	2020
2.WoS	236		3	Green Econ.	not target	survey & t	Dong, Yulin; Ren, Zhibin; Fu, Yao;…	10.3390/rs12152451	Recording Urban Land Dynamic and Its Effects during 2000-201	REMOTE SENSING	2020
2.WoS	237		3	Application	not target	model dev	Gupta, Neeraj; Khosravy, Mahdi; Patel, Nilesh;…	10.1007/s10489-020-01744-x	Economic data analytic AI technique on IoT edge devices for hea	APPLIED INTELLIGENCE	2020
2.WoS	238		3	Green Econ.	not target	review	Singh, Raghuveer; Yadav, Dharam Bir; Ravisankar, N.;…	10.1007/s10668-019-00370-z	Crop residue management in rice-wheat cropping system for res	ENVIRONMENT DEVELOPMENT AND SU	2020
2.WoS	239		3	Architecture	not target	model dev	Pamuklu, Turgay; Cavdar, Cicek; Ersoy, Cem	10.1007/s11036-020-01544-0	Renewable Energy Assisted Function Splitting in Cloud Radio A	MOBILE NETWORKS & APPLICATIONS	2020
2.WoS	240		3	Allocation	not target	simulation	Chen, Jianhong; Zhang, Youlang; Li, Xinzhou;…	10.1016/j.apenergy.2020.114603	Strategic integration of vehicle-to-home system with home distrit	APPLIED ENERGY	2020
2.WoS	241		3	Green Econ.	not target	simulation	Arevalo, Paulo; Olofsson, Pontus; Woodcock, Curtis E.	10.1016/j.rse.2019.01.013	Continuous monitoring of land change activities and post-disturb	REMOTE SENSING OF ENVIRONMENT	2020
2.WoS	242		2	Architecture	not target	survey & t	Bazgaou, A.; Fatnassi, H.; Bouharroud, R.;…	10.1016/j.solener.2020.01.041	Performance assessment of combining rock-bed thermal energy	SOLAR ENERGY	2020
2.WoS	243	66	1	VM	software &	review	Shirvani, Mirsaeid Hosseini; Rahmani, Amir Masoud; Sahafi, Amii	10.1016/j.jksuci.2018.07.001	A survey study on virtual machine migration and server consolid	JOURNAL OF KING SAUD UNIVERSITY-C	2020
2.WoS	244		3	Green Econ.	not target	simulation	Kumar, Dipesh; Singh, Bhaskar	10.1016/j.fuel.2019.116631	Effect of winterization and plant phenolic-additives on the cold-flc	FUEL	2020
2.WoS	245		2	Architecture	hardware {	model dev	Priya, Padma R.; Rekha, D.	10.1007/s11276-019-02207-z	Sustainability modelling and green energy optimisation in microg	WIRELESS NETWORKS	2018
2.WoS	246		2	Architecture	hardware {	review	Etengu, Richard; Tan, Saw Chin; Kwang, Lee Ching;…	10.1109/ACCESS.2020.3022291	AI-Assisted Framework for Green-Routing and Load Balancing ir	IEEE ACCESS	2020
2.WoS	247		3	Green Econ.	not target	model dev	Castaldi, Abio; Chabrillat, Sabine; Don, Axel;…	10.3390/rs11182121	Soil Organic Carbon Mapping Using LUCAS Topsoil Database a	REMOTE SENSING	2019
2.WoS	248		3	Green Econ.	not target	survey & t	Wu, Xutong; Wang, Shuai; Fu, Bojie;…	10.1016/j.scitotenv.2019.05.022	Socio-ecological changes on the Loess Plateau of China after G	SCIENCE OF THE TOTAL ENVIRONMENT	2019
2.WoS	249		2	Architecture	CSC	model dev	Li, Jing; Fang, Hong; Song, Wenyan	10.1016/j.jclepro.2019.03.070	Sustainable supplier selection based on SSCM practices: A rou	JOURNAL OF CLEANER PRODUCTION	2019
