

Original Article

Cloud Computing: Architecture, Intelligent Applications, Security, and Open-Source Case Studies

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Abstract - Cloud computing has become a fundamental computing paradigm for delivering scalable computing, storage, networking, and software services. Its flexibility and resource-sharing capabilities have enabled applications in Artificial Intelligence (AI), Machine Learning (ML), cybersecurity, intelligent transportation, energy systems, and distributed computing. This paper presents a concise review of cloud computing architecture, service requirements, intelligent applications, security requirements, and emerging cloud-edge technologies, grounded in twenty-six references spanning foundational cloud computing literature and applied AI/systems research. The paper relates cloud computing to research involving face recognition, electronic toll collection, peer-to-peer energy trading, human-bot detection, federated intrusion detection, intelligent automation, graph algorithms, honeypot-based cybersecurity, and pedestrian trajectory prediction. Two open-source cloud platforms, OpenStack and Apache CloudStack, are examined through real-world case studies. Reported results demonstrate that open-source cloud platforms can operate at substantial scale: OpenStack reports deployments involving more than 40 million cores globally, while its Walmart case study reports more than 170,000 cores across over 30 regions; Apache CloudStack's IKOULA case reports more than 100 hosts across eight zones and more than 6,600 customers. The paper concludes that future cloud systems will increasingly integrate cloud, edge computing, AI, and privacy-preserving distributed learning.

Keywords - Cloud Computing, OpenStack, Apache CloudStack, Artificial Intelligence, Machine Learning, Federated Learning, Cloud Security, Open-Source Cloud, Edge Computing.

1. Introduction

Cloud computing provides computing resources through network-accessible services rather than requiring organizations to maintain all infrastructure locally. The most widely used formal definition characterizes cloud computing as a model for enabling ubiquitous, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned with minimal management effort [1], a definition echoed by an influential early survey that framed cloud computing's core promise as the illusion of infinite computing resources available on demand [2].

Virtualization, resource pooling, automation, and elastic provisioning allow cloud platforms to dynamically allocate resources according to workload requirements. The growth of Artificial Intelligence (AI) and Machine Learning (ML) has

further increased the importance of cloud computing. Modern ML applications often require large datasets, scalable storage, and substantial computational resources. Ahmed et al. investigated different machine-learning approaches for face recognition [3]. Such applications can benefit from cloud infrastructure for model training, data storage, and scalable inference.

Cloud computing is also applicable to intelligent transportation. Mujeeb et al. proposed an electronic toll collector framework [4], demonstrating how automated transportation systems can be supported by centralized computing. Similarly, Ahmed et al. developed software for simulating peer-to-peer energy trading [5], illustrating the computational requirements of distributed energy applications.



Security and privacy remain significant challenges. Recent research has investigated privacy-preserving intrusion detection using federated learning [6], kernel code and data protection [7], and honeypot-based threat intelligence [8]. These studies are particularly relevant to cloud environments in which sensitive data and applications are hosted on shared infrastructure. A widely-cited survey of cloud computing's state of the art and research challenges situates security, resource management, and data management among the field's most persistent open problems [9].

This paper has four objectives: 1) to summarize cloud computing architecture and service models; 2) to examine its relationship with AI, cybersecurity, transportation, and distributed applications; 3) to evaluate open-source cloud platforms using real-world case studies; and 4) to identify future directions for secure and intelligent cloud computing.

2. Cloud Computing Architecture

Cloud computing can be viewed as a layered architecture consisting of physical infrastructure, virtualization, platform services, applications, and management/security functions.

2.1. Infrastructure and Virtualization

The infrastructure layer consists of physical servers, storage, networking equipment, and data-center facilities.

Infrastructure as a Service (IaaS) provides these resources as virtualized and programmable services. Virtualization allows multiple virtual machines to execute on shared physical hardware, an approach whose modern practical foundation is documented in the Xen hypervisor, which demonstrated that paravirtualization could deliver near-native performance while isolating multiple operating-system instances on shared hardware [10]. It improves resource utilization and enables workload migration, isolation, provisioning, and elastic scaling. Container orchestration has since become a further layer above raw virtualization: Google's experience operating Borg, Omega, and Kubernetes across a decade of production container-management systems documents the shift toward declarative, API-driven cluster management that underlies most modern cloud platforms [11].

