



Multicloud Computing in the Enterprise: A Strategic, Architectural, and Governance Framework for Resilient and Compliant Cloud Adoption

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Abstract – Considered one of the most significant enterprises in information technology (IT) in the last 10 years, multicloud computing is a trend that is continuing to grow and demonstrate its importance. Organisations are no longer tying workload to a single cloud provider, but are now hosting applications, data, and services on two or more cloud providers public or private based on the specific strengths of each. First, this article addresses multi-cloud from a few different perspectives, starting with the definition and the difference between multi-cloud and hybrid cloud deployments. It then examines the benefits that make these attractive less vendor lock-in, more fault tolerance, geographic flexibility, and cost flexibility and considers how the multiple environments introduce operational complexity and interoperability challenges and expose security vulnerabilities. According to the study, there are four key elements of a successful multicloud strategy. Cloud Agnostic Architecture, Governance and Compliance, Cost Optimization, and Unified Security. It provides guidance on best practices for evaluation, the selection of vendors and the ongoing monitoring, and outlines representative use cases from disaster recovery to regulatory compliance and specific services consumed. The article concludes with a discussion on the ongoing industry trends, challenges, new solutions, and the future of multicloud computing. The main takeaway is that if backed by disciplined governance, portable architectures, and investments in workforce, then multicloud provides measurable value, and that the complexity of multicloud should not be an afterthought.

Keywords: Multicloud, Hybrid cloud, Cloud strategy, Cloud security, Cloud governance, Vendor lock-in, Cloud computing, Cloud architecture.

1. INTRODUCTION

Cloud Computing is the underlying foundation of the digital economy today, and it is changing the way organizations design, deploy and scale their technological resources. The invention of cloud computing services was a 20-year-old convenient solution to on-premises data centers, but the cloud has now grown to a full-fledged ecosystem of services covering compute, storage, networking, data analytics, artificial intelligence, and even industry specific platforms. This ecosystem has grown and enabled enterprises to break free of any single cloud supplier and implement a multicloud strategy, placing workloads in two or more public cloud environments. This change mirrors a general awareness that no one provider can provide the best service to all workloads, meet all regulatory needs, or offer all features and services an organization requires to stay competitive.

Multicloud computing isn't merely coexistence of multiple cloud subscriptions on an enterprise. It is a conscious design and strategy to distribute workloads, data and services intentionally between providers to meet desired business, technical and regulatory goals. Multi-cloud is adopted because of the benefits of resilience against outage on a provider level, no overdependence in one provider, cost optimization of

the different pricing models, best of breed services of different ecosystems, and data sovereignty regulations at a global increasingly fragmented level. Meanwhile, adopting a multi-cloud approach presents other challenges in terms of governance, security, cost management, interoperability and workforce capabilities, all of which are hotly contested in academic and practitioner fields.

Multi-Cloud Computing

The right workload, on the right cloud, for a stronger and smarter digital future.

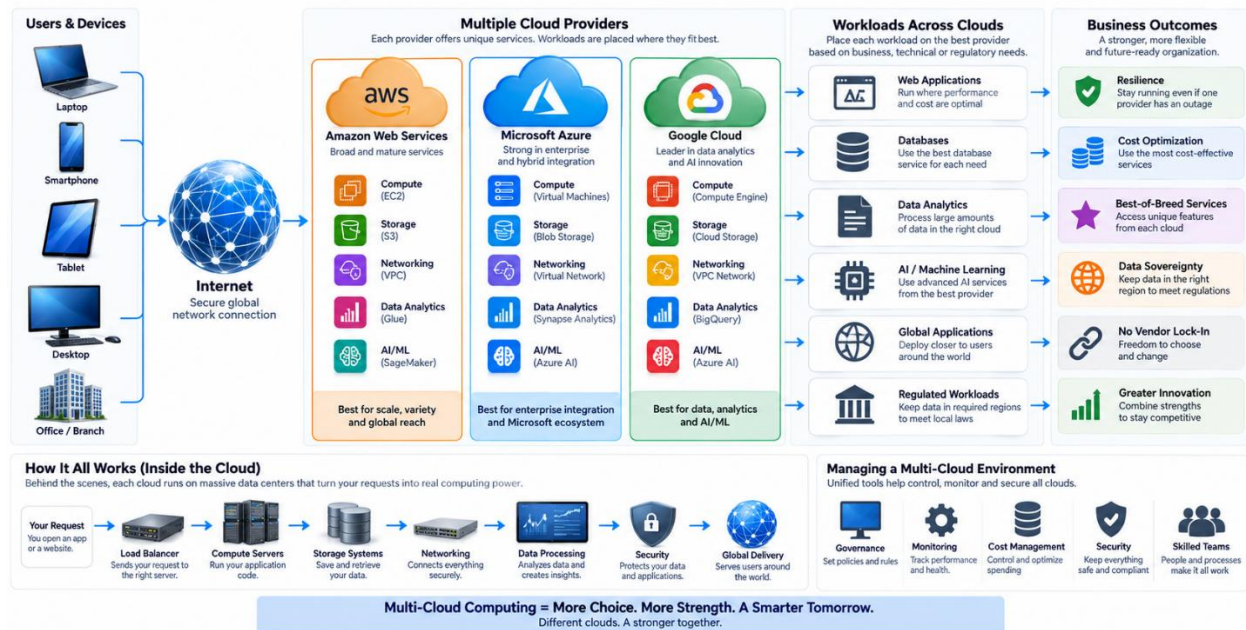


Fig -1: Multi-Cloud Computing

Although multicloud deployments are becoming more common, literature on the topic is disjointed. Both technical publications and strategic analyses of multicloud usually concentrate on certain tools or integration patterns, and the latter may not be a genuine architectural discipline but rather a marketing concept. Full scale therapies, treating the strategic, architectural, governance and ethical dimensions are relatively scarce. The result is especially significant as cloud infrastructure becomes increasingly critical to other industries, such as financial, health services, government and research.

In this article, we aim to fill this void and give a structured discussion on multi-cloud computing along its key dimensions. It explores the evolution of cloud adoption from single provider deployments to intentional multicloud strategies, introduces fundamental concepts and differentiates multicloud from related cloud paradigms like hybrid cloud, and examines strategic intent, architectural models, governance models, security, and operational practices that give rise to today's multicloud architectures. The article also reflects on the latest trends and ethical aspects, providing a well-rounded and evidence based basis for those who are involved in the future of enterprise cloud computing in their research, practice, or policy making.

2. OBJECTIVES

This article aims to examine multicloud computing in detail, using a rigorous and practical approach, for the benefit of technology leaders, architects and operations teams and policy professionals who are tasked with evaluating or operating in multiple cloud environments. Specific objectives are listed below.



The first goal of the article is to provide a clear and exact definition of multicloud and differentiate it from some of the closely related terms, hybrid cloud and distributed cloud. There is still confusion over the terminology, and proper definitions are the basis for well-informed architecture decisions.

Second, the article aims to assess the business and technical motivations that led the multicloud approach to go from niche to mainstream. These range from the need to achieve resilience, geographic coverage, regulatory alignment, service access and negotiation leverage.

Third, the article explores tradeoffs to consider when adopting multicloud. Complexity, cost uncertainty, interoperability challenges, and increased attack surface are not theoretical risks, but practical design issues ones that can be mitigated.

Fourth, the study highlights architectural and operational characteristics that can differentiate between successful and troubled multicloud programs such as portable application design, centralized governance, financial operations maturity, and consistent security controls.

Fifth, the article reviews actual use cases from the real world that demonstrate how multicloud can be used to facilitate disaster recovery, data residency, specialization of services or cost control, based on patterns reported throughout the enterprise technology sector.

In conclusion, it looks at the current state of multicloud, along with the growing adoption of orchestration platforms, policy as code, service meshes, and the use of AI for managing distributed workloads.

Lastly, the article is set on providing actionable, industry trend based wisdom that can be implemented in real-life situations in your own organisation. The idea is to get decision makers to think of multicloud as a conscious decision and not an incidental of departmental buying.

3. WHAT MULTICLOUD ACTUALLY MEANS

Multicloud is a computing strategy that intentionally runs multiple cloud vendors. All of the clouds could be public, all private or a mixture. The key is that every cloud is considered a distinct cloud for specific workloads based on its specific capabilities, pricing, geographical presence or regulatory stance. The idea is to diversify. An organization that isn't focused on using a single provider or holding all its applications and data with one provider can also choose the best provider for each need, meaning that they have more bargaining power with providers and can withstand the effects of any single provider failure. A content streaming service may have their main compute on one platform, machine learning inference on a second platform and cold storage archives on a third platform. A regulated bank, for example, may run customer transactions in one cloud and analytical workloads in a separate cloud, to adhere to regional data protection requirements.

Multicloud isn't just a byproduct of having multiple cloud accounts. Many businesses find that separate teams are simply signing up with separate cloud vendors with no attempt to manage the sprawl, but all the expenses of multicloud and none of the advantages. Multicloud is on purpose and a true multicloud. This includes conscious workload placement, portability planning, unified operational practices and governance which covers all environments used. The model also recognizes there is no one-size-fits-all cloud solution. They each have their own set of advantages in terms of features like data analytics, container orchestration, serverless computing, high performance computing and dedicated hardware. By employing a multicloud strategy, an organization can build its technology estate from the most suitable

components, instead of having to settle for options available from a single vendor. This composability is particularly important as workloads differ, and regulatory mandates become more stringent.

WHAT MULTICLOUD ACTUALLY MEANS

Use multiple cloud providers on purpose — choose the best cloud for each workload.
Different clouds. Different strengths. A stronger, more flexible future.

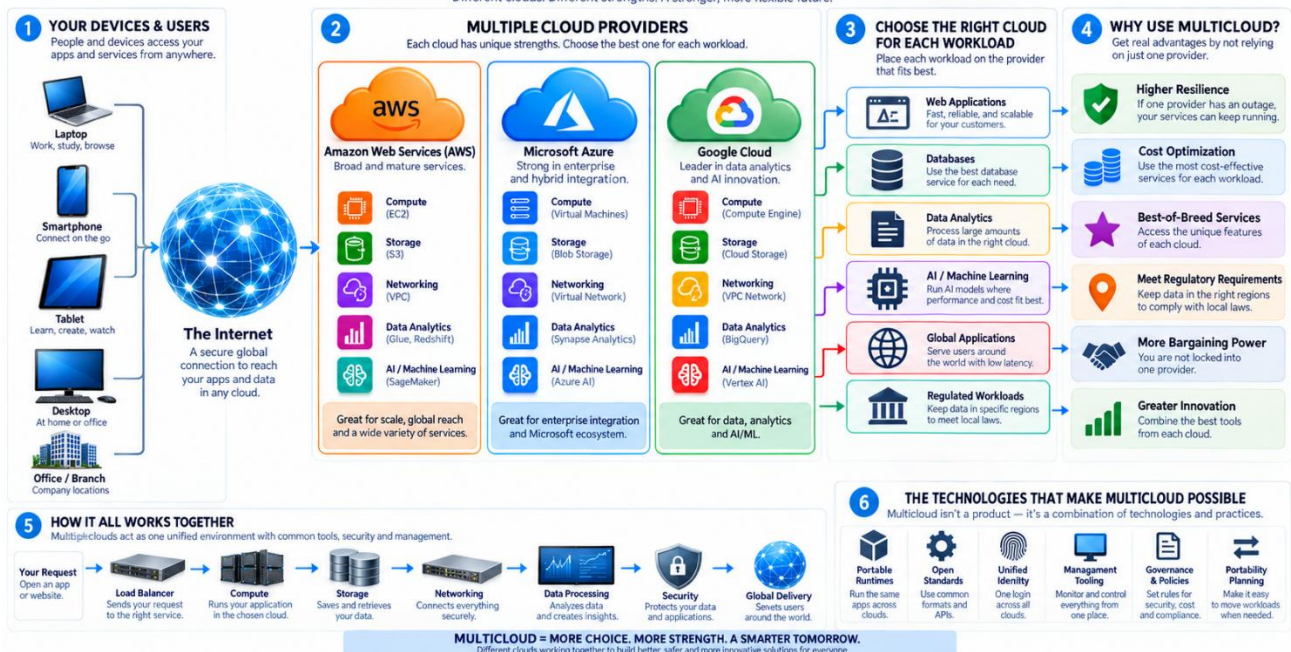


Fig -2: Multi-Cloud Actually Means

It is important to note, that multicloud is a strategic posture, not a product. Multicloud isn't achieved through any one technology. Rather, it is a mix of portable runtimes, open standards, uniform identity management, and management tooling that spans providers that enables the pattern.

