Designing a performance measurement tool for the environmental performance of cloud computing

Delft University of Technology

Image on cover page: Green Cisco Server Room, retrieved from: http://pixshark.com/cisco-server-room.htm

Author	K. (Koen) van Schijndel
Student number	1510983
Graduation date	30th of April, 2015
Course	SPM5910 Master's Thesis Project
Graduation section	Information, Communication and Technology (ICT)
Master	Systems Engineering, Policy Analysis and Management
Faculty	Technology, Policy and Management (TPM) Jaffalaan 5, 2628 BX, Delft
University	Delft University of Technology

Graduation committee

Chair	Prof.dr.ir. M.F.W.H.A. Janssen
First supervisor	Prof.dr. W.A.G.A. Bouwman
Second supervisor	Dr. M.L.C. de Bruijne
External supervisor KPMG	Ir. Tim de Koning
External supervisor KPMG	Ir. Johan Noltes

Commissioned by KPMG Advisory N.V.
Laan van Langerhuize 1
1186 DS Amstelveen

Designing a Performance Measurement tool for the Environmental Performance of Cloud Computing

K. (Koen) van Schijndel

Faculty of Technology, Policy and Management

Delft University of Technology

30th of April 2015

A data center is a very peculiar and special place. It is the place where different worlds meet each other. A place where organizational (and individual) information needs and demands are translated in bits and bytes that are subsequently translated in electrons that are moved around the world. It is the place where the business, IT and energy world come together. Jointly they form a jigsaw puzzle of stakeholders with different and sometimes conflicting interests and objectives that are hard to manage and to control.

Rien Dijkstra in: *Data Center 2.0 – The Sustainable Data Center* (2014)

EXECUTIVE SUMMARY

Research problem

The carbon footprint and energy consumption of cloud data centers are skyrocketing. This negatively affects the environmental performance of cloud computing services, while customers expect to positively contribute to the environment through migrating to the cloud. Therefore, cloud service providers need to manage and control the environmental performance of their cloud services. Analysis of the existing measurement effort of cloud service providers, shows that a structural approach for environmental performance management is lacking. For this reason, the objective of this research was to develop a performance management tool that supports cloud service providers in the management and control of the environmental performance of their cloud computing services. This objective had to be reached through answering the following research question: What requirements should a tool meet to support the management of the environmental performance of cloud computing and to be of added value for the involved stakeholders?

Research deliverable

The deliverable of this research is a visual translation of design requirements into a performance management cycle based on the Deming-Wheel for quality management (see Figure 31 on page 78). The scope of this tool includes the environmental and economic impact that is the result of the energy consumed by IT resources on the virtualization level for provisioning the cloud services. The management tool uses six steps to guide the user in managing the environmental and economic impacts in terms of the carbon footprint and energy costs respectively: (1) evaluate current performance, (2) set targets, (3) determine and execute plan to reach targets, (4) measure energy consumption, (5) translate energy consumption into environmental and economic impact and (6) interpretation of these impacts. These steps and their content follow from requirements that have been derived from theory and practice.

Design requirements for the performance measurement tool

The requirements for the measurement tool have been translated to structural specifications to be able to visualize the structure of the measurement tool as presented in Figure 24 on page 61. This visualization of the measurement tool was used to systematically select design constructs needed for creating the final design of the measurement tool. Requirements have been derived from practice (see Table 14 on page 54), through performing a case study, which involved six cloud service providers of different size (in terms of total data center floor surface) and geographical orientation (national versus international, based on data center locations). These cloud service providers were asked to describe and provide requirements for a measurement tool that supports the management of environmental performance. Requirements have been derived from theory (see Table 13 on page 53) by means of a literature study on (1) existing methods and approaches for measuring environmental performance, (2) governance theory and (3) sourcing theory. These theoretical concepts were analyzed as they were expected to suggest implications for the measurement tool.

Most important findings based on these requirements can be summarized as follows. First of all, requirements implied to use the Plan-Do-Check-Act cycle of Deming to stimulate continuous improvement, which resulted in the main structure of the measurement tool as visualized in Figure 24 on page 61. Secondly, the importance of performing the measurements on the virtualization level was emphasized, which resulted in presenting environmental and economic impacts on the level of the virtual machine and its virtual CPU, memory and storage components, Third, the requirements implied that the added value of the measurement tool can be increased through the ability to generate comparable results, which can be used to perform vendor selection and service comparison on the basis of environmental performance. This resulted in including an external benchmark in the measurement tool, which allows to compare the carbon footprint on the virtualization level of cloud service provider A with the carbon footprint on the virtualization level of cloud service provider B.

Added value of the performance measurement tool

Previous research is mainly aimed at the development of detailed and specific solutions for improving data center efficiency. In contrast, this measurement tool provides a comprehensive, structural approach for dealing with data center efficiency to improve the environmental performance of cloud computing. Moreover, the added value of the measurement tool is in the metrics and equations the measurement tool combines for calculating and interpreting the environmental and economic impacts of cloud computing together with setting goals and creating plans to improve these impacts.

From a more practical point of view, this measurement tool adds value to cloud service providers, because it enables them to develop a well-considered strategy for improving the environmental performance of their services. The possibility to benchmarks against other providers can be used for improvement of the quality of services based on environmental performance. For the cloud customer, this external benchmark can be used in the process of vendor selection to judge cloud service providers based on the environmental performance of their services, which is currently not possible.

Discussion

The most important discussion points can be summarized as follows. First of all, the measurement tool is based on a narrow scope, which means that it applies to a particular part of the cloud computing life-cycle, while neglecting other impacting parts of this life-cycle. Secondly, the reliability and validity has not been properly tested yet due to a lack of data, despite this being a basic condition for the development of measurement methodologies.

Recommendations

Following the discussion points, it is recommended to perform research on possible ways to gather data for testing the reliability and validity of the measurement tool. Next to that, the environmental impact of other elements of the cloud computing life-cycle should be investigated, to work towards a more comprehensive model for managing the environmental performance of cloud computing.

ACKNOWLEDGEMENTS

This report is the result of the graduation research for the course SPM5910 Master Thesis Project that I have performed in collaboration with KPMG from September 1st 2014 till April 30th 2015. This work is the final effort for completing the Master Systems Engineering, Policy Analysis and Management of the Faculty of Technology, Policy and Management and for obtaining the title of 'Master of Science'.

In the summer of 2014, after some consultations with my first supervisor Harry Bouwman, several ideas for performing a graduation project in the ICT-sector were merged into the idea of 'designing a measurement tool for measuring the environmental performance of cloud computing',

I am happy to say that I have enjoyed working on this graduation research. Entering the world of cloud computing and visiting impressive and complex data centers, kept me being motivated to work on this research. I desire to contribute to controlling the energy efficiency and environmental performance of data centers in the rapidly growing cloud computing market.

First of all, I would like to thank the interviewees at T-Systems, Atos, KPN, Previder, CloudVPS and ReasonNet for their time, cooperation and sharing relevant insights regarding their current measurement efforts and requirements for a new measurement tool.

Secondly, my thanks go to the experts involved in the expert reviews. Albert, Marco, Johan, Wim and Rien, you provided relevant insights to further improve the design of the measurement tool, contributing to a more thoughtful design. Erik, special thanks go to you, for freeing your busy schedule and helping me out with the validation of the measurement tool.

Third, I would like to say that I am grateful for being given the opportunity to perform my graduation research at KPMG in Amstelveen. In particular, I would like to thank Tim de Koning, Johan Noltes and Erna Gerritsen-Gooren for guiding me through the graduation process, setting me up with relevant contacts in their network and judging the content of my thesis.

Fourth, I would like to say that I have appreciated working with Harry, Mark and Marijn. Regular consultations with my first supervisor Harry Bouwman, resulted in straightforward and useful comments that helped me a lot with improving the quality of my thesis. I would like to thank Mark de Bruijne for being available for a couple of hours of discussion, which helped to structure my thoughts and keep being motivated. Thanks also go to Marijn Janssen, for freeing some time in his busy schedule, to chair the graduation committee.

Fifth, the end of my time as a student, is the right time for expressing to my parents, brother and sister how grateful I am to have received their unconditional love and support and never doubting, but supporting my decisions.

Last but not least, my words go to my girlfriend. Marieke, thanks a lot for always believing in me, supporting me and waiting for me to go on an unforgettable trip to Central-America.

I wish you a pleasant read.