2.2. Platform and Application Services

Platform as a Service (PaaS) provides development frameworks, databases, middleware, APIs, and runtime environments. Software as a Service (SaaS) provides complete applications through network interfaces. A further evolution, serverless computing, abstracts server management away entirely so developers deploy individual functions rather than provisioning virtual machines or containers directly, though this shift introduces its own open problems in cold-start latency, state management, and vendor portability [12].

Table 1. Cloud service models

Model	Main Resource	Typical Use
IaaS	Virtual machines, storage, networks	Infrastructure hosting
PaaS	Development platform and runtime	Application development
SaaS	Complete applications	End-user services

The main advantages of cloud computing include scalability, elasticity, resource sharing, rapid deployment, and reduced infrastructure-management requirements. However, these advantages must be balanced against security, privacy, latency, interoperability, and vendor-lock-in concerns.

3. Cloud Computing for Intelligent Applications

3.1. Machine Learning and Face Recognition

Face recognition is an important AI application. Ahmed et al. compared different machine-learning approaches for face recognition [3]. Cloud computing can provide scalable computing resources for training and deploying such models. However, biometric information is highly sensitive. Centralized cloud processing can increase privacy risks, making federated learning and other privacy-preserving approaches attractive alternatives.

3.2. Intelligent Transportation

The electronic toll collector framework proposed by Mujeeb et al. [4] represents an application that can be extended using cloud infrastructure. A cloud-based

transportation platform could manage vehicle records, transactions, monitoring, and analytics centrally. Pedestrian trajectory prediction is another relevant application. Ahmed et al. developed an interaction-aware 3D-dual contextualized model for pedestrian trajectory prediction [13]. Cloud infrastructure can support large-scale model training, while edge devices can perform low-latency inference close to cameras and sensors.

3.3. Energy Trading

Peer-to-peer energy trading requires transaction management, simulation, forecasting, and optimization. Ahmed et al. developed software for simulating peer-to-peer energy trading [5]. Cloud platforms can provide scalable storage and computational resources for simulations involving large numbers of participants.

3.4. Human-Bot Detection

Khalil, Ahmed, and Yang studied mouse-pointing endpoint prediction for distinguishing humans from bots using kinematic template matching [14]. A cloud-based

implementation could support large-scale behavioral analysis and ML inference. However, behavioral information should be protected using appropriate privacy and access-control mechanisms.

3.5. Intelligent Automation

Ahmed et al. investigated the synergy between low-code/no-code development and AI/ML for intelligent automation [15]. Cloud platforms can support such systems through hosted databases, APIs, AI services, workflow engines, and automated deployment.

4. Cloud Computing and Cybersecurity

Security is essential because cloud systems process data and applications belonging to multiple users. An early and widely-cited survey of security issues across cloud service-delivery models (IaaS, PaaS, SaaS) catalogued the confidentiality, integrity, and availability risks specific to multi-tenant shared infrastructure [16], and this risk landscape remains active: a 2024 industry survey of over 500 security professionals ranked misconfiguration and inadequate change control, followed by identity and access management weaknesses, as the two most significant current cloud security threats [17].

4.1. Infrastructure and Kernel Security

Ahmed et al. discussed the protection of kernel code and data [7]. This issue is important in cloud environments because vulnerabilities in operating systems or virtualization layers can potentially affect multiple workloads.

4.2. Federated Learning

Bounceur et al. investigated privacy-preserving multiclass intrusion detection in in-vehicle CAN networks using federated learning [6]. Federated learning allows multiple participants to train a shared model without directly transferring their raw datasets to a central server. A cloud coordinator can aggregate model updates while individual devices retain their local data - a coordination pattern a comprehensive survey of federated learning identifies as one of the field's central architectural approaches, alongside open problems in non-IID data and communication efficiency directly relevant to a cloud-hosted coordinator.