4. MULTICLOUD AND HYBRID CLOUD RELATED BUT DISTINCT

While the term **multicloud** and **hybrid cloud** are sometimes used interchangeably in casual conversations, they are two distinct architectural patterns. It is important to understand what the difference is to plan accordingly and to communicate with stakeholders.

Multicloud is the term used when an enterprise has more than one cloud computing and cloud storage service. Workloads are deployed independently on public clouds, private clouds or on both. Cloud companies offer a variety of features, geographic availability, and cost. Multicloud is driven by a desire to avoid vendor lock in, add more redundancy, optimize costs or performance and access the services of various providers. The focus is on using different providers parallel, not having close integration between providers.

But hybrid cloud is an environment that allows for data and applications to move between a private cloud or on premises and one or more public clouds. Hybrid means, private resources are used in combination with public resources with sensitive data and mission critical applications staying on-premises while

elastic workloads burst into the public cloud. The hybrid is flexible, scalable and has a managed security perimeter.

Both of these models do not compete. If the public cloud element is made up of multiple cloud providers, then the hybrid cloud deployment can be considered a multicloud deployment. In many companies, the combination of several public clouds and an on premises private cloud, each one with its own kind of workloads, is used. The difference can be simply summarized as follows. Hybrid cloud is all about the unification of the public and private. Multicloud is a concept of parallel use of multiple providers. One deals with the on premises public cloud relationship and the other deals with the number of cloud providers involved.

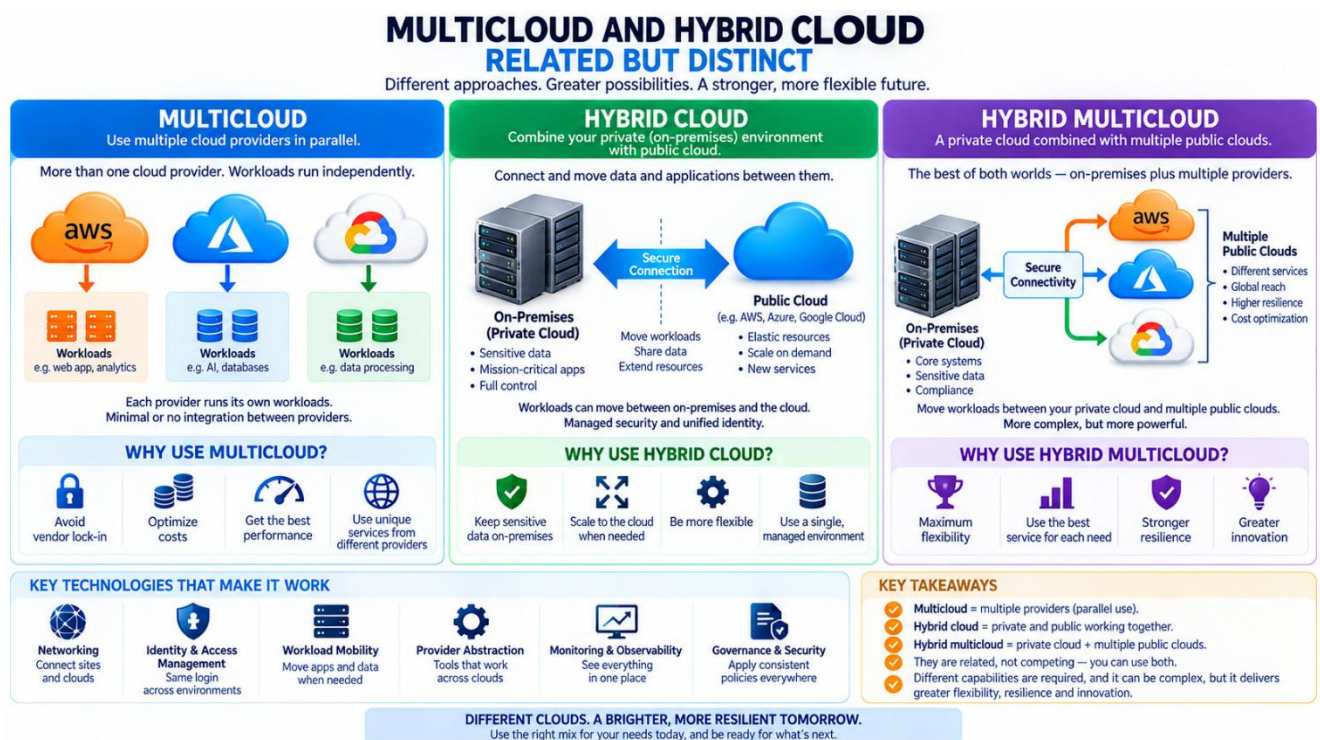


Fig -3: Multi-Cloud And Hybrid Cloud

The bottom line is these models require different capabilities. For hybrid cloud, connectivity is an essential part, as is the need for seamless identity between the private and public side of the cloud boundary, and the ability to move workloads between the two sides. One of the requirements for multicloud is provider abstraction, which is also needed for cross cloud governance, and unified observability. An organization that wants to do both will need to invest in both types of capabilities, hybrid multicloud environments are one of the most challenging environments to operate well.

5. ADVANTAGES AND DISADVANTAGES OF A MULTICLOUD STRATEGY

While there is an obvious attraction to multicloud, there's also an obvious price tag. It's important to consider both sides when making an evaluation. The pluses include the lack of vendor lock in, which is first mentioned. An organisation with this situation has leverage in commercial negotiations, flexibility in

architectural decisions and has the opportunity to move workloads to a different provider should their company make a change or increase prices. Walking away is its own form of value, or the ability to credibly threaten to walk away.

Resilience and redundancy becomes a natural consequence. Having workloads run across various cloud environments lowers the blast radius of any one cloud outage. Even the biggest cloud service providers have service disruptions and businesses with important workloads in one region, or one provider may be down for hours. A well-planned multicloud deployment provides services to continue functioning even if a cloud provider is affected. Geographic diversity is important for performance and compliance. There are various providers with varying data centre presence, and some places are better served by certain providers. Multicloud enables an organization to place workloads nearer the user, for lower latency, as well as respect data residency requirements that mandate that some data must stay within a certain country.

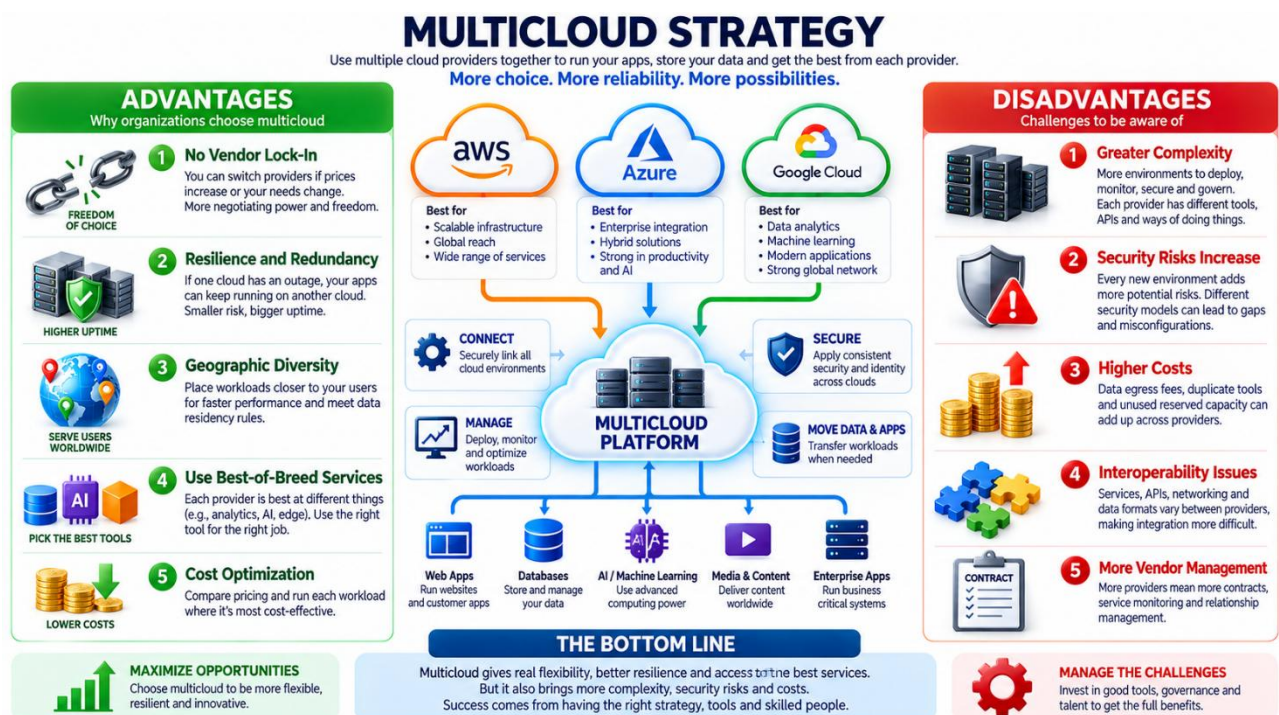


Fig -4: Multi-Cloud Strategy

Special specific services are another impetus. Cloud providers are competing for innovation, and the best cloud provider isn't necessarily the best for every capability. With multicloud, an organization can use, for instance, one provider's data warehousing services, another provider's machine learning accelerators, or edge computing network. The benefits are completed by cost optimization. Pricing models are very different across providers, and workloads can be deployed in those that allow them to be consumed most optimally as per the pricing structure.

The downside is not far behind. Things get really complicated when there are multiple environments to deploy, monitor, secure and govern. Every provider has its own control plane, service catalog, and other nitty-gritty details. APIs, networking models, and data formats vary and that can cause interoperability problems. As each new environment must be secured, the security risks increase, and the lack of uniformity

among providers ensures there are opportunities for exploitation. Data egress fees, redundant tooling, and unused reserved capacity may add up across providers, driving up costs. Vendor management also gets more difficult as more vendors mean more contracts, monitoring of services, and relationship management. Multicloud is real flexibility, it's just that it may require commensurate investments in tooling and talent. Companies that take a casual stance are likely to end up paying for it without realizing the benefits.

