

# Cloud Service Selection And Ranking: A Comparative Analysis Based On Energy Efficiency Parameters

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## Abstract

Amidst the expanding online usage and escalating demand for public cloud services, cloud service providers (CSPs) are grappling with the challenge of meeting diverse consumer demands while maintaining optimal computing capabilities. A key concern revolves around migrating applications and data across multiple cloud platforms, where variations in CSPs' pricing strategies and service offerings can significantly impact computing efficiency. For instance, while some CSPs may offer lower storage costs but higher computation expenses, others might adopt the opposite pricing structure. In addressing these complexities and enhancing the quality of service (QoS) for cloud clients, this study introduces a fuzzy cloud selection model. This model is designed to optimize the cloud service selection process by integrating criteria such as Power Consumption, Resource Utilization, Virtualization Efficiency, and Load Balancing within an energy-efficient framework.

**Keywords:** Virtualization, Cloud Computing, Fuzzy, Load balancing.

## 1. Introduction

Cloud computing has emerged as a transformative force, reshaping the landscape of technology across industries. Its profound impact extends to diverse application domains, empowering businesses to streamline operations and focus on core activities while relegating concerns about technological intricacies and infrastructure upkeep to the cloud. This paradigm shift not only enhances software functionality by optimizing storage, reducing maintenance efforts, and accommodating unpredictable demands but also offers users a suite of robust, versatile, reliable, and scalable services [1][2]. Within the realm of cloud computing, users are charged based on their utilization of cloud services, a model that has become increasingly relevant as online users surge in numbers. This surge has led to a proliferation of Cloud Service Providers (CSPs), intensifying competition within the market [3]. Amidst this competitive landscape, the challenge for CSPs is to deliver quality-driven cloud services that meet evolving customer needs in a dynamic environment. Conversely, users face the complex task of navigating this abundance of options to select the most suitable cloud service for their requirements [4]. The scope of cloud computing's offerings is vast, facilitating access to a multitude of applications such as social media platforms like Facebook and search engines like Google [5]. Moreover, the Platform-as-a-Service (PaaS) segment, exemplified by services like Microsoft Azure, empowers customers to develop a wide array of robust software applications. This versatility extends further, as cloud computing serves as the foundation for cloud users to structure personalized virtual machines, tailor-made to their specific hardware (CPU, memory, storage) and software configurations [6]. This flexibility and adaptability underscore the transformative potential of cloud computing in modern IT ecosystems, where efficiency, scalability, and innovation are paramount [7][8]. As cloud computing continues to evolve, addressing challenges in security, data privacy, and regulatory compliance will be crucial. Furthermore, advancements in edge computing, serverless architecture, and hybrid cloud solutions are poised to further enhance the capabilities and reach of cloud services, ushering in a new era of digital transformation and business agility.

Energy efficiency in cloud computing is a critical aspect that has gained significant attention in recent years. As the demand for cloud services continues to grow, so does the need to optimize energy consumption and reduce environmental impact. This article delves into the various aspects of energy efficiency in cloud computing, including its importance, challenges, solutions, and future trends.

## 1.1 Importance of Energy Efficiency in Cloud Computing

Cloud computing has become an integral part of modern business operations, offering scalability, flexibility, and cost-effectiveness. However, the energy consumption associated with cloud infrastructure and data centers has raised concerns about sustainability and environmental impact. Improving energy efficiency in cloud computing is crucial for several reasons:

1. **Cost Reduction:** Efficient use of energy leads to cost savings for cloud service providers and users. Lower energy consumption translates to reduced operational costs and can contribute to competitive pricing strategies.
2. **Environmental Sustainability:** Reducing energy consumption in data centers helps mitigate the environmental impact of cloud computing. It reduces carbon emissions, minimizes resource depletion, and promotes eco-friendly practices.
3. **Scalability and Performance:** Energy-efficient infrastructure enables cloud providers to scale their services efficiently while maintaining optimal performance. It ensures that resources are utilized effectively, leading to better service delivery for users.
4. **Regulatory Compliance:** Many regulatory bodies have established guidelines and standards for energy efficiency in data centers. Adhering to these regulations not only avoids penalties but also demonstrates a commitment to sustainability and corporate responsibility.