4.3. Honeypot-Based Security

Shahbaz et al. investigated honeypot deployment for threat detection and intelligence [8]. Cloud infrastructure can provide scalable environments for deploying distributed honeypots and centrally analyzing their security logs.

5. Cloud-Edge and Real-Time Computing

Although cloud computing provides substantial scalability, network latency can make fully centralized

processing unsuitable for real-time applications. Ahmed's work on real-time operating-system concepts [18] emphasizes the importance of predictable timing and execution. Cloud-edge architectures can address this limitation by distributing workloads, motivated by the same latency and bandwidth constraints a foundational edge-computing survey identifies as the reason for pushing computation toward the data source rather than a distant cloud [19].

Table 2. Cloud-edge workload division

Location	Typical Processing
Edge	Sensor data preprocessing
Edge	Real-time AI inference
Edge	Immediate control decisions
Cloud	Large-scale model training
Cloud	Long-term data storage
Cloud	Historical analytics
Cloud	Global optimization

For example, a pedestrian-monitoring system can process camera data locally while using cloud infrastructure for model training and historical analysis [13]. This architecture combines the scalability of cloud computing with the low latency of edge processing.

6. Open-Source Cloud Case Studies

Open-source cloud platforms provide organizations with alternatives to proprietary infrastructure. They can offer greater customization, transparency, and control while reducing dependence on a single vendor.

6.1. OpenStack Case Study

OpenStack is an open-source cloud infrastructure platform supporting compute, networking, storage, and related cloud services. Its official site reports that OpenStack is used to manage more than 40 million cores worldwide across multiple industries [20]. A notable deployment is Walmart's e-commerce infrastructure. OpenStack reports that Walmart uses an OpenStack cloud with more than 170,000 cores across more than 30 regions, including support for peak shopping periods [20].

6.2. Apache CloudStack Case Study

Apache CloudStack is an open-source Infrastructure as a Service (IaaS) cloud management platform designed for managing large networks of virtual machines [21]. A real-world example is IKOULA, a European cloud and hosting provider. Its CloudStack environment includes more than 100 hosts across eight zones and more than 6,600 customers. The case also reports support for thousands of virtual machines and Kubernetes clusters and live updates without service interruption for end users [21].

The graphical summaries in Figs. 1 and 2 complement the tabulated case-study results.

6.3. Case Study Results

The values in Table 3 are reported case-study figures, rather than experiments performed in this paper. These cases demonstrate that open-source cloud platforms can support

substantial infrastructure while providing flexibility and reducing dependence on proprietary cloud-management technologies.

Table 3. Open-source cloud case-study results

Platform / Organization	Deployment Scale	Reported Result
OpenStack	Global	40M+ cores managed worldwide
OpenStack / Walmart	30+ regions	170,000+ cores
OpenStack / China Mobile	Telecom infrastructure	50,000+ servers
CloudStack / IKOULA	8 zones	100+ hosts
CloudStack / IKOULA	Customer base	6,600+ customers
CloudStack / IKOULA	Virtual infrastructure	Thousands of VMs/Kubernetes clusters
CloudStack / IKOULA	Maintenance	Live updates without end-user interruption

7. Cloud Technologies and Research Applications

Table 4. Cloud technologies and research applications

Application	Reference	Cloud Contribution
Face recognition	[3]	ML training and inference
Electronic toll collection	[4]	Centralized transactions
Peer-to-peer energy trading	[5]	Simulation and analytics
Human-bot detection	[14]	Behavioral analytics
Federated intrusion detection	[6]	Model coordination
AI/ML automation	[15]	AI services and workflows
Kernel protection	[7]	Secure infrastructure
Real-time computing	[18]	Cloud-edge workload division
Graph algorithms	[22]	Distributed computation
Honeypot security	[8]	Threat intelligence
Pedestrian prediction	[13]	AI training and deployment

The graph-isomorphism research by Sankal et al. [22] is also relevant to cloud computing because computationally intensive graph problems can benefit from parallel and distributed processing.