6. KEY COMPONENTS OF A SUCCESSFUL MULTICLOUD STRATEGY

There are only a few basic components on which a multicloud strategy can succeed or fail. There are four of these that are especially significant.

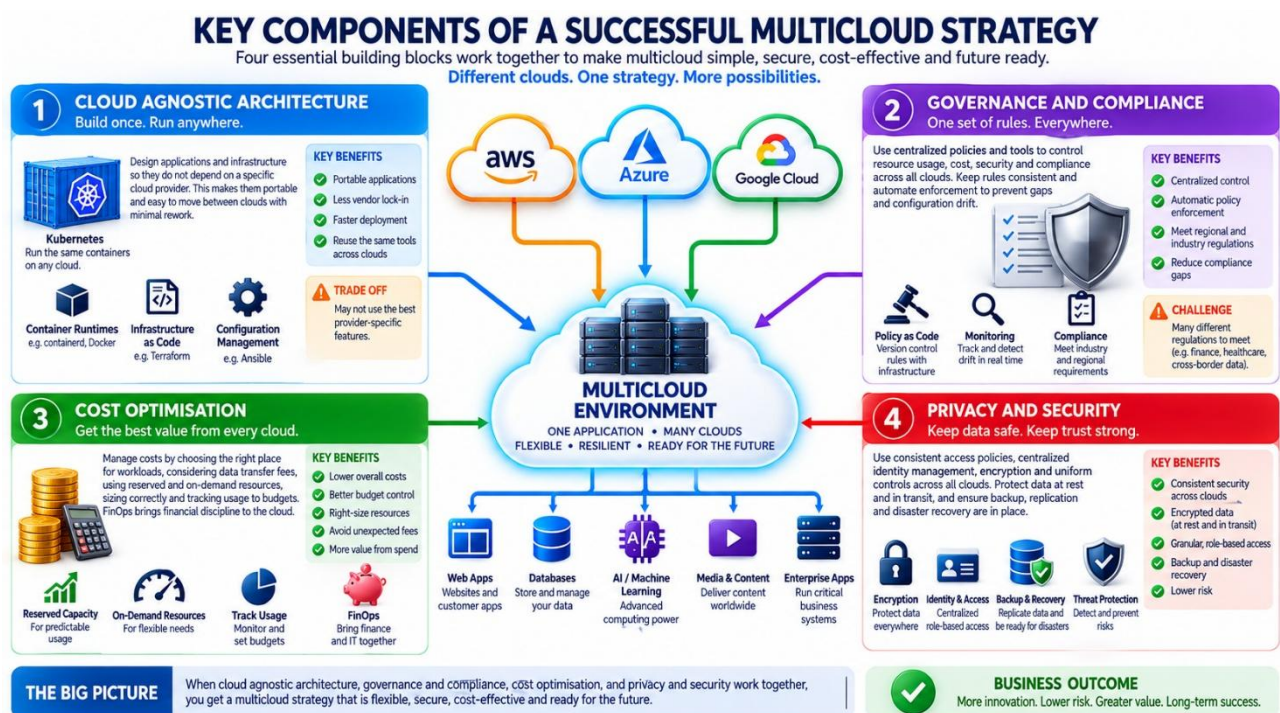


Fig -5: Key Components of A Successful Multi-Cloud Strategy

The first one is a cloud agnostic architecture. The basic concept is to develop application and infrastructure in such a way that it is not dependent on any particular cloud provider. Decoupling applications from proprietary services makes them portable and able to be redeployed in other environments, requiring little rework. It's the technical underpinning of reduced lock in. Containerization platforms like Kubernetes, container runtimes, infrastructure as code tools, and configuration management systems de-emphasize infrastructure and allow the same deployment artifacts to be deployed across different clouds. The downside is that cloud agnostic designs may not be able to take advantage of the best provider specific functionality. Choices about portability will have to be made by teams, who need to be conscious about where it is most important and where it is worth sacrificing the portability for a more tightly integrated provider.



The second one is governance and compliance. Effective governance policies are in place to help control resource usage, cost, security and compliance in all environments used. The problem is that organisations with a multicloud estate are likely to have a host of regional and industry specific requirements to meet think financial services regulations, healthcare data protection or cross border data transfer regulations. Centralized governance tooling can help simplify monitoring and automate policy enforcement to keep compliance gaps low even as it is mitigated against drift between environments. A pattern that's now becoming a reality is to maintain policy as code alongside infrastructure, which means governance rules are version controlled and codified alongside infrastructure definitions.

Cost optimisation is the third. The placement of workloads, data transfer costs, and pricing models of cloud providers are critical factors in multicloud economics. If workloads are placed without consideration for data gravity, idle capacity is allowed to build up, or egress fees are not taken into account, costs can mount up rapidly. Successful cost management is a mix of reserved capacity for predictable usage, on-demand resources for those who cannot predict their usage, instance sizing and consistently tracking usage to budgets. The field of financial operations FinOps for short is a key component of every multi-cloud initiative.

The fourth one is privacy and security. Multicloud security is based on consistent access policies, centralized identity management, coherent encryption and uniform controls. Data-at-rest and data-in-transit MUST be encrypted with well managed keys. Access should be granular and be based on role. No matter which provider, multicloud backup, replication and disaster recovery procedures ensure data protection. With a disjointed security posture, each new cloud is another point of risk.

Deliberate organizations that tackle these 4 components are more likely to realize the promise of multicloud. Those that don't pay attention to any of them are likely to see their deployments become increasingly costly, fragile, or unmanageable.

7. BEST PRACTICES FOR MULTICLOUD ADOPTION

Multicloud is not a decision, rather, a journey. Based on established patterns from other industries, there are a few best practices that can be identified which increase the likelihood of success.

The first set has to do with assessment and planning. It is important to have clear objectives. It is important for an organization to understand why they are adopting multicloud, whether it be to reduce costs, achieve resilience, attain flexibility, access specialized services, or to meet regulatory requirements. The purposes of a building vary and so do the priorities of the architecture, which means that if the purpose is not clear, the team will optimize for the wrong purpose. Compliance and security evaluations should take place early in the process, followed by a delineation of which data classes can reside in which jurisdictions, as well as which controls should be implemented in all jurisdictions. Workload analysis helps determine where the workloads are most likely to perform best and where they can be most cost-effective across different providers, depending on workloads' performance characteristics, pricing, and dependency relationships. Continually invest in skills and training to make sure that teams don't fall into expensive knowledge voids while operating in environments.

The second set is related to the selection and integration of vendors. When choosing a provider, it shouldn't just be about the brand. Availability, specific services, pricing structure, performance, responsiveness of support and compliance with certifications are all important factors in a region. Seamless integration once the providers are identified requires to pick services that have compatible APIs when possible, and uniform deployment patterns across environments. Inconsistencies can be restricted through container

orchestration, infrastructure as code and API gateways. Architecture must also be a conscious effort to not rely on any services that would cause lock in without any benefit.

The third set of questions relate to continuous monitoring and optimisation. Operations are streamlined by using tools and processes across cloud platforms. One pane of glass to see, monitor, and track security and cost reduces cognitive overhead for ops teams. Optimization strategies involve ongoing resource allocation monitoring, instance sizing and consumption monitoring. Auto-scaling, right-sizing and workload re-distribution should be common practice and not something that is done as an exception. Regular monitoring of performance metrics and costs, on a per provider basis, should be undertaken to see and act upon optimisation opportunities.

BEST PRACTICES FOR MULTICLOUD ADOPTION

A simple, step-by-step journey to get more value from multiple clouds.
Plan well. Choose wisely. Integrate smoothly. Monitor and improve. Keep supporting it.



Fig -6: Best Practices For Multi-Cloud Adoption

In addition to these basic disciplines, there are some other disciplines that are supporting. A clear model of charge back or show back, helps business units understand their consumption and thereby promotes cost conscious behavior. A written incident response plan including multi provider scenarios helps to decrease response time when an incident occurs. Technical debt can be avoided by a regular cycle of architecture review. Plus a positive relationship with each provider regular executive meetings to bring up issues early, and to keep the organisation up-to-date about service changes. These practices combine and help to transform multicloud from aspiration to repeatable operating model. They do not remove complexity but they get it into **work** that is manageable.

8. USE CASES AND ILLUSTRATIVE EXAMPLES

The best proof of the value of multicloud is the use cases it can facilitate. There are some common trends among sectors.

Redundancy and risk mitigation is a prevalent motivation. An organization's use of multiple providers provides protection from outages or incidents affecting any one region. For example, a financial institution could mirror transactions between two providers, enabling transactions to proceed without much disturbance in the event that one provider suffers a lengthy outage. Organizations with defined recovery time requirements (RTOs) have adopted the cross cloud backup pattern as the norm backing up production data to another cloud provider, instead of just another region of the same provider.

Geographic flexibility compliance is another common motivator. Data placement policies differ significantly between jurisdictions and in some countries, certain types of data must be kept in country. A company with a global e commerce footprint may use a variety of providers based on which has the best regional presence, and the most compliant stance in the respective markets. This way, the company can ensure that its users can have low-latency experiences, while still following data protection regulations in every region.

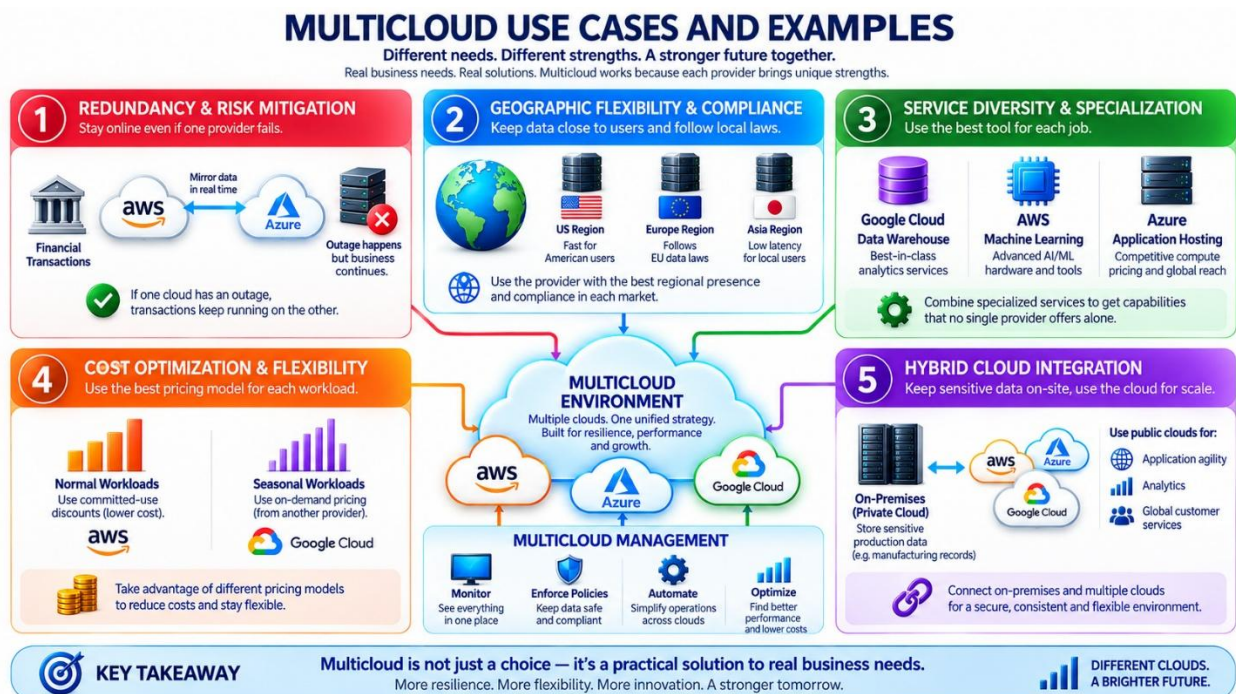


Fig -7: Multi-Cloud Use Cases And Examples

Many organisations are forced to move to multicloud as a result of service diversity and specialization. A data-heavy enterprise may choose to rely on a single service provider for its data warehouse solution, a different one for running machine learning models, and a third one for its application hosting because they offer the best data warehousing, best hardware for machine learning, and best compute pricing. The combination of specialized services enables organizations to combine capabilities that do not exist in quite the same form from a single provider.