Koen van Schijndel

Delft, 30th of April, 2015

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. Introduction

1 INTRODUCTION

1.1 Cloud Computing and its Data Center Challenge

As it promises major benefits, the use of IT within businesses has exploded. Unfortunately, IT also contributes significantly to environmental problems at the same time (Uddin & Rahman, 2012). Therefore, the pursuit of 'Green IT' in organizations has become the new standard (Chou & Chou, 2012). Companies and organizations are looking to integrate sustainable technologies with the goal to increase the environmental friendliness, sustainability and cost effectiveness of their business (Lamb, 2009). Cloud computing is an example of a sustainable technology and a widely adopted 'Green IT phenomenon'. It can best be defined as: *"a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction"* (Mell & Grance, 2009, p.2). Cloud computing has the ability to *"convert capital expenses to operational expenses"* (Armbrust et al., 2010, p. 53), because it does not require large up-front investments (Grossman, 2009). Cloud computing eliminates the problem of over- and under capacity of IT resources since it promises 'infinite' capacity and instantaneous scalability (Armbrust et al., 2010). This 'elasticity of resources', combined with the 'pay-as-you-use' concept, results in significant cost and energy reductions compared to owning and amortizing expensive and energy consuming hardware (Armbrust et al., 2010).

At the supply side however, intensification of the cloud data center takes place (Uddin & Rahman, 2012). This development challenges the potential of cloud computing and puts the environmental performance under pressure. According to Garg and Buyya (2011, p. 1) *"the growing demand of cloud infrastructure has drastically increased the energy consumption of data centers, which has become a critical issue"*. Cloud services are provisioned in large complex data centers, that function as the backbone of cloud computing (Elgelany & Nada, 2013). As these data centers comprise of a large amount of servers, a data center can use as much energy as a small city (EPA, 2009). Data centers currently account for up to 3% of the global amount of energy produced and the generation of 200 million metric tons of CO_2 (Lavallée, 2014).

Forecasts for the upcoming years show an increasing demand for cloud data center services. A survey performed by 2nd Watch indicates that companies will spend at least 15% more on public cloud infrastructure in 2015, based on the observed trend of companies moving their IT from privately owned data centers to public cloud (2nd Watch, 2014). The Global Cloud Index of Cisco (2014) predicts that in 2018, 78 percent of all workloads will be processed by cloud data centers and a report of Market Research Media (2014) predicts that the cloud computing market will grow at an compound annual growth rate (CAGR) of 30% to comprise of 270 billion dollars in the year 2020. Non-surprisingly, data center emissions will also further increase as a result of this growing demand for cloud services: an acknowledged study of the Global e-Sustainability Initiative and the Boston Consulting Group Inc. (2012) forecasts a 7.1% increase of data center emissions per year up to 2020. Due to the disruptive growth of the market and businesses becoming more dependent on IT, the data center requirements are multiplied, while environmental, technological and economic sustainability issues are becoming even more urgent (Uddin & Rahman, 2012).

To realize green cloud computing, the environmental performance of the cloud's data centers must be improved through reducing their energy consumption and CO_2-emissions. This requires the environmental performance of the cloud to be manageable, which it is currently not due to the inability to measure the environmental performance of the cloud.

1.2 The need for a performance measurement tool

As the old saying goes: *"you cannot manage, what you cannot measure"* (Uddin & Rahman, 2012, p. 4083). The inability to measure the environmental performance of cloud computing, leads to a lack of control on the data center's CO_2-emissions. This lack of control is reflected through uncertainty about the effectiveness and return-on-investment of interventions that have been done to improve the energy efficiency and reduce the CO_2-emissions of a cloud data center (Alger, 2009). This makes it difficult to set benchmarks for future improvements (Jenkin et al., 2011). The inability to manage CO_2-emissions is not the only negative consequence. Energy consumption accounts for the highest operational costs of a data center (Alger, 2009). To prevent the profit margins of cloud service providers from being significantly reduced, interventions to increase energy efficiency should be implemented (Buyya, Beloglazov, & Abawajy, 2010), which again invokes the problems with measuring the effectiveness of the interventions.

These consequences should not only be the concern of the cloud service provider. Despite the cloud customer saving costs and energy by moving its IT-infrastructure to the cloud, the high energy consumption and CO_2-emmissions at the supplier side cannot be ignored. Moreover, Qu, Wang, and Orgun (2013) mention that evaluating cloud performance is also a problem of cloud customers as it is important for them to have an idea of the quality of the services they are paying for. The extent to which cloud customers value environmental measures in these performance evaluation is questionable. What is a major concern of the cloud customer, is business continuity (Harvard Business Review Analytic Services, 2011). Provisions on business continuity in service level agreements must protect the continuity of cloud services delivered by the cloud service provider to the cloud customer. Jing, Ali, She, and Zhong (2013, p. 446) mention that if the energy efficiency of a cloud data center can be improved, without harming the service level agreements, significant cost reductions and contributions to environmental sustainability can be realized.

Existing research on measuring the environmental performance for example consists of studies that compare a specific cloud service of a company with on premise IT infrastructure (Salesforce.com & WSP, 2011), study the potential for CO_2-savings in the UK and France (Verdantix, 2011) or compare applications of a specific company in on premise and cloud configurations (Accenture & WSP, 2010). However, these studies do not include comprehensive implications for the environmental impact of cloud computing.

Making IT greener will remain a necessity and not an option (Murugesan, 2008). Also, being 'ahead of the curve' in environmental performance management may provide a competitive advantage. Therefore, the objective of this research is to develop a performance measurement tool for measuring the environmental performance of cloud computing that is of added value for the involved stakeholders. These stakeholders and interactions between these stakeholders, together form the cloud computing eco-system which the measurement tool should fit.

1.3 Context of the measurement tool: the cloud computing eco-system

The cloud customer and the cloud service provider are part of the cloud computing eco-system, together with the certification company and the end customer as displayed in Figure 1. Finding a balance between economic, ethical and social performance is influenced by the complexity of the cloud computing eco-system in which the stakeholders all have different interests and business goals. These differences could to limit or enhance the possibilities for measuring the environmental performance of cloud computing. Therefore, a better understanding of the stakeholder interactions in this eco-system (indicated with the arrows in Figure 1) is needed to create a tool that is supported by the involved stakeholders and deals with the mechanisms of sourcing, governance and customer satisfaction that influence these stakeholders.

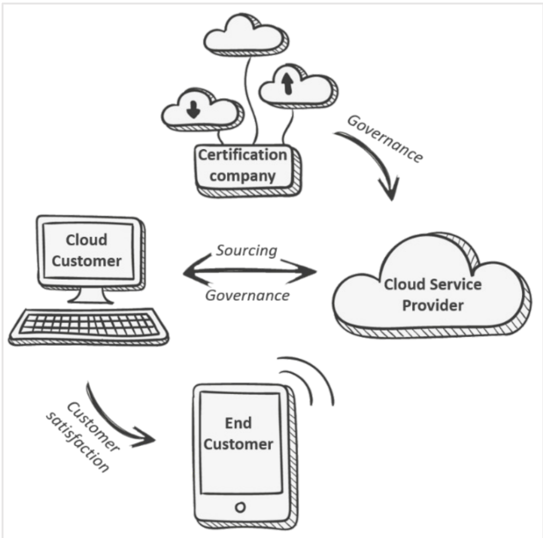


Figure 1: the cloud computing eco-system

1.3.1 *Sourcing cloud computing services*

According to Clemons and Chen (2011) cloud computing is a form of outsourcing. Arnold (2000) mentions the realization of cost reductions together with suppliers as an important driver of outsourcing. Specifically for IT outsourcing, Katsikas, Gritzalis, Karyda, Mitrou, and Quirchmayr (2006) states that a higher return on investment and benefits from economies of scale on which vendors are operating, are the primary reason for companies to turn to outsourcing of information technology. However, financial benefit is certainly not the only driver. Katsikas et al. (2006, p. 404) state that drivers for outsourcing information technology also include:

- The ability to benefit from specialized knowledge and best-practices of the supplier.
- Receiving services of higher quality.
- A higher level of business continuity.
- Lower dependency on choice for technology.

Schniederjans et al. (2005) describe the outsourcing process as presented in Figure 2. Starting point of the process is the identification of non-core competencies, indicating that it should only be non-core competencies that are outsourced by a company. Whether or not the sourcing of cloud services replaces a non-core or core competence in an organization, depends on the situation and the characteristics of the organization and is a discussion outside the scope of this research. Nonetheless, this process model helps to analyze the role of environmental performance measurements in the sourcing process. Given the assumption that the environmental performance of a cloud service is of interest for the involved stakeholders, two parts of the outsourcing process are expected to include a role for environmental performance measurements: vendor selection (orange frame) and management of the outsourcing activity (blue frame). Selecting a vendor is a strategic decision (Wadhwa & Ravindran, 2007). The decision to select a vendor often has a multi-objective nature (Weber & Current, 1993) This poses the question if environmental performance is, or should be a criterion in the vendor selection process. Therefore, insight into the role of environmental performance of cloud services offered by a cloud service provider in the vendor selection process is of added value. Once a vendor has been selected, the cloud customer needs to negotiate measures of outsourcing performance and needs to decide on how to monitor and control the outsourcing activity (Schniederjans et al., 2005). In this part of the outsourcing process, insight into how and to what extent the environmental performance should be monitored and controlled is of added value.