8. Challenges and Future Directions

Security and privacy: Cloud platforms require strong authentication, authorization, encryption, monitoring, and secure isolation. **Latency:** Real-time applications require edge computing or geographically distributed cloud infrastructure. **Vendor lock-in:** Proprietary APIs can make migration difficult; open-source platforms such as OpenStack and CloudStack can provide greater control.

Resource management: AI-based scheduling can predict workloads and dynamically allocate resources. **Energy efficiency:** Data centers consume substantial energy, making

efficient workload placement important. **Interoperability:** Hybrid and multi-cloud environments require standardized interfaces and portable applications.

A particularly promising research direction is the integration of cloud computing, edge computing, and federated learning. In such an architecture, sensitive data remains near its source, edge devices perform local inference, and cloud infrastructure provides large-scale coordination, training, and storage.

9. Graphical Results and Discussion

Fig. 1 summarizes the reported scale of selected OpenStack deployments. The values are heterogeneous (cores and servers) and are therefore presented as deployment indicators rather than as a direct performance comparison.

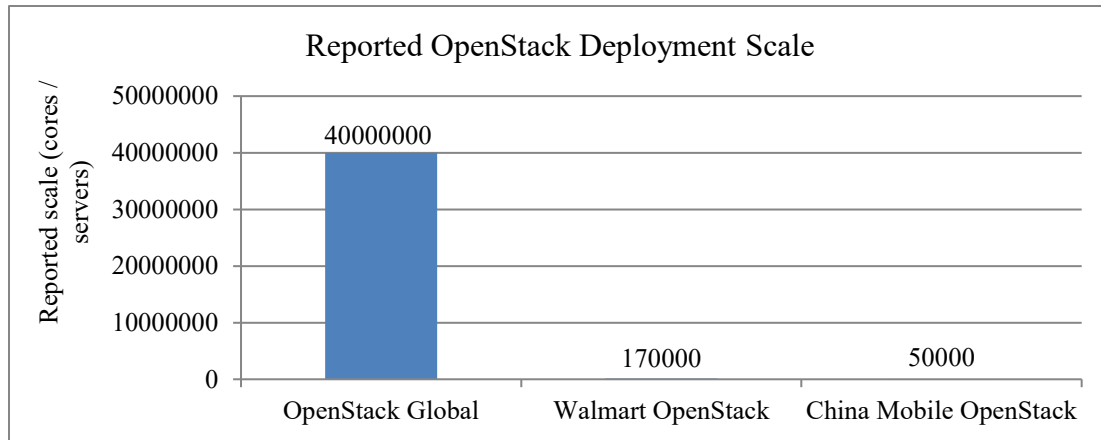


Fig. 1 Reported scale of selected OpenStack deployments [20]

Fig. 2 presents the reported IKOULA CloudStack deployment indicators. Customer count is shown in thousands to keep the different units visually comparable. These figures are descriptive case-study results, not controlled experiments.