2.WoS	250		3	Green Econ.	not target	empirical ι	Balbaa, Alsnosy; Swief, R. A.; El-Amary, Noha H.	10.3390/su11082218	Smart Integration Based on Hybrid Particle Swarm Optimization	SUSTAINABILITY	2019
2.WoS	251	67	1	Allocation	hardware {	model dev	Pierson, Jean-Marc; Baudic, Gwilherm; Caux, Stephane;…	10.1109/ACCESS.2019.2930368	DATAZERO: DATAcenter With Zero Emission and Robust Mana	IEEE ACCESS	2019
2.WoS	252	68	1	Architecture	software &	model dev	Khalid, Adia; Aslam, Sheraz; Aurangzeb, Khursheed;…	10.3390/en11123500	An Efficient Energy Management Approach Using Fog-as-a-Serv	ENERGIES	2018
2.WoS	253		3	Green Econ.	not target	model dev	Singh, Akshit; Kumari, Sushma; Malekpoor, Hanif;…	10.1016/j.jclepro.2018.07.236	Big data cloud computing framework for low carbon supplier sele	JOURNAL OF CLEANER PRODUCTION	2018
2.WoS	254		3	Green Econ.	not target	survey & t	Tabatabai, Behnam; Chen, Huan; Lu, Jie;…	10.1007/s12155-018-9919-y	Fremyella diplosiphon as a Biodiesel Agent: Identification of Fatt	BIOENERGY RESEARCH	2018
2.WoS	255	69	1	Architecture	hardware {	model dev	Guan, Xuan; Zhang, Hualing; Xue, Chunyang	10.1016/j.jclepro.2018.04.099	A method of selecting cold and heat sources for enterprises in a	JOURNAL OF CLEANER PRODUCTION	2018
2.WoS	256		3	Green Econ.	not target	model dev	Liao, Jing; Hu, Yueming; Zhang, Hongliang;…	10.3390/su10072570	A Rice Mapping Method Based on Time-Series Landsat Data for	SUSTAINABILITY	2018
2.WoS	257	70	1	Green Econ.	hardware {	model dev	Lykou, Georgia; Mentzelioti, Despina; Gritzalis, Dimitris	10.1016/j.cose.2017.12.008	A new methodology toward effectively assessing data center sus	COMPUTERS & SECURITY	2018
2.WoS	258		3	Green Econ.	not target	model dev	Nekouei, Shahram; Nekouei, Farzin; Zadeh, Mohammad Ali Ferd	10.1016/j.cherd.2018.04.008	Fast and green separation of malachite green in water samples I	CHEMICAL ENGINEERING RESEARCH &	2018
2.WoS	259		3	Green Econ.	not target	model dev	Anasis, John G.; Khalil, Mohammad Aslam Khan; Butenhoff, Chri	10.1016/j.apenergy.2018.02.145	A Combined Energy and Geoengineering Optimization Model (C	APPLIED ENERGY	2018
2.WoS	260	71	1	Economy	hardware {	survey & t	Yang, Fan; Chien, Andrew A.	10.1109/TPDS.2017.2782677	Large-Scale and Extreme-Scale Computing with Stranded Greer	IEEE TRANSACTIONS ON PARALLEL ANI	2018
2.WoS	261		3	Application	not target	review	Zhang, Jiandong; Qu, Xiaoyu; Sangaiah, Arun Kumar	10.1109/MCOM.2018.1700789	A Study of Green Development Mode and Total Factor Productiv	IEEE COMMUNICATIONS MAGAZINE	2018
2.WoS	262	72	1	Economy	CSC	simulation	Dupont, Corentin; Vecchio, Massimo; Congduc Pham;…	10.1155/2018/1028578	An Open IoT Platform to Promote Eco-Sustainable Innovation in	WIRELESS COMMUNICATIONS & MOBILE	2018
2.WoS	263		3	Economy	not target	simulation	Goodbody, Tristan R. H.; Coops, Nicholas C.; Hermosilla, Txomir	10.1080/01431161.2017.1402387	Assessing the status of forest regeneration using digital aerial pl	INTERNATIONAL JOURNAL OF REMOTE S	2018
