Personal Project

Green Cloud Computing:
Sustainable Azure Architecture.

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Summary

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1. Introduction

Green sustainable cloud computing has emerged as a crucial approach to address the environmental challenges that have emerged from traditional IT infrastructure. As organizations increasingly rely on cloud computing to meet their computational, managerial, operational and storage needs, there is a growing emphasis on minimizing energy consumption, reducing carbon emissions, and promoting sustainability within the cloud ecosystem. Azure, Microsoft's cloud computing platform, has recognized the importance of sustainability and has undertaken significant initiatives to create a sustainable and more environmentally responsible cloud infrastructure. This project will explore green, sustainable cloud computing in Azure, diving into the programs and tools for users to analyze and gain knowledge to design eco-friendly architectures. Within the Azure cloud ecosystem, we will investigate a variety of tools, services, and best practices that can assist enterprises in maximizing energy use, cutting waste, and reducing their overall environmental impact. The benefits of utilizing Azure's serverless computing capabilities, right-sizing virtual machines, and optimizing data storage to further enhance energy efficiency and resource utilization will be discussed. Furthermore, Azure’s support for infrastructure-as-code techniques will be researched. This lets businesses automate resource provisioning and management to ensure reliable deployments and reduce human error.

2. Overview

2.1 Problem Definition

The problem being undertaken in this project are the implementation strategies and technologies required to effectively deploy green cloud computing architectures in enterprise networks using the Azure Cloud Provider. Enterprises face challenges in identifying the specific tools, configurations, and best practices that enable companies to optimize resource utilization, reduce energy consumption, and minimize environmental impact within the Azure environment. In addition, investigate what are the technical, environmental and business benefits and challenges when implementing and considering a sustainable architecture in an enterprise environment compared to on-premises infrastructure.

2.2 Project Goal

The goal of this research project is to investigate and identify the strategies and technologies for implementing green cloud computing in enterprise networks, focusing on the Azure Cloud Provider. The purpose of this study project is to look into and pinpoint the technologies and implementation plans for green cloud computing in enterprise networks, with a particular focus on the Azure Cloud Provider. In order to provide useful information and direction for businesses looking to include environmentally friendly practices into their cloud infrastructure, the project intends to assess the possible advantages and difficulties involved with implementing these approaches in Azure. By focusing on this objective, the research seeks to close the knowledge gap and show possibilities for businesses that want to use Azure's capabilities for having a sustainable enterprise infrastructure.

2.3 Situation

According to Enlyft, a data analyzing platform for companies to analyze their insights, claim that they have data on 537,837 companies that use Microsoft Azure. The companies using Microsoft Azure are most often found in United States and in the Retail industry. Microsoft Azure is most often used by companies with 1-10 employees and 1M-10M dollars in revenue. In Figure 2.3.1, we can see a bar graph created based on the information found. The graph represents the number of companies per employee quantity. The y-axis represents the number of companies, and the x-axis represents the companies with the represented number of employees. For example, there are 257,671 companies that use Azure with 10-50 employees. Of all the customers that are using Microsoft Azure, a majority (59%) are small (<50 employees), 11% are large (>1000 employees) and 31% are medium-sized (Enlyft, 2023).

Based on this information, the research will focus on a case study regarding a small retail company. Currently the company has around 30 employees and have their infrastructure on-premises. The project will focus on analyzing the migration of this company’s infrastructure from on-premises to a sustainable cloud solution.

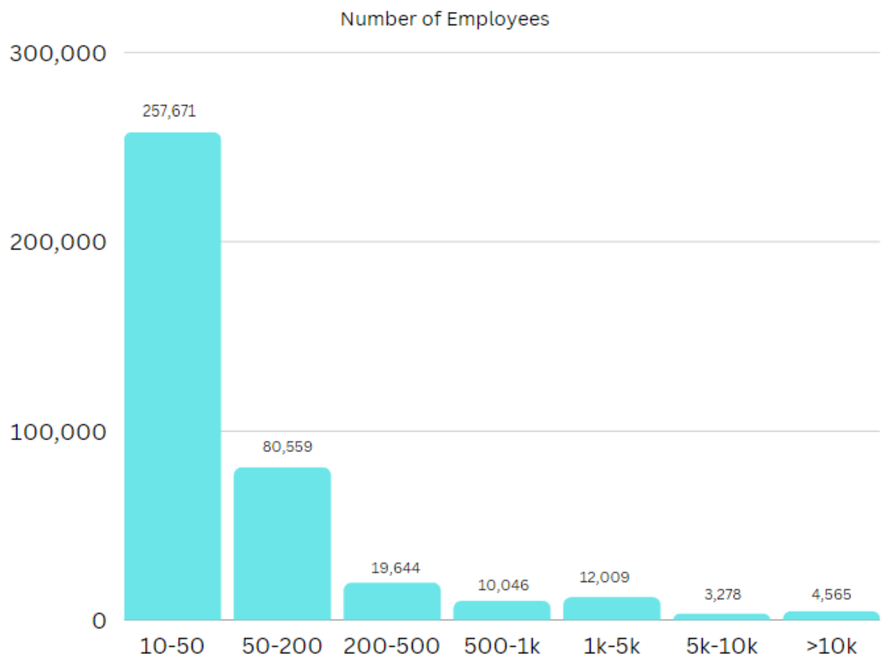


Figure 2.3.1 Chart that represents the employees per companies according to Enlyft.