## 2. Literature Review

Goscinski and Brock (2010) employed Dynamic Programming within a Resource using Web oriented Services to optimize time and effort, focusing on enhancing the efficiency of resource allocation. Their research delved deep into the intricacies of dynamic programming algorithms, exploring how these techniques could be harnessed within the context of web services to achieve optimal resource utilization. By developing a framework that integrates dynamic programming principles with web service functionalities, they aimed to streamline the allocation of resources, ultimately leading to improved performance and reduced operational overheads[9].

Menzal et al. (2011) delved into the intricacies of the Analytic Hierarchy Process (AHP) within their MC2 framework, aiming to comprehensively evaluate Cost, Benefits, Opportunities, and Risks (CBOR) associated with cloud services. Their work involved a thorough analysis of decision-making criteria and the development of a multi-criteria decision model (MCDM) to facilitate informed decision-making. By leveraging the AHP methodology within the MC2 framework, they sought to provide stakeholders with a systematic approach to assess and prioritize various aspects related to cloud service adoption, thereby enabling more informed and strategic decision-making processes[10].

He et al. (2012) undertook a comprehensive study on the application of Greedy algorithms within the MSS Optimizer (Multi-tenant SaaS Optimizer) framework, with a specific focus on optimizing Cost, Response Time, Availability, and Throughput (CRAT) metrics. Their research involved the development and implementation of novel optimization techniques based on Greedy algorithms to address the complex challenges faced by multi-tenant SaaS environments. By integrating Greedy algorithms into the MSS Optimizer framework, they aimed to enhance resource utilization efficiency, improve system responsiveness, and ensure high availability and throughput for cloud-based services[11].

Klein et al. (2012) delved into the domain of Genetic Algorithms (GA) within a Network Alert Approach framework, with the primary objective of addressing scalability challenges in cloud environments. Their research focused on developing innovative approaches based on Genetic Algorithms to optimize network alert management

and resource allocation in large-scale cloud infrastructures. By leveraging the inherent capabilities of Genetic Algorithms, they aimed to enhance scalability, improve resource utilization, and ensure robust performance in dynamic and demanding cloud computing environments[12].

Lo et al. (2013) conducted an in-depth investigation into the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method within the context of cloud service selection. Their research aimed to develop a comprehensive framework for evaluating and ranking cloud services with on key criteria viz Scalability, Capability, Performance, Reliability, and Availability (SCPRA). By employing TOPSIS methodology within their framework, they sought to provide decision-makers with a structured approach to assess and compare alternative cloud services, thereby facilitating informed decision-making and optimizing cloud service selection processes[13].

Ghosh et al. (2014) embarked on a rigorous exploration of the SELCSP framework, designed to manage risk between cloud providers and consumers effectively. Their research focused on developing innovative strategies and frameworks to assess and mitigate risks associated with cloud service adoption. By integrating risk assessment methodologies within the SELCSP framework, they aimed to enhance trust, reliability, and transparency in cloud service engagements, ultimately fostering a more secure and trustworthy cloud computing environment[14].

Supriya et al. (2015) delved into the intricacies of Fuzzy Analytic Hierarchy Process (Fuzzy-AHP) within a Sugeno Fuzzy Inference System (FIS), aiming to evaluate and prioritize key aspects such as Agility, Assurance, Cost, and Performance (AACP) in cloud service selection. Their research involved the development and implementation of fuzzy logic-based decision-making models to handle uncertainties and complexities inherent in cloud service evaluation. By leveraging Fuzzy-AHP methodology within the Sugeno FIS framework, they aimed to provide decision-makers with a robust and flexible approach to assess and compare alternative cloud services, taking into account multiple criteria and uncertainties effectively[15].

Pan et al. (2016) conducted a comprehensive study on trust modeling methods within a Trust Approach framework, focusing on evaluating and enhancing Capacity, Cost, and Security (CCS) aspects in cloud service selection. Their research involved the development of innovative trust modeling techniques and frameworks to assess and prioritize key aspects related to cloud service trustworthiness. By integrating trust modeling methodologies within the Trust Approach framework, they aimed to provide decision-makers with a systematic and reliable approach to evaluate and compare cloud services based on trust-related criteria, thereby facilitating more informed and trustworthy cloud service selection processes[16].

Supriya et al. (2020) extended their research into Genetic Algorithms (GA) within a Trust Estimation Method framework, aiming to evaluate and enhance Security, Dependability, Availability, and Ability (SDAA) aspects in cloud service selection. Their research focused on developing novel trust estimation techniques and methodologies based on Genetic Algorithms to assess and prioritize key aspects related to cloud service trustworthiness. By integrating Genetic Algorithms within the Trust Estimation Method framework, they aimed to provide decision-makers with a robust and adaptable approach to evaluate and compare cloud services based on trust-related criteria effectively[17].