2.WoS	264	73	1	Green Econ.	hardware {	survey & t	Gu, Chonglin; Fan, Longxiang; Wu, Wenbin;…	10.1016/j.future.2016.12.029	Greening cloud data centers in an economical way by energy tra	FUTURE GENERATION COMPUTER SYST	2018
2.WoS	265	74	1	Green Econ.	CSP	review	Radu, Laura-Diana	10.3390/sym9120295	Green Cloud Computing: A Literature Survey	SYMMETRY-BASEL	2017
2.WoS	266	75	1	Application	software &	model dev	Kumar, Neetesh; Vidyarthi, Deo Prakash	10.1016/j.future.2017.01.015	An Energy Aware Cost Effective Scheduling Framework for Hete	FUTURE GENERATION COMPUTER SYST	2017
2.WoS	267	76	1	Architecture	hardware {	model dev	Wang, Ke-Qin; Liu, Hu-Chen; Liu, Liping;…	10.3390/su9050688	Green Supplier Evaluation and Selection Using Cloud Model The	SUSTAINABILITY	2017
2.WoS	268		3	Green Econ.	not target	model dev	Price, B.; Gomez, A.; Mathys, L.;…	10.1007/s10661-017-5816-7	Tree biomass in the Swiss landscape: nationwide modelling for i	ENVIRONMENTAL MONITORING AND AS	2017

DataBase	No	relevant	Excl.	Dim.	Group	Method	Author Full Names	DOI	Article Title	Source Title	Year
2.WoS	269	77	1	Architecture	hardware &	model dev	Tomas Cotes-Ruiz, Ivan; Prado, Rocio P.; Garcia-Galan, Sebasti	10.1371/journal.pone.0169803	Dynamic Voltage Frequency Scaling Simulator for Real Workflo	PLOS ONE	2017
2.WoS	270		3	Architecture	not target	survey & t	Azene Temesgene, Dagnachew; Nunez-Martinez, Jose; Dini, Pac	10.1109/ACCESS.2017.2771938	Softwarization and Optimization for Sustainable Future Mobile N	IEEE ACCESS	2017
2.WoS	271		2	Architecture	hardware &	empirical	Kim, Kibaek; Yang, Fan; Zavala, Victor M.;…	10.1109/TSTE.2016.2593607	Data Centers as Dispatchable Loads to Harness Stranded Powe	IEEE TRANSACTIONS ON SUSTAINABLE	2017
2.WoS	272		2	Application	software &	model dev	Siddiqui, Isma Farah; Lee, Scott Uk-Jin; Abbas, Asad;…	10.1109/ACCESS.2017.2752242	Optimizing Lifespan and Energy Consumption by Smart Meters	IEEE ACCESS	2017
2.WoS	273	78	1	Economy	CSP	model dev	Schniederjans, Dara G.; Hales, Douglas N.	10.1016/j.dss.2016.03.009	Cloud computing and its impact on economic and environmental	DECISION SUPPORT SYSTEMS	2016
2.WoS	274		3	Green Econ.	not target	simulation	Kumar, Mukesh; Sharma, Mahendra Pal	10.1016/j.rser.2015.12.032	Selection of potential oils for biodiesel production	RENEWABLE & SUSTAINABLE ENERGY	2016
2.WoS	275		3	Green Econ.	not target	empirical	Lessel, Jerrod; Ceccato, Pietro	10.1080/2150704X.2016.1252471	Creating a basic customizable framework for crop detection usin	INTERNATIONAL JOURNAL OF REMOTE	2016
2.WoS	276		2	Application	not target	simulation	Pan, Jianli; Jain, Raj; Paul, Subharthi;…	10.1109/JIOT.2015.2413397	An Internet of Things Framework for Smart Energy in Buildings:	IEEE INTERNET OF THINGS JOURNAL	2015
2.WoS	277		3	Green Econ.	not target	simulation	Aaheim, Asbjorn; Romstad, Bard; Wei, Taoyuan;…	10.1016/j.scitotenv.2015.05.106	An economic evaluation of solar radiation management	SCIENCE OF THE TOTAL ENVIRONMENT	2015