Cost optimization and flexibility is a related use case. The pricing models, discount programs and reserved capacity options vary from provider to provider. A software as a service provider could leverage committed use discounts from one provider during its normal, steady state workloads, and on demand pricing from

another provider during the seasonal workloads when on demand pricing is more attractive. With careful management, this arbitrage opportunity can yield substantial savings.

Many enterprise deployments have hybrid cloud integration, and hybrid cloud integration overlaps with multicloud. For regulatory purposes, a manufacturer may prefer to store sensitive production data on premises while leveraging public cloud services for application agility, analytics and global customer facing services. Multicloud management tools enable the organization to monitor and enforce policies on these environments in a single place, ensuring operational consistency across the various cloud footprints, including private and multiple public clouds. These all follow a similar pattern. In every instance, it isn't a multi-cloud for multi-cloud sake, but because the business need is not met as cleanly within a single provider. Multicloud is in response to actual constraints, not a theoretical choice.

9. WHY ORGANIZATIONS PURSUE A MULTICLOUD APPROACH

It's not just the use cases that organizations seek to pursue when they're looking at multicloud. The model creates a number of values at strategic level which are hard to attain in other ways.

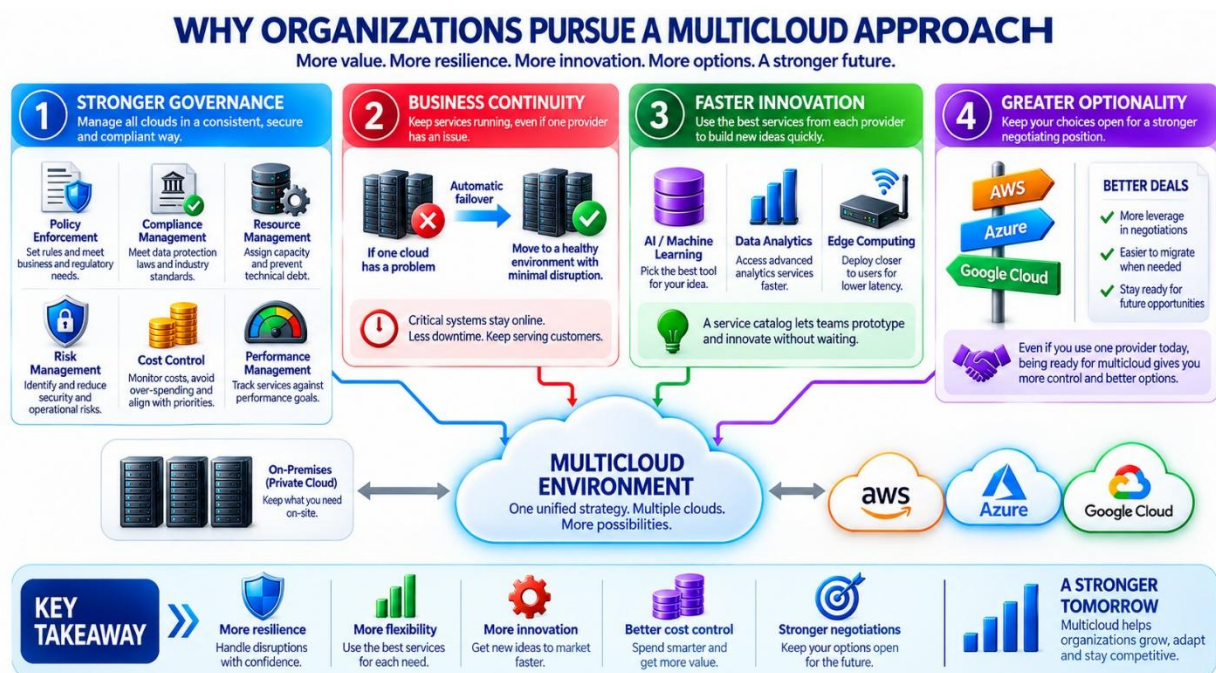


Fig –8: Why Organizations Pursue A Multi-Cloud Approach

The value of governance is one of these. Good governance of cloud resources means that they are managed in an efficient, secure and business rule compliant manner. There are some responsibilities under the governance in multicloud context. Policy enforcement sets the guidelines of usage of cloud resources and ensures that corporate and regulatory needs are fulfilled. Compliance management validates that the environment is meeting the data protection and privacy laws as well as industry specific standards. Resource management is the process of assigning capacity to align with business priorities, and to prevent technical debt. Risk management helps to identify and reduce risks, such as security risks and operational risks. Cost Control is used to monitor the costs and avoid overspending our budget and to ensure our



investments reflect our strategic priorities. Performance management is used to track cloud resources and services against a set of cloud performance goals.

In a multicloud context, the dimensions of concern get multiplied, making it even more important to have a balanced governance. Consistent application of a policy across three providers will be more difficult if it is easy to implement at one provider. Governance tooling therefore needs to be carefully selected, as is preferred the ability to see and control multiple environments, all from a single tooling set.

The second reason for organisations seeking multicloud is that of business continuity. In today's business environment, hardly any organizations can afford long downtimes of customer facing applications. Multicloud deployments, with active failover, enable services to fail over from a degraded environment to a healthy one with minimal disruption. Economic viability of this capability is dependent on criticality of the service. The concept of multicloud redundancy doesn't really matter, if the core revenue system is in question. If workloads are not time-critical, then simpler single provider patterns, may be more appropriate.

The third is **innovation velocity**. With multiple providers also being accessible via a service catalog, development teams can prototype more quickly, selecting the service that makes the best fit for a particular idea, instead of waiting for a provider to provide capability. This flexibility is especially important in regions where providers are vying for competitiveness through fast innovation, like artificial intelligence, data analytics and edge computing. Last, there's the strategic worth of optionality itself. Even if an organization is today relying on one provider mainly, the credibility of migration of workloads to other providers has an impact on every commercial negotiation. There's value in being **ready** for multicloud although it may not be fully used.

10. BUILDING A MULTICLOUD THE ROLE OF CONNECTIVITY

Establishing a multicloud isn't simply obtaining accounts with multiple vendors. The availability of operations across the entire estate, the security and policy matrix that spans the entire estate and the connections between the environments are all critical to the quality of the deployment.

Multicloud is all about connectivity that gives end to end reach. How connectivity is designed and put in place can either enable or impede the ability to extend security and operational control throughout the architecture. Public Internet connections are easy to set up, but don't have the same performance level as private connections and are likely to put extra data at risk along the way. Dedicated interconnects between providers or via neutral exchange points provide improved latency, higher throughput and enhanced security attributes. In many respects, many organizations are now implementing SD-WAN overlays that hides the underlying transport mechanism and ensures that the SD-WAN policies are enforced irrespective of the provider at each end of the connection.

Multicloud understood end to end is more than just data centers and public clouds. It also encompasses the applications themselves, users consuming the applications, branch sites and campus environments workers are connected in and the devices interacting with services from the edge. If these endpoints are not included in a multicloud architecture, then it's incomplete. true end to end multicloud means that, no matter which cloud the workload is hosted on at any time, there is consistency in identity, security policy and observability across all segments from the user device to the backend database.

The takeaway for architects is that the network design and security design should go hand-in-hand when deciding on workload placement. An application deployed in a provider that does not have a good

connection to the users or to its data will suffer performance problems even if the compute platform is robust. Similarly, if the workload is constantly changing between providers and there is no consistent identity or policy enforcement, it's likely that there will be some kind of security incident.

So to create a Multi-Cloud, you need a number of parallel work streams. The first is determining the workloads that will be placed where and why. The second is to plan the network topology, which connects the network environments together and to users. The third is to create an across-the-board identity, policy and observability fabric. The fourth is the establishment of operational practices which will maintain fabric health in the changing environment.

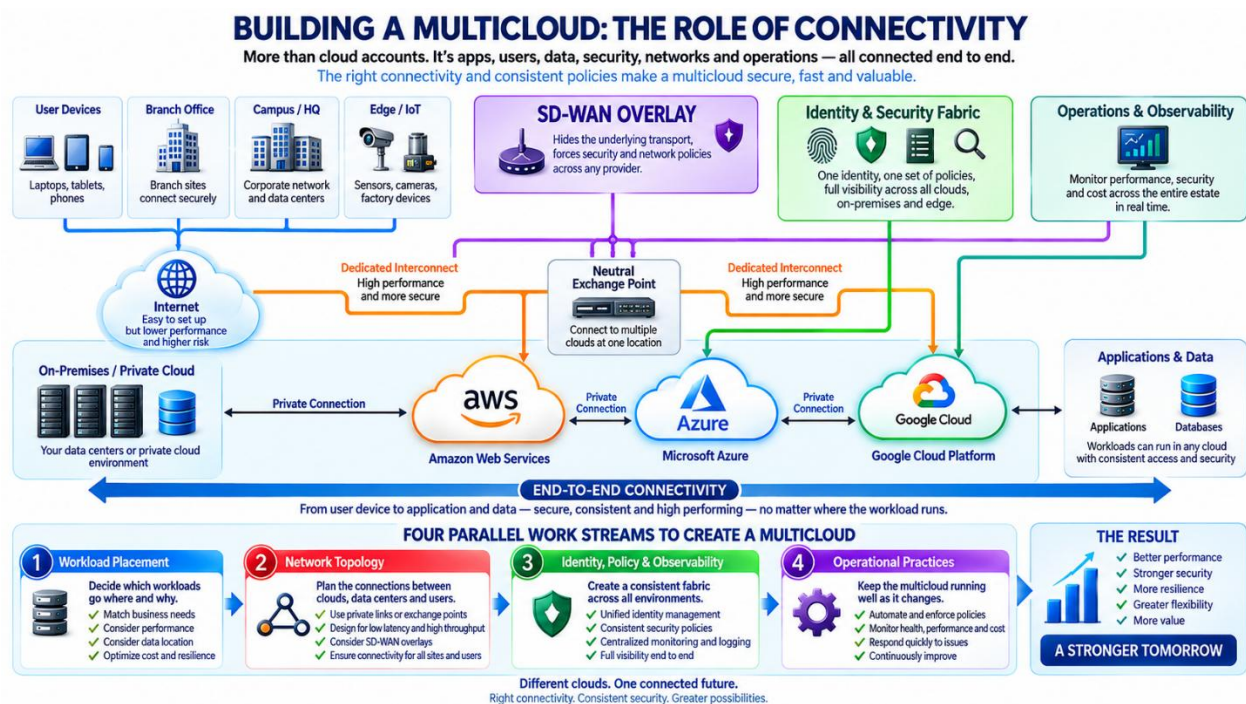


Fig –9: Building A Multi-Cloud Role of Connectivity

Investing in all four streams means that organizations are seeing the benefits of multicloud. The ones that only look at workload placement usually end up with having network and operational gaps that constitute a lack of value.