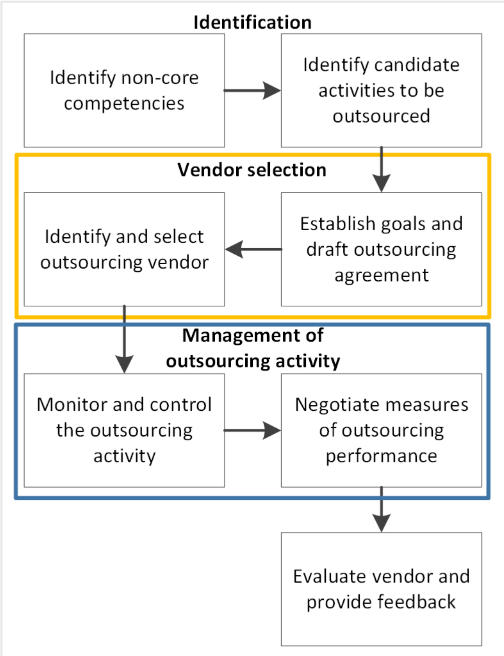


Figure 2: the outsourcing process
Based on: Schniederjans, Schniederjans, and Schniederjans (2005)

1.3.2 *Governance of cloud computing services*

Weill and Ross (2004b, p. 8) define IT governance as *"specifying the decision rights and accountability to encourage desirable behavior in the use of IT".* For this research, encouraging desirable behavior would comprise of enabling energy efficient use of IT. Weill and Ross (2004a, p. 1) state that because measuring the outcomes of IT is difficult, organizations *"must assign responsibility for desired outcomes and assess how well they achieve them".* It is assumed that the responsibility for desired outcomes, being the environmental performance of cloud services, is a shared responsibility of the involved stakeholders. However, the larger part of this responsibility lies at the cloud service provider, because they operate the data center, which is the backbone of cloud computing (Elgelany & Nada, 2013). In this phase of the research, the assessment on how well desired outcomes are achieved is relevant. This because assessing the desired outcomes inevitably includes measuring these outcomes. The part of the governance structure that assigns responsibilities between stakeholders for using the measurement tool for achieving desired outcomes is of later concern, because it is expected to be dependent on the design of the measurement tool that is developed. For this research, it is therefore of added value to use governance theory to derive implications for measuring the outcomes of IT and environmental performance in particular.

Besides internal governance, there is another form of external governance provided by independent certification companies. Certification regimes are increasingly being used in partnership with the private sector to regulate particular kind of behavior (Haufler, 2003). Sustainability labels and certificates are an example of such regimes and are established to ensure a certain quality standard or to enable comparison of services and goods. Think of the ISO-standards, the EnergyLabel for the car industry and the EnergyStar for computers (Energielabelhulp, 2008). Further insights into cloud governance and certification regimes are therefore helpful to find the implications for measuring environmental performance.

1.3.3 Customer satisfaction: interaction between the cloud customer and its customers

The relationship between the cloud customer and its end customer merely provides a motivation for the cloud customer to keep track of their environmental performance, for the following reason.

When corporate social responsibility is not integrated as it should within a business, the phenomenon of greenwashing can occur. *"Greenwashing is the act of misleading consumers regarding the environmental practices of a company or the environmental benefits of a product or service"* (Delmas & Cuerel Burbano, 2011). Since companies are not obliged to publish environmental policies and there is no external body that has the task to regulate and control these policies, external stakeholders are wondering to what extent companies actually adhere to their environmental ambitions (Ramus & Montiel, 2005). Therefore, Lantos (2001) emphasizes that a company must achieve a balance together with multiple stakeholders in the areas of economic, ethical and social performance. The expected effects of this mechanism on measuring environmental performance are small. Therefore, this mechanism is only interpreted as another perspective on the need for a measurement tool.

1.4 Research problem and delineation

The information provided so far, describes the problem area of measuring environmental performance of cloud computing. To turn this into a manageable research problem, specification and delineation is needed which is done in this paragraph.

1.4.1 Problem statement

Cloud computing has been presented as a valuable concept for organizations to reduce the costs and environmental impact of their IT. In the rapidly growing cloud computing market, the energy consumption of data centers increases, leaving the cloud service provider with challenges in managing the environmental performance of the cloud. The absence of tools and a methodology that helps keeping track of the environmental performance further complicates this situation. Therefore, the problem statement of this research is:

There is no measurement tool to measure the environmental performance of cloud computing in the cloud computing eco-system that supports the management and improvement of environmental performance.

This problem statement contains several terms such as 'environmental performance' and 'cloud computing' that describe broad concepts, which indicates further delineation is necessary.

1.4.2 Delineation of the research problem

Measuring environmental performance can be done in multiple ways. Ilinitch et al. (1999) have established a corporate environmental performance matrix as presented in Table 2, to be able to categorize the wide variety of environmental performance measures. First of all, a distinction is made between *process* and *outcome* measures. Process measures use process indicators to measure environmental performance and outcome measures entails observable and quantifiable results (Ilinitch et al., 1999). Further distinction is made between internal and external processes and outcomes.

For this research, the choice is made to delineate environmental performance measurements of cloud computing services to the external outcome (blue frame) of the process of provisioning these services: the environmental impact in terms of CO_2-emissions. Two reasons for doing so are provided. First of all, the category of process measures is too much focused on the evaluation of the preconditions for measuring environmental performance, such as the presence of a management system. In the outcome category, environmental impacts measures are preferred over regulatory compliance measures, because they are most directly linked to the CO_2-emissions of cloud data centers that should be managed. Given this first step in the delineation, The environmental performance of a cloud service is based on the environmental impact which is defined as: *"the degree to which an organization's business processes, activities and operations positively or negatively affect the natural environment"* (Jenkin, Webster, & McShane, 2011, p. 19).

Table 1: corporate environmental performance matrix by: Ilinitch, Soderstrom, and Thomas (1999)

	Internal	External
Process	Organizational Systems	Stakeholder Relations
Outcome	Regulatory Compliance	Environmental Impacts

The provided definition refers to 'business processes'. The process of provisioning a cloud service can also be seen as a business process. To further specify the research problem, delineation of this process is needed. Chou and Chou (2012) define four complementary paths in the environmental impacts of IT: green design, green manufacturing, green use, and green disposal. According to Alger (2009) the energy consumption of a data center determines its environmental impact for the larger part. Therefore, the focus is on the path 'green use', which reflects the larger part of the cloud's energy consumption.

Now that the term environmental performance has been delineated and defined, the next step is to define cloud computing. The most used categorization of cloud computing services (see Figure 3) is Software-as-a-Service (SaaS), Platform-as-a-Service (PaaS) and Infrastructure-as-a-Service (IaaS). For this research, cloud computing is defined as IaaS (see blue frame in Figure 3), meaning the cloud customer uses the physical resources of the cloud service provider, and *"has control over operating systems, storage, and deployed applications"* (Mell & Grance, 2009, p.3). The focus is on the IaaS-layer, as it *"consumes a huge part of total energy in a cloud computing system"* (Jing et al., 2013, p.445). More specifically, the hardware resources in the IaaS-layer are mainly responsible for the energy consumption of cloud computing. Defining the cloud as PaaS or SaaS is not relevant for this research, because it would always imply taking into account the infrastructure-layer, as the resources on this level are actually consuming energy.

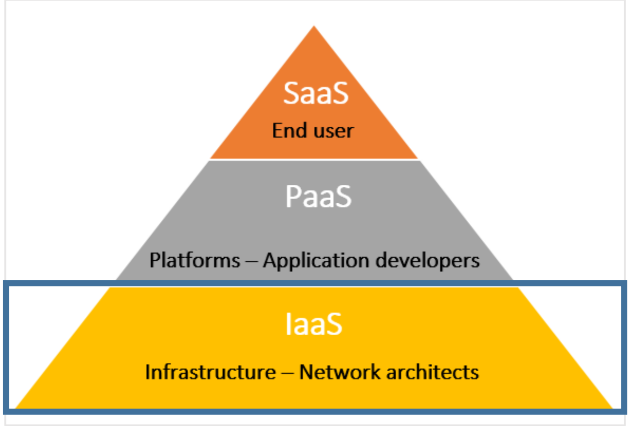


Figure 3: IaaS - PaaS - SaaS

To conclude, this delineation implies that: the environmental performance of cloud computing is the environmental impact in terms of CO_2-emissions caused by IT hardware resources on the infrastructure layer, needed for using cloud computing services. Furthermore, it implies the following elements not to be included in the scope of this research:

- The energy consumed by cooling facilities and other auxiliary equipment (such as lightning).
- Energy consumption of network resources outside the data center or data center hall where the cloud service is provisioned.
- Energy consumption of other departments of the cloud service provider other than the data center.
- The *materials* used to build the data center, IT infrastructure and manufacture IT hardware.
- *Waste* that is produced by the data center (such as cooling water).

1.4.3 The goal for the measurement tool

Following the problem statement presented in paragraph 1.4.1 and the delineation, the goal that should be met by the measurement tool is:

> To facilitate the added value of *managing* the environmental performance of cloud computing by *measuring* the environmental performance of cloud computing within the boundaries of the cloud computing eco-system.