2.WoS	278	79	1	Application	software &	review	Uddin, Mueen; Darabidarabkhani, Yasaman; Shah, Asadullah;…	10.1016/j.rser.2015.07.061	Evaluating power efficient algorithms for efficiency and carbon er	RENEWABLE & SUSTAINABLE ENERGY	2015
2.WoS	279		3	Green Econ.	not target	survey & t	Letu, Husi; Hara, Masanao; Tana, Gegen;…	10.1021/acs.est.5b02471	Generating the Nighttime Light of the Human Settlements by Ide	ENVIRONMENTAL SCIENCE & TECHNOL	2015
2.WoS	280		3	Green Econ.	not target	survey & t	Tomasi, Claudio; Petkov, Boyan H.; Mazzola, Mauro;…	10.3390/rs70607157	Seasonal Variations of the Relative Optical Air Mass Function fo	REMOTE SENSING	2015
2.WoS	281		3	Green Econ.	not target	review	Pode, Ramchandra	10.1016/j.rser.2015.01.003	Battery charging stations for home lighting in Mekong region cou	RENEWABLE & SUSTAINABLE ENERGY	2015
2.WoS	282		2	Economy	hardware &	simulation	Whitehead, Beth; Andrews, Deborah; Shah, Amip	10.1007/s11367-014-0838-7	The life cycle assessment of a UK data centre	INTERNATIONAL JOURNAL OF LIFE CYCL	2015
2.WoS	283	80	1	Green Econ.	CSP	survey & t	Agusti-Torra, Anna; Raspall, Frederic; Remondo, David;…	10.1016/j.adhoc.2014.11.004	On the feasibility of collaborative green data center ecosystems	AD HOC NETWORKS	2015
2.WoS	284		2	Allocation	software &	model dev	Liao, Bin; Yu, Jiong; Zhang, Tao;…	10.1016/j.jnca.2014.10.008	Energy-efficient algorithms for distributed storage system based	JOURNAL OF NETWORK AND COMPUTE	2015
2.WoS	285		3	Architecture	not target	simulation	Chuah, Seong-Ping; Yuen, Chau; Cheung, Ngai-Man	10.1109/MWC.2014.6882299	CLOUD GAMING: A GREEN SOLUTION TO MASSIVE MULTIP	IEEE WIRELESS COMMUNICATIONS	2014
2.WoS	286		3	Green Econ.	not target	survey & t	Dandois, Jonathan P.; Ellis, Erle C.	10.1016/j.rse.2013.04.005	High spatial resolution three-dimensional mapping of vegetation	REMOTE SENSING OF ENVIRONMENT	2013
2.WoS	287		3	Green Econ.	not target	review	Liu, Guangrui; Yan, Beibei; Chen, Guanyi	10.1016/j.rser.2013.03.025	Technical review on jet fuel production	RENEWABLE & SUSTAINABLE ENERGY	2013
2.WoS	288		3	Architecture	not target	survey & t	Chen, Min; Leung, Victor C. M.	10.1093/comjnl/bxt051	Green Mobile Networking and Communications	COMPUTER JOURNAL	2013
2.WoS	289	81	1	Economy	CSC	simulation	de Alfonso, Carlos; Caballer, Miguel; Alvarruiz, Fernando;…	10.1016/j.future.2012.08.014	An economic and energy-aware analysis of the viability of outsou	FUTURE GENERATION COMPUTER SYST	2013
2.WoS	290		3	Green Econ.	not target	simulation	Unger, Nadine	10.1146/environ-082310-100824	Global Climate Forcing by Criteria Air Pollutants	ANNUAL REVIEW OF ENVIRONMENT AN	2012
2.WoS	291		2	Architecture	not target	model dev	Isom, P. K.; Miller-Sylvia, S. L.; Vaidya, S.	10.1147/JRD.2010.2051750	Intelligent Enterprise Architecture	IBM JOURNAL OF RESEARCH AND DEVE	2010
2.WoS	292		3	Green Econ.	not target	simulation	Unger, Nadine; Bond, Tami C.; Wang, James S.;…	10.1073/pnas.0906548107	Attribution of climate forcing to economic sectors	PROCEEDINGS OF THE NATIONAL ACAD	2010