11. BENEFITS OF MULTICLOUD DEPLOYMENT

When applied correctly, the tangible use cases of multicloud revolve around 3 main themes.

Perhaps the most obvious advantage is high availability. Multicloud enables the service and storage of data to be redundant in case of security incidents and provider outages. As one cloud becomes unavailable, workloads on the other clouds serve users. The extent of availability attained will be dependent on the design of applications. With just a little complexity, simple active passive patterns provide resilience by having one provider host production and another host a warm standby. Active pattern is the most available but will need much more engineering resources, especially for stateful workloads that need data to be consistent between active patterns.

Second is flexibility. Multicloud provides organizations with the option to choose the cloud that is best suited for each of their needs, depending on technical ability, geographic location, price, and timing. In reality, organisations will have a mix of clouds, with various mixes of data, infrastructure and applications handled by each cloud. One of the most obvious benefits of the model is the ability to choose the best solution for every requirement without having to settle for a provider with an inferior solution. Moreover, it offers a route towards the avoidance of vendor lock. Applications and data can be moved around when they're portable, giving the organization flexibility to move workloads due to changes in price, performance, or strategy.

BENEFITS OF MULTICLOUD DEPLOYMENT

One strategy. Many clouds. A stronger, more flexible, and resilient future.

Use the best of each cloud, keep your business running, control costs, and stay in control.

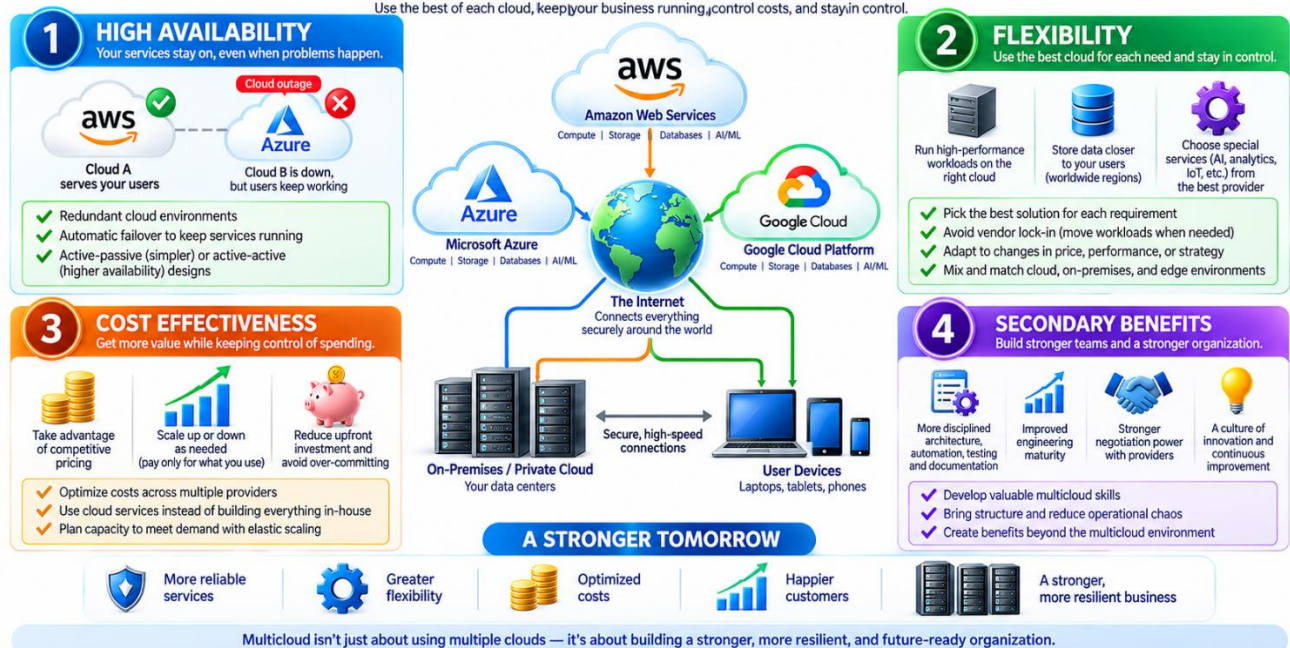


Fig -10: Benefits of Multi-Cloud Deployment

The third benefit is cost effectiveness, which needs to be managed. Multicloud enables organizations to manage capital and operational costs, leverage competitive pricing between public cloud and infrastructure vendors and prevents over-committing to a single pricing model. Organizations can also provide additional functionality to their customers by leveraging public cloud services, without the need to hire and keep the people they need to have on staff to run similar capabilities in house. The capacity allocated is planned across the multicloud estate to optimize spend for the given service level requirements making sure that the capacity can be elastically scaled with demand.

There are several secondary benefits of using green roofs. Multicloud deployments often lead to disciplined architectural practices, otherwise there's chaos in the operations. Teams that craft multicloud skills are additionally more apt to have powerful automation, documentation, and testing processes. These capabilities combine to make an impact beyond just the multicloud estate and elevate engineering maturity. Multicloud also bolsters provider negotiations. Even if an organization doesn't end up leaving a provider, the perception that it can isn't lost and makes a difference in the tone of commercial discussions. The benefits are there, but the investment is required to make those benefits real, rather than simply

adoption. The most complete benefits of multicloud are harvested by organizations that go beyond a tactical procurement decision, and view it as a strategic program.

12. PREPARING FOR MULTICLOUD ARCHITECTURE

Since the operating environment for multicloud is so wide, it's important for organizations to plan carefully before increasing their presence. There are many steps that will always help to improve outcomes. One of the initial priorities is to create a unified toolchain. Operations teams operating across multiple clouds shouldn't have to learn and switch between totally different tool stacks for every cloud. By having a unified configuration management, deployment, monitoring, and incident response toolchain, it's easier to reduce mental effort, to increase the speed of responding, and to make it more difficult for gaps to creep between environments. The tools used are not as important as their use and consistency.

PREPARING FOR A MULTICLOUD ARCHITECTURE

Plan. Connect. Standardize. Secure. Grow.

The right preparation turns multiple clouds into one stronger, more flexible, and future-ready environment.

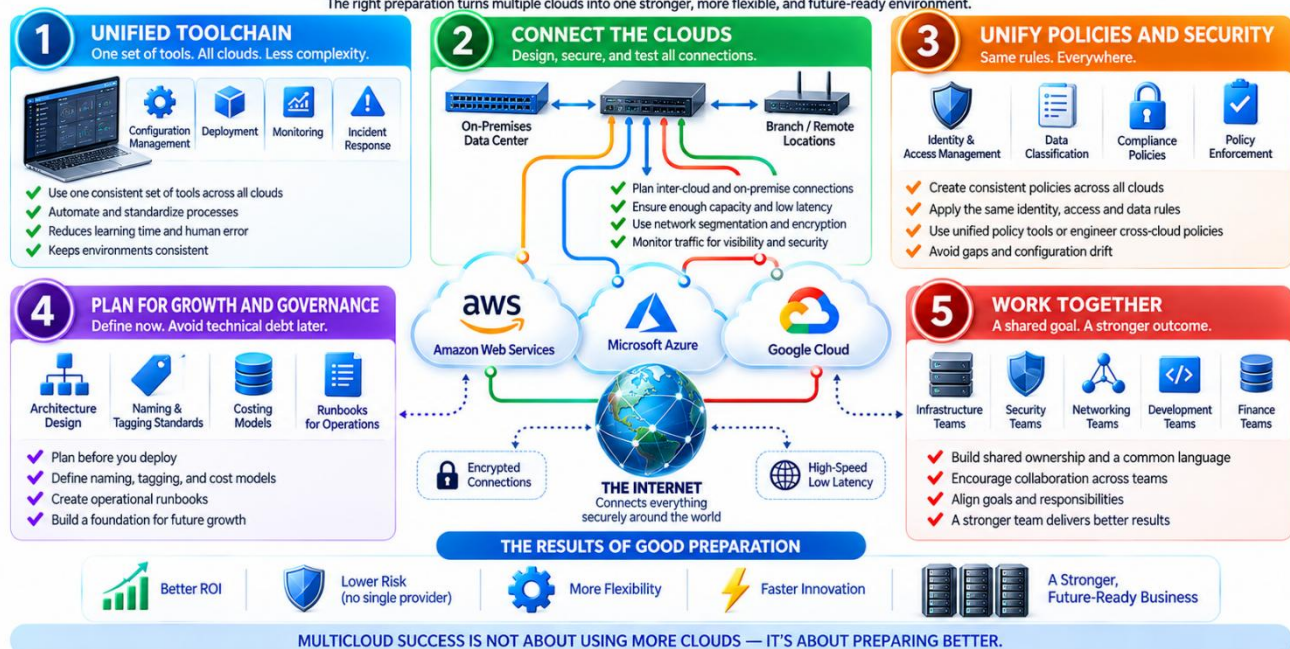


Fig -11: Preparing For A Multi-Cloud Architecture

The next concern is to connect the clouds. Connectivity design should be intentional and have the capacity, latency and security properties documented and tested. This encompasses inter-cloud connections, connections from the clouds to on-premise environments and connections to users at branch and remote locations. Security, in the form of network segmentation, encryption in transit and traffic observability should be engineered from the ground up, not retrofitted for the network.

The policy unification and simplification is a parallel work. The policies relating to identity, access, data classification and compliance should be established and applied in all environments. This is certainly easier said than done. There are different identity and access management systems, policy languages and enforcement models for each cloud provider. Changing the intent of a single policy to consistent enforcement of it across providers will take either lots of engineering, or the use of platforms that are built

for this purpose. In either case, the other approach environment-specific policies inevitably leads to drift and gaps. Making plans and preparations ahead of time is worthwhile and will benefit the whole life of deployment. When multicloud deployments are rushed to market, they may be built on a lack of architectural best practices, which can add up to a heavy burden of technical debt that is hard to manage down the road. Investing time at the start defines architecture, naming, tagging norms, costing models, and runbooks for operations to set a base for growth, not a hindrance.

By operating in more than one cloud, organisations can benefit from better ROI and limit the risk of being over-dependant on a single cloud. A well-managed multicloud platform is flexible and adds strategic value for ongoing business benefits and agility. The organizations that reap these benefits most reliably are the ones that prepare for it, as opposed to the ones that take a **sloppy** approach that ends up in the **multicloud** category due to a series of purchasing decisions. The last aspect of readiness is cultural. Multicloud is not without its share of challenges, particularly when it comes to teamwork, because teams might not have always worked together. There are parts to be played for infrastructure, security, networking, application development and finance. It is much easier if a shared ownership and a common language is developed early.

13. WHAT MULTICLOUD MEANS FOR SECURITY

Multicloud puts geographic location on the map as one of the most important factors of information technology today. Data storage and data sovereignty regulations can differ widely across jurisdictions, and with the advent of multicloud deployments, data locality is a growing area of concern across the globe.