The research approach of Verschuren and Hartog (2005) that is used (see 1.5) implies to evaluate this goal, because it is an important starting point for the research. Verschuren and Hartog (2005) have identified several criteria, which can be used to perform this evaluation, such as clearness, consensus of the stakeholders and feasibility. The choice is made to use the criterion 'clearness' to evaluate the goal, because the clarity of the goal is important as it is used frequently throughout this research. The goal that has been set is straightforward, but could be further clarified. It is yet unclear what conditions should be met to achieve a desirable result. Common knowledge on designing a measurement tool indicates that it should be reliable and valid. The reliability of the measurement tool can be examined along two dimensions: the reliability of the measurement tool itself and the reliability of results. The validity of the measurement tool can be seen as the extent to which the measurement tool is able to measure what it was designed for: the environmental performance of the energy consumption of cloud computing in the cloud computing eco-system. Paragraph 3.7 provides the methodology that is used to judge the measurement tool on the basis of reliability and validity.

1.5 Research question and sub questions

The goal that was set in paragraph 1.4.3 is to be achieved by a measurement tool. Therefore the research question, taking into account the boundaries of the cloud computing eco-system and the delineation of the cloud computing life-cycle for this research, the research question is:

What requirements should a tool meet to support the management of the environmental performance of cloud computing and to be of added value for the involved stakeholders?

The deliverable of this research is not only a list of requirements, but also a minimum viable product in the shape of a prototype which has the core capabilities of the measurement tool, following from the requirements. A minimum viable product is preeminently suitable for showing the added value of the measurement tool to its users (Moogk, 2012). According to Ries (2014) a minimum viable product allows *to "collect the maximum amount of validated learning about customers with the least effort".* Therefore, the development of the prototype for the measurement tool helps to specify existing requirements and identify new requirements. To be able to answer the main research question and arrive at the final design of the measurement tool, it is decomposed into sub questions. The sub questions are divided into the categories: requirements and assumptions, structural specifications, design, implementation and evaluation. These categories are derived from the research approach that is based on Verschuren and Hartog (2005) and introduced in the next paragraph.

First hunch	▪ What is the set of goals that should be met by the measurement tool?
Requirements and Assumptions	▪ What requirements can be derived from theory on measuring the environmental impact of cloud computing in the cloud computing eco-system? ▪ What requirements can be derived from cloud service providers and cloud customers?
Structural Specifications	▪ What does the structure of the measurement tool look like?
Prototype	▪ What does a prototype of the measurement tool look like?
Implementation	▪ To what extent does the prototype fit the set of structural specifications?
Final Design	▪ What does the final design of the measurement tool look like?
Evaluation	▪ To what extent is the prototype successful in measuring the environmental impact of cloud computing?

1.6 Research approach and outline

This part presents the research approach which is based on the design oriented approach by Verschuren and Hartog (2005) followed by the outline of the thesis, which is based on the used research approach.

1.6.1 The Design Oriented Approach

To be able to answer the main and sub questions, the design cycle as described in the design oriented approach by Verschuren and Hartog (2005) is used. Verschuren and Hartog (2005) present a design cycle that can be used to develop an artifact from the first ideas for developing such an artifact to its actual development and evaluation. A specified version of the design cycle of Verschuren and Hartog (2005) for this research is presented in Figure 4. Main reasons for choosing this research approach are (1) the combination of design oriented research and evaluation research contributes to a design that fulfills the requirements of stakeholders and future users (Verschuren & Hartog, 2005) and (2) the use of existing research methodologies is widely supported by this approach, which allows for choosing suitable methodologies within the phases and (3) this design cycle focuses on the development of an artifact.

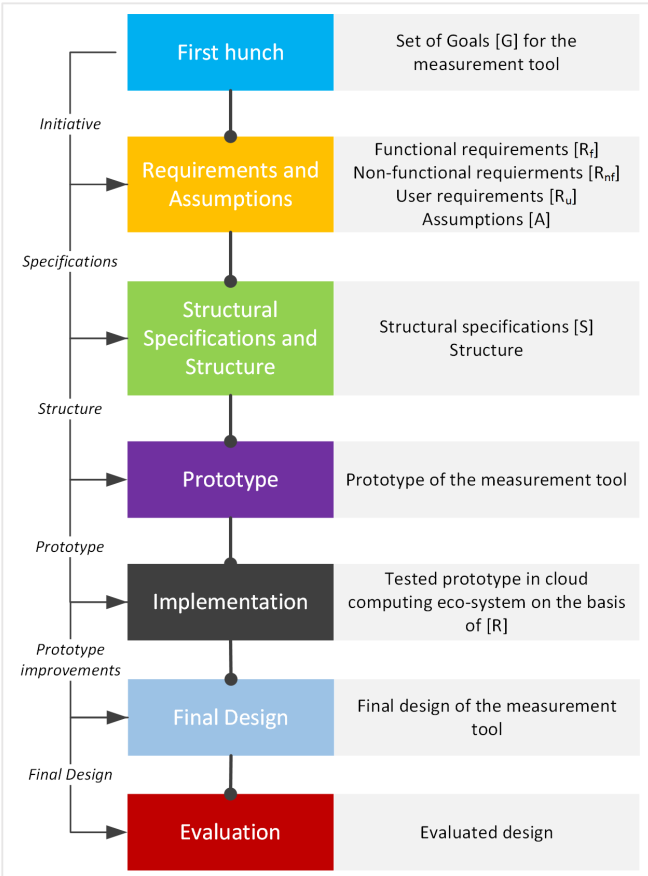


Figure 4: design cycle of Verschuren and Hartog (2005)

The design cycle consists of six stages (Figure 4 shows 7 stages, but the ‘final design’ phase has been added for this research). The first stage is called the ‘first hunch’ in which the initiative to start the research on developing a measurement tool to measure the environmental performance of cloud computing is presented. To further specify the purpose for which this research is initiated and to be able to evaluate later on, a set of goals [G] is defined. The second stage is called 'requirements and assumptions' and focuses on specifying the need for a measurement tool by using functional [R_f], non-functional [R_{nf}] and user requirements [R_u]. Besides requirements, assumptions that "*specify what qualities the users and context should have in order to make a fruitful use possible"* are defined (Verschuren & Hartog, 2005, p. 735). These requirements [Rf] and assumptions [A] are used in the third stage, 'structural specifications', for creating the (conceptual) structure [S] of the measurement tool. The structural specifications provide the input for creating prototypes in the fourth stage, which is called 'prototype'. Phases 5 and 6, 'implementation' and 'evaluation' respectively, focus on testing the prototypes of the measurement tool in the cloud computing eco-system to see which prototype fits the set of requirements best and evaluating the chosen prototype on the basis of the set of goals [G] to see to what extent the prototype is able to fulfil these goals. See Chapter 3 for a detailed description of the Methodology.

1.6.2 Thesis outline

Figure 5 presents the thesis outline. The colors represent the phases of the design cycle of Verschuren and Hartog (2005). Pink colored elements are not part of the design cycle. Chapter 1 contains the 'first hunch', in which the initiative of this research is presented together with a set of goals for the measurement tool. Chapter 2 provides a literature review to understand the cloud computing domain and to analyze theoretical concepts from which requirements can be derived. Chapter 3 presents the methodology, followed by chapter 4 and 5 in which the case study design and case study results are presented respectively. This case study is aimed at evaluating the current measurement effort and deriving requirements from practice. Chapter 6 describes the requirements and assumptions, derived from the results of chapter 2 and 5. Chapter 7 presents the structure of the measurement tool in the form of an IDEF0-model, which is based on the structural specification. Chapter 8 presents a prototype for the measurement tool, which is developed on the basis of the structure presented in chapter 6. Chapter 9 describes the expert review performed for evaluating the prototype in the cloud computing eco-system with the help of the structural specifications. The measurement tool is evaluated in chapter 9 on the basis of theory and its reliability and validity. Chapter 10 presents the final design of the measurement tool, followed by the conclusion, discussion and recommendations in chapter 12.