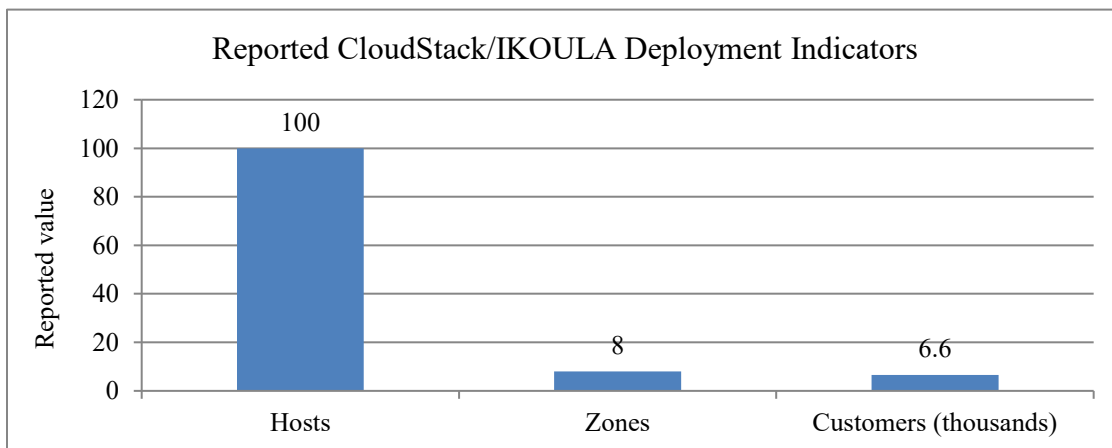


Fig. 2 Reported CloudStack/IKOULA deployment indicators [21]

10. Current Public Cloud Metrics and Graphical Results

To complement the historical case studies, this section uses current publicly available metrics from OpenStack,

Synergy Research Group, the Cloud Native Computing Foundation (CNCF), and Flexera. The figures below are observational industry metrics and should not be interpreted as controlled experimental results.

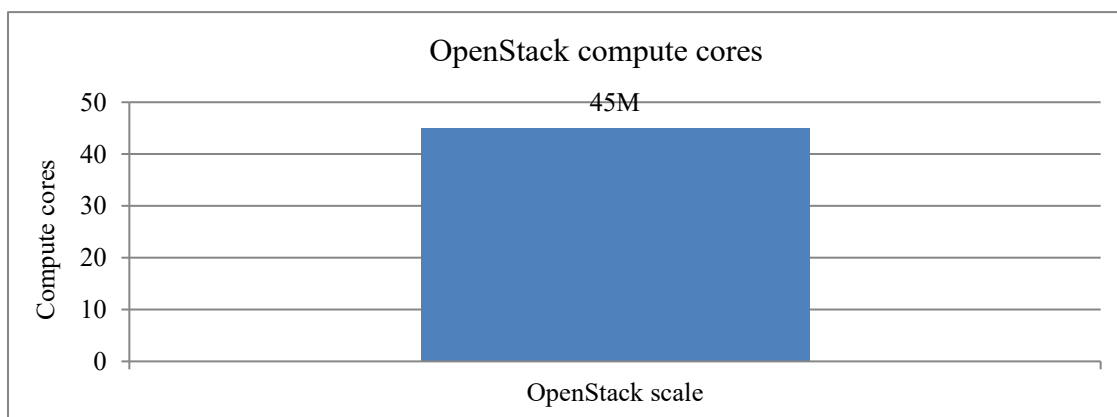


Fig. 3 OpenStack reported compute-core scale (45 million cores) [20]

OpenStack reported 45 million compute cores powered by OpenStack in its February 2025 publication [20].

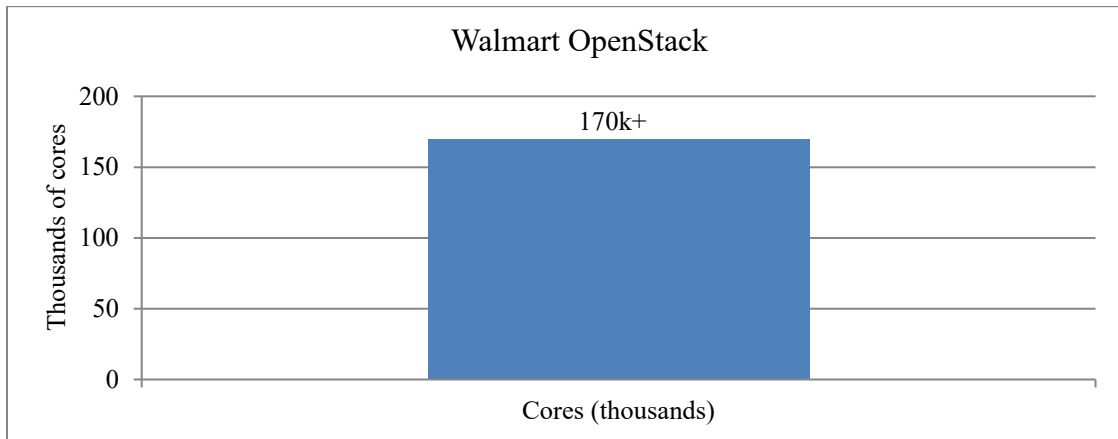


Fig. 4 Walmart OpenStack deployment scale (170,000+ cores) [20]

OpenStack reports Walmart's deployment at more than 170,000 cores across more than 30 regions [20].