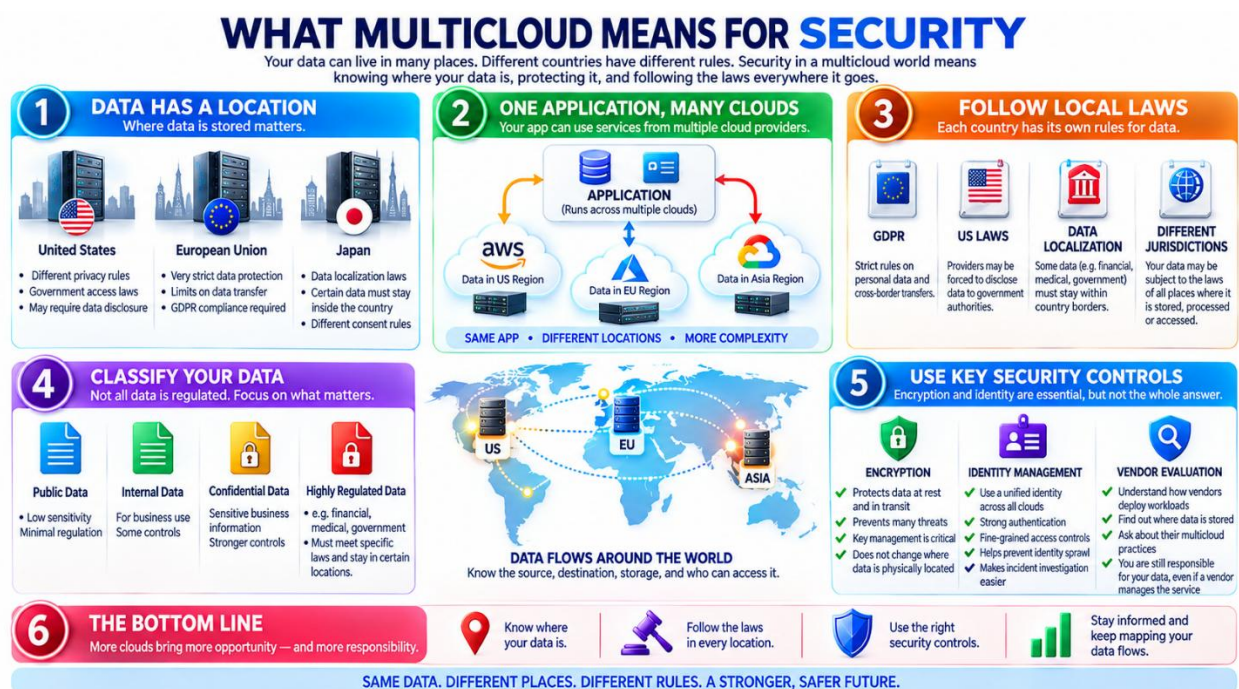


Fig -12: What Multi-Cloud Means For Security

The regulatory environment is now extremely complex, especially in recent years. European data protection laws provide very strict limitations as to where personal data can be processed, and under what conditions



personal data can be shared with other jurisdictions. Some jurisdictions have enacted data localization laws, which mandate that specific types of data such as financial records, medical data and government related data must stay within their country's borders. Through a number of legal instruments, the United States still has legal powers to force disclosure of information of providers under its jurisdiction, causing some conflict with the privacy expectations of other regions. The challenge of working through these layering and at times conflicting needs is a major component of multicloud security practice.

If an organisation is running an application that has a multicloud under the hood, but isn't managed by the organisation, then it needs to understand the implications. In most jurisdictions, the end user that is, the user of the application service is responsible for all potential storage locations of the data by the application. Depending on the type of data and the jurisdictions involved the data may have to abide by the laws of all the jurisdictions in which it may be stored, processed or accessed. This responsibility is not contractable, even if a vendor agreement tries to contract this responsibility.

The consequences for the security teams are very real. Data classification is the first step that is crucial. Not every kind of data is regulated subjecting all data to regulation is burden and complexity. Data can be classified as to sensitivity and by regulatory regime for targeted controls. Secondly, it is important that data flow mapping is kept up-to-date. Teams need to understand the source of the data, its destination, and its repository as well as who can access it at these points. Third, vendor evaluations need to dig deeper to learn how vendors deploy workloads, and how they use multicloud.

While encryption is certainly a key component to multicloud security, it is not an answer to all the challenges. Crypting data at rest and in transit will prevent many types of threat, but will not modify the territoriality analysis of where the data is physically located. The key management who has and who controls the encryption keys is often more important than the encryption algorithms themselves. The other pillar is identity management. Having a unified identity across clouds and with robust authentication and fine-grained access controls helps reduce the impact of a compromised credential and simplifies investigation in an incident. One of the top security vulnerabilities in a multicloud environment is identity sprawl, the condition in which users have multiple accounts and privileges across various clouds.

14. HOW SECURE IS MULTICLOUD IN PRACTICE

The ability of the people running the environments and the maturity of the vendors involved are critical to multicloud security. All components of infrastructure and all applications in a multicloud deployment needs to be secured both individually and collectively. More components means more points where it can be set up wrong or have a vulnerability. Each cloud in a multicloud environment is a unique infrastructure that needs to be designed, deployed, monitored and maintained on an ongoing basis. Security characteristics of one cloud are not necessarily valid for another cloud. If a control is implemented in one environment but not in another, an external connection between the two could provide the entry point to compromise the other environment, if not handled in a consistent fashion.

In addition to the infrastructure, there are security issues associated with the applications and data that run on the multicloud. Application security techniques like secure coding, dependency management, vulnerability scanning, and runtime protection are independent of the applications environment. But, variations in application security practices from one cloud to another, due to multiple teams deploying to multiple cloud providers, can lead to gaps that can be exploited. This is because there are several patterns that enhance multicloud security results. The risk of credential compromise is lowered with centralised

identity, where authentication is required and has a high level of security such as multi factor authentication and conditional access. Collecting logs and monitoring them in a consistent manner and then having them all collected in a single analytics platform enables the identification of threats that cross environments. Policy as code is the concept of declarative and automated policy enforcement that cuts down drift and offers evidence for audits. Weaknesses are discovered before exploitation through regular security assessments via automated scanning as well as periodic manual review.

HOW SECURE IS MULTICLOUD IN PRACTICE?

People. Process. Technology. All working together to keep your data and applications safe across every cloud.

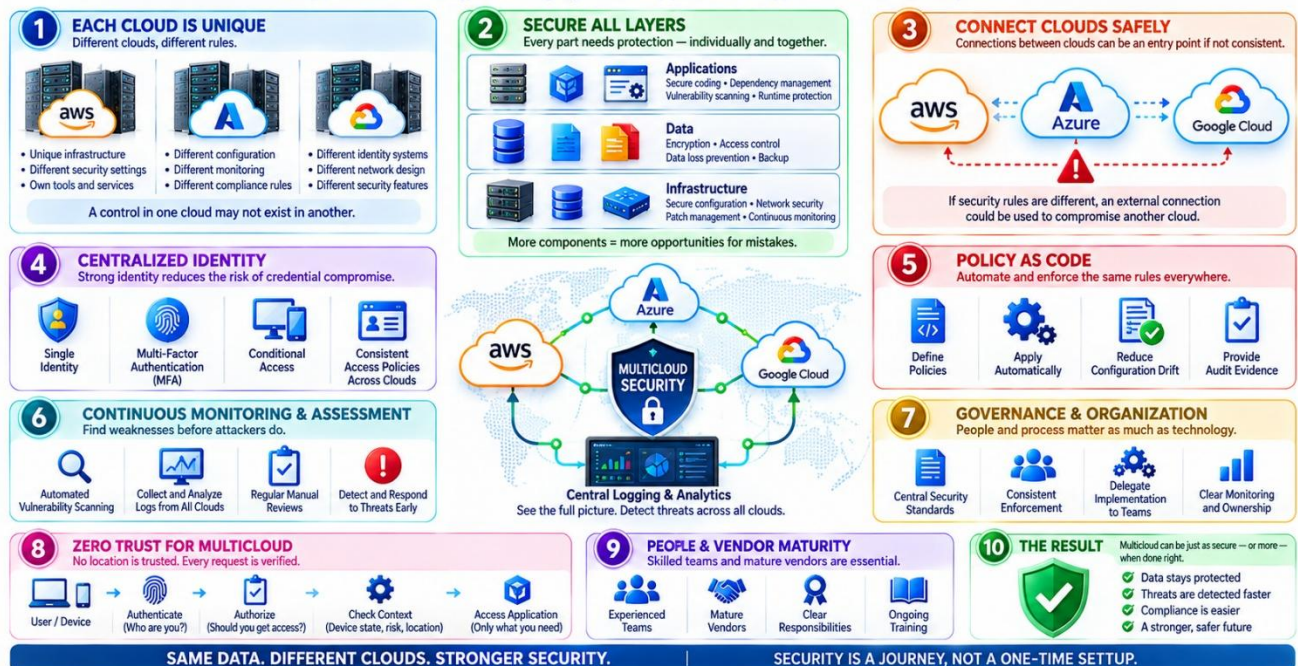


Fig -13: How Secure Multi-Cloud Is in Practice

Many of the most difficult security issues with multicloud aren't technical, but organizational. There are inconsistencies between different clouds with different cultural context that leads to gaps that can be exploited by different teams. This risk is diminished by a single security governance model, with standards being set in a central location and being consistent in enforcement. The downside is that a centralised security can be a restriction. A pragmatic solution is to have policy and automation centralized, while delegating implementation to the teams which are closest to the workloads, with clear monitoring and ownership of compliance.

Zero trust (ZTA) is a popular context for multicloud security. The basic concept is that no network location is trusted and every request needs to be authenticated and authorized depending on the context, device state, and identity. Zero trust is especially suited for the multicloud environment since it is not based on perimeter boundaries that are hard to maintain on a per-provider basis. Rather, it shifts the security enforcement to the identity and application layers, which can be consistent across all infrastructure.

Multicloud can be just as secure, or even more, as any one cloud deployments since it mandates consideration of practices that may be overlooked in single cloud deployments. But security is not a result of multicloud adoption. An active investment that needs to be maintained during deployment.

15. A BRIEF HISTORY OF MULTICLOUD

This multicloud model was not a direct product of the discussions. It went through a few stages of enterprise cloud adoption spanning about 20 years.