2.WoS	293		3	Green Econ.	not target	model dev	Nandi, Sanjoy Kumar; Ghosh, Himangshu Ranjan	10.1016/j.enpol.2009.04.039	A wind-PV-battery hybrid power system at Sitakunda in Banglac	ENERGY POLICY	2009
2.WoS	294		3	Green Econ.	not target	model dev	Pandey, N		Equity in climate change treaty	CURRENT SCIENCE	2004
2.WoS	295		3	Green Econ.	not target	survey & t	HULME, M; JONES, PD	10.1016/0269-7491(94)90019-1	GLOBAL CLIMATE-CHANGE IN THE INSTRUMENTAL PERIOD	ENVIRONMENTAL POLLUTION	1994
BSC	296	82	1	Green Econ.	CSP	survey & t	Patchell, Jerry; Hayter, Roger	10.1016/j.jclepro.2020.125501	The Cloud's fearsome five renewable energy strategies: Coupling	Journal of Cleaner Production	2021
BSC	297		3	VM	software &	model dev	Liu, Yang; Zhang, Yingfeng; Ren, Shan;…		product lifecycle management?	Journal of Cleaner Production	2020
BSC	298	83	1	Allocation	CSP	model dev	Zhou, Zhi; Liu, Fangming; Chen, Shutong;…	10.1109/TPDS.2018.2882174	A Truthful and Efficient Incentive Mechanism for Demand Respo	IEEE Transactions on Parallel & Distributed	2020
BSC	299		3	Green Econ.	hardware &	survey & t	Sotelo Monge, Marco Antonio; Maestre Vidal, Jorge; …		Detection of economic denial of sustainability (EDoS) threats in	Computer Communications	2019
BSC	300		2	Architecture	hardware &	review	García-Berná, José A.; Fernández-Alemán, José L.; …		Green IT and sustainable technology development: Bibliometric	Sustainable Development	2019
BSC	301	84	1	Allocation	software &	model dev	Yuan, Haitao; Bi, Jing; Zhou, MengChu		Spatial Task Scheduling for Cost Minimization in Distributed Gre	IEEE Transactions on Automation Science	2019
BSC	302	85	1	Green Econ.	CSC	review	Attaran, Mohsen; Woods, Jeremy		Cloud Computing Technology: A Viable Option for Small and Me	Journal of Strategic Innovation & Sustainabi	2018
BSC	303	86	1	Green Econ.	hardware &	survey & t	Lykou, Georgia; Mentzelioti, Despina; Gritzalis, Dimitris	10.1016/j.cose.2017.12.008	A new methodology toward effectively assessing data center sus	Computers & Security	2018
BSC	304		2	Application	hardware &	survey & t	Tipley, Roger		BOOST YOUR PRODUCTIVITY.	Data Centre Management	2018
BSC	305		2	Green Econ.	hardware &	survey & t	Wellbrock, Richard		BUILDING A GREENER FUTURE.	Data Centre Management	2018
BSC	306	87	1	Green Econ.	hardware &	simulation	Gu, Chonglin; Fan, Longxiang; Wu, Wenbin;…	10.1016/j.future.2016.12.029	Greening cloud data centers in an economical way by energy tra	Future Generation Computer Systems	2018
BSC	307	88	1	Architecture	hardware &	model dev	Liu, Qiang; Ma, Yujun; Alhussein, Musaed;…	10.1016/j.comnet.2015.11.024	Green data center with IoT sensing and cloud-assisted smart ter	Computer Networks	2016
BSC	308		2	Architecture	hardware &	survey & t	Giacobbe, Maurizio; Celesti, Antonio; Fazio, Maria;…		Towards energy management in Cloud federation: A survey in th	Computer Networks	2015