3. Research Questions

The research questions for this paper aim to explore the implementation of a sustainable cloud architecture in an enterprise environment and identify the challenges, benefits, and best practices associated with using this type of architecture. By addressing these research questions, a comprehensive overview of sustainable cloud architecture in an enterprise environment will be done and intends to help organizations make informed decisions about their architecture workflow, workload, and strategies.

3.1 Main Question

- What are the environmental and business-related impact of implementing Azure infrastructure compared to on-premises architectures when considering sustainable strategies and technologies?

3.2 Sub Questions

1. What are the key strategies and technologies that enterprises can employ to implement green cloud computing in their networks within the Azure Cloud Provider?
2. What are the specific environmental impacts of implementing Azure infrastructure compared to on-premises architectures?

3. What are the operational impacts that differ between Azure infrastructure and on-premises architectures?
4. What are the non-technical benefits of sustainable cloud computing? (For example, market impact).

4. Research Methodology

The research methodology section of this paper describes the approach used to answer the research questions and achieve the objectives of the study. In this section, the DOT framework will be taken into consideration to perform the investigation. The strategies or methods that will be used during this research are mostly library and lab strategies. Through Chapter 4, the research will explain about the infrastructures, cloud computing, workloads and the different benefits of using cloud providers to enable sustainability in IT operations.

4.1 On-Premises Infrastructures vs Cloud Infrastructures

On-premises infrastructure refers to the traditional approach of hosting and managing IT resources within an organization's physical premises, such as data centers or server rooms. In an on-premises infrastructure, the organization is responsible for procuring, installing, configuring, and maintaining the hardware, software, and networking components required to support its IT operations (Team Cleo, 2023). Organizations may fully customize and have control over configuration, security policies, and data management using on-premises infrastructures, which provide them full ownership and control over the hardware, software, and data. However, the company needs a large initial capital outlay for the purchase and upkeep of hardware and software. It takes a lot of time and resources to scale an on-premises infrastructure since it requires accurate forecasting of future requirements and provisioning of extra resources. The organization's IT team is in charge of maintenance duties, such as hardware repairs, software upgrades, and security patches, which necessitate ongoing efforts to assure availability, performance, and security.

On the other hand, cloud service providers like Azure offer cloud infrastructures. They provide a variety of resources and services that can be accessed online from a distance. They function according to a pay-as-you-go, allowing businesses to pay for resources according to usage, obviating the need for up-front capital expenditure, and enhancing cost effectiveness. The near-instant scalability of cloud infrastructures enables prompt resource reallocation in response to changes in demand. Cloud service providers take care of maintenance activities like hardware updates and software patches, relieving companies of the load of infrastructure. With redundant data centers, cloud infrastructures are accessible from anywhere in the world, offering availability and resilience. Additionally, they provide a variety of services that let businesses use virtual computers, storage, databases, networking, AI, and analytics without having to set up or manage a sizable infrastructure.

4.2 Green Cloud Computing & Sustainable Workloads

Green cloud computing, also known as environmentally friendly or sustainable cloud computing, refers to the use of cloud computing technologies and practices that aim to minimize the environmental impact associated with data centers and IT infrastructure. It focuses on reducing energy consumption, carbon emissions, and waste generation (Lucid Team, 2023). There are many benefits for an enterprise when considering sustainability and environmental responsibility in an enterprise when it comes to IT operations, workloads and other processes. Benefits are not only technical, but also increase the market value of the company. In the following chart it is possible to observe the most important benefits when considering sustainability in an enterprise cloud architecture.

A sustainable workload describes the practice of designing solutions that maximize utilization while minimizing waste, ultimately reducing the footprint on the environment. Combining efforts for cost optimization, carbon emission reduction, and energy consumption optimization is necessary to increase the efficiency of workloads in the cloud. Making workloads more sustainable begins with optimizing the cost of the application (Microsoft, 2023).

According to Microsoft, in order to build an efficient sustainable cloud solution there are several design areas that have to be taken into consideration. The following chart shows the key design areas to be analyzed when building a green cloud solution for an enterprise architecture:

Design area	Description
Application design	Cloud application patterns that allow for designing sustainable workloads.
Application platform	Choices around hosting environment, dependencies, frameworks, and libraries.
Testing	Strategies for CI/CD pipelines and automation, and how to deliver more sustainable software testing.
Operational procedures	Processes related to sustainable operations.
Storage	Design choices for making the data storage options more sustainable.
Network and connectivity	Networking considerations that can help reduce traffic and amount of data transmitted to and from the application.