Eisa et al. (2020) undertook a comprehensive study on hybrid approaches for QoS-aware cloud service selection, focusing on evaluating and optimizing key QoS attributes such as Security, Usability, and Performance (SUP) in cloud service selection. Their research involved the development and implementation of innovative hybrid approaches and decision-making models to assess and prioritize cloud services based on QoS-related criteria. By integrating hybrid approaches within their QoS-aware selection model, they aimed to provide decision-makers with a flexible and comprehensive approach to evaluate and compare cloud services based on key QoS attributes effectively[18].

Faiz et al. (2020) delved into the domain of Fuzzy Techniques within a Trust-based Model framework, aiming to evaluate and optimize key aspects such as Capacity, Cost, and Performance (CCP) in cloud service selection. Their research focused on developing fuzzy logic-based decision-making models and methodologies to handle uncertainties and complexities inherent in cloud service evaluation. By integrating Fuzzy Techniques within the

Trust-based Model framework, they aimed to provide decision-makers with a robust and adaptable approach to assess and compare cloud services based on multiple criteria effectively[19].

Tiwari et al. (2021) extended their research into the RE-TOPSIS method within a Modified-TOPSIS framework, aiming to evaluate and optimize key aspects such as Cost, Performance, and Scalability (CPS) in cloud service selection. Their research focused on developing modified TOPSIS-based decision-making models and methodologies to handle complexities and uncertainties in cloud service evaluation effectively. By integrating the RE-TOPSIS method within the Modified-TOPSIS framework, they aimed to provide decision-makers with a structured and comprehensive approach to assess and compare cloud services based on key criteria effectively[20].

### 3. Proposed Work

In this section, we delve into the intricacies of a Multi-criteria based selection approach and the functioning of the proposed methodology designed to address cloud customers' ambiguous needs for cloud regarding Quality of Service (QoS) requirements. Fuzzy logic, as employed in this context, is a multi-valued logic system rooted in fuzzy technique. Its purpose is to select the most suitable cloud service for users based on their requirements across various selection parameters [21][22].

Let's consider an input point 'k' within the space of discourse 'X', is a member of a fuzzy logic set 'F'. The degree of membership is denoted by the fuzzy membership function  $\mu_F(k)$ , where the membership degree ranges between 0 and 1, as expressed in equation (1):

$$0 \leq \mu_F(k) \leq 1 \quad (1)$$

The methodology for ranking clouds encompasses four major phases:

1. Setting up criteria and identifying cloud offerings that align with these criteria.
2. Creating a Fuzzy input set by transforming crisp input values using the proposed approach.
3. Defining the output membership function, which determines the degree of suitability of cloud services based on the fuzzy input set.
4. Designing an appropriate reasoning algorithm(Fuzzy IF-ELSE-THEN) to compute the final Cloud ranking via the proposed fuzzy logic. This algorithm integrates the input-output mappings established through the fuzzy logic methodology to generate a ranked list of cloud services that best meet the users' requirements [23][24].

### 4. Parameters considered

1. **Power Consumption:** This parameter measures the amount of electrical power consumed by the cloud infrastructure to deliver services to users. Lower power consumption indicates higher energy efficiency, as it reduces the overall environmental impact and operational costs associated with running the cloud services [25][26].

**Power Consumption (P):**  $P=VI$

Where:

- P is the power consumption in watts (W).
- V is the voltage in volts (V).
- I is the current in amperes (A).

2. **Resource Utilization:** Efficient utilization of computing resources such as CPU, memory, and storage directly impacts energy consumption. Maximizing resource utilization ensures that hardware components are utilized optimally, reducing idle time and unnecessary energy consumption.

$$RUE = (\text{Maximum Resource Capacity} / \text{Actual Resource Utilization}) \times 100\%$$

Where:

- *Actual Resource Utilization* ActualResourceUtilization is the actual usage of computing resources.
- *Maximum Resource Capacity* MaximumResourceCapacity is the maximum capacity of the resources.