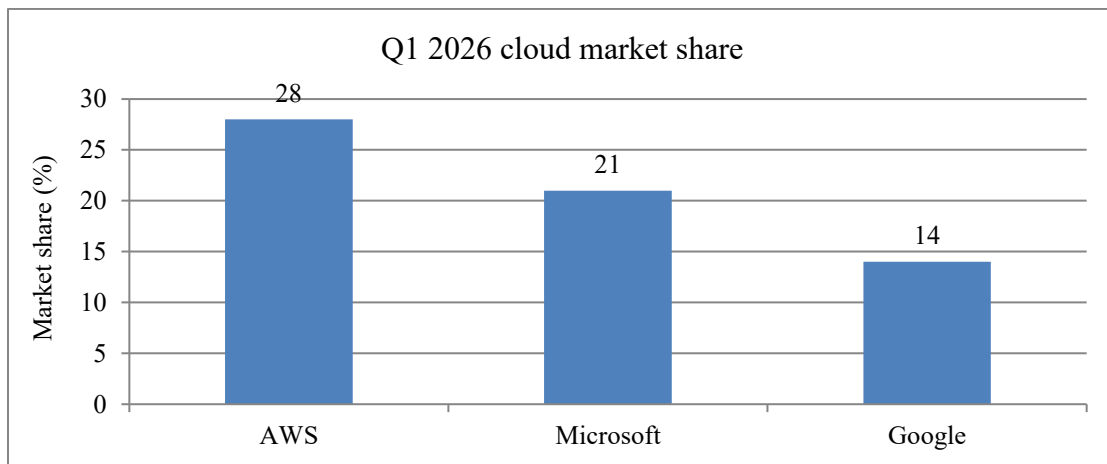


Fig. 5 Q1 2026 worldwide cloud infrastructure service market shares [23]

Synergy Research Group reports Q1 2026 worldwide shares of 28% for Amazon, 21% for Microsoft, and 14% for Google [23].

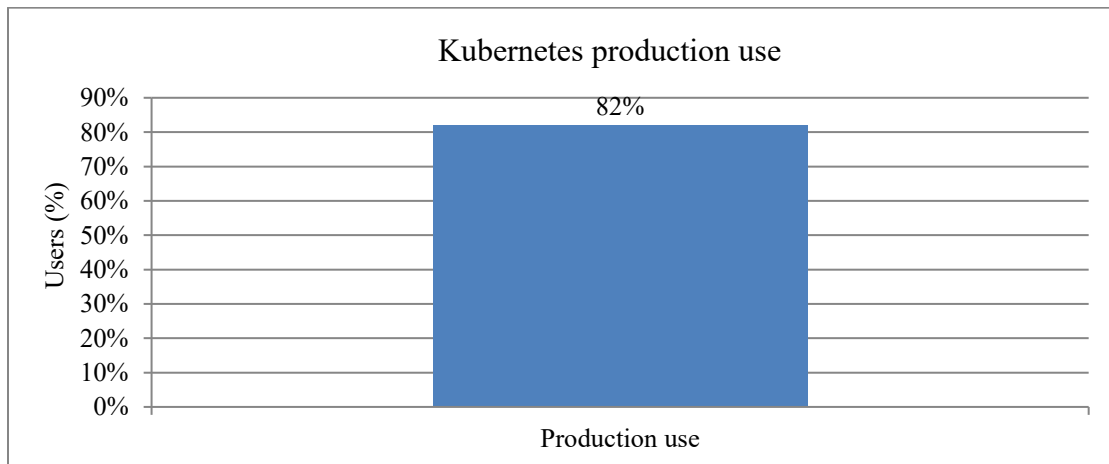


Fig. 6 Kubernetes production use among container users in the 2025 CNCF Annual Cloud Native Survey [24]

CNCF reports that 82% of container users were using Kubernetes in production in 2025 [24].