BSC	309	89	1	Green Econ.	CSC	survey & t	Karunakaran, Sowmya; Krishnaswamy, Venkataraghavan; Sundarraj, R.P.		Business view of cloud: decisions, models and opportunities – a	Management Research Review	2015
BSC	310	90	1	Green Econ.	CSC	model dev	Nanath, Krishnadas; Pillai, Radhakrishna		A Model for Cost-Benefit Analysis of Cloud Computing.	Journal of International Technology & Inform	2013
BSC	311	91	1	Architecture	hardware &	survey & t	Xiong, N.; Han, W.; Vandenberg, A.	10.1049/iet-com.2011.0293	Green cloud computing schemes based on networks: a survey.	IET Communications (Institution of Engineer	2012
BSC	312		2	Allocation	CSP	review	FERRÉ, JAMES		Into the green cloud.	Periodical	2011
IEEE	313		2	Architecture	software &	model dev	ShenYao Sun; XianJi Wang; Fang Zuo	10.1109/iThings50389.2020.00126	RPCC: A Replica Placement Method to Alleviate the Replica Co	2020 International Conferences on Internet c	2020
IEEE	314		2	Allocation	hardware &	model dev	Mohammad Shojafar; Claudia Canali; Riccardo Lancellotti;…	10.1109/TCC.2016.2617367	Adaptive Computing-Plus-Communication Optimization Framew	IEEE Transactions on Cloud Computing	2020
IEEE	315		2	Allocation	CSP	model dev	Zhi Zhou; Fangming Liu; Shutong Chen;…	10.1109/TPDS.2018.2882174	A Truthful and Efficient Incentive Mechanism for Demand Respo	IEEE Transactions on Parallel & Distributed	2020
IEEE	316		3	Green Econ.	not target	survey & t	Wei Song; Jinkun Han; Junwei Xie;…	Conference Publication	System for Detecting and Forecasting PM2.5 Concentration Lev	2019 International Conference on Internet of	2019
IEEE	317		2	VM	software &	model dev	Fabio Lopez-Pires; Benjamin Barn; Carolina Pereira;…	10.1109/FAS-W.2019.00028	Evaluation of Two-Phase Virtual Machine Placement Algorithms	2019 IEEE 4th International Workshops on	2019
IEEE	318		3	Green Econ.	not target	simulation	Ying Hu; Richard O. Sinnott	10.1109/CCGRID.2019.00083	Big Data Analytics Exploration of Green Space and Mental Heal	2019 19th IEEE/ACM International Sympos	2019
IEEE	319		3	Architecture	not target	model dev	Kai Lin; Wenjian Wang; Yin Zhang;…	10.1109/TSUSC.2017.2678159	Green Spectrum Assignment in Secure Cloud Radio Network wi	IEEE Transactions on Sustainable Computi	2019
IEEE	320		2	VM	software &	simulation	Benjamin Camus; Fanny Dufoss; Anne Blavette;…	10.1109/CAHPC.2018.8645901	Network-Aware Energy-Efficient Virtual Machine Management in	2018 30th International Symposium on Com	2018
IEEE	321		3	Architecture	not target	model dev	Xiaorong Gong; Chao Yin; Xiaobin Li	10.1109/Cybermatics_2018.2018.00152	Dynamic Construction and Evolution Analysis of Manufacturing	2018 IEEE International Conference on Inter	2018
IEEE	322		2	Green Econ.	CSP	survey & t	Fan Yang; Andrew A. Chien	10.1109/TPDS.2017.2782677	Large-Scale and Extreme-Scale Computing with Stranded Greer	IEEE Transactions on Parallel & Distributed	2018
