Adaptive computing and server virtualization in German data centers - Potentials for increasing energy efficiency today and in 2020

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Abstract

Adaptive computing solutions can significantly contribute to saving energy and other resources in data centers. Examples of such solutions include load and power management of servers, adapting air conditioning to dynamic loads, and dynamic distribution of computing loads to various data centers. Several solutions of this kind were developed and their potentials for saving energy and other resources were calculated in the project Adaptive Computing for Green Data Centers (AC4DC).

Server virtualization is the fundamental prerequisite for using adaptive computing technologies. Therefore, this contribution focuses first on the extent to which server virtualization is used in data centers and calculates both the current figure and the development through 2020. The calculations are based esp. on market research surveys, surveys of data centers, and a Delphi survey, which generated data for calculating possible energy savings through the use of adaptive computing technologies.

1. Introduction

Adaptive computing promises high potentials for improving energy efficiency in data centers, but the opportunities for using it depend strongly on the extent to which server virtualization is used today and in the future. Unfortunately, cross-company studies that permit conclusions about the average usage of server virtualization are few. Previous studies on virtualization and energy efficiency focus mainly either on the advantages of virtualization for individual companies [e.g., 1-4] or the share of companies using various kinds of virtualization [e.g., 5]. Hardly any data on the numbers of physical servers in Germany or other countries on which virtual systems are installed or the average numbers of virtual machines (VMs) running on a physical host are available to date. The few studies and statements on this topic by analysts and market research institutions such as Gartner, IDC, or Techconsult [e.g., 6-8] usually refer to the current situation and look only at the near future (two to three years), if at all.

This paper first presents the research questions and the methods employed to answer them (chapter 2) and then the potentials for savings provided by adaptive computing solutions. Of the solutions developed in AC4DC, this contribution focuses on two technologies promising major energy savings: dynamic load and power management of servers and comprehensive HVAC (heating, ventilation and air conditioning) control algorithms (chapter 3). Scenarios for the future development of server virtualization from which the energy savings potentials of adaptive computing solutions in 2020 can be derived are presented in chapter 4. Savings potentials will be calculated for a selected reference data center and estimated for the totality of data centers in Germany (chapter 5). A brief discussion of the results concludes this contribution (chapter 6).

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2. Research questions and methods

The following research questions will be studied, using Germany as an example:

- To what extent is server virtualization used in German data centers today? How large is the total number of VMs? What is the proportion of physical hosts running VMs?
- How can the usage of virtualization be expected to develop through 2020?
- What are the implications of the increasing usage of virtualization for the potentials of adaptive computing to achieve energy savings?

The results of previously conducted surveys, statements by analysts, and data generated by the market research institutions EITO/IDC [7] and Techconsult [8] on the number of physical hosts and the prevalence of virtual systems in Germany provided the basis for answering these questions. The Borderstep Institute purchased these data from the market research institutions. Unfortunately, the contractual arrangements do not permit publication of the data, so this contribution can only provide figures derived from the original data.

In addition, statements with regard to the importance of server virtualization in data centers of various sizes were derived using a structural data center model for Germany developed at the Borderstep Institute.

A Delphi survey among IT manufacturers, data center operators, trade association representatives, firms offering total system-based solutions, and IT analysts was conducted in the spring of 2014 in order to estimate the future development of server virtualization through 2020. The selection of interviewees is very important concerning the quality of the results of Delphi surveys. Interviewing a large number of respondents does not necessary lead to a better result [9], and limiting the number of experts surveyed to a small number of carefully selected specialists regarding very detailed aspects of future developments [e.g., 10-12] has proven advisable. We surveyed eight experts, including four leading manufacturers of IT hardware (servers, storage, network technology), two IT executives in major data centers, one analyst, and one trade association representative.

An online tool was used for the two-round expert survey. The results of the first round were anonymized and presented to the experts at the beginning of the second round. The overall results of the survey were discussed with the AC4DC project partners, some of the respondents, and additional experts at a workshop on 17 June 2014.

3. Potentials for savings provided by adaptive computing solutions

3.1. Load and power management of servers

The proactive load and power management (LPM) for servers and services that was developed in AC4DC adapts the number of active servers to the actual resource needs of the services at any point in time [13]. This requires that the servers are operated in a virtualized environment and that the services are encapsulated in VMs. Live migration, a technique that enables uninterrupted shifting of VM between servers, permits dynamic management of the services and consolidation of entire servers.

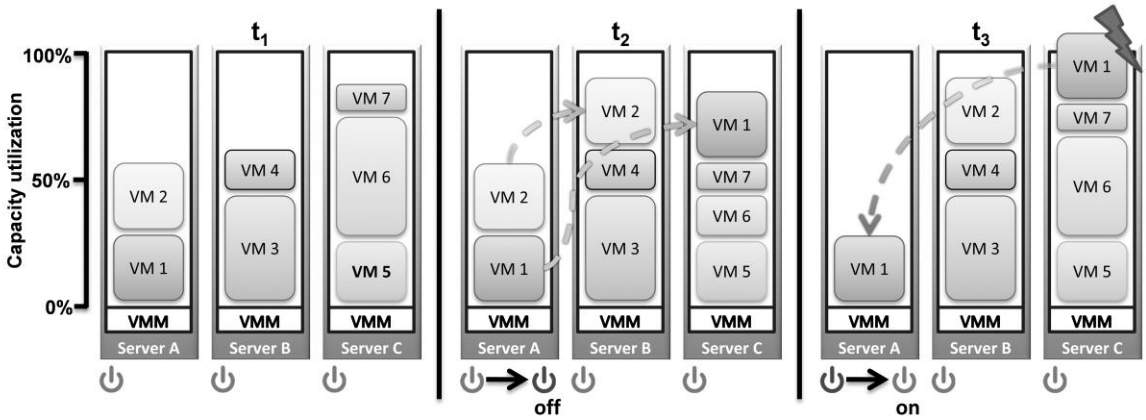

Figure 1: The principle of dynamic load shifting to save energy in virtualized environments [Offis]

Figure 1 shows the principle approach using the example of an environment with three servers. If sufficient server capacity is available (t2), servers can be consolidated by migrating the VM of one server to other servers. Then, the idle server is deactivated. As idle servers still require a certain amount of their maximum power consumption (20% to more than 50%), this approach can save a lot of energy [14]. But LPM must also react if resource needs increase, as shown for t3. Since booting a server and migrating VMs takes time, proactive measures are essential to avoid bottlenecks. Therefore, LPM uses predictions of the services' resource needs.

The application of LPM was compared with a static, pessimistic distribution of the VMs using simulations, resulting in savings potentials of 30% to 55% of the server hardware's energy needs. The maximum savings potential was achieved even if the number of VMs was as low as approx. 100. Measurements in a test environment – consisting of 8 blade servers running 62 virtual machines – confirmed the results of the simulations. Here, energy consumption for operating the server was roughly halved.

3.2. Comprehensive HVAC control algorithm

One adaptive computing solution pertaining to data center infrastructure is a comprehensive HVAC control algorithm. The solution was developed by AC4DC project partner Rittal and is to be incorporated in the manufacturer's future products.

Climate control in data centers involves equipment for generating, transporting, and distributing cold. So far, the components in such a cold chain have been regulated individually, with an operating point selected for each one. This local optimization approach disregards the interrelationships within the system. The comprehensive HVAC control algorithm succeeds in regulating the entire system so that the data center reaches an optimal operating point and operating costs are minimized.

The solution was tested in a data center. Controllable load banks simulate the server load with typical load curves. Cold air is taken in and heated, and warm air is blown out at the back. All components and monitoring points were recorded by data center infrastructure management software (DCIM). Figure 2 shows the improvement of Power Usage Effectiveness[4] (PUE) compared with a configuration without a comprehensive HVAC control algorithm. Although the basic configuration, with a PUE between 1.13 and 1.27, is already a very good climate control solution, the solution with the comprehensive HVAC control algorithm was significantly better, in

[4] PUE is a measure of the efficiency of data center infrastructure, indicating the ratio between energy use of the entire data center and the IT hardware's energy use. The closer the PUE value is to 1, the more efficient the data center's infrastructure. By definition, the PUE is always greater than 1.

particular when the load was low. If the basic configuration is not as good, the comprehensive HVAC control algorithm can improve PUE by 0.2 to 0.3. Overall, this technology permits data centers to cut power consumption by 15 to 20%.

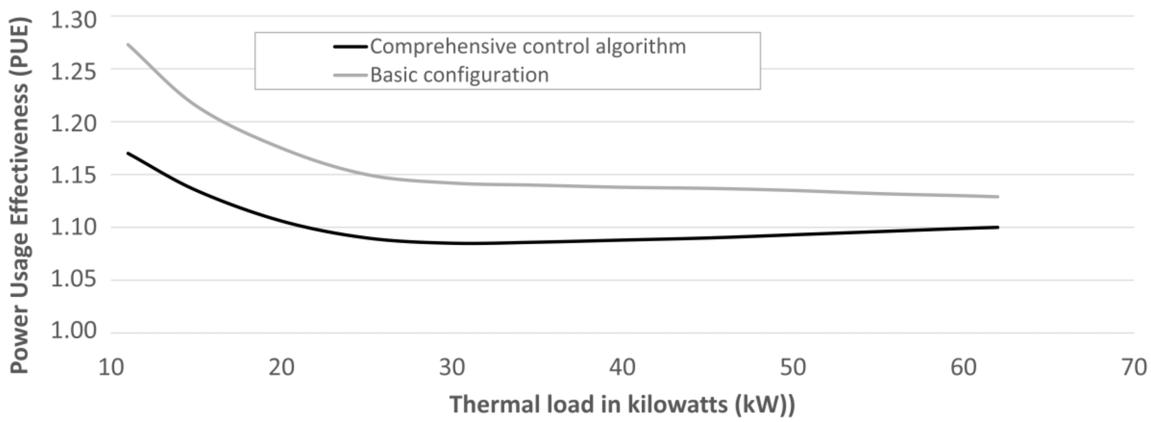

Figure 2: Improvement of Power Usage Effectiveness (PUE) by means of a comprehensive HVAC control algorithm [Representation by Borderstep on the basis of measurements by Rittal]

4. Scenarios for the future development of server virtualization

4.1. Goals and substance of the scenarios

In this section, the potential development of the extent of server virtualization in German data centers through 2020 is presented on the basis of various scenarios. A baseline scenario (trend scenario) and two scenarios based on the results of the Delphi survey were developed. The three scenarios assume the same development of the economy and the underlying conditions for Germany as a data center location.

The difference between the scenarios is the number of VMs in 2020 and the number of physical systems required for them. Even if the various possible developments also may affect the data centers' network and storage infrastructures, this is not taken into account.

4.2. Use of server virtualization in German data centers in 2014

Various indicators can be used to describe the extent of virtualization. The data center model with various categories of data center sizes developed at the Borderstep Institute uses the following indicators:

- The number of physical servers in 2020 ($n_{phy\ Systems,i}$)
- The percentage of physical servers running virtual systems ($p_{virt,i}$)
- The average number of virtual servers per physical host on which systems are virtualized ($\rho_{virt,i}$)
  (given in each case for the data center category i)

These indicators are also the relevant factors for developing the scenarios and serve to calculate the total number of virtual systems (n_{virt}). It results from the formula:

$$n_{virt} = \sum_{i=1}^{n} n_{phy\ Systems,i} * p_{virt,i} * \rho_{virt,i} \quad (1)$$

The number of virtual systems and the indicators mentioned above can be used to calculate the degree of virtualization. It is defined as the quotient of virtual systems divided by the total number of systems (virtual systems + non-virtualized physical servers) and is given in percent. In cases of complete virtualization, the degree of virtualization is 100%.

The indicators are subject to considerable uncertainties even for the present. In the following, we show the results of the analyses conducted in the project AC4DC. A Monte Carlo analysis was conducted as a final step to determine the magnitude of the uncertainties.

The number of physical servers in Germany was calculated on the basis of the sales figures for physical servers gathered by market research companies such as Gartner, IDC, or Techconsult. The figures presented by the various institutes differ – in part significantly – because of different survey methods, among other things. According to Techconsult, for example, the number of servers sold in Germany in 2013 is more than 30% higher than the figures given by EITO/IDC. The Borderstep Institute has been calculating the number of servers installed in Germany on the basis of Techconsult figures every year since 2009. For 2013, the number of servers installed in data centers was 1.6 million [15]. An additional approx. 700,000 servers are operated as standalone servers outside of data centers, so a total of 2.3 million physical servers can be assumed.

Various studies by Gartner, IDC, and Veeam provide information for determining the percentage of physical systems running VMs. Gartner assumes that 14.3% of the newly purchased x86 servers in 2012 are virtualized and expects the percentage to rise to 21.3% in 2016 [5]. IDC assumes higher numbers and states that 33% of the x86 servers purchased new in 2013 are virtual systems. Their share was to have been just 30% in 2012 [16]. A 2011 survey of larger data centers by Veeam [17] determined that VMs are running on approx. 18% of the physical systems. Taking into account that the number of virtualized servers is smaller for x86 systems than for other ones (Unix/mainframe), it is safe to assume that VMs are running on an average of approx. 25% of the physical systems in German data centers in 2014. The degree of virtualization varies between data centers of different sizes. Up to 35% of the physical servers in the two medium data center categories (100 to 5,000 physical servers) run VMs. In the smaller locations, the percentages can be significantly lower (10 to 15% for average server closets). In large data centers with more than 5,000 servers, the fraction of virtualized physical hosts is approx. 25%. One reason for this is that 45% of large data centers in Germany are colocation data centers with many different customers. A significantly lower fraction of virtualized servers is to be assumed for standalone servers. Calculations based on the Techconsult data [8] show that the number of physical hosts is approx. 5% for standalone servers.

Hardly any information is available to date regarding the average number of virtual systems per physical host. Although 20 or more VMs per physical x86 host are technically possible without problems, the average figure seems to be significantly lower in practice. Veeam calculated a figure of 6.3 VMs per physical host in 2011. An average of approx. 7 VMs per physical host is assumed for 2014.

On the basis of these estimates, the number of VMs in Germany was calculated to be 3.045 million. This number is slightly lower than the approx. 3.1 million VMs in 2014 assumed by Techconsult [8] (see Figure 3). In other words, the number of VMs is clearly larger than the number of physical servers today. This corresponds to the statements made by Gartner's analysts, who assume that approx. 2/3 of the server load of x86 servers are virtualized [18].

The Monte Carlo analysis conducted in AC4DC showed that, with a probability of 95%, the number of VMs in Germany in 2014 is between 2.5 and 3.6 million.

4.3. Baseline scenario

The baseline scenario is based on the current use of server virtualization and an extrapolation of the development of previous years into the future. The baseline scenario includes in particular the figures and prognoses by Techconsult [8] and EITO/IDC [7] for server sales and the number of virtual systems in Germany through 2015.

According to the baseline scenario, the number of VMs in Germany will continue to increase at a constant rate. Both Techconsult and EITO/IDC assume slightly increasing server sales in Germany in the coming years. That is why the baseline scenario assumes that the number of physical servers will also continue to increase slightly (Figure 3). The average number of virtual systems per virtualized physical host will continue to rise slightly and will be approx. 8 in 2020. The share of physical systems in data centers that are virtualized is approx. 30%. This amounts to a degree of virtualization of 74% in 2020.

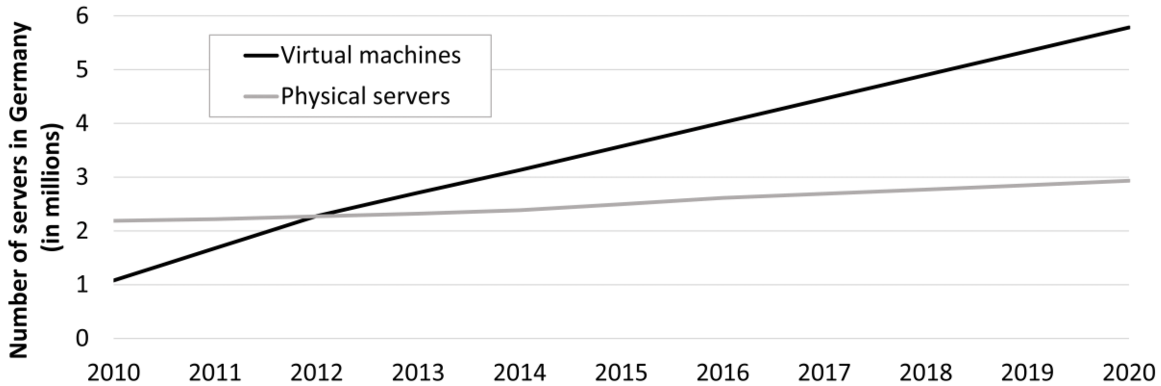

Figure 3: Development of the number of servers (physical servers and VMs) in Germany through 2020 in the baseline scenario (Borderstep – calculations based on Techconsult)

4.4. Alternative scenarios

The analysis of the results of the Delphi survey showed that the experts assume significantly higher rates of virtualization in 2020 than described in the baseline scenario. This applies both to the average number of VMs per physical host and the percentage of the systems that are virtualized (Figure 4).

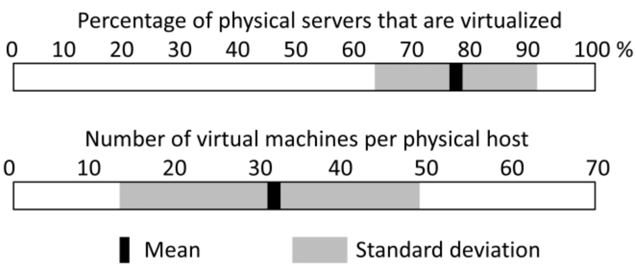

Figure 4: Results of the Delphi survey (Borderstep)

It is known that technology experts interviewed in Delphi surveys often tend to overestimate the development of technology. This was also discussed in the expert workshop and accepted as plausible. Two scenarios were developed on the basis of these deliberations and the results of the Delphi surveys: the scenario “Virtualization as the standard technology – scenario A,” which assumes comprehensive server virtualization in 2020, and the scenario “Accelerated virtualization – scenario B,” which assumes significant acceleration of the trend developments toward virtualization (Table 1).

Scenario	Number of VMs in data centers	Number of physical servers in data centers	Percentage of virtualized physical servers	VMs per hypervisor	Degree of virtualization
Virtualization as the standard technology (A)	25.6 million	0.8 million	80%	40	99%
Accelerated virtualization (B)	12 million	1.6 million	50%	15	94%

Table 1: Scenarios for increased usage of virtualization in 2020 (Borderstep)

Scenario A assumes a distinct decline in the number of physical servers in Germany, dropping to half their number compared with 2014. The number of VMs, in contrast, will be more than four times as large as in the baseline scenario in 2020. Scenario B, in which the number of physical servers remains constant at the 2014 level, also sees the number of VMs increasing sharply, to twice the number in the baseline scenario.

5. Energy savings potentials of adaptive computing solutions in 2020

The energy savings potentials of the adaptive computing technologies calculated in the AC4DC project are presented in this section. They are based on the results of the analysis of the scenarios on the development of server virtualization and differentiated between the level of data centers and the level of the German economy.

As demonstrated in section 3.1, LPM enables energy savings of up to 50% in the server systems even today. Taking into account, however, that VMs are running on only approx. 25% of physical servers in average data centers and that storage systems and network technology also consume electricity, significantly smaller savings potentials of 6 to 11% emerge, depending on the type and size of the data center. Further power savings of a similar magnitude can be achieved by the comprehensive HVAC control algorithm. An average medium-sized data center (approx. 1,000 physical servers) can cut its energy usage by approx. 25% by using the technologies mentioned.

The potential savings increase with increasing usage of virtualization. According to the baseline scenario, the potential savings in an average medium-sized data center in 2020 are approx. 30 %, in scenario B 35%, and in scenario A up to 45%.

The electricity consumption of servers and data centers in Germany was just under 10 terawatt-hours (TWh) in 2013, and it will continue to increase slightly through 2020. This already takes into account that adaptive computing will be used to a certain extent. Necessary basic technologies such as live migration or distributed power management are already available today. The comprehensive HVAC control algorithm developed in AC4DC will be marketed by project partner Rittal.

The scenarios reflecting increased usage of virtualization, compared with the baseline, result in dual energy savings potentials, which were calculated in AC4DC. Virtualization saves energy because fewer physical servers are needed. The potential savings this can achieve amount to 0.8 TWh for scenario B and 3 TWh for scenario A. Adaptive computing can achieve additional energy savings of 1.6 TWh (scenario B) or 1.7 TWh (scenario A) in Germany.

6. Discussion

The results concerning the development of server virtualization presented in this contribution show two things very clearly. Firstly, the extent of server virtualization through 2020 is unclear even among experts. Regarding the number of VMs in 2020, the scenarios, all of which describe plausible possible future developments, differ by a factor of four. The number of physical servers in 2020 also depends on the extent of virtualization. Here, developments ranging from a continuing slight increase in the number of systems to a 50% drop are plausible. Secondly, the contribution shows clearly that server virtualization has the potential to save energy and other resources directly. In addition, adaptive computing (which requires server virtualization) has enormous savings potentials of roughly 20 to 40%.

7. References

[1] Beloglazov, A., and Buyya, R., “Energy efficient resource management in virtualized cloud data centers”, in *Proceedings of the 2010 10th IEEE/ACM International Conference on Cluster, Cloud and Grid Computing*, IEEE Computer Society. 2010, pp. 826-831.

[2] Jin, Y., Wen, Y., Chen, Q. and Zhu, Z., “An Empirical Investigation of the Impact of Server Virtualization on Energy Efficiency for Green Data Center”, *The Computer Journal* 56(8). 2013, pp 977-990.

[3] Kommeri, J., Niemi, T., and Helin, O., “Energy efficiency of server virtualization”, in *ENERGY 2012, The Second International Conference on Smart Grids, Green Communications and IT Energy-aware Technologies.* 2012, pp 90-95.

[4] Younge, A.J., Henschel, R., Brown, J.T., von Laszewski, G., Qiu, J. and Fox, G.C., “Analysis of Virtualization Technologies for High Performance Computing Environments”, in *Proceedings of the 4th International Conference on Cloud Computing (CLOUD 2011)*. 2011, pp 9-16.

[5] Csaplar, D., *Optimierung der Unternehmensperformance*, Aberdeen Group 2013.

[6] Wu, J., Tian, U. and Atwal, R, (2012, Oct 23). *Forecast: x86 Server Virtualization, Worldwide, 3Q12 Update* [Online]. Available: https://www.gartner.com/doc/2210316/forecast-x-server-virtualization-worldwide

[7] EITO/IDC, EITO Costumized Report for Borderstep. Berlin 2014.

[8] Techconsult (2014). *Data of the e-analyzer* [Online].Available: www.eanalyzer.biz/.

[9] Häder, M., *Die Expertenauswahl bei Delphi-Befragungen. Zentrum für Umfragen, Methoden und Analysen Mannheim*, ZUMA How-To-Reihe Nr. 5. Mannheim. 2000.

[10] Gorden, S.N. and Gallo, K., “Structuring expert input for a knowledge-based approach to watershed condition assessment for the Northwest Forest Plan, USA.” In: *Environ Monit Assess*. 2011, Jan;172 (1-4,. pp 643-661.

[11] Fichter, K.; Clausen, J. and Hintemann, R., *Roadmap: »Resource-efficient workplace computer solutions 2020«*. BMU, Umweltbundesamt & BITKOM: Berlin. 2012.

[12] Helmink, L.F., *Objectives, strategies and indicators for Social Media Marketing*. Masterthesis. Universiteit Twente. 2013, Aug 21.

[13] Hoyer, M., Schröder, K., Schlitt, D., and Nebel, W., “Proactive dynamic resource management in virtualized data centers”, in *Proceedings of the 2nd International Conference on Energy-Efficient Computing and Networking.* ACM. 2011, pp. 11-20.

[14] Barroso, L. A., and Hölzle, U., “The case for energy-proportional computing”, *IEEE computer*, 40(12), 2007, pp 33-37.

[15] Hintemann, R. and Clausen, J., *Rechenzentren in Deutschland: Eine Studie zur Darstellung der wirtschaftlichen Bedeutung und Wettbewerbssituation*. Borderstep. Berlin 2014.

[17] IDC (2014, Apr 4), *Server Virtualization Continues to Grow in EMEA but Mega-Datacenters are Changing the Game*, [Online]. Available: http://www.idc.com/getdoc.jsp?containerId=prDE24788414.

[16] Veeam (2011, Jul 18). *Veeam startet den V-Index. Bestandsaufnahme zum Stand der Server-Virtualisierung in großen Unternehmen* [Online]. Available: http://www.veeam.com/de/news/veeam-startet-v-index-bestandsaufnahme-zum-stand-der-server-virtualisierung-in-grossen-unternehmen.html.

[18] Rubens, P., (2013, Aug 5). *Taking Stock of the State of the Server Virtualization Market* [Online]. Available: http://www.serverwatch.com/server-trends/the-state-of-the-server-virtualization-market.html.