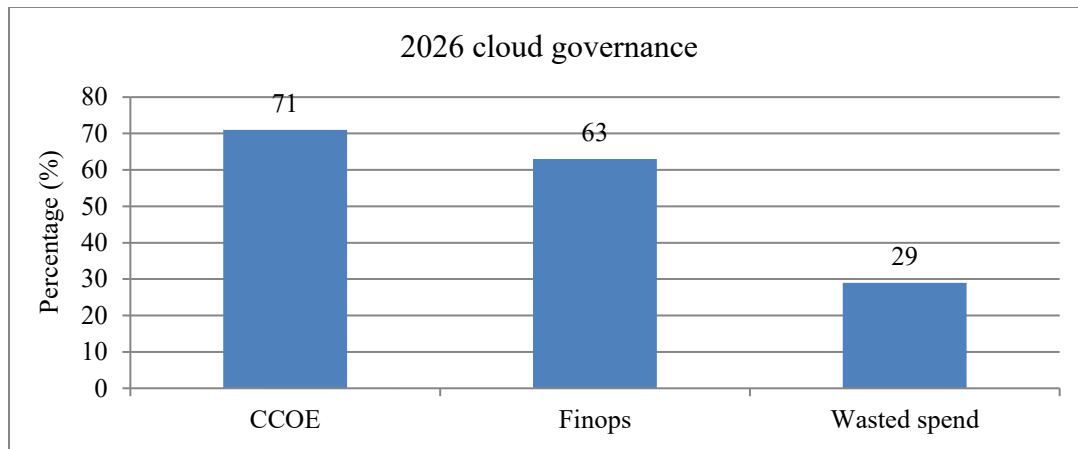


Fig. 7 Selected 2026 cloud governance and FinOps metrics reported by Flexera [25]

Flexera's 2026 State of the Cloud reports 71% CCOE adoption, 63% FinOps-team prevalence, and 29% cloud spend wasted [25].

11. Conclusion

Cloud computing has evolved into a fundamental infrastructure for modern intelligent and distributed applications, formally defined around on-demand, elastic access to shared computing resources [1], [2]. Its scalability, elasticity, and resource-sharing capabilities make it suitable for AI/ML, cybersecurity, transportation, energy systems, simulation, and intelligent automation.

The reviewed studies demonstrate the broad applicability of cloud-supported technologies. Machine-learning-based face recognition [3], electronic toll collection [4], peer-to-peer energy trading [5], human-bot detection [14], federated intrusion detection [6], intelligent automation [15], kernel protection [7], real-time systems [18], graph algorithms [22], honeypot-based security [8], and pedestrian trajectory prediction [13] all represent application areas that can benefit from scalable computing infrastructure, built on the virtualization and orchestration foundations [10], [11] and the serverless, security, and edge-computing considerations [12], [16], [17], [19] discussed throughout this paper.

The open-source case studies provide practical evidence of this scalability. OpenStack reports more than 40 million

managed cores globally and a Walmart deployment exceeding 170,000 cores across more than 30 regions [20]. Apache CloudStack's IKOULA case reports more than 100 hosts across eight zones and more than 6,600 customers [21].

The future of cloud computing is likely to involve an integrated cloud-edge-AI architecture. Such systems can combine cloud scalability, edge responsiveness, federated privacy [26, 27] and intelligent automation. Open-source platforms can further support this evolution by providing organizations with flexibility, transparency, and greater control over their cloud infrastructure.

Author Contributions

R.H.S.K. conceived the review scope, collected and synthesized the literature and public cloud metrics, prepared the manuscript, and approved the final version.

Data Availability

Data sharing not applicable to this review and case-study paper. All numerical cloud metrics used in the graphical analysis are from publicly available sources cited in the manuscript.

Conflict of Interest

The author declares no conflict of interest.

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