An Investigation into the Use of Solar Power in Cloud Computing Environments

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Abstract: Cisco predict that by 2019, 86% of computing workloads will be carried out within a cloud computing environment. This is leading to the dramatically increasing need for data centre expansion which in turn is consuming more and more of the world's natural resources to generate the electricity needed to power them. This paper uses a fictitious electronics recycling company called Compucycle to investigate the feasibility and cost of integrating solar power generation into Compucycle's IT Infrastructure compared to completely outsourcing it to a cloud service provider. It was discovered that a complete solar power solution was not feasible due to the excessive costs it brought to the business. It was then decided that two out of four proposed solutions in this paper were a good fit for the business. The first being a hybrid power solution where a small portion of power is derived from the grid along with solar power generation. The second being the outsourced option. The third and fourth solutions were disregarded due to the fact that one was completely unfeasible and the other went against what Compucycle wanted to achieve.

1 INTRODUCTION

Compucycle Ltd is an electronics recycling company based in Bristol, United Kingdom (UK). They are accredited by a number of large technology companies such as Dell (Dell, 2016), HP Inc (HP, 2016), Hewlett Packard Enterprise (HPE) (Hewlett Packard Enterprise, 2016) and Lenovo (Lenovo, 2016). Compucycle primarily deal with the recycling of computing hardware. Sustainability and environmental conservation are very important parts of Compucycle and they're currently in year 3 of a 5 year process to make the business as energy efficient as possible. The next stage in this process is to attempt to power their IT infrastructure from renewable energy sources. Compucycle have 3 sites spread across the UK. The Bristol, Manchester and Chatham sites each have a recycling plant and the head office is located in Bristol. Compucycle have stated that they would like to continue using Hewlett Packard hardware as they are happy with it's reliability and performance and don't see the need for change. Due to the location of their sites which are in developed urban environments where local legislation prohibits the use of wind or hydroelectric solutions, only a solar solution will be feasible. Although being able to power their IT infrastructure

Ũs a key part of their plan Compucycle stress that it must be cost effective. Compucycle will consider cloud outsourcing methods as part of this IT initiative. This paper only deals with the feasibility of powering new server hardware and not existing networking, computing, printing or electrical systems.

Technology companies are already using sustainable energy sources to power their data centres, most notable are Google and Amazon Web Services. In 2007 Google installed the largest corporate solar panel installation at their Mountain View campus (Google, 2016). The 1.9MW system has been able to produce over 3,000,000kWh of energy per year. Amazon Web Services is another example (Amazon Web Services, 2014). As of April 2015 25% of the power consumed by their global infrastructure is supplied from renewable energy resources. Their 3 wind farms and 1 solar farm in the United States generates more than 1.6 million MWh per year.

The objectives of this research paper are:

- Understand different types of solar power technologies and how they are utilised in different environments. This can be found in section 3 of this paper.
- Understand the concept of virtualisation and cloud service platforms. This can be found in

section 4.

- Design a cloud computing solution to replace the existing Compucycle IT infrastructure based on the requirements set out in section 2. The proposed solution can be found in section 5 of this paper.
- Determine whether or not the proposed solution can be powered by electricity generated from solar panels which can be found in section 5.2, 5.4 and 5.5.

The rest of this paper is organised as follows: Section 2 states the requirements Compucycle have for the proposed solution. Section 3 examines solar power technologies, how they are utilised, what factors can impact solar power generation and power storage methods. Section 4 introduces the concept of virtualisation. Finally, section 5 presents the proposed solutions and recommendations in order to determine the most appropriate solution for Compucycle.

2 REQUIREMENTS

Compucycle are currently using a number of HP tower servers, a central storage array for backup and networking switches to make up their IT Infrastructure. The storage and networking is relatively new but the servers are reaching the end of their lifespan. Each site currently has exactly the same hardware with the exception of head office in Bristol.

Compucycle Ltd have stated that they wish to transition to a virtualised environment in order to reduce underutilisation of resources, real estate space and power consumption. As part of this Compucycle want to attempt move their entire IT infrastructure to the Bristol head office. Table 1 shows the resource requirements for their systems.

3 SOLAR POWER

In recent years the adoption of solar energy generation has increased exponentially. The (International Energy Agency, 2015) states that the biggest adoption rate has been since 2010, where the total global solar power capacity was 40,336MW. Since then it has continued to grow year on year when in 2014 the total global capacity is 178,391MW figure 1. In 2015 this was expected to reach 233,000MW, at the time of writing this, that data was not available. As shown in figure 1 a large

Table 1: Resource requirements for Compucycle systems.

| Server Name	Role	Location	CPUs	RAM	Storage (GB)
DC1	Domain Controller & DNS Server & DHCP	Bristol	2	4	64GB
EXCH 1	Mail Exchange Server	Bristol	6	16	1024
FS1	File Server 1	Bristol	2	8	2048
FS2	File Server 2	Bristol	2	8	2048
FS3	File Server 3	Manchester	2	8	2048
FS4	File Server 4	Chatham	2	8	2048
RCP1	Recycling Plant Control Server	Bristol	2	8	64
RCP2	Recycling Plant Control Server	Manchester	2	8	64
RCP3	Recycling Plant Control Server	Chatham	2	8	64
ERP 1	ERP Software Server	Bristol	4	16	1024
DB 1	Database Server	Bristol	2	4	64
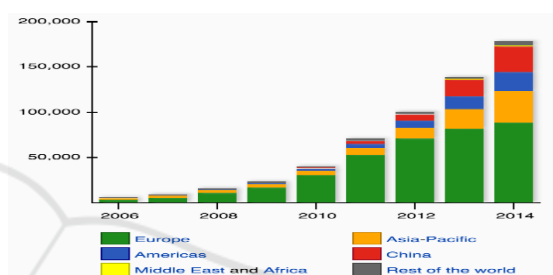
Figure 1: A graphical representation of the adoption rate of solar power. (Growth of Photovoltaics, 2016).

portion of this growth was in Europe. As of 2014 the UK was in the top 10 countries globally having the capacity to produce a total of 5,104 MW. This is a relatively small amount compared to Germany who have the capacity to produce 38,200MW.

3.1 Solar Panel Technologies

Almost 90% of the world's solar panels are made from some type of silicon. The main difference is the purity of the silicon which has a direct impact on the efficiency of the solar panel. Silicon purity is determined by how aligned the silicone molecules are, this is referred to as Crystalline Silicon. From this it is possible to create a number of different types of solar panel. Energy Informative has written an article on the different types of solar panels, a summary of which can been seen in section 3.1.

3.1.1 Polycrystalline

Polycrystalline based silicon solar panels have been on the market since 1981. They have an efficiency range of 13 – 16%. Being able to generate 255W of electricity.

Advantages:

- The process to make polycrystalline solar panels is simple and more cost effective.
- The process to make polycrystalline produces less waste silicon compared to others.

Disadvantages

- The efficiency of polycrystalline solar panels is considerably less than monocrystalline based solar panels.
- Polycrystalline solar panels have a much lower space efficiency compared to other solar panel types.

3.1.2 Monocrystalline

Monocrystalline solar panels are made up of cylindrical silicon ingots. Monocrystalline solar panels are the most efficient solar panels with having a maximum efficiency of 21.5% being able to generate up to 345W of electricity per year.

Advantages:

- Monocrystalline solar panels are more space efficient compared to other types of solar panels.
- They have a longer life span than other types of solar panels.
- Monocrystalline solar panels perform better in lower light conditions.

Disadvantages:

- They are the most expensive type of the solar panel types.
- If the panel becomes covered with debris or shade the panel will cease to operate.
- The production of Monocrystalline solar panels produces a large amount of waste silicon.
- Monocrystalline solar panels are not as efficient in warmer weather.

3.1.3 Thin-Film Solar Panels (TFSP)

Thin-Film Solar panels are relatively new compared to Crystalline based solar panels. They are constructed by depositing one or several layers of solar cell material onto conductive material. TFSP prototypes have reached an efficiency rate of 7-13% and production models operate at 9%.

Advantages:

- Mass production of TFSP is very simple.
- They can be made flexible opening up numerous more applications.
- They are less affected by temperature and shading.

Disadvantages:

- They require a large amount of space.
- They don't produce as much electricity compared to other types of solar panels.
- They degrade a lot faster than other types of solar panels.

It is clear from this that the Monocrystalline solar panel is the better performing solar panel with much higher efficiency, smaller footprint, longer lifetime and better performance in lower light conditions. Therefore, the recommendation for Compucycle at this point is to use monocrystalline solar panels. Comparison of a range of monocrystalline solar panels can be found in 3.4.

3.2 Factors Affecting Solar Power Generation

A report written by the NREL comparing studies of solar panel degradation across a diverse range of countries and environments states that the speed and amount they degrade varies greatly on the type of solar panel as well as the environment that it operates in.

3.2.1 Sunshine Hours

Geographical locations can impact the ability to generate solar power as different areas of the world have varying amounts of sunshine hours throughout the year. Sunshine hours need to be taken into account when exploring solar solutions. Table 2 shows the average amount of sunlight hours over a 29 year period at the closest weather monitoring station to the Compucycle Bristol site.

Table 2: Average sunlight hours over 29 years at the Filton Weather station provided by the Met Office.[12].

Month	Sunshine Hours
Jan	58.5
Feb	74.8
Mar	112.7
Apr	170.8
May	199.6
Jun	214.7
Jul	217.7
Aug	201.8
Sep	149.9
Oct	104.8
Nov	69.1
Dec	52.7
Annual	1627.0

When this is compared to a different geographical location entirely such as Las Vegas, the amount of

sunshine hours per year is completely different. Table 3 shows that Las Vegas has more than twice the amount of sunshine hours as the UK. Bringing into question the amount of power than can actually be generated from solar technology in that particular location.

Table 3: Average sunlight hours in Las Vegas, Nevada provided by Weather2Travel.com.

Month	Sunshine Hours
Jan	248
Feb	252
Mar	310
Apr	360
May	403
Jun	390
Jul	403
Aug	372
Sep	330
Oct	310
Nov	240
Dec	248
Annual	3866

3.2.2 Placement of Solar Panels

The sun moves across the sky at different elevations during different periods of the year. Therefore, it is important to understand the impact sun elevation on solar power generation. Figure 2 is a graph that shows the elevation of the sun at the Compucycle Bristol head office site. This graph specifically plots the elevation of months December to June. The graph shows a massive variation in elevation making it difficult to best determine at what angle to install a solar panel. During summer the elevation is as follows:

- Sunrise: 04:00AM at elevation 2°
- Mid-Morning: 10:00AM at elevation 53°
- Mid-Day: 12:00PM at elevation 62°
- Mid-Afternoon: 3:00PM at elevation 46°
- Sunset: 8:00PM at elevation 2°

Winter elevation is as follows:

- Sunrise: 08:00AM at elevation 1°
- Mid-Morning: 10:00AM at elevation 9°
- Mid-Day: 12:00PM at elevation 14°
- Mid-Afternoon: 3:00PM at elevation 5°
- Sunset: 3:50PM at elevation 1°

From this it is clear that if the solar panels are installed to best capture the sunlight during summer will capture very little or no sunlight during the winter months.

Charles Landau states that it has always been common practice to place solar panels facing true south in the Northern Hemisphere and true north in the Southern Hemisphere. This is to ensure that sunlight always reaches solar panels throughout the day. The elevation paths in figure 2 seem to support this. Whilst this may be true for most cases Professor Ralph Gottschalg from Loughborough University claims this method is wrong and can lead to spikes of energy at midday.

Although this may sound like good news to someone storing energy this is in fact bad news if they are feeding energy back to an electricity grid. Gothschalg uses Germany in his example, a country that has the most solar panel installations in Europe. He states that having too many installations facing south causes huge spikes in the electricity grid at midday making the grid not only unstable but forcing suppliers to give power away very cheaply because there is so much of it.

To combat this Gothschalg recommends that the UK follows Germany's new policy of only installing solar panels facing east or west in order to achieve a smoother flow of electricity throughout the day. Although this information is very useful it does not give any reference on what angle to best place the solar panels. Landau however does give guidance on this problem.

He recommends that it is best to adjust the elevation of panels twice a year. The elevation angles should be the latitude of the location plus 15° in winter and minus 15° in summer. From this it is possible to work out the best angles for solar panel elevation for the Compucycle Bristol site:

- Summer: 37.53°
- Winter: 67.53°

3.2.3 Shading

It is clear that solar panels need direct uninterrupted sunlight in order to perform at their highest levels. When talking about solar panel shading it does not only mean shadow created by physical objects.

It also extends to weather conditions such as overcast skies. A paper written by G. Pachpande et al studying the effects of solar shading, describes two forms of shading:

Soft source shading: An object that is in the path of the sunlight reducing the amount of light reaching the solar panel. Examples are trees, birds, leaves and rooftop chimneys. Soft sources do not permanently stop light from reaching the panel and often cast shadows that move across the panel with the sun.

Hard source shading: This can be described as objects that completely prevent sunlight from

reaching the panels. This is commonly debris that is resting on the panel itself such as leaves.
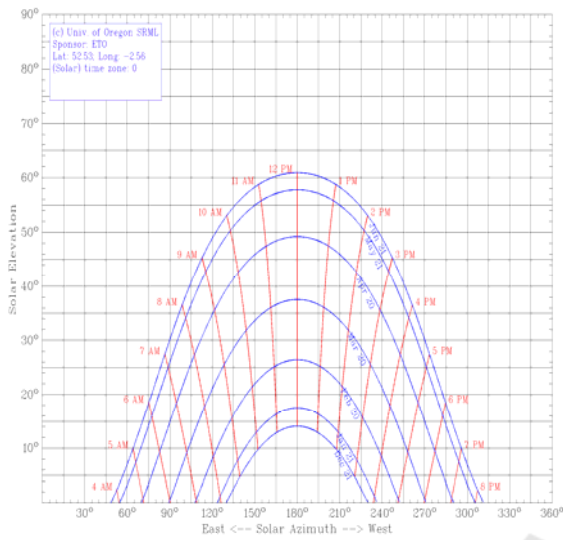

Figure 2: A graph plotting the elevation of the sun at the Compucycle site in Bristol from Jun -Dec. Generated using a tool created by the University of Oregon.
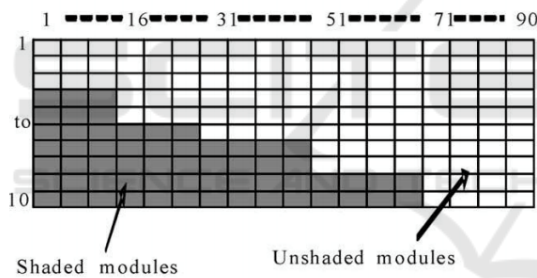

Figure 3: Example of Solar Panel Shading.

Pachpande goes on to state that when a single solar panel cell is covered by a hard source the voltage of that module will drop to half of it's unshaded value in order to protect itself. If enough cells are shaded, then the panel will not generate any electricity at all and will become a drain on the system. Figure 3 is a graphic showing shading on a solar panel.

Considering the Compucycle head office in Bristol is also a recycling site that is not surrounded by other buildings and trees, there will be very little shading in this location.

3.3 Methods for Utilising Solar Technology

There are many different ways of utilising solar energy to generate power. Some methods are for small domestic and business implementations others are for larger implementations built to feed power straight into the grid. This sections explores the different methods for utilising solar technology.
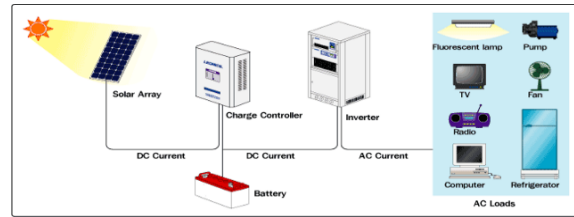

Figure 4: Diagram of a rooftop based solar panel system.

3.3.1 Conventional Rooftop

Rooftop solar panels have become more and more prevalent in the UK in recent years. This is mainly due to government grants and schemes where surplus energy can be sold back to energy suppliers. Figure 4 is a system model showing the process of how solar energy is converted into electricity for home use. DC current produced from the solar array is transferred to a charge controller where it is regulated and transferred to a battery for storage. Either from the battery or straight from the charge controller the DC current it transferred to an inverter where it is converted to AC current thus suitable for home appliance use. Power being transferred back to the utility grid is transferred via the inverter. Figure 4 does not show this.

3.3.2 Solar Farms

Solar farms are the large scale implementation of solar panels that generate electricity to feed straight into the utility grid. They can range between 1 acre and 100 acres in size and are often found in rural areas. They are eligible for grants and discounts from the UK government. They are currently the most natural and eco friendly way to generate energy. Solar farms are designed in such a way that they can be combined with agricultural farming thus making the maximum use of the land they use. To put things into perspective for every 5MW solar farm installed it can produce electricity for up to 1,515 homes. Each 5MW installation takes up approximately 25 acres of land.

3.3.3 Concentrated Solar Power

Concentrated solar power generates electricity by using mirrors to concentrate the sun's energy and convert it to high temperature heat. This heat is then captured and converted into electricity. There are

three different methods for concentrating the solar energy and capturing it:

Trough Systems: This is a large U shaped reflective surface with a cylinder filled with oil in the middle. This oil is heated up to 750°F which in turn is used to boil water to create steam to power turbines and generators. Figure 5 shows how a trough system works.

Power Tower Systems: This method uses large flat reflective surfaces to track the sun's rays throughout the day and reflect them towards a central receiver. Again this receiver contains liquid that's heated to produce steam to power turbines and generators in order to produce electricity. Figure 6 shows a power tower system.

Dish Engine Systems: This method uses a large reflective dish to reflect sunlight to a receiver mounted on the focal point. This dish tracks the sunlight as it moves across the sky. The dish is connected to an external combustion engine filled with hydrogen gas. When the heat is transferred from the dish to the engine the gas expands causing the pistons inside to turn and power a crankshaft connected to an external electricity generator. Figure 7 shows the dish used in this method, it is very similar to a conventional satellite dish but they are in fact much larger.
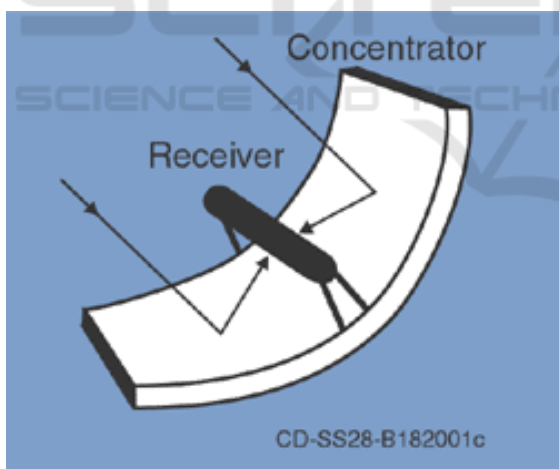

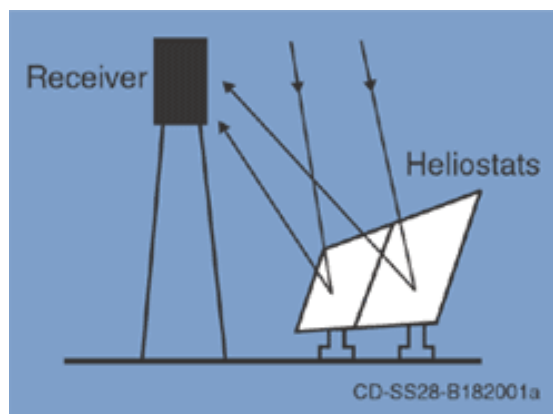Figure 5: Trough System for Concentrating Solar Power.

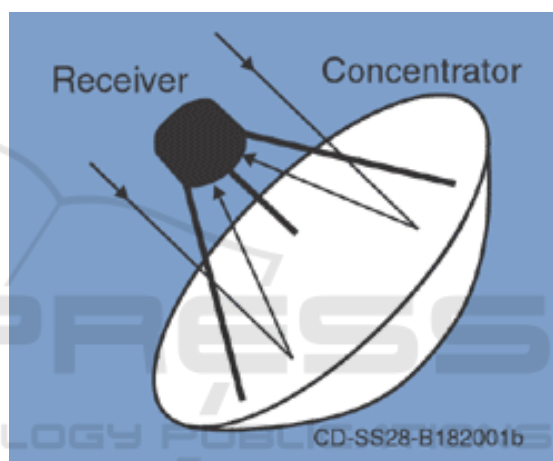Figure 6: Power Tower System for Concentrating Solar Power.

Figure 7: Dish Engine System for Concentrating Solar Power.

3.4 Comparison of Solar Panels

As established in section 3.1 monocrystalline solar panels are the better performing. This section compares several solar panels to find the best fit for Compucycle. According to the solar panel comparison website theecoexperts.com the top monocrystalline solar panels are:

- SunPower X21-345-COM
- Sanyo HIT Double 195
- SunPower 327-320
- AUO SunForte PM318B00

Tables 4, 5, 6 and 7 give further specification of these panels.

Table 4: Technical information on the SunPower X21-345-COM.

SunPower X21-345-COM	
Maximum Efficiency	21.5%
Maximum Power Output	345W
Solar Cells Per Panel	96
Size HxWxD (mm)	1559 x 1046 x 46
Warranty	25 Year Product and Power Warranty
Price	Not publically available

Table *5:* Technical information on the Sanyo HIT Double 195 solar panel.

Sanyo HIT Double 195	
Maximum Efficiency	20.5%
Maximum Power Output	249W
Solar Cells Per Panel	96
Size HxWxD (mm)	1351 x 898 x 60
Warranty	5 Year Product and 20 Year Power Warranty
Price	$849.00 (£507.09)

Table 6: Technical information on the SunPower 327-320 solar panel.

SunPower 327-320	
Maximum Efficiency	20.4%
Maximum Power Output	327W
Solar Cells Per Panel	96
Size HxWxD (mm)	1559 x 1046 x 46
Warranty	25 Year Product and Power Warranty
Price	Not publically available

Table 7: Technical information on the AUO SunForte PM318B00 solar panel.

AUO SunForte PM318B00	
Maximum Efficiency	19.5%
Maximum Power Output	318W
Solar Cells Per Panel	96
Size HxWxD (mm)	1559 x 1046 x 46
Warranty	10 Year Product and 25 Year Power Warranty
Price	Not publically available

Notes: ecoexperts.com stated Ja Solar JAC M6PA-4 as the second best solar panel, upon further research this is in fact an individual solar cell. Therefore, it has not been included in this paper. SunPower solar panel prices are not publically available as they are not sold individually.

It is clear that the SunPower X21-345-COM best panel with a much higher power output of 345W compared to the others and a higher efficiency rate of 21.5%. It offers the best warranty out of the selection. It is recommended that Compucycle use this panel or SunPower 327-320. There is very little difference between these two panels and are the best performing out of the selection. Price will have to be accounted for but is not possible in this paper due to prices per panel not being published by SunPower or AUO.

3.5 Solar Battery Technologies

Kathie Zipp claims that the batteries used in solar power systems have to operate under unusual circumstances compared to others. They have to cope with unstable and irregular power flows along with heavy charging and discharging. For a conventional battery this would cause significant damage to the battery. Two types of battery technology, Lead Acid and Lithium Ion are the most common in solar power systems. Deep cycle lead acid batteries are very similar to car batteries and have been used for off-grid power storage for many decades due to their low cost, reliability and predictable performance. Solar lead acid batteries are designed to be able to charge at very low currents so they are able to take advantage of any power available.

Lithium ion batteries are commonly found in most household electrical goods such as laptops and smartphones. However, they are applicable in solar energy environments. They have high energy density making the battery much lighter and smaller than lead acid batteries, the life of the battery is much longer and very high efficiency ratings providing much faster charge times.

3.5.1 Tesla Powerwall

The Tesla Powerwall is a wall mounted lithium ion battery developed by Tesla Motors. It charges using power generated from solar panels and stores it for later use. Each Powerwall unit has a 6.4kWh storage capacity which is sufficient for the average home, however it is possible use multiple batteries in a single environment. Tesla is not only targeting the Powerwall at home users but commercial environments as well with a 10kWh variation of the Powerwall called Powerpack. May 2015 Tesla announced it would be partnering with Amazon Web Services to trial the Powerwall technology in their data centres with a 4.8MW installation in their US

West data centre. The cost of a Powerwall is $3000 and $3500 for the Powerpack. At the time of writing that is approximately £2112 and £2464.

Here the clear choice for Compucycle would be a Lead Acid Battery. It is a proven and reliable technology that has been used for a number of years to store power generated from solar panels. The recommended battery for Compucycle is the Sonnenschein A600 Solar OPzV Gel 3500. Each battery is able to store up to 42 kWh of energy. Each battery costs £1,578.78 which is half the price of the Tesla battery and comes with over four times more storage.

4 VIRTUALISATION TECHNOLOGIES

The concept of Virtualisation can be defined as using hardware and software to create the illusion that two or more entities are present when only one physical entity exists. There are many forms of virtualisation, the most common computing forms are:

Server Virtualisation: Making multiple servers run virtually on one physical server. This provides greater compute resource utilisation across a set of servers for example. These can also be referred to as Virtual Machines (VMs).

Desktop Virtualisation: Allows a user to switch between different operating systems on the same computer. These can also be referred to as Virtual Machines (VMs).

Network Virtualisation: This gives the illusion that a user is connected directly to a network even though no physical connection exists. This is most commonly used to create Virtual Private Networks where users are access a network via the internet without physically being connected to the network.

Storage Virtualisation: Similar to server virtualisation, it gives users the ability to create individual virtual hard disks that can spread across several physical hard disks. Again providing greater resource utilisation due to data not being restricted to a physical hard drive.

4.1 Hypervisors

Virtualisation is achieved through the use of Hypervisors. A hypervisor is a layer of software that sits below the virtual machines and above the hardware it is running on. They control the communication between the virtual machines and

the hardware. Without the Hypervisor multiple operating systems will want simultaneous control of the same piece of hardware. There are two types of Hypervisor, Type 1 and Type 2. Type 1 is often referred to as a bare-metal implementation. Meaning the Hypervisor runs directly on the compute hardware essentially as it's own operating system see figure 8.
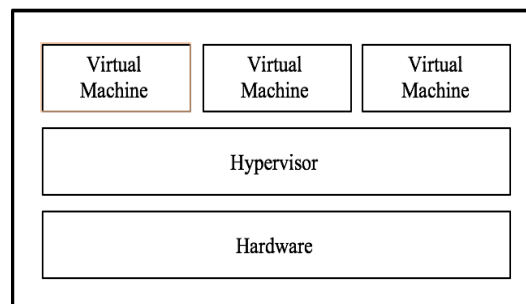

Figure 8: Type 1 Hypervisor Architecture.

Type 2 is where the hypervisor runs on a hosted operating system. Figure 9 is an example of a Type 2 Hypervisor. Type 2 hypervisors are considered easier to implement compared to Type 1 but can be slower as it has to rely on the hosted operating system to handle the communication to the hardware. Type 2 hypervisors are considered less secure than Type 1 due to the fact that the host operating system could become infected with malicious software.
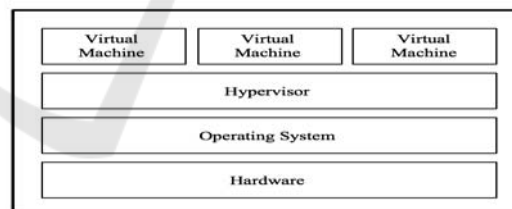

Figure 9: Type 2 Hypervisor Architecture.

4.1.1 Hypervisor Features and Examples

According to Software Insider the typical features in a Hypervisor are: VM creation, VM cloning, VM backup/restore, VM snapshots, live migration, dynamic resource allocation, VM migration, storage migration, performance reports, virtual firewalls, failover and thin provisioning.

4.1.1.1 VMware vSphere

vSphere is a data centre management and

virtualisation application suite developed by VMware and is one of the most widely used data centre management and virtualisation packages globally. It is a cloud operating system that can manage large collections of infrastructure such as servers, storage arrays and networks and provide them as a pool of resources within the data centre. Key features include VM creation, cloning and migration, x86 support, integration with operations management giving better insights, API integration, workload capacity optimisation, workflow automation and performance monitoring. vSphere is a Type 1 hypervisor allowing it to be more secure and perform better than some Type 2 hypervisors.

4.1.1.2 Microsoft Hyper-V

Hyper V is Microsoft's main virtualisation platform, it utilises the virtualisation technology built into Windows Server. It has much the same features as vSphere and can be integrated with with System Centre, Microsoft's separate data centre management suite.

4.2 Hypervisor Recommendation

vSphere is essentially an all in one data centre management package that can be installed straight onto the hardware as a Type 1 hypervisor which makes it more secure and faster. Hyper V is a Type 2 hypervisor and on it's own doesn't provide the data centre management features that vSphere does. Based on this the recommended hypervisor package for Compucycle is VMware vSphere.

5 SOLUTIONS

This section looks at the possible solutions for Compucycle and attempts to determine their approximate cost over a 5 year period. Starting with various solar panel solutions and on premise solutions. Then looking at alternative solutions such as cloud platforms.

Based on the requirements set out in section 2 it has been decided Hewlett Packard Enterprise (HPE) Hyper Converged 250 System is the best fit for Compucycle. It's all in one design where the Server, Storage and Networking is contained in one compact box immediately satisfies the requirements. The Hyper Converged 250 system is purpose built to host virtualized systems and offers support for both VMware vSphere and Microsoft Azure.

Before the solutions can be designed it is necessary to first understand: the server configurations, power requirements, grid electricity cost, roof space and solar panel placement.

5.1 Server Configurations

Considering the infrastructure will be virtualized and there is sufficient network bandwidth to all of the sites it is possible to house all of the servers in one location. Using the requirements provided in table 1 the following configuration has been provided for a Hyper Converged 250 chassis. Nodes 3 & 4 are duplicates of 1 and 2. They will be used for failover and redundancy purposes.

Node 1: 2x Intel Xeon E5-2640v3 CPUs, 512GB RAM, 2x960GB SSD, 4x 1.2TB 10K SAS, 2x10GbE SFP Ports.

Node 2: 2x Intel Xeon E5-2640v3 CPUs, 256GB RAM 2x960GB SSD, 4x 1.2TB 10K SAS, 2x10GbE SFP Ports.

Node 3: 2x Intel Xeon E5-2640v3 CPUs, 512GB RAM, 2x960GB SSD, 4x 1.2TB 10K SAS, 2x10GbE SFP Ports.

Node 4: 2x Intel Xeon E5-2640v3 CPUs, 256GB RAM 2x960GB SSD, 4x 1.2TB 10K SAS, 2x10GbE SFP Ports.

The price for this configuration is not publically available, however the starting list price per system is approximately $121,483. At the time of writing this that is equivalent to £85,437.09.

System backups will take place on a separate existing storage array that is not in the scope of this paper.

5.2 Power Requirements

This section will use the maximum power consumption possible for the Hyper Converged 250 system.

The power requirements per site for the new HPE Hyper Converged system are calculated using a number of equations to establish the maximum Kilowatts per hour used. The equation for this is as follows:

Power in Kilowatts = S (Volt amps or VAC) x Power Factor / 1000.

$$P_{(KW)} = S_{(VA)} \times PF / 1000 \tag{1}$$

In order to calculate the power factor, the following equation is required.

Power Factor = input watts / voltage amps.

$$PF = W/VA \tag{2}$$

735

HPE do not publish the power factors of their servers, hence the need to calculate it. Each system has 2x 1400 power supplies of which the VA is 1570 making the equation PF = 2800/3140. The result of which is 0.8917197452. Meaning the system is 89% power efficient.

To calculate the power consumption in kWh of the system the equation will be P = 3140 x 0.89/1000. The result of which is 2.7946kWh. Considering these systems are likely to be on 24/7 365 days a year each system will use a maximum of 67.0704KW every 24 hours, 469.4928KW per week, 2040.0607946KW per month and 24,480.696KW per year. Using this it is possible to establish the maximum power requirements for the system.

Table 8: Power consumption of the HPE Hyper Converged 250 System.

Daily	Weekly	Monthly	Yearly
0.0670704 MW	0.4694928 MW	2.040.0607946 MW	24.480696 MW

5.3 Grid Electricity Cost

This section calculates the cost of powering the solution using electricity from the grid. As calculated in 6.2 each system uses 2.7946kWh per hour. Using the EDF Energy unit rate comparison calculator it is possible to determine the electricity price per kWh for the Bristol head office area which is 13.35p per kWh. Table 9 shows the prices per hour, day, week, month and year to power the Hyper Converged 250 system from the electricity grid.

Table 9: Grid Electricity cost of the HPE Hyper Converged 250 System.

Hourly	Daily	Weekly	Monthly	Yearly
37.30791p	895.38984p	6,267.72888p	26,861.6952p	326817.2916p
£0.375	£8.955	£62.675	£268.615	£3268.175

5.4 Roof Space

The main building at the Compucycle Bristol site is 67m x 25m. Making the roof space 1675m². This means that the rooftop can accommodate the following maximum amount of solar panels:

- SunPower X21-345-COM: 966
- Sanyo HIT Double 195: 966
- SunPower 327-320: 1323
- AUO SunForte PM318B00: 966

Obviously these numbers are excessive and way beyond what Compucycle need to power their infrastructure.

5.5 Solar Panel Placement

As described in section 3.2.2 the recommended angle for the solar panels to be installed in Bristol is 37.5 degrees in the summer and 67.53 degrees in the winter. Next the direction of the solar panels needs to be considered. Compucycle will not be feeding any energy back to the electricity grid so there is no need to compensate for the spikes in the electricity grid mentioned by Gothschalg. Therefore, the recommendation at this point is to have the solar panels facing true south. As stated in section 6.2 the daily power requirement of the Hyper Converged 250 system is 67.0704kWh. Using the solar panels listed in section 3.4 the minimum amount of solar panels required to power the system entirely are:

- SunPower X21-345-COM: 195
- Sanyo HIT Double 195: 270
- SunPower 327-320: 206
- AUO SunForte PM318B00: 211

5.6 Proposed Solutions

Solution 1: On premise solution using the Hewlett Packard Enterprise Hyper Converged 250 System running Microsoft Azure. This solution uses solar energy to entirely power the system.

- 1 x Hyper Converged 250 System (£85,437.09)
- Hyper Converged 250 System 24/7 Care Pack (£7150 per year)
- 195 x SunPower X21-345-COM Solar Panels (N/A)

OR

- 270 x Sanyo HIT Double 195 Solar Panels (£161,215)

OR

- 206 x SunPower 327-320 (N/A)

OR

- 211 x AUO SunForte PM318B00 (N/A)
- 2x A600 Solar OPzV Gel 3500 (£3,157.56)
- Installation, maintenance and solar panel fixings. (N/A)
- Azure professional support (£7330.80 per year)

Total Cost over 5 years.

Year 1 - £261,132.80
Year 2 - £14,480
Year 3 - £14,480

Year 4 - £14,480
Year 5 - £14,480
Total: £319,052.8

Solution 2: On premise solution using the Hewlett Packard Hyper Converged 250 System running Microsoft Azure. This solution is powered by electricity from the grid.

- 1 x Hyper Converged 250 System (£85,437.09)
- 1x Hyper Converged 250 System 24/7 Care Pack (£7150 per year)
- Electricity from the grid (£3268.175)
- Azure professional support (£7330.80 per year)

Total Cost over 5 years.

Year 1 - £103,186.07
Year 2 - £17,748.98
Year 3 - £17,748.98
Year 4 - £17,748.98
Year 5 - £17,748.98
Total: £174,181.99

Solution 3: On premise solution using the Hewlett Packard Enterprise Hyper Converged 250 System running Microsoft Azure. This solution uses a hybrid power system where up to 42 kWh can be derived from solar sources and the rest is derived from the power grid.

- 1 x Hyper Converged 250 System (£85,437.09)
- Hyper Converged 250 System 24/7 Care Pack (£7150 per year)
- 98 x SunPower X21-345-COM Solar Panels (N/A)

OR

- 135 x Sanyo HIT Double 195 Solar Panels (£68,492)

OR

- 104 x SunPower 327-320 (N/A)

OR

- 106 x AUO SunForte PM318B00 (N/A)
- 1x A600 Solar OPzV Gel 3500 (£1,578.78)
- Installation, maintenance and solar panel fixings. (N/A)
- Azure professional support (£7330.80 per year)
- Electricity from the grid (£1634.9)

Total Cost over 5 years.

Year 1 - £171,622.90
Year 2 - £16,114.90
Year 3 - £16,114.90

Year 4 - £16,114.90
Year 5 - £16,114.90
Total: £236,082.50

Solution 4: Cloud solution using the Azure platform hosted by Microsoft. The prices shown below are the closet possible match to the requirements set out in Table 1.

- Virtual machines (£26,290.72 per year)
- Storage (£8,407.56 per year)
- Azure Professional Support (£7,330.8 per year)

Total Cost over 5 years.

Year 1 - £42,029.08
Year 2 - £42,029.08
Year 3 - £42,029.08
Year 4 - £42,029.08
Year 5 - £42,029.08
Total: £210,145.40

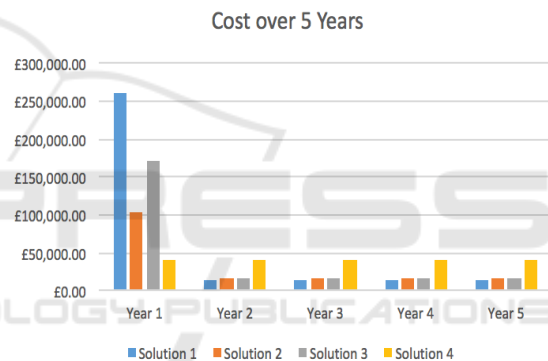Figure 10: Graph comparing the cost of the proposed solutions over 5 years.

6 CONCLUSIONS

It is clear that solution 2 has the lowest overall cost spread over 5 years. It does however go against what Compucycle are trying to achieve by including no sustainable power sources at all and drawing power directly from the utility gird. Solution 4 outsources Compucycle's server infrastructure altogether to a 3rd party and as figure 10 shows it has the most even cost spread over 5 years compared to the other solutions.

Solution 1 attempts to completely power the infrastructure from renewable energy which is highly unfeasible for Compucycle, not only from a cost perspective but because solar power is not guaranteed power due to the factors mentioned in section 3.2. Perhaps, the most appropriate solution

for Compucycle is solution 3. This is a hybrid solution, in the sense that only part of the power the solution consumes comes from renewable energy resources. This is more realistic for the business and it's what companies such as Amazon Web Services and Google are implementing themselves.

It is important to note that as previously mentioned in section 6.1 the price stated for the Hyper Converged 250 is entry list price. The configuration stated is most likely to be much higher, thus driving the overall cost of solutions 1, 2 and 3 up significantly. Where as solution 4 will stay at the same price over the 5 years.

Therefore, the most appropriate solutions at the time of writing this paper are solution 3 being the hybrid solar approach and solution 4 being the complete cloud outsourcing approach.

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