3. **Virtualization Efficiency:** Virtualization plays a significant role in cloud computing by enabling the creation of virtual machines (VMs) and containers. Efficiency in virtualization refers to how effectively VMs and containers are utilized to consolidate workloads on physical servers. Efficient virtualization minimizes resource wastage and contributes to overall energy savings [27][28].

$$\text{Virtualization Efficiency (VE)} = (\text{Number of Virtual Machines} / \text{Number of Physical Servers}) \times 100$$

- *Number of Virtual Machines* NumberofVirtualMachines is the total number of virtual machines.
  - *Number of Physical Servers* NumberofPhysicalServers is the total number of physical servers.
4. **Dynamic Scaling and Load Balancing:** Dynamic scaling allows cloud resources to scale up or down based on workload demands. Load balancing ensures that workloads are distributed evenly across servers, preventing overloading and underutilization of resources. Efficient dynamic scaling and load balancing algorithms contribute to energy efficiency by optimizing resource allocation based on real-time demand fluctuations.

$$DSLBE = T(\text{otal Active Instances} / \text{Total Instances} / \text{Capacity}) \times 100$$

Where:

- *Total Active Instances* TotalActiveInstances is the total number of active instances (virtual machines or containers).
- *Total Instances Capacity* TotalInstancesCapacity is the total capacity of instances available for scaling.

## 5. Simulation Results

The simulation process is facilitated through the Matlab fuzzy tool, leveraging Cloud ranking parameters sourced from the specified instances in Table-1 as the basis for reference data. To evaluate and rank different Clouds (C1, C2, ... C5) for various users (U1, U2, U3, and U4), randomized data inputs are employed. Table 1 shows the generated crisp data for the selected parameters with fuzzy values. The simulation framework adopts the 'Mamdani' Fuzzy Inference System (FIS) as the flow control mechanism, chosen for its enhanced representation capabilities in simulation compared to the 'Sugeno'. The input membership configurations utilized in this simulation are visually illustrated in Figure 1 and Figure 2, aiding in the comprehensive analysis of cloud ranking dynamics.

**Table 1.** Fuzzy dataset used for Cloud ranking using selected parameters

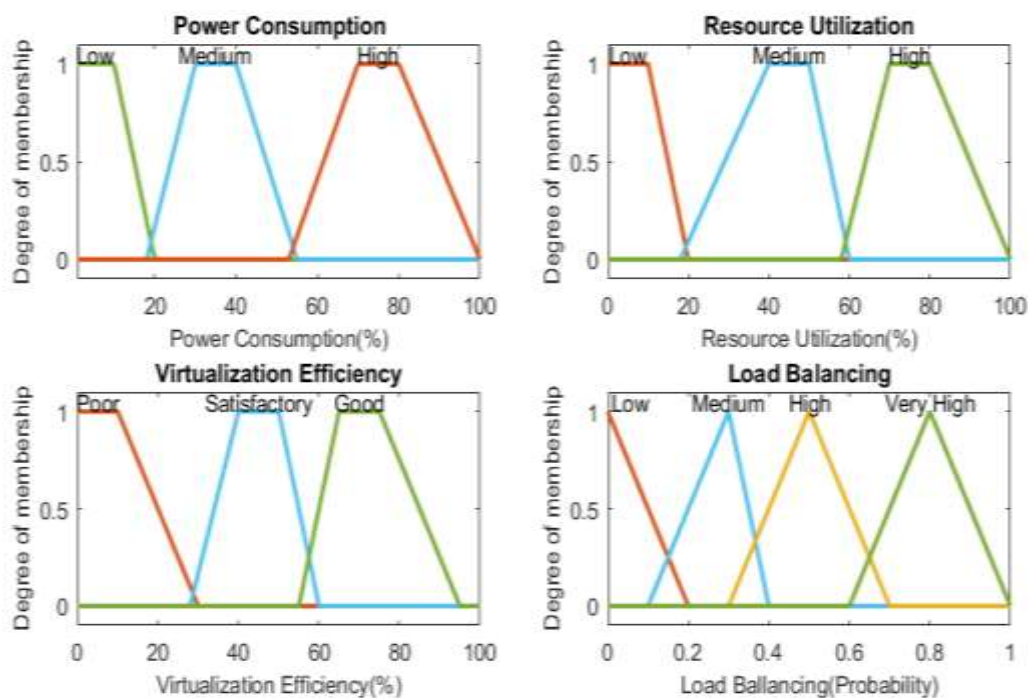
No.	Parameter	Fuzzy Term	Crisp(Input Values)
1	Power Consumption	Low	[0 0 10 20]
2		Medium	[18 30 40 55]
3		High	[53 70 80 100]