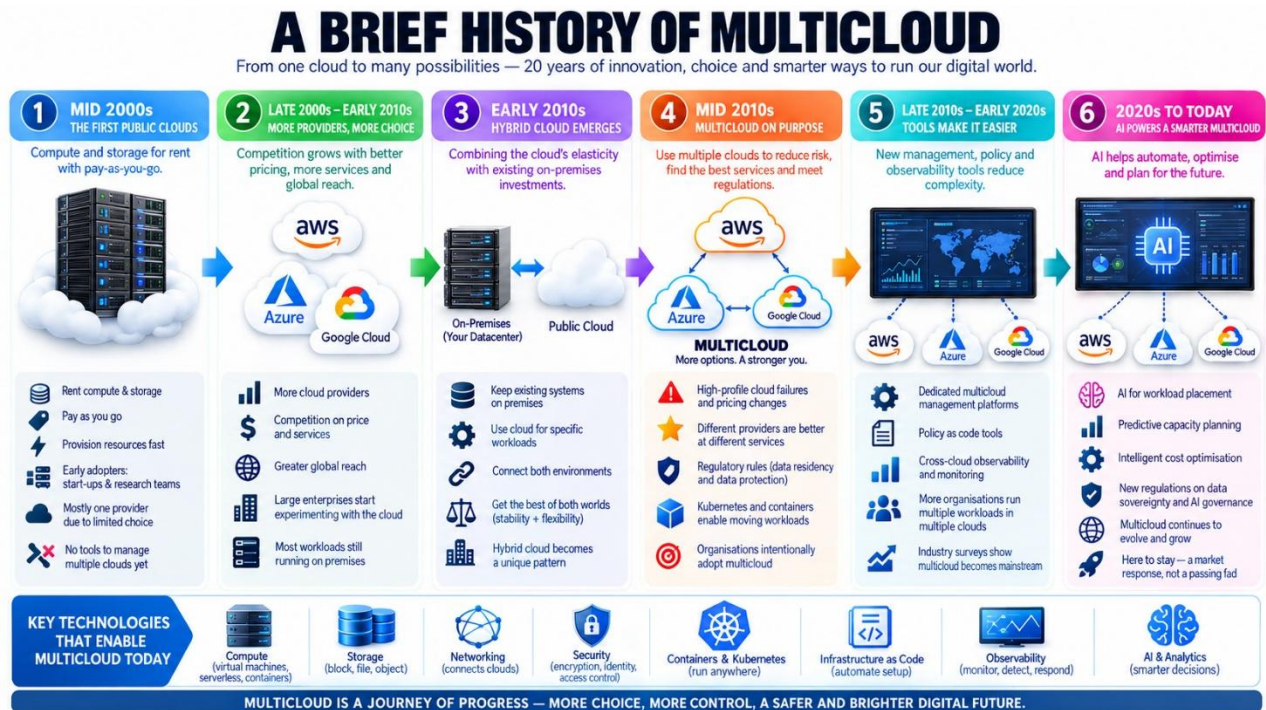


Fig -14: A Brief History of Multi-Cloud

Compute and storage resources were available for rent on the first commercial public cloud services in the mid-2000s, with the pay as you go model. Early adopters were mainly start-ups and research teams, who were attracted to provision resources fast, without capital expenditure. At this point, many organizations had only one provider due to a lack of choice, and an operational tooling to manage multiple providers didn't exist. During the late 2000s and early 2010s, there was a proliferation of additional providers, with competition on the ground in terms of pricing, services and geographic reach. As larger enterprises started to experiment public cloud for specific workloads with the bulk of their estate remaining on premises. This time gave rise to hybrid cloud as a unique pattern, incorporating the need to come together with the cloud elasticity and existing investments on premises.

The use of multicloud as a purposeful approach began to take place from the mid-2010s. Several factors contributed. The first is that the vendors' concentration issues were increasingly apparent with high-profile failures and shifting pricing impacting customers' economics. Second, meaningful differences emerged among the different services offered by service providers, such that no single provider was the **best** in all services. Third, regulatory constraints, notably data residency and data protection, complicated matters when operations needed to be conducted at a global level, with a single provider. Fourthly, the runtime portability of container orchestration platforms, especially Kubernetes, enabled the potential of moving workloads between providers.

As of the late 2010s and early 2020s, there were dedicated multicloud management platforms, policy as code tools, and cross cloud observability services. All of these tools lowered the burdens of running multiple

environments and opened multicloud access up to organisations that would otherwise have deemed it too complicated. Industry surveys throughout this period showed that a majority of enterprises had multiple workloads running in multiple public cloud, with varying level of commitment and awareness. The incorporation of AI in cloud activities has started to transform the practice of multicloud more recently. Multicloud management platforms are increasingly offering automated workload placement, predictive capacity planning and intelligent cost optimisation capabilities. The regulatory landscape is also continuously changing new regulations on data sovereignty and cross border transfers, and governance of artificial intelligence (AI) systems are also giving new dimensions to multicloud architecture decisions. The history is a good indicator that multicloud is no passing fad. It's a Market Response, in a market where cloud services are now too diverse, too important and too critical to tie up with a single provider.

16. CURRENT TRENDS IN MULTICLOUD

There are a few trends now that are influencing the practice of multicloud and will likely shape the multicloud practice in the coming few years.

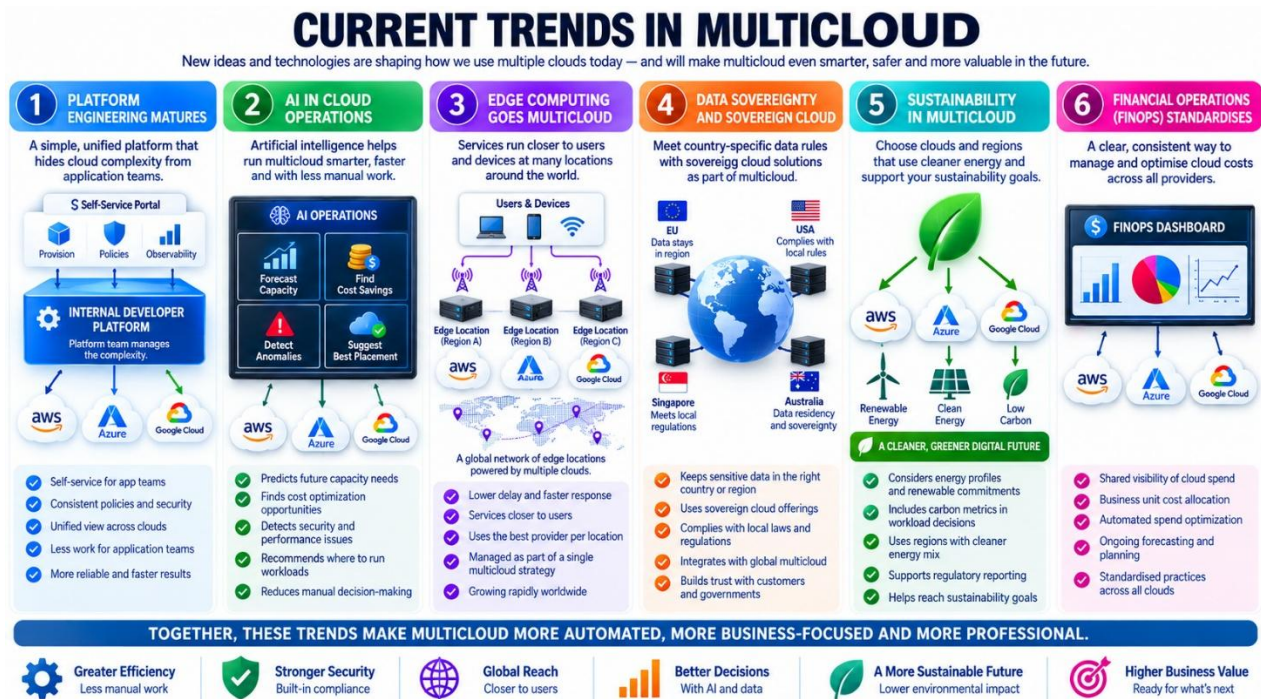


Fig -15: Current Trends In Multi-Cloud

The first is the fact that platform engineering is a maturing field. No longer do app teams want to handle the complexity of working with multiple clouds on their own, so many organizations are now creating internal developer platforms that normalize clouds on top. The developer faces a self-service interface to provision resources, enforce policies and gain observability, all the cross cloud complexity is managed by the platform team. This allows a lot of application teams to off-load the operation to a smaller platform team that is more specialized and generally has more consistent results.



The second trend is the use of AI in cloud operations. Capacity needs are being forecasted, cost optimization opportunities identified, security and performance data anomalies identified and workload placement decisions suggested with the help of machine learning models. These capabilities can mitigate the complexity of running a multicloud operation by eliminating the need for lots of manual decision-making.

The third trend is the rise of edge computing and the adoption of multicloud approach. Workloads are becoming closer to the users and devices and organizations are deploying services at hundreds or thousands of edge locations. This is because many of these edge environments are geographically dependent and or need to be on different provider networks based on partnership agreements, thus bringing the multicloud model to the edge. Whilst handling the deployment of edges in a unified way is an architectural priority, doing so as part of a multicloud strategy, not separately, is gaining momentum.

Rising to the fourth trend is the growing significance of data sovereignty and sovereign cloud offerings. Various countries have implemented conditions for the processing of some types of data, in particular with regard to citizenship or ownership of the operator. To meet these requirements, providers have responded with sovereign cloud solutions that meet these requirements and can be compatible with their larger portfolio of services. Sovereign cloud has become a part of multicloud strategies, with at least one sovereign cloud element in them to meet data residency requirements.

The 5th is the merging of multicloud with sustainability goals. Each provider will have varying levels of energy profiles, renewable commitments and carbon reporting capabilities. Companies aiming for sustainability goals are starting to include carbon metrics when selecting where and which provider to place their workloads, choosing areas and providers with a cleaner energy mix. This practice is at different levels of maturity, but has a rapid pace of growth due to increasingly stringent regulatory reporting requirements.

So, the sixth trend is the financial operations practices are becoming more and more standardised across multicloud estates. The practice of FinOps, a combination of finance, engineering and operations practices for managing cloud costs, is a key component of any serious multicloud program. Shared visibility of spend, business unit cost allocation, automated spend optimization and ongoing forecast to business plans are all features of mature FinOps practices.

In combination, the trends indicate that multicloud is becoming more automated, more attuned to the wider issues of business and more professional. The days of ad hoc multicloud are behind us and well toolled operating models are taking over.

17. PERSISTENT CHALLENGES IN MULTICLOUD OPERATIONS

While there have been strides in the past few years, there are still some current challenges in multicloud operations that need to be addressed directly. The issue of complexity is still the leading one. Each new cloud provider introduces more points of configuration, monitoring, security and governance. Despite these complicated tooling solutions, the cognitive load for operations teams is still much greater than what it is in a single provider setting. This complexity is often underestimated in organisations and makes the operational cost of multicloud eat into the cost saving or flexibility benefits that were anticipated.

There is the problem of skills shortage which adds to the complexity. It's hard to find anyone who knows the inside and out of any one cloud provider; to find someone with deep expertise in more than one provider is

rare. To attract and retain engineers who can work in a variety of settings, continuous efforts should be made to provide training, career growth and competitive salaries. Many organisations discover that they can't hire the personnel they require to run their multicloud ventures.



Fig -16: Persistent Challenges In Multi-Cloud Operations

The uncertainty of costs is another constant problem. Even though FinOps is a well-established practice, it's hard to accurately predict spending across multiple clouds. Data transfer costs these vary from provider to provider and vary depending on the direction of the data transfer can come as surprises when workloads change. Reserved capacity commitments generate savings on anticipated workloads which can end up stranded as workloads change. Idle resources occur when teams are provisioned for peaks that don't come. These are all problems which can in principle be solved, but the solution must be maintained. Interoperability remains imperfect. Although the container platform and open source tooling have come a long way, work still needs to be done to move workloads from one provider to the next. Managed services are increasingly a part of cloud consumption, but they may have interfaces that are specific to the service provider, making it difficult to port them. Data gravity, or the notion that large amounts of data tend to dictate where workloads live, makes these kinds of workloads essentially immobile, no matter how technically portable their application code is.

It is hard to ensure security consistency. There is a multitude of security primitives per provider and it is challenging to convert a uniform security posture across all the providers without custom engineering, or relying on 3rd party platforms. Similarly, auditing and compliance reporting is difficult if evidence needs to be collected from several places and needs to be reconciled. Governance fragmentation occurs when various teams are using various providers for various reasons. The end result can be technically referred to as "multicloud" but is not necessarily the result of a conscious strategy. It is a common challenge for enterprise architecture teams to deal with such accidentally-cloudy estates and make them manageable.

Finally, an on-going challenge is change management among providers. All the providers roll out new services, phase out older services and change pricing when they see fit. It's only when there's a surprise that people focus on the changes across providers and their implications, and that's only if they are dedicated enough to do so. While each of these obstacles is not insurmountable, it's important to recognize them. Multicloud is a brainchild, not a solved problem.

18. SOLUTIONS AND MITIGATIONS

Industry experience has come up with practical mitigations for each of the persistent challenges.



Fig -17: Solutions And Mitigations For Multi-Cloud Challenges

Platform Engineering and Automation are the best answers to complexity. With internal platforms that abstract away cloud provider nitty-gritty and store the operations within these platforms, organizations can keep most teams from touching any of the cloud provider specifics. In addition, automated testing, infrastructure as code and policy as code further decrease the manual work for maintaining consistency. When dealing with skills shortages, proactive skill building initiatives yield better results than reactive recruitment. Delivering training, certifications, rotations and communities of practice enables the development of internal capability over the long term. For certain needs, organisations can contract out specialist services to complement in-house capacity but should exercise caution when outsourcing in-depth knowledge which the organisation will require for an indefinite period.

FinOps practices with its disciplined approach replace cost unpredictability. The regular review cadences, shared accountability of engineering and finance, automated anomaly detection, and clear chargeback models all add to greater predictability. Reserved capacity commitments should be made with caution and regularly re-evaluated, and not as **set and forget** commitments. The more portability is considered as



a first class architectural concern, the better interoperability is. Using portable abstractions, being able to run your workloads in a **portable** way across multiple environments, and testing your portability regularly all helps to avoid hidden dependencies. In managed services where portability isn't an option, the compromise should be made with awareness and recorded, to enable later teams to be aware of the consequences.

Centralized identity, consistent policy frameworks and unified monitoring can help achieve security consistency. A zero trust architecture applied consistently, decreases the requirement for provider specific security primitives. By testing across the entire multicloud estate regularly, with penetration testing and red team exercises, these issues that single environment testing would have missed up will be found out. The best way to manage governance fragmentation is to create an operating model with decision making rights, and roles and standards that are clearly defined across the multiple clouds. Cloud CoEs, cross functional governance structures, and codified reference architectures facilitate bringing diverse teams together to work with common goals without losing innovation.

Structured provider announcement, implications analysis and communication tracking processes among the provider(s) streamline provider change management. Now there are several commercial and open source tool which can be used to collect provider announcements and change notes, which will help to keep manual efforts to a minimum for this task. In addition to the above mentioned mitigations, there are a number of cross cutting practices that improve multicloud outcomes. Too often underestimated documentation discipline comes in for special significance when multiple environments and tools are involved. Postmortem culture, which looks for lessons learnt in the system not the individual, results in ongoing improvements to operational practices. Drift is detected during regular architecture reviews, before it turns into tech debt. While these practices don't make multicloud go away, they make it a more manageable and ongoing task.

19. ETHICAL AND SOCIETAL DIMENSIONS OF MULTICLOUD

The introduction of multicloud is not just an operational issue, but also poses ethical and societal concerns. Such a high degree of consolidation of computing power by a few providers, even if spread out among them, poses issues of market power, systemic risk, and critical infrastructure resilience. If public services, financial systems, and health care platforms rely on a handful of providers, any failure of or policy change by a single provider can have ramifications beyond just those with the specific customer. Another concern is that of data stewardship. Multicloud organizations are responsible not just for following the law, but are also stewards of information that is placed under their care. This means being clear about the location of data processing with users, obtaining meaningful consent for cross-border transfers and taking into account the intersection of data transfers with human rights structures.

There are also workforce implications that need to be considered. Multicloud expertise skills is the focus of experts in specific areas and companies, and this may exacerbate economic inequalities. Policies and programs affecting the workforce, such as public investments in cloud literacy and equal opportunities for training, shape the extent to which the rewards of cloud computing are distributed or concentrated. The topics are related to environmental responsibility. The energy consumption of cloud infrastructure is significant and on the rise, and where workloads are placed can have an impact on the climate. Incorporating ethics in the use of multicloud involves clear transparency on environmental impact and being willing to make compromises between cost efficiency and sustainability.

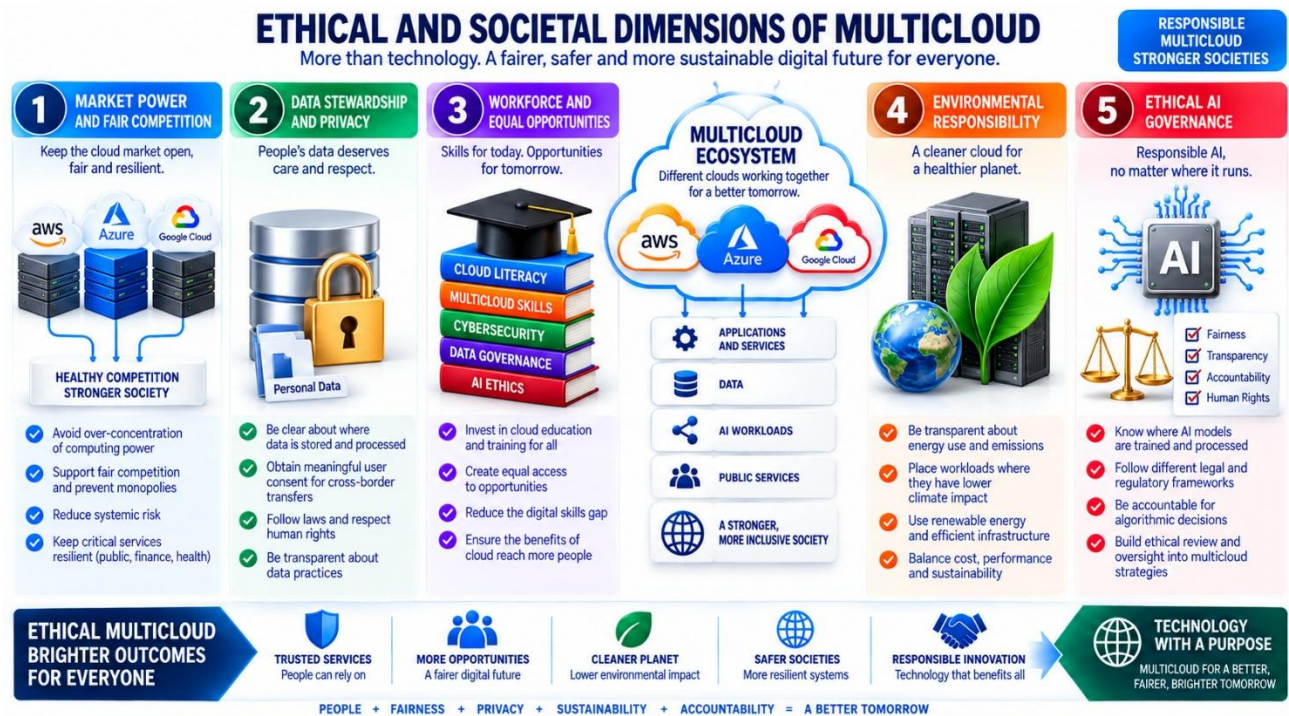


Fig -18: Ethical And Societal Dimensions of Multi-Cloud

Last, running AI workloads across a multi-cloud setup requires new ethical considerations of the governance of these workloads. The training, inference and processing of models can be done in different jurisdictions, and with different supervisory frameworks, making it difficult to hold responsible parties liable for algorithmic decisions. These ethical aspects must be part of a thoughtfully developed multicloud strategy and not just ancillary issues, but rather integral to responsible practice.

20. FUTURE PROSPECTS FOR MULTICLOUD

In the future, there are a number of developments that are likely to influence the future of multicloud computing.

The first is the ongoing de-materialization of infrastructure. Higher level abstractions are starting to appear for data, machine learning models and even patterns of applications just like containers did for applications and made them portable across providers. Additionally, over time, these abstractions will make multicloud more affordable and accessible and make workloads that are attached to specific providers candidates for multicloud.

The second is the further integration of AI in the cloud. Autonomous or semi-autonomous systems which postpone the workload, optimize costs, detect threats and respond to incidents are already under development. The systems will eventually help to alleviate the burdens of operating multi-cloud, and enable smaller teams to manage larger and more complex estates.

The third are changing regulations. Rules on data sovereignty, restrictions on cross border transfers of data and sectoral rules will continue to multiply. These policies will drive more workloads towards the multicloud

by eliminating the possibility of a single provider deployment for workloads handling global operations. Meanwhile, compliance requirements will increase and compliance tooling will become more complex.

The fourth is the coming of age of sustainability factors. Due to growing climate-related reporting requirements and the continuing move towards tangible corporate sustainability goals, carbon metrics will be increasingly considered when deciding on workload placement. Partly due to the carbon footprint of their operations, providers will be competing, and the environmental impact (as well as cost and performance) will be routinely weighed into multi-cloud strategies.



Fig -19: Future Prospects For Multi-Cloud

The fifth one is the continuing trend towards edge and distributed computing. The perception of the core cloud/edge divide will become indistinct as increasing amounts of processing occur closer to the user/device. Multicloud will also expand to hundreds or thousands of edge sites, and those practices that work well for a few centralized clouds will have to be scaled accordingly.

The sixth is the possibility for truly open interoperability standards to come to fruition. There are a number of industry initiatives that seek to bring consistency in APIs, data styles and operational interfaces among providers. With all of these efforts, the multicloud friction will be significantly reduced. But if, like other attempts, they fail to take off, differentiation between providers will continue to be dominant and multicloud complexity will continue.

The economic shift between cloud and on premises is the 7th. Cloud economics has changed a number of times and evolving hardware costs, power consumption and workloads may bring some workloads back on premise or onto private clouds. The future multicloud approaches will probably involve a more porous public cloud, private cloud and on premises separation.



The route of travel is clearly indicated. Multicloud will become more automatic, smarter, more controlled and more business strategy aligned. When it comes to working in this environment, those that invest in the capabilities to do so will have a sustainable advantage. Multicloud, as an incidental outcome of departmental purchasing will leave those who do so increasingly disadvantaged.

21. CONCLUSION

Multicloud is no longer a niche play, and has become an operating model for enterprise tech. The motives are based on actual business needs. None of the cloud providers has the best in any category, is invulnerable to failures, or meets all regulation standards in all jurisdictions that modern businesses operate. Multicloud is a solution that helps to overcome these, with the deliberate distribution of workloads to environments with particular strengths. Based on the analysis detailed in this article, it is clear that multicloud can be a valuable solution but only when treated as a strategic program, and not an incidental. Success ingredients are universal to all industries. Cloud agnostic architecture decisions mean that portability is maintained. Centralized governance makes things consistent across environments. The financial operations are well-managed, with costs that are predictable. Integrated security policies deliver security throughout the entire estate. All of these need investment and a short cut in any one area is likely to have a negative impact on the whole.

Multicloud is not without its difficulties, but it is a situation that can be controlled. There are proven practices and the right tools which can be used to overcome complexity, skills shortages, cost uncertainty, interoperability challenges, and security consistency. Those groups that embrace these issues as design constraints and find solutions to them have better results. The path forward is towards increased automation, greater business integration and increasing regulatory complexity. Multicloud doesn't represent end state of enterprise computing. It's the next step in a long-term progression toward flexible, resilient and distributed information technology.

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