IEEE	323	92	1	Application	CSP	model dev	Benedikt Pittl Werner Mach; Erich Schikuta	10.1109/FiCloud.2017.45	GreenCloudTax: A Flexible IaaS Tax Approach as Stimulus for C	2017 IEEE 5th International Conference on I	2017
IEEE	324		3	Application	not target	survey & t	M. H. Riaz; U. Rashid; M. Ali, L. Li	10.1109/iThings.2017.180	Internet of Things Based Wireless Patient Body Area Monitoring	2017 IEEE International Conference on Inter	2017
IEEE	325		3	Architecture	not target	model dev	Xu Wenxia; Li Guodong; Tu Jun	10.1109/ICSCSE.2016.0103	Hail Prevention Model Design on "Silk Road"	2016 International Conference on Smart City	2016
IEEE	326	93	1	Allocation	software &	model dev	Santiago Iturriaga; Sergio Nesmachnow; Andrei Tchernykh;…	10.1109/CCGrid.2016.34	Multiobjective Workflow Scheduling in a Federation of Heterogen	2016 16th IEEE/ACM International Sympos	2016
IEEE	327		2	Allocation	software &	simulation	Fan Yang; Andrew A. Chien	10.1109/IPDPS.2016.96	ZCCloud: Exploring Wasted Green Power for High-Performance	2016 IEEE International Parallel and Distribu	2016
IEEE	328		2	Allocation	hardware &	survey & t	Enrique Castro-Leon	10.1109/MITP.2016.5	IT-Driven Power Grid Demand Response for Datacenters	IT Professional	2016
IEEE	329		3	Allocation	software &	model dev	Chao Li; Yang Hu; Longjun Liu;…	10.1145/2749469.2750381	Towards sustainable in-situ server systems in the big data era	2015 ACM/IEEE 42nd Annual International	2015
IEEE	330	94	1	VM	software &	model dev	Antonio Marotta; Stefano Avallone	10.1109/CLOUD.2015.66	A Simulated Annealing Based Approach for Power Efficient Virtu	2015 IEEE 8th International Conference on	2015
IEEE	331		2	Green Econ.	software &	survey & t	Patricia Lago	10.1109/PLEASE.2015.8	Challenges and Opportunities for Sustainable Software	2015 IEEE/ACM 5th International Workshop	2015
IEEE	332		2	Allocation	software &	model dev	Chao Li; Yang Hu; Ruijin Zhou;…		Enabling datacenter servers to scale out economically and susta	2013 46th Annual IEEE/ACM International S	2013
IEEE	333		3	Architecture	software &	simulation	Pekka Abrahamsson; Sven Helmer; Nattakarn Phaphoom;…	10.1109/CloudCom.2013.121	Affordable and Energy-Efficient Cloud Computing Clusters: The E	2013 IEEE 5th International Conference on	2013
IEEE	334		3	Green Econ.	not target	survey & t	Margeret Hall; Stefan Glanz; Simon Caton;…	10.1109/CGC.2013.51	Measuring Your Best You: A Gamification Framework for Well-B	2013 International Conference on Cloud and	2013
IEEE	335		2	Application	hardware &	model dev	Dario Bruneo; Audric Lhoas; Francesco Longo;…	10.1109/CGC.2013.21	Analytical Evaluation of Resource Allocation Policies in Green Ia	2013 International Conference on Cloud and	2013

DataBase	No	relevant	Excl.	Dim.	Group	Method	Author Full Names	DOI	Article Title	Source Title	Year
IEEE	336		3	Architecture	not target	model dev	Tobias Widmer; Marc Premm; Paul Karaenke	10.1109/CBI.2013.31	Sourcing Strategies for Energy-Efficient Virtual Organisations in	2013 IEEE 15th Conference on Business Int	2013
IEEE	337		2	Allocation	software &	model dev	Tram Truong Huu; Chen-Khong Tham	10.1109/IC2E.2013.21	An Auction-Based Resource Allocation Model for Green Cloud C	2013 IEEE International Conference on Clou	2013
IEEE	338		3	Application	CSP	model dev	Xuyun Zhang; Chang Liu; Surya Nepal;…	10.1109/CGC.2012.43	Privacy-Preserving Layer over MapReduce on Cloud	2012 International Conference on Cloud and	2012
IEEE	339		3	Application	not target	review	Simon Caton; Christoph Dukat; Tilo Grenz;…	10.1109/CGC.2012.89	Foundations of Trust: Contextualising Trust in Social Clouds	2012 International Conference on Cloud and	2012
IEEE	340	95	1	Application	CSC	survey & t	Keith G. Jeffery	10.1109/QUATIC.2012.47	Quality Aspects in CLOUD Computing	2012 Eighth International Conference on the	2012
IEEE	341	96	1	Green Econ.	CSC	model dev	Qing Gu; Patricia Lago; Simone Potenza	10.1109/GREENS.2012.6224258	Aligning economic impact with environmental benefits: A green s	2012 First International Workshop on Green	2012
IEEE	342	97	1	Application	CSP	model dev	Markus Hedwig; Dirk Neumann; Simon Malkowski	10.1109/HICSS.2012.509	Risk-Aware Service Level Agreement Design for Enterprise Inforr	2012 45th Hawaii International Conference c	2012
IEEE	343	98	1	Application	CSP	model dev	Karim Djemame; Mariam Kiran; Django J. Armstrong;…	10.1109/DASC.2011.89	Towards a Service Lifecycle Based Methodology for Risk Asses	Dependable, Autonomic and Secure Compu	2011
IEEE	344		2	VM	software &	model dev	Ricard GavaldÃ ; Jordi Torres; Josep Ll. Berral	10.1109/Grid.2011.18	Adaptive Scheduling on Power-Aware Managed Data-Centers Us	Grid Computing, IEEE/ACM International W	2011
IEEE	345		3	Green Econ.	not target	survey & t	Tom Costello	10.1109/MITP.2011.1	2011 IT Tech and Strategy Trends	IT Professional	2011
IEEE	346		3	Green Econ.	not target	simulation	Roberts Masillamani; Padmaveni	10.1109/GreenCom-CPSCom.2010.142	Resource Sharing Cloud for University Clusters	IEEE-ACM International Conference on Gree	2010
IEEE	347	99	1	Architecture	CSP	model dev	Ryan Jansen; Michal Witkowski; David B. Go;…	10.1109/CloudCom.2010.111	Enabling Sustainable Clouds via Environmentally Opportunistic (	2010 IEEE Second International Conference	2010
IEEE	348	100	1	Architecture	hardware &	survey & t	Ryan Jansen; Doug Thain; David Go;…	10.1109/GREENCOMP.2010.5598289	Environmentally Opportunistic Computing transforming the data	International Conference on Green Computir	2010
IEEE	349	101	1	Allocation	hardware &	survey & t	C.-C. Jay Kuo Ishfaq Ahmad; Hang Yuan	10.1109/GREENCOMP.2010.5598292	Energy efficiency in data centers and cloud-based multimedia se	International Conference on Green Computir	2010
IEEE	350		3	Green Econ.	not target	survey & t	K. Abdullah; M.Z. MatJafri; H.S. Lim;…	10.1109/CGIV.2009.38	Land Use/Cover Classification by Using Digital Camera Imagery	2009 Sixth International Conference on Com	2009

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