4	Resource Utilization	Low	[0 0 10 20]
5		Medium	[18 40 50 60]
6		High	[58 70 80 100]
8	Virtualization Efficiency	Low	[0 0 10 30];
9		Medium	[28 40 50 60]
10		High	[55 65 75 95]
12	Load Balancing	Low	[0 0 0.2]
13		Medium	[0.1 0.3 0.4]
14		High	[0.3 0.5 0.7]
15		VeryHigh	[0.6 0.8 1.0]

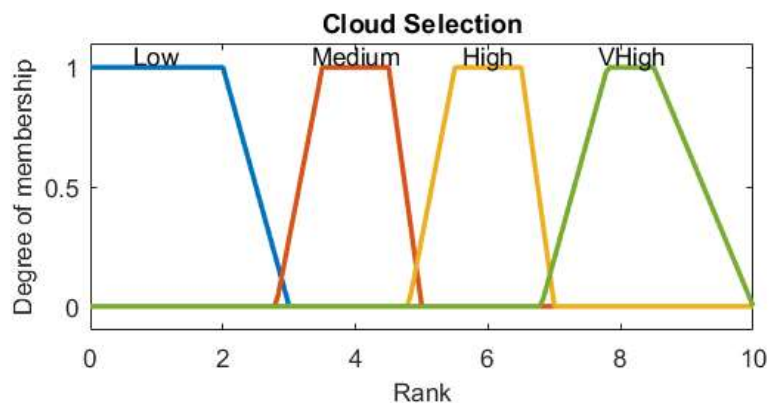
### Fuzzy Inference Rules example:

1. IF Power Consumption is Low and Resource Utilization is Low and Virtualization Efficiency is High and Load Balancing is High then the Rank is 'VHigh'.

Similarly 81 fuzzy rules were created and used in the FIS of the proposed work.



**Figure 1:** Fuzzy membership for different input parameters



**Figure 2:** Fuzzy membership for output parameter

These crisp input values are derived from the specified range values for each parameter. The corresponding ranks are determined based on these crisp input values and the fuzzy rules previously defined. Table 2 shows different user rankings.

**Table 2:** Ranking of different users using proposed methodology

User	Power Consumption	Resource Utilization	Virtualization Efficiency	Load Balancing	Rank
User 1	10	10	55	0.2	VeryHigh
User 2	30	40	28	0.3	High
User 3	80	20	55	0.4	Medium
User 4	40	60	75	0.5	Medium

## 6. Future Trends in Energy Efficiency

The future of energy efficiency in cloud computing is driven by emerging technologies and innovative strategies. Some key trends to watch out for include:

1. **Edge Computing:** Edge computing brings data processing closer to the source of data generation, reducing the need for extensive data transfers to centralized cloud data centers. This proximity improves energy efficiency by minimizing network latency and optimizing resource utilization at the edge.
2. **AI-driven Optimization:** Artificial intelligence (AI) and machine learning (ML) algorithms play a crucial role in optimizing energy usage in cloud environments. AI-driven optimization techniques analyze historical data, predict workload patterns, and dynamically adjust resource allocation to maximize energy efficiency.
3. **Green Data Centers:** The concept of green data centers focuses on designing and operating data centers with minimal environmental impact. Green data centers leverage advanced cooling technologies, renewable energy integration, waste heat recovery, and efficient hardware designs to achieve sustainability goals.
4. **Containerization:** Containerization technologies, such as Docker and Kubernetes, offer lightweight, portable, and scalable deployment options for cloud applications. Containerized environments promote resource efficiency and enable efficient resource sharing, leading to energy savings.
5. **Hybrid and Multi-Cloud Strategies:** Hybrid and multi-cloud architectures allow organizations to distribute workloads across multiple cloud providers and on-premises infrastructure. Optimizing workload placement based on energy efficiency metrics and cost considerations is a key focus area for future energy-efficient cloud deployments.

## 6. Conclusion and Future Work

This study proposes a model for cloud service selection based on key parameters including Power Consumption, Resource Utilization, Virtualization Efficiency, and Load Balancing. The model computes the rank of cloud services using these parameters, providing insights into energy efficiency, resource optimization, and performance management in cloud environments. Future work aims to enhance the model's applicability by incorporating real cloud data instances, enabling more accurate and practical evaluations of cloud service offerings. This upgrade will further improve decision-making processes for selecting cloud services that align with specific requirements and sustainability goals.

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