Security	Relevant recommendations to design more efficient security solutions on Azure.

4.3 Right Sizing

Right sizing in infrastructures refers to optimizing the allocation of resources to match the specific needs of an application or workload. This practice helps organizations achieve sustainability goals by minimizing resource waste, reducing energy consumption, and optimizing the overall environmental impact of their infrastructure. Furthermore, right sizing supports scalability and elasticity. As applications and workloads change over time, the resource requirements may continuously change. Right sizing in infrastructures promotes sustainability by optimizing resource allocation, reducing waste, improving energy efficiency, and minimizing the environmental impact of data centers. By accurately matching resource allocation to workload demands, organizations can achieve a more sustainable and environmentally conscious infrastructure while still meeting performance requirements.

Azure provides auto-scaling capabilities, allowing resources to be automatically adjusted based on predefined conditions or performance metrics. This helps ensure optimal resource allocation during peak times while reducing resource waste during low-demand periods (Microsoft, 2023).

Organizations operating on-premises infrastructures need to carefully analyze resource usage patterns, anticipate future demands, and allocate resources accordingly to prevent underutilization or overprovisioning. This requires proactive monitoring, capacity planning, and resource management practices. While on-premises infrastructures may not have the same level of automation and scalability as Azure, organizations can still implement right sizing practices by continuously monitoring resource utilization, identifying opportunities for optimization, and making informed decisions about resource allocation and capacity planning.

In Figure 4.3.1, it is represented the alarm rules I put in place for a virtual machine. These alerts will let the IT admin or the person responsible that certain metrics have been reached. In addition to being notified, the alerts will work together with an autoscaling group in order to auto scale accordingly to the rules. By setting the alert rules properly, a lot of energy can be saved and less wasted resources, concluding in environmental impact and cost reduction.

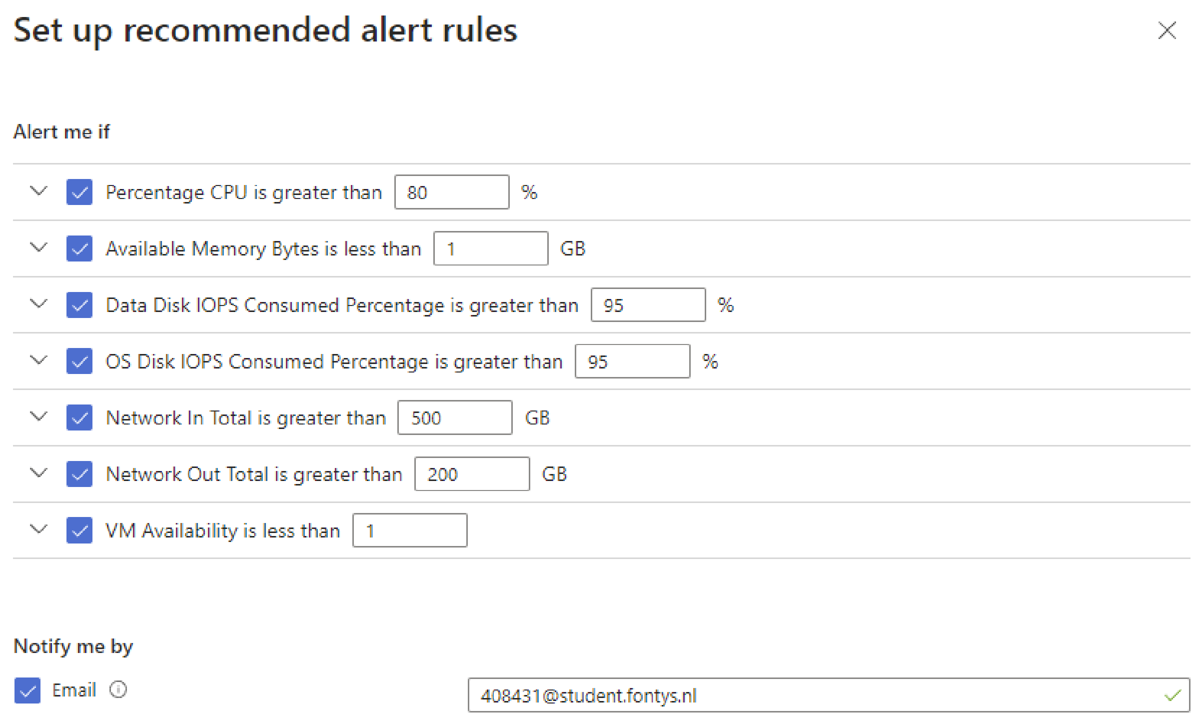


Figure 4.3.1 Settting up alert rules and thresholds.

4.4 Monitoring

Monitoring resource usage is crucial in both Azure and on-premises environments to avoid wasting resources and promote sustainability. Azure provides robust monitoring tools and services that enable organizations to gain insights into resource utilization, performance metrics, and cost optimization. Companies can identify resources, zombie workloads, detect performance bottlenecks, and make informed decisions on right sizing. This proactive monitoring approach helps prevent resource waste, optimize resource allocation, and reduce unnecessary costs. In addition, Azure's cloud-based infrastructure allows for dynamic scaling as mentioned on 4.3 Right Sizing chapter, enabling companies to set resource allocation with actual demand and minimize wastage.

Compared to Azure, on-premises infrastructures are not very different to cloud solutions in terms of monitoring, although monitoring on-premises infrastructures will have limitations when scaling dynamically. Both types of infrastructures will help organizations identify areas of resource waste, such as underutilized servers or inefficient configurations. By analyzing the collected data, organizations can make informed decisions on right sizing, capacity planning, and infrastructure optimization. This helps prevent resource overprovisioning and reduces energy consumption, leading to improved sustainability.

Furthermore, in Figure 4.4.1, it is possible to observe a CPU stress test on a virtual machine. The graph shows the first part, which is when the VM is being deployed. After a while, the machine is ready to be functional. After the stress test it is clear a rise in the CPU usage. Due to the previous configuration for the alert rules shown in Figure 4.3.1, after the stress test an email was received to the given address in the alert rules as seen in Figure 4.4.2.

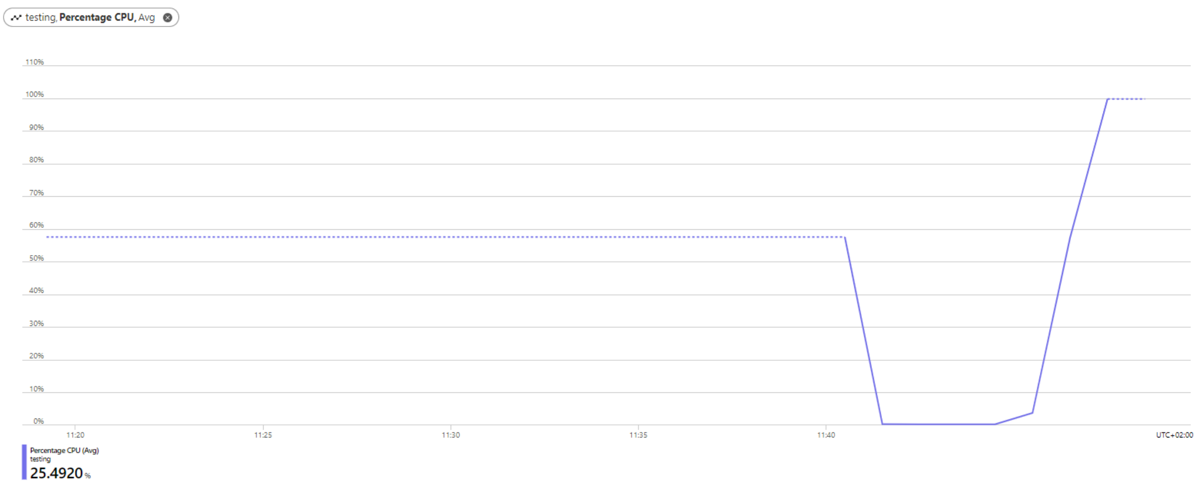
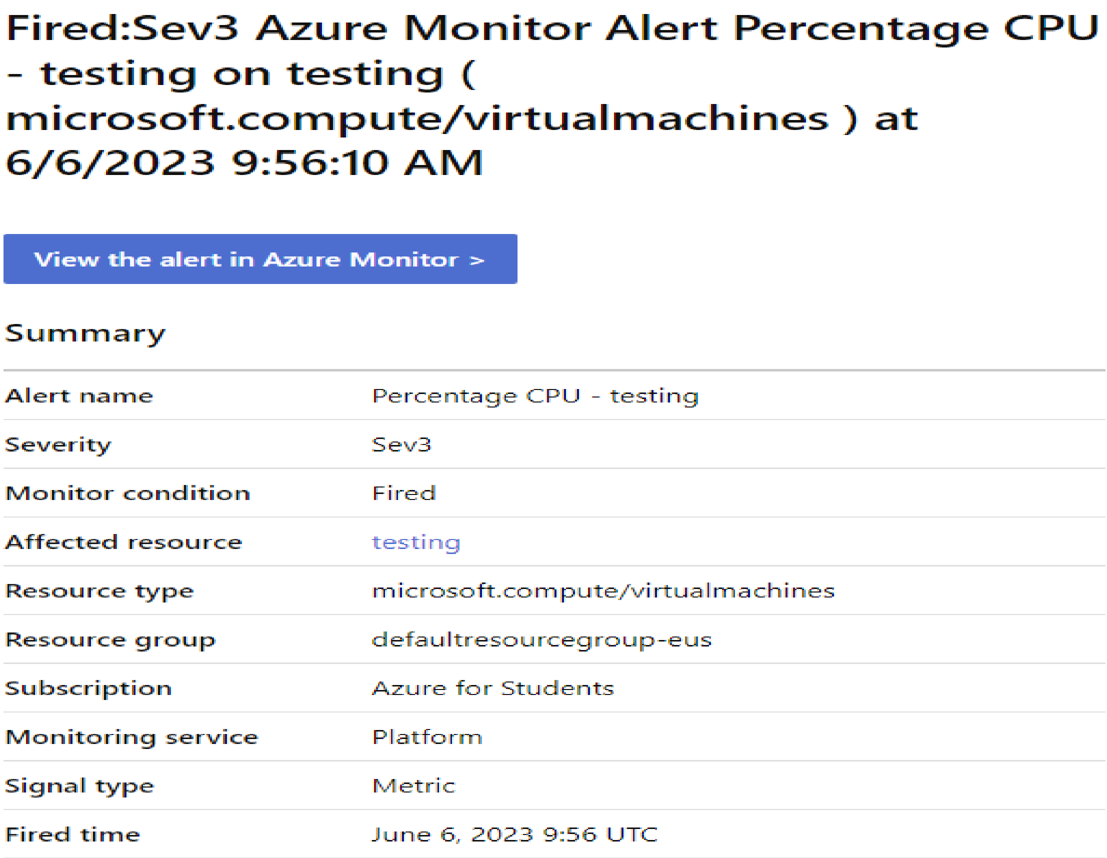


Figure 4.4.1 Testing for energy usage and alarms.



Fired:Sev3 Azure Monitor Alert Percentage CPU - testing on testing (microsoft.compute/virtualmachines) at 6/6/2023 9:56:10 AM

View the alert in Azure Monitor >

Summary

Alert name	Percentage CPU - testing
Severity	Sev3
Monitor condition	Fired
Affected resource	testing
Resource type	microsoft.compute/virtualmachines
Resource group	defaultresourcegroup-eus
Subscription	Azure for Students
Monitoring service	Platform
Signal type	Metric
Fired time	June 6, 2023 9:56 UTC

Figure 4.4.2 The alarm received when using too much energy.

4.5 Automation

Regarding automation, there are several key differences between Azure cloud provider and on-premises infrastructure. To begin with, in the Azure cloud, automation tools like Azure Functions or serverless computing abstract the infrastructure layer, allowing developers to focus solely on writing code or scripts. The cloud provider handles resource provisioning, scalability, and management. In addition, automation in the enterprise will benefit from the cloud provider's built-in redundancy and high availability. Azure Functions and other cloud services are deployed across multiple data centers, ensuring reliability and fault tolerance in IT operation and development operations. Furthermore, automation services can help manage and maintain the infrastructure in the cloud provider, including regular updates and security patches. This reduces the burden on IT staff and ensures the infrastructure remains up-to-date and secure. Finally, on of the most important aspects is costs. Costs in Azure when it comes to automation more efficient as organizations are billed based on usage and resource consumption. This provides cost flexibility and scalability compared to on-premises.

On the other hands, on-premises automation, requires manual provisioning and management of infrastructure resources, such as servers, networking equipment, and storage, which can be more time-consuming and require dedicated IT staff. On-premises also require organizations to handle maintenance tasks, updates, and security patches themselves, which can be more time-consuming and resource-intensive. Lastly, on-premises infrastructure requires planning to scale, and zombie workloads can run undetected. On-premises is usually, less cost effective because it requires upfront investment in hardware, software licenses, and ongoing maintenance costs.

In Figure 4.5.1, we can see an AKS Cluster deployed. By using this service automation in the deployment, management and scalability through the node pool. The scalability of the node pool depends on the configurations and alarms on the AKS.

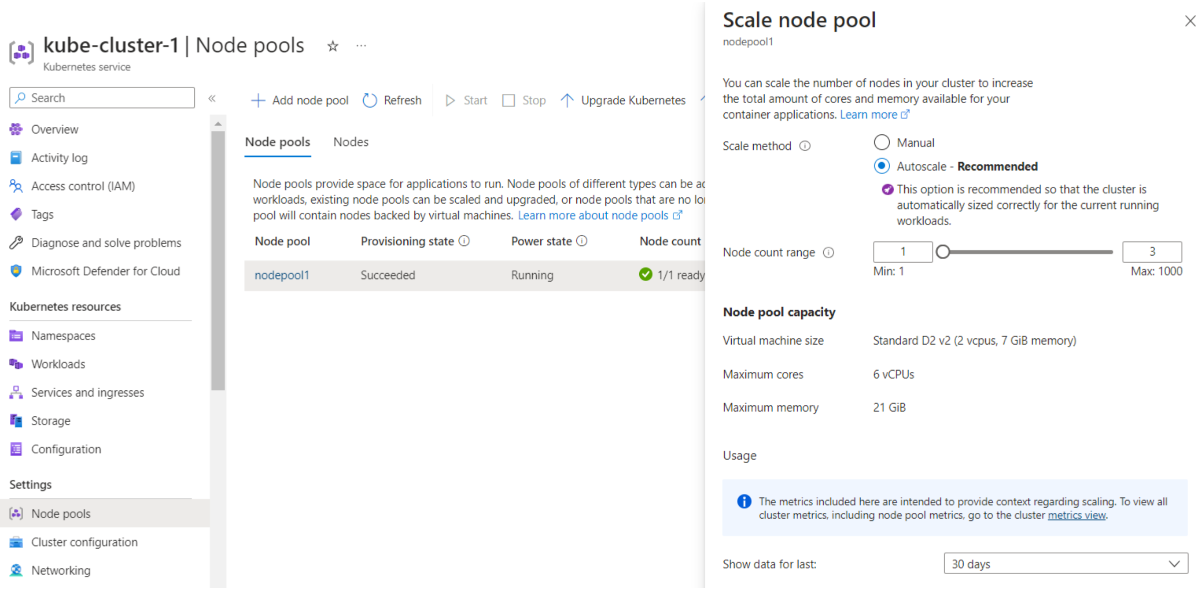


Figure 4.5.1 Shows the possibility of scaling automatically and other automation options in a Cluster and Node Pool.

4.6 Infrastructure as a Code

Infrastructure as code (IaC) is a DevOps practice that involves the management of infrastructure, such as networks, compute services, databases, storages, and connection topology, in a descriptive model. IaC allows teams to develop and release changes faster and with greater confidence (Microsoft, 2023). In Azure it refers to the practice of defining and deploying infrastructure resources, such as virtual machines, storage accounts, networks, and other components, using declarative code. The infrastructure defined in the code can be deployed and destroyed as the user sees convenient. IaC automates the deployment and management of infrastructure, reducing the need for manual intervention. This reduces the risk of human error and increases the speed of deployment. The code can be written in different programming languages.

Some of the most popular tools and/or programming languages that can deploy IaC to Azure services are the following:

1. **Azure Resource Manager (ARM) Templates**: ARM templates are JSON-based templates specific to Azure. They allow you to define and deploy infrastructure resources using a declarative syntax.
2. **Terraform**: Terraform is an open-source infrastructure provisioning and management tool that supports multiple cloud providers, including Azure. Terraform also has libraries for different programing languages called Cloud Development Kit. This library enables developers deploy IaC using more popular programming languages such as Python, Typescript, Golang and others.

3. **Azure CLI**: Azure Command-Line Interface (CLI) is a command-line tool that provides a set of commands for interacting with Azure resources. This service will let you connect to Azure service from your command line. It will allow scripts and automation of infrastructure provisioning and management using shell scripts.

The above service and/or programming languages are the most popular ways to deploy infrastructure as a code in Azure Cloud services.

An example of a piece of code of IaC can be seen in Figure 4.6.1. The snippet was taken from a project where I personally participated (SUE Multi-Cloud Terraform using CDK), and CDK for Terraform in Python was used to deploy a scalable development environment. This code snippet shows the creation of and AKS cluster in Azure Cloud Provider using Terraform and CDK. In detail the code creates an AKS Cluster and a node pool where the services can be executed.

```
# AKS Cluster ceation
            identity = KubernetesClusterIdentity(type="SystemAssigned")

            node_pool = KubernetesClusterDefaultNodePool(
                name=f"nodepool{index+1}",
                vm_size="Standard_D2_v2",
                vnet_subnet_id=azurerm_subnet_voteapp_aks.id,
                zones=["1", "2", "3"],
                enable_auto_scaling=True,
                max_count=3,
                min_count=1
            )

            networkprofile = KubernetesClusterNetworkProfile(
                network_plugin="azure",
                dns_service_ip="10.0.0.10",
                docker_bridge_cidr="172.17.0.1/16",
                service_cidr="10.0.0.0/16",
                load_balancer_sku="standard"
              )

            cluster = KubernetesCluster(self, f"kube-cluster-{index+1}",
                name=f"kube-cluster-{index+1}",
                default_node_pool=node_pool,
                dns_prefix=f"kubecluster{index+1}",
                location=Token().as_string(resource_group.location),
                resource_group_name=Token().as_string(resource_group.name),
                identity=identity,
                network_profile=networkprofile,
            )
```

Figure 4.6.1 The image from SUE Multi-Cloud project that deploys AKS environmnent.

4.7 Azure Tools and Services

To create a sustainable cloud architecture in Azure there are several tools and services that can be used. The tools and services that are going to be researched can assist a company to optimize resource usage, reduce energy consumption, and minimize environmental impact. The following services and tools are the most commonly used when planning or deploying a sustainable cloud architecture in Azure (Microsoft, 2023):

- **Azure Advice**: Azure Advisor makes suggestions to optimize resource utilization, cost optimization, boost performance, and strengthen security in your Azure setup.
- **Azure Monitor**: It offers metric, log, and diagnostic monitoring and alerting features. Organizations can optimize resource allocation, increase efficiency, and minimize environmental impact by carefully monitoring resource utilization and spotting inefficiencies or anomalies.
- **Azure Cost Management and Billing**: Helps optimizing resource usage and controlling costs, organizations can reduce waste and promote sustainability.
- **Azure VM Sizing**: By choosing the right VM size, businesses can improve sustainability by not overprovisioning resources and consuming less energy.
- **Azure Autoscaling**: Azure Autoscaling enables organizations to automatically adjust resource capacity based on predefined conditions or performance metrics. By using this service, organizations can ensure optimal resource utilization depending on the controlled metrics.
- **Azure Resource Manager**: Organizations may automate infrastructure provisioning, standardize deployment procedures, and guarantee consistency by using ARM templates. By managing infrastructure effectively, this helps avoid manual errors, streamline resource allocation, and encourage sustainability.
- **Azure Automation and Functions**: You can run event-driven code using Azure Functions' serverless computing features without setting up or managing infrastructure. With serverless computing, you can automatically scale your applications based on demand, minimizing resource waste and energy usage during downtime.

5. Results

Technical Benefits	
Benefit	**Explanation**
Scalability	Cloud computing offers scalability advantages as resources can be dynamically allocated and adjusted based on demand and the predefined metrics, allowing organizations to efficiently handle varying workloads. In a small company, scalability enables the company to only pay for the resources they need, leading to cost savings and improved operational efficiency.
Availability	Availability refers to the accessibility and reliability of services and resources. This ensures that services and applications are accessible to users even in the event of hardware failures, network disruptions, or other unexpected incidents. This allows small companies to provide uninterrupted services to their customers and minimize any potential loss of revenue or productivity.
Adaptability	It involves the capability to modify configurations, allocate resources, and scale the system to meet evolving needs. This enables organizations to respond efficiently to changing business demands and optimize resource allocation, leading to improved agility and cost efficiency.
Monitoring	Monitoring in cloud computing involves the continuous tracking and measurement of system components, resources, and applications to collect data on performance, availability, and utilization. Monitoring helps small companies maintain a high level of service quality and make event driven decisions to improve their operations.
Automation	Automation refers to the application of software and tools to the management, provisioning, and upkeep of cloud resources in order to eliminate manual labor and repetitive operations. It

	lets firms to scale more easily, focus on higher-value operations rather than routine administrative work, and quickly adjust to shifting demands. Automation helps small companies improve efficiency, reduce human errors, and achieve consistent and reliable performance in their cloud-based operations.

Business Related Benefits	
Benefit	**Explanation**
Regulations and Compliance	Regulations and compliance refer to adhering to legal requirements, industry standards, and guidelines related to environmental sustainability and data protection. Small companies often have limited resources to dedicate to managing regulatory compliance. By utilizing sustainable cloud solutions, they can leverage the compliance frameworks and certifications offered by cloud service providers.
Costs Savings	Cost savings can be achieved through right-sizing resources, adopting pay-as-you-go models, optimizing data storage, and implementing efficient cooling systems. Sustainable cloud architectures aim to achieve a balance between environmental responsibility and cost efficiency. Overall, sustainable cloud solutions enable small companies to optimize their IT expenses and allocate their resources more efficiently.
Corporate Social Responsibility	It entails incorporating social and environmental factors into corporate strategies and daily operations. In the context of cloud computing, CSR can encompass tasks like employing renewable energy sources to power data centers, decreasing carbon footprint, supporting neighborhood activities, fostering diversity and inclusion, and guaranteeing data privacy and security. By making use of sustainable cloud solutions, small companies can demonstrate their commitment to

	environmental sustainability and enhance their reputation among customers, partners, and stakeholders.
Innovation	Innovation is the creation and application of novel techniques, strategies, and answers that advance environmental stewardship and sustainability. For example, containerize workloads where applicable and/or serverless technologies. The scalability and flexibility of cloud solutions enable small companies to experiment and innovate with new services or ideas that might add more value to a sustainable cloud solution.

Environmental Benefits	
Benefit	**Explanation**
Environmental Impact	Environmental impact refers to the effects that the operation and utilization of cloud infrastructure and services have on the environment. The environmental impact by choosing renewable energy sources and adopting sustainable practices throughout the lifecycle of their cloud infrastructure. By properly building a sustainable cloud solution, taking into consideration all of operational impact and business impact, will enable companies for better service utilization and energy efficiency, resulting in lower overall environmental impact.
Energy Efficiency	Energy efficiency refers to the optimization of energy usage in data centers and cloud services. It involves designing and operating cloud infrastructure in a way that minimizes energy consumption without compromising performance or functionality. By prioritizing energy efficiency, organizations can reduce their carbon footprint, lower operating costs, and contribute to a more sustainable IT ecosystem.

In addition, implementing the above mentioned benefits in an infrastructure as code, could add even more value to the companies goal of being sustainable.

According to Microsoft, it is possible to save a significant amount of energy by using sustainable cloud architecture instead of on-premises IT and DevOps operations. In a study done in 2020, suggests that Microsoft Azure offers sustainable cloud infrastructure that can be up to 93% more energy efficient and up to 98% more carbon efficient than on-premises solutions (Microsoft, 2020). Furthermore, Cloud service providers operate large data centers designed to be energy efficient and reliant on renewable energy sources. Microsoft Azure uses efficient cooling systems and renewable energy sources in their data centers, which compared to on-premises who control their own energy and systems can be more efficient. In Figure 4.7.1, it is possible to see a chart done by Microsoft team. This chart shows that infrastructure is one of the sectors of larger energy consumption. By properly enabling cloud solutions in a company, Azure can be 79% to 93% more energy efficient than on-premises data centers and a reduction on up to 98% carbon emissions, as mentioned before.

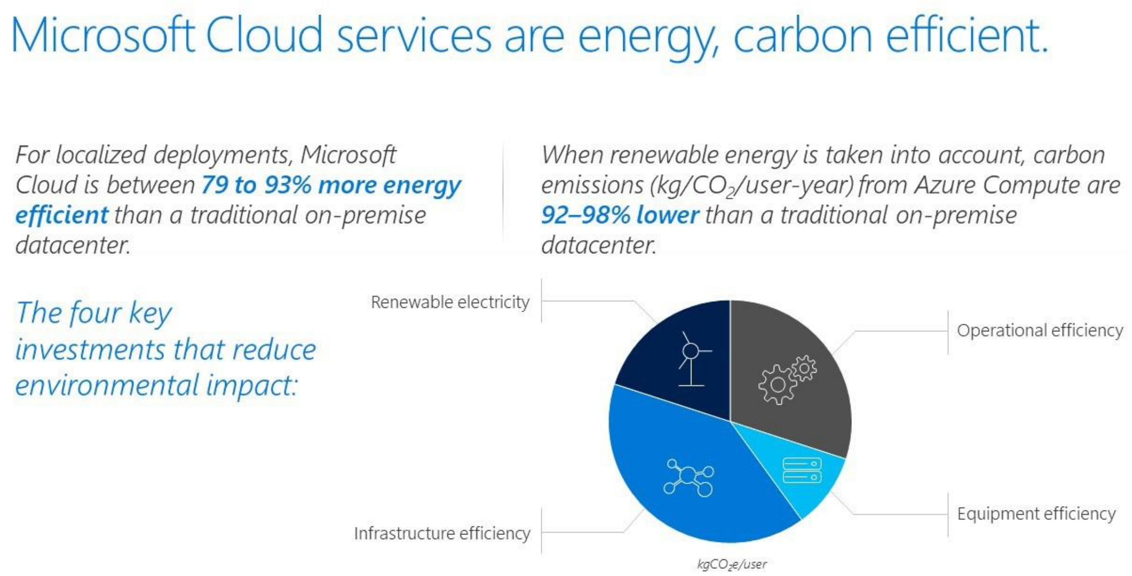


Figure 4.7.1 The image represents energy and carbon efficiency by using Azure according to Microsoft Azure (Microsoft, 2020)

6. Conclusion

In conclusion, the exact amount of energy that can be saved by using sustainable cloud architecture vs on-premises IT and DevOps operations may depend on various factors. The search results suggest that it is possible to achieve significant energy savings by moving to the cloud and prioritizing sustainability goals. To sum up, sustainable cloud solutions offer several advantages over on-premises infrastructure in a business, operational, and environmental context.

Increased flexibility, scalability, and agility offered by cloud technologies enable enterprises to quickly adjust to changing business requirements. The pay-as-you-go cloud service model minimizes costs by not having up-front capital expenditures and enabling companies to increase resources as needed. This makes it possible for small and medium enterprises to utilize enterprise-level IT capabilities without having to make large infrastructure investments. Azure services also handle maintenance, upgrades, and security patches, freeing up internal resources to focus on core business activities. Sustainable cloud solutions have the potential to drastically cut energy use and carbon emissions from a global perspective. Finally, dynamically scaling resources ensures that energy is utilized effectively, preventing over-provisioning and waste.

To sum up, in my opinion, a move to the cloud should be a part of any enterprise and public sector organization’s sustainability strategy, as cloud providers can achieve much higher resource utilization and energy efficiency than typical on-premises data centers.

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