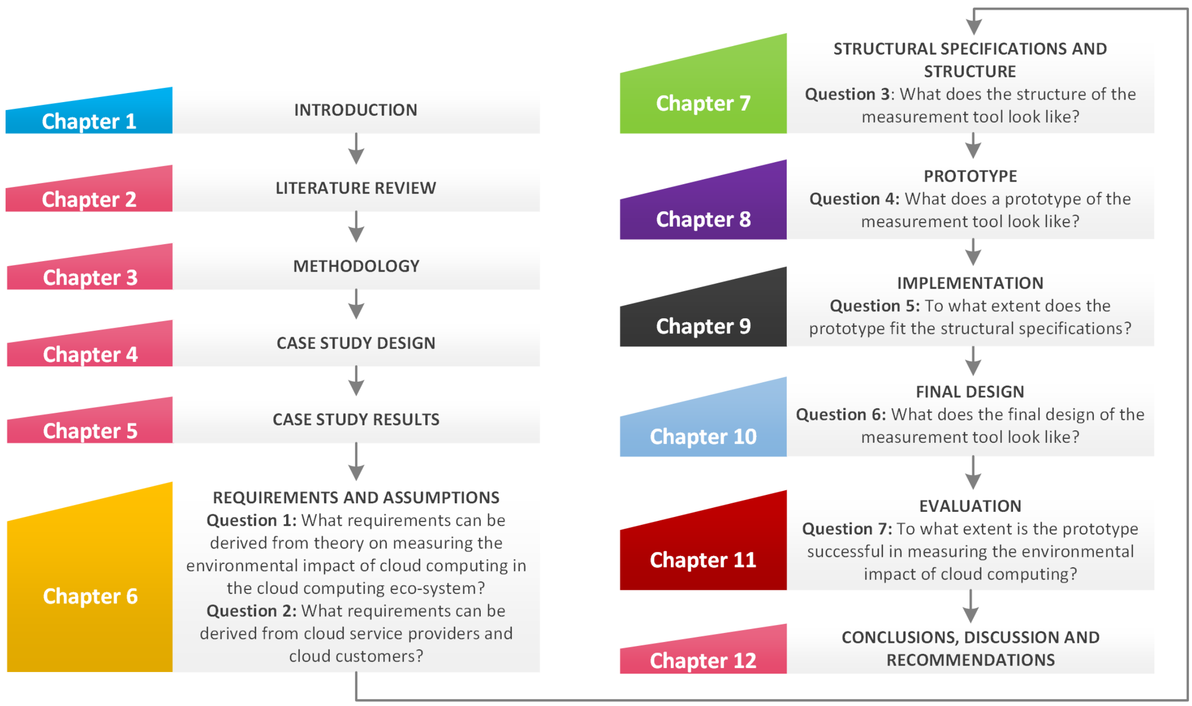


Figure 5: outline of thesis

2.

Literature review

2 LITERATURE REVIEW

The literature review consists of two parts: a domain exploration and theoretical insights. The goal of the domain exploration is to understand the concept of cloud computing, its characteristics, its potential to create energy and cost reductions and the data center system that functions as the backbone of cloud computing. The second part, theoretical insights, consists of insights from existing methodologies and approaches for measuring environmental performance and insights from the mechanisms of the cloud computing eco-system. More specifically, the literature review contains the elements as presented in Table 1.

Table 1: overview of literature review

Part/paragraph	Contents
Domain Exploration	
2.1: Cloud Computing and its environmental benefits	This paragraph presents a brief history of cloud computing to show that its concept is not entirely new. It presents the key characteristics of cloud computing that makes it a valuable concept for both customers and providers and it shows how these characteristics enable environmental benefits. The goal of this paragraph is to better understand cloud computing as a concept and its ability to enable energy and cost reductions.
2.2: The Data Center Energy System	The data center is the backbone of cloud computing and the part of the cloud computing supply chain that consumes the largest part of the energy that results in environmental impact. Therefore, insight into the functioning of this system is relevant.
Theoretical insights	
2.3: Existing methodologies and approaches for measuring environmental performance	Since measuring environmental performance is not a new concept, it is valuable to analyze existing methods and approaches and to determine the implications these existing methods have for the measurement tool.
2.4 & 2.5: Mechanisms in the cloud computing eco-system – sourcing and governance.	In 0, several knowledge gaps related to the mechanisms of sourcing and governance and their role on measuring the environmental performance were presented. The goal of these paragraphs in the literature review is to address these knowledge gaps.

2.1 Cloud Computing and its environmental benefits

2.1.1 History of cloud computing

In a Berkeley report, Armbrust et al. (2010) referred to cloud computing as the long-held dream of computing as a utility. This because it should provide advantages for companies, compared to being responsible for their single-owned and costly IT-infrastructure (Armbrust et al., 2010). Cloud computing qualifies to be called a 'disruptive technology' (Marston, Li, Bandyopadhyay, Zhang, & Ghalsasi, 2011). However, the idea of cloud computing is not new. In 1961, computing pioneer John McCarthy already predicted that *"computation may someday be organized as a public utility"*. Moreover, Youseff, Butrico, and Da Silva (2008) and Sadashiv and Kumar (2011) state that cloud computing is a descendant of other research areas such as Service-Oriented-Architecture (SOA), cluster computing, grid computing and virtualization. Cloud computing uses the ideas of SOA, since it provides computing as a service. Though cluster, grid and cloud computing are all examples of distributed computing and have a lot of similarities, cloud computing managed to really pervade the business models of companies. The cloud computing paradigm managed to grasp other technological developments combined with possibilities to use idle resources at data centers as a major utilitarian advantage (Youseff et al., 2008).

2.1.2 *Key characteristics of cloud computing*

Key characteristics of cloud computing are the use of virtualization technology (Gong, Liu, Zhang, Chen, & Gong, 2010), the scalability of resources (Dillon, Wu, & Chang, 2010; Grobauer, Walloschek, & Stocker, 2011; Jadeja & Modi, 2012; Pallis, 2010; Zhang, Cheng, & Boutaba, 2010), the pay-as-you-use model (Armbrust et al., 2010; Buyya, Yeo, Venugopal, Broberg, & Brandic, 2009; Dillon et al., 2010; Foster, Zhao, Raicu, & Lu, 2008; Gong et al., 2010; Grobauer et al., 2011; Grossman, 2009; Jadeja & Modi, 2012; Leavitt, 2009; Marston et al., 2011; Vaquero, Rodero-Merino, Caceres, & Lindner, 2008), the absence of up-front investments (Armbrust et al., 2010; Grossman, 2009; Jadeja & Modi, 2012; Leavitt, 2009; Leimeister, Böhm, Riedl, & Krcmar, 2010; Marston et al., 2011; Zhang et al., 2010), on-demand accessibility (Dillon et al., 2010; Grobauer et al., 2011; Mell & Grance, 2009; Pallis, 2010; Zhang et al., 2010), high amount of resources that can be devoted to reliability and security and the transference of risk (Jadeja & Modi, 2012). Less positive characteristics or challenges of the cloud include *"the loss of physical control of the data that is put on the cloud",* while organizations have to be compliant with data regulations (Marston et al., 2011, p. 181). Another challenge is related to placing mission-critical applications in the cloud, as service levels provided by cloud service provider may not always be high enough for large organizations (Marston et al., 2011). The key characteristics of the cloud as described in this paragraph, enable the reduction of the IT energy consumption compared to owning and managing in-house IT. This is further discussed in the next paragraph.

2.1.3 *Environmental benefits through virtualization*

Virtualization, scalability of resources and on-demand self-service are mainly responsible for the environmental benefits that cloud computing promises. According to Gong et al. (2010) *virtualization* is the most appealing characteristic of cloud computing. Zhang et al. (2010, p.8) state that *"virtualization is a technology that abstracts away the details of physical hardware and provides virtualized resources for high-level applications".* Figure 6 presents a traditional architecture and a virtual architecture. The virtual architecture uses a hypervisor (for example VMware) to create multiple virtual machines (with an Operating System and Applications) on a single server, where the traditional architecture only hosts a single Operating Systems and Application on one server. This means less physical servers are needed to serve the same amount of workload and customers, saving a significant amount of energy.

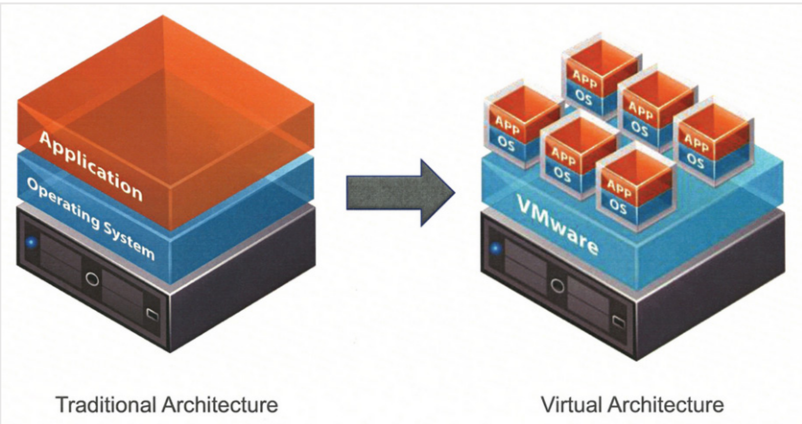


Figure 6: traditional versus virtual architecture, VMWare (n.d.)

Cloud computing resources are *highly scalable* (Zhang et al., 2010), due to *dynamic resource provisioning* and *shared resource pooling* (Dillon et al., 2010; Grobauer et al., 2011; Jadeja & Modi, 2012; Pallis, 2010; Zhang et al., 2010). This provides the cloud customer with the *appearance of infinite resources* (Armbrust et al., 2010) and *rapid elasticity* (Dillon et al., 2010; Grobauer et al., 2011). This makes it easier for the cloud customer to *scale services* (Marston et al., 2011). More important, the cloud customer only uses the cloud services when they are needed, due to the on-demand self-service (Dillon et al., 2010; Grobauer et al., 2011; Mell & Grance, 2009; Pallis, 2010; Zhang et al., 2010). These cloud characteristics together eliminate the need for excess capacity, which enables significant energy reductions.

From the customer perspective, the environmental benefits of the cloud are clearly visible, due to the contrast with their old traditional on-premises architecture. However, as mentioned before, due to the continuously increasing demand for cloud services, data centers at the supplier side are consuming enormous amounts of energy, generating large amounts of CO_2-emissions. Therefore, the data center energy system is discussed in the next paragraph.

2.2 The Data Center Energy System

Understanding the data center energy system is necessary for this research, because energy consumption accounts for the larger part of the data center's environmental performance (Alger, 2009). Moreover, because the data center is the backbone of cloud computing (Elgelany & Nada, 2013), analyzing the data center energy system also helps to analyze the formation of the environmental performance of cloud computing services.

Beloglazov et al. (2011) present a model for energy consumption at different levels in computing systems. This model has been slightly adjusted and specified specifically for this research. The result is presented in Figure 7. Users access cloud services through the internet or through a direct connection. Beloglazov et al. (2011) states that the energy efficiency of computing affects the end-users in terms of resource usage costs, which are based on the total cost of ownership (TCO) at the provider side. The energy consumption and efficiency of a computing system can be viewed on three different levels as presented in Figure 7: the application domain, the virtualized computing environments and the physical resources. These interconnected levels determine the energy consumption of computing, which can be expressed through the cloud service provider's electricity bill, CO_2-emissions and power budget (in terms of power capacity) (Beloglazov et al., 2011). Bohra and Chaudhary (2010a) mention that energy requirements are becoming "*increasing significantly in terms of operation cost as well as their indirect impact on ecology due to high carbon emissions*". To fulfill these energy requirements, interventions have to be done.

Therefore, the model of Beloglazov et al. (2011) has been complemented for this research with categories of interventions (see green frames in Figure 7) that can be done by a cloud service provider to increase the energy efficiency of cloud computing and positively affect the power/energy consumption criteria. Each layer and its components is further explained in the following paragraphs followed by the

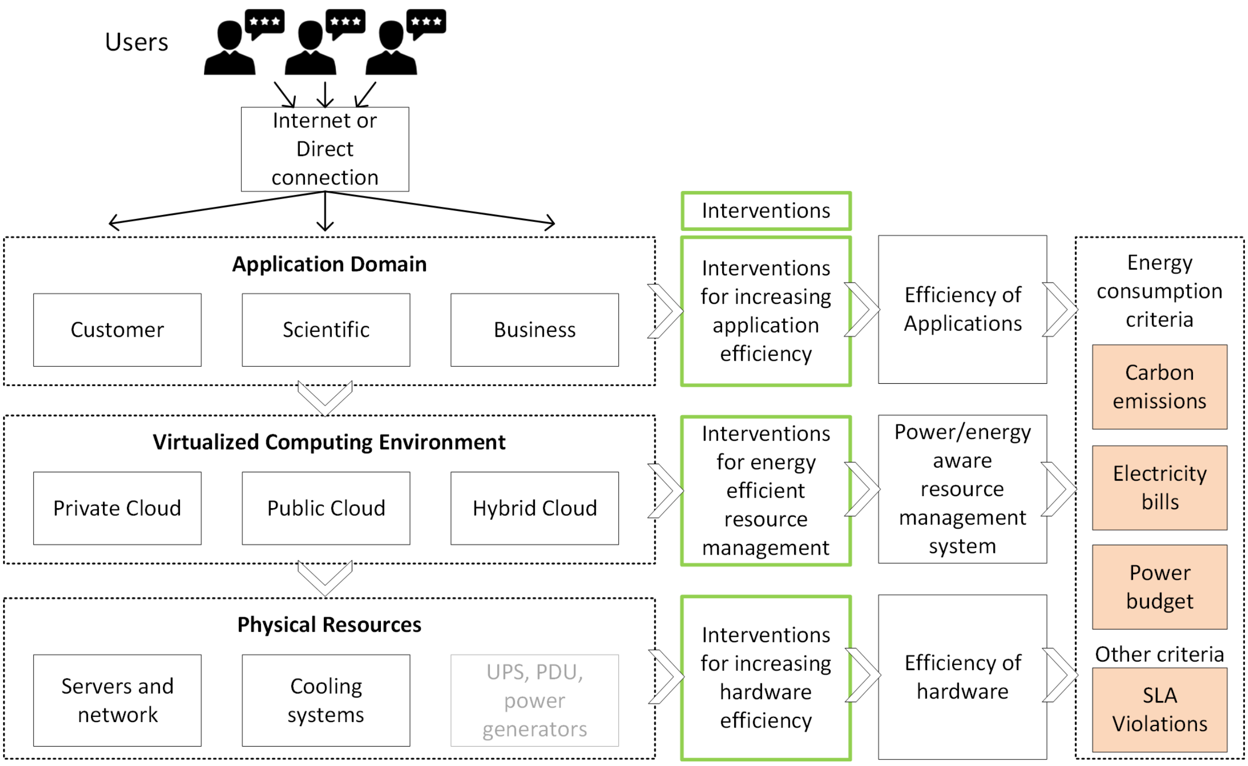


Figure 7: energy consumption for different layers in a computing system
Adapted from: (Beloglazov, Buyya, Lee, & Zomaya, 2011)

discussion of an important challenge in the managing energy efficiency and a final conclusion with the most important findings on the data center energy system.

2.2.1 Application domain

Within the application domain, Beloglazov et al. (2011) identified three different types of applications: customer, scientific and business. Beloglazov and Buyya (2010a, p. 577) mention that *"IT infrastructures continue to grow rapidly driven by the demand for computational power created by modern compute-intensive business and scientific applications"*. This indicates that the demand for computational power to run applications influences the amount of IT resources needed. Moreover, it is assumed that the efficiency of these applications can positively affect the amount of resources required. However, the focus of this research on the IaaS-layer of cloud computing, implies measuring the environmental performance of cloud computing on the level of the IT resources and not on the application level. Nonetheless, since the efficiency of applications influences resource usage, it is assumed to be covered by the layers of virtualized computing environments and physical resources.

2.2.2 Virtualized computing environment

Three types of cloud deployment models are distinguished by Mell and Grance (2009): public, private and hybrid. According to Mell and Grance (2009), (1) a private cloud is an exclusive cloud infrastructure for a particular organization which can be located on or off premises, (2) a public cloud is a cloud infrastructure for open use (by multiple users), which is located on the premises of the cloud service provider and (3) a hybrid cloud is a cloud infrastructure consisting of a combination of two or more other deployment models. Based on the characteristics of these deployment models, it is assumed that they set different requirements for the virtualized computing environment. For example, a private cloud does not allow for virtual resources to be provisioned on a server that is not exclusively used for one particular organization. The extent to which the virtualized computing environments are managed power and energy aware, determines the energy efficiency of this layer of the computing system. To influence the energy efficiency on this level of the computing systems, the model indicates to use certain interventions. Relevant examples of interventions include virtual machine migration and Dynamic Resource Allocation:

- *Virtual machine migration*. According to Jing et al. (2013), VM migration can be used to transfer a VM across physical machines to enable server consolidation, which in its turn increases energy efficiency, because it allows servers to be turned off.
- *Dynamic Resource Allocation*. Pu et al. (2010) mentions "*the effective allocation of virtual machines to handle both CPU intensive and I/O intensive workloads*" as one of the challenges of effective management of virtualized cloud environments. Dynamic Resource Allocation allows to determine the 'size' of a VM on the basis of the workload it needs to process (Jing et al., 2013).

A virtualized computing environment is provisioned on a combination of physical resources. The energy consumption and energy efficiency of these physical resources forms the third layer of Figure 7 and is discussed in the next paragraph.

2.2.3 Physical resources

This layer consists of the physical resources needed for provisioning a cloud services, such as servers, network, cooling systems, an Uninterruptable Power Supply ((UPS), which temporary takes over the power supply in case of an interruption in energy delivery), a Power Distribution Unit (PDU) and power generators. The contribution of these different physical resources to the total data center consumption varies. A lot of data center energy consumption breakdowns exist, but they are constantly subjected to change as the data center energy consumption varies over time. However, most breakdowns indicate IT-systems and cooling as the most energy consuming data center resources. Figure 8 provides an example of a data center energy breakdown in which IT-systems and cooling accounts for 78% of the data center's energy consumption. Compared to IT-systems and cooling, energy consumed by the UPS and PDU only accounts for 11%. Therefore, the choice is made to only discuss servers and network and cooling systems (in Figure 7, the element representing the UPS, PDU and power generators is therefore presented in grayscale).

The efficiency of the physical resources determines the hardware efficiency and can be influenced by several interventions. First, examples of interventions for increasing the efficiency of servers and network are discussed. Server consolidation through VM migration as mentioned in the previous paragraph is an example of the interconnection between the different layers in the model in Figure 7. However, it is assumed that the term 'server' refers to a machine that also includes other components, such as a Central Processing Unit (CPU) and storage. To increase the energy efficiency of a CPU, Dynamic Voltage Scaling is mentioned as an important technique by Jing et al. (2013). This technique enables active low-power modes, resulting in the CPU only using a fraction of the its total power (Beloglazov et al., 2011). With regard to the energy efficiency of the network Jing et al. (2013) mentions Network Traffic Consolidation (NTC), to minimize network traffic through optimizing the route of the network traffic. Second, as being one of the most energy consuming parts of the data center, the efficiency of the cooling system within a data center is discussed. Jing et al. (2013) states that due to increasing power density (among others due to increasing demand), thermal management becomes more and more a priority and increases the probability of thermal failure which may result in a lower and undesired level of availability of systems. Examples of interventions include closed cold corridors, which allows for separating the air streams and increasing cooling efficiency (Niemann, Brown, & Avelar, 2011). For these interventions it also holds that properly implementing them is often challenging. The next paragraph further elaborates on some of these challenges.

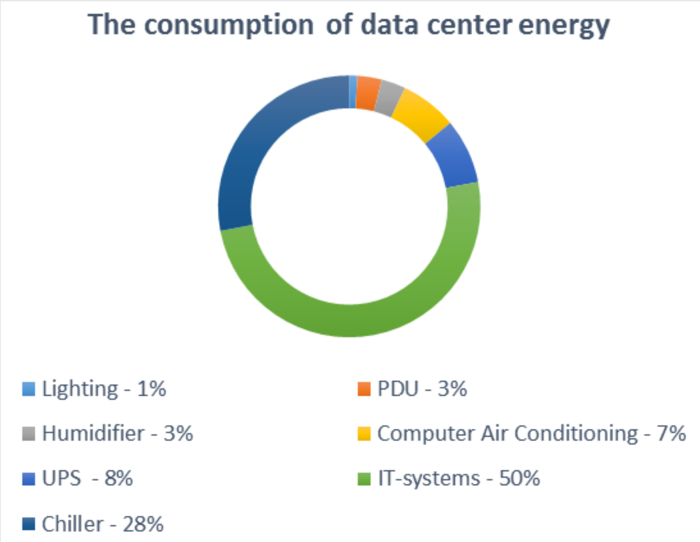


Figure 8: data center energy consumption breakdown
Adapted from: Fujitsu (n.d)

2.2.4 Challenge: the trade-off between performance and energy efficiency

First of all, Dikaiakos, Katsaros, Mehra, Pallis, and Vakali (2009) state that *"deploying an autonomous system to efficiently provision services in a cloud infrastructure is a challenging problem due to the unpredictability of consumer demand, software and hardware failures, heterogeneity of services, power management, and conflicting signed service level agreements between consumers and service providers*". An important trade-off that reflects this challenging problem is the one between the performance delivered to the cloud customer and energy efficiency. Beloglazov and Buyya (2010a) states that delivering reliable quality of services (QoS) towards customer as agreed in service level agreements is of crucial importance. However, interventions for increasing energy efficiency in data centers may affect the performance delivered to the customer. Literature contains several examples. Beloglazov and Buyya (2010a) mentions that cloud providers should manage the trade-off between power and performance, because performance losses may be the result of aggressive VM consolidation. According to Beloglazov and Buyya (2010b), aggressive VM consolidation in combination with varying workloads, may result in VM's not receiving the amount of physical resources requested. Zhang et al. (2010) mentions difficulties with managing this trade-off when implementing optimal resource allocation policies, for which prior knowledge about the effects of allocation is needed to set future requirements. This trade-off does not only have implications for virtualization and virtual machines. For example, Zhang et al. (2010) mentions that using disk power management schemes to increase the energy efficiency of hard disks, often results in disks switching between high and low power mode with a related performance trade-off. Research of Choi, Soma, and Pedram (2005) into Dynamic Voltage and Frequency Scaling of CPU's in particular focuses on finding solutions for which the performance loss can be controlled and minimized. The problems mentioned by Dikaiakos et al. (2009) such as unpredictability of demand, heterogeneity of services and conflicting service level agreements even further complicate this trade-off, as they seem to imply different levels of performance. Inadequate management of this trade-off is expected to result in violations of service level agreements (see Figure 7), as the agreed quality of services or performance cannot be delivered to the customer.

2.2.5 Conclusion: important findings on the data center energy system

According to the model of Beloglazov et al. (2011) that was adjusted for this research (see Figure 7), the energy consumption of computing systems consists of three interconnected layers: the application domain, the virtualized computing environment and the physical resources. For each layer, Beloglazov et al. (2011) mention a measure for the efficiency: the efficiency of application, power/energy aware resource management and the efficiency of hardware respectively. For each domain, interventions were added to this model for which examples were provided in the previous paragraphs. These interventions all have potential to increase the energy efficiency, but often have to deal with the trade-off between performance delivered to the customer and energy efficiency. It is assumed that this trade-off sets limits to the possibilities for cloud service providers to increase the energy efficiency and thus the environmental performance of their cloud services. This should be kept in mind when designing the measurement tool.

Analyzing the energy consumption at different levels of a computing system as done in the previous paragraphs, has provided insight into the determinants of the environmental performance of cloud computing and how they can be influenced at the same time. Further relevant insights into environmental performance, consist of how environmental performance can be measured, which is discussed in the next paragraph.

2.3 Existing methodologies and approaches for assessing environmental impact

Measuring environmental performance is not a new concept, but doing so specifically for cloud computing services is. To be able to build the new measurement tool on existing knowledge instead of 'reinventing the wheel', this paragraph presents an overview of existing methodologies for assessing and measuring environmental performance. But first, environmental performance as a concept is placed in literature, because this may provide relevant insights on how to measure environmental performance.

2.3.1 Defining environmental performance

Environmental performance is related to corporate sustainability. Sustainability has more and more been a subject of research in management literature over the last decades (Dao, Langella, & Carbo, 2011). On the business side, companies are now hiring new employees to fulfill sustainability positions (Montiel & Delgado-Ceballos, 2014). Sustainability is defined by Broadbent and Weill (1997, p.8) as *''(..) development that meets the needs of the present without compromising the ability of future generations to meet their needs.''* The literature review of Montiel and Delgado-Ceballos (2014) shows ambiguity in the use of the concept of corporate sustainability as a tridimensional construct consisting of economic, social and environmental dimensions, a bidimensional construct consisting of social and environmental dimensions or as a single-dimension construct consisting of environmental management. Fortunately, the research of Montiel and Delgado-Ceballos (2014) also shows that a major part of the scholars agree that corporate sustainability entails economic, social and environmental dimensions.

A sustainability framework that adequately combines these dimensions is the Triple Bottom Line (TBL) as developed by Elkington (2004) and presented in Figure 9. TBL consists of three dimensions along which organizational sustainability is assessed: environment, society and economic performance (Elkington, 2004). As presented in Figure 9, the TBL is related to people, planet and profit, where the environmental performance accounts for 'planet'. This framework fits the scope and purpose of this research, because the three dimensions of TBL can be clearly recognized in the cloud computing eco-system, for the following reasons. First of all, literature often mentions CO_2-emissions (environmental dimension) together with the high costs (economic dimension) incurred by the high energy consumption of cloud data centers and vice versa (e.g. Garg and Buyya (2011), Berl et al. (2010) and Sabbaghi and Vaidyanathan (2012)). Second, the social dimension also seems to be present in the cloud computing eco-system through for example the end-customer, cloud customer and private certification companies who are putting pressure on the cloud service provider as green products and companies are preferred over conventional ones (Ilinitch et al., 1999).

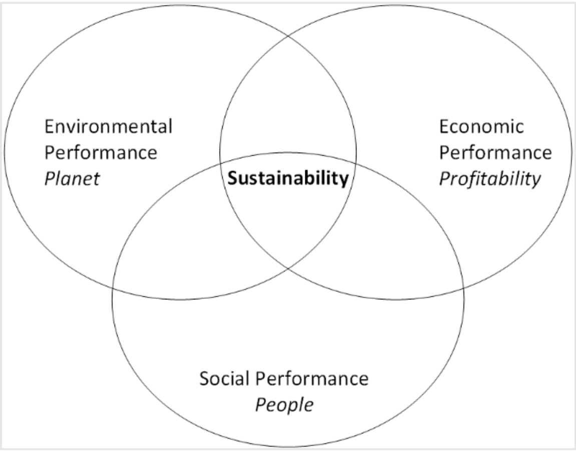


Figure 9: Triple Bottom Line for Sustainability

Despite the focus of this research being explicitly on the environmental dimension, it seems valuable to understand the cohesion of this dimension with the economic and social dimension, because stakeholders in the cloud computing eco-system may use different dimensions to look at the same problem. Keeping the connection between these dimensions in mind when designing the measurement tool, could result in a design that receives broader support of stakeholders. For the measurement tool this means that at least the environmental dimension should also be included, because compared to CO_2-emissions, the high energy costs are expected to be a more appealing problem for the cloud service provider. Therefore, the economic dimension should be included in the measurement tool through presenting the economic impact of the energy consumption of cloud computing.

2.3.2 Assessing environmental performance on different organizational levels

A wide variety of methods to assess environmental performance exists. To structure these methods, a categorization of different organizational levels is used: strategic, business process and system, as displayed in Figure 10. The most comprehensive level is the strategic level in which the environmental performance of the organization as a whole should be captured. The second level comprises of measuring the environmental performance on the level of business processes that takes place in an organization. The third level is the system level, in which the environmental performance of systems such as the data center or the Green IT infrastructure can be assessed. For each organizational level, relevant methods and approaches for measuring environmental performance are presented, followed by a conclusion with implications for the measurement tool.

2.3.3 Strategic level (organizational)

As the strategic level is the highest level on which environmental performance can be assessed, the efforts on this level often

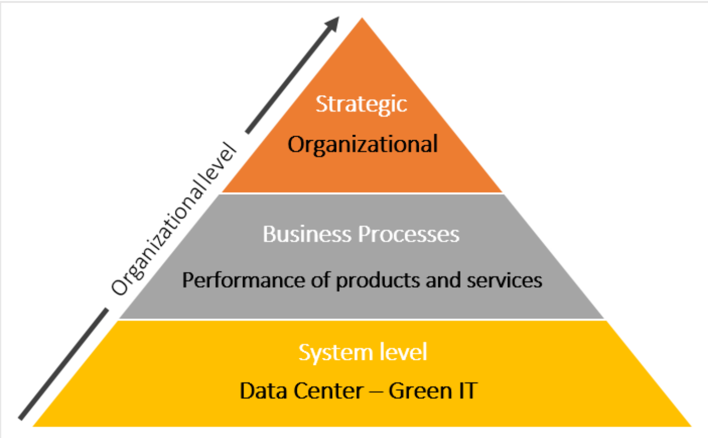


Figure 10: organizational levels for assessing environmental

comprise a comprehensive and holistic view of the environmental performance of the whole organization. This is expected to come at the cost of information transparency and detailed assessment of the lower organizational levels.

Organizations have to find their way in dealing with the *"growing demand for transparency about corporate behavior"* (Kolk, 2008, p. 1). Fifka and Drabble (2012) argue that this requirement does not only come from consumers, media and civil society organizations, but mention Kolk (2004) who states that investors play an important role in this too. Therefore, sustainability reporting is now a serious area of focus for large corporations (Fifka & Drabble, 2012). The literature review performed by Montiel and Delgado-Ceballos (2014) showed that actual measurements of corporate sustainability are often outsourced in empirical studies. Montiel and Delgado-Ceballos (2014) have made an overview of the standards used by corporate sustainability studies for measuring and comparing the performance of different companies. As corporate sustainability is measured along the three dimensions of economic, social and environmental performance, Montiel and Delgado-Ceballos (2014) present an overview of relevant measures on these three dimensions, using the secondary sources MSCI Environmental Indexes, the Dow Jones Sustainability Index, the SAM Corporate Sustainability Assessment and the Dow Jones Sustainability Index EURO STOXX and the Global Reporting Initiative (GRI). These secondary sources help to compare the corporate sustainability of different firms. As this research mainly focuses on environmental impact, Table 2 presents the measures on the environmental dimensions based on the findings of Montiel and Delgado-Ceballos (2014).

Table 2: sources and measures for assessing corporate environmental performance.

Source	Measures	
MSCI Environmental Indexes	▪ Environmental indexes*	
Dow Jones Sustainability Index (DJSI), Sam Corporate Sustainability Assessment, Dow Jones Sustainability Index EURO STOXX	▪ Environmental footprint* ▪ Environmental reporting ▪ Environmental policy/management system* ▪ Operational eco-efficiency*	
Global reporting initiative	▪ Materials ▪ Energy* ▪ Water ▪ Biodiversity	▪ Emissions, effluents and waste* ▪ Products and services ▪ Compliance ▪ Transport

According to Montiel and Delgado-Ceballos (2014), the outsourcing of measuring corporate sustainability means that other organizations who were already in possession of models and metrics were used (such as presented in Table 2) to express the level of corporate sustainability. Measures in Table 2 marked with a star, are relevant for this research, because they are in line with the scoping of this research.

The environmental indexes of MSCI (former FTSE KLD 400 Social Index) contains two families of indices relevant for this study: the low carbon family and the thematic family. The low carbon family includes a benchmark for carbon emissions and the thematic family comprehends several sub-indices such as the 'clean technology index', the 'green building index' and the 'pollution prevention index' (MSCI, 2014a).

The DJSI is a collaboration between Standard & Poor's, Dow Jones Indices and SAM (Montiel & Delgado-Ceballos, 2014). In the environmental dimension, organizations are among others assessed on the basis of their environmental footprint, environmental reporting, the presence of an environmental policy and management system and their operational eco-efficiency (Montiel & Delgado-Ceballos, 2014).

The GRI provides a guideline for helping organizations to establish sustainability reports (Montiel & Delgado-Ceballos, 2014). For this research, in particular the measures 'energy' and 'emissions' are of interest. The guideline describes how to report on energy in a sustainability report and advices to for example present the energy consumption within and outside the organization, the energy intensity and the reduction of energy consumption of the organization as a whole and specifically for products and services. Appendix 15 provides an overview of the measures energy and emissions and the content of their guidelines.

For the development of the measurement tool, the following remarks are important. The indices of the MSCI use yearly reports or estimations to retrieve data from the organizations (MSCI, 2014b), which means that the MSCI does not prescribe how to measure the data needed for their indexes. The same holds for the Dow Jones Sustainability Indices. The focus of the GRI is on providing guidelines for reporting. For relevant measures such as energy, the GRI does prescribe for example how to measure the total energy consumption within the organization, but at a very superficial level (Global Reporting Initiative, 2013). This means that the methods and approaches on the organizational level do not provide useful implications for the way the measurement tool should measure environmental performance.

2.3.4 Business process level – the carbon footprint of products and services

Environmental performance can also be measured on the business process level. Life-cycle assessment (LCA) is a method that can be used to determine the environmental impact caused by a product or service, in which 'life-cycle' means that all phases of the business process from the cradle to the grave should be included (Vink, Rabago, Glassner, & Gruber, 2003). As mentioned before, for this research, the environmental impact of a cloud service consists of CO_2-emissions. When data centers are consuming energy for provisioning cloud services, they are producing CO_2-emissions at the same time, leading to environmental harm and global warming (Uddin & Rahman, 2012). A study performed by the Climate Group shows that IT emissions are increasing with 6% per year, which would result in IT accounting for 12% of the global emissions in 2020 (Webb, 2008). The definition of carbon footprint fits the definition of LCA, because it also suggests to include different life stages. Therefore, determining the carbon footprint of a service through LCA seems a suitable method for measuring the environmental performance on the business process level. Carbon footprint is defined by Wiedmann and Minx (2008, p.4) as *"(..) a measure of the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product*". In this definition, products also include services (such as cloud computing) (Wiedmann & Minx, 2008). Determining the carbon footprint of products and processes is done all over the world (Pandey, Agrawal, & Pandey, 2011). The carbon footprint of different products and processes provides input for determining the carbon footprint of the organization as a whole. The term 'carbon footprint', has become popular despite 'footprint' being the wrong name, as it is not a measure of area, but the mass of cumulative CO_2-emissions (Hertwich & Peters, 2009). The amount of CO_2-emissions is measured in units of mass such as kg or tons (Wiedmann & Minx, 2008).

Compared to the organizational level, the business process level fits the scope of this research much better due to its focus on environmental impacts and CO_2-emissions of a business process within an organization. However, the scope of this research does not allow a full life-cycle analysis of the process of provisioning a cloud service, given the focus on the impact of the use of IT resources within the boundaries of the data center. Nonetheless, it is valuable to use carbon footprint in the measurement tool, since it is a commonly used metric for expressing the impact caused by energy consumption.

2.3.5 System level – green IT and the data center system

Looking at the cloud computing eco-system, can be done from multiple system perspectives. One can analyze an aspect of the system, the functioning of the system during a certain phase or a sub system that is part of the whole system. To gain insight into measuring the environmental performance of cloud computing on the system level, two of these perspectives are used. First, the system is analyzed as a Green IT system, which consists of the green IT aspects of the systems. This seems relevant, because frameworks and models exist that evaluate the value and performance of green IT. Moreover, cloud computing is a well-known green IT phenomenon. Second, the data center and its efficiency is analyzed as a sub system of the complete system responsible for delivering cloud services.

Green IT. According to Jenkin et al. (2011, p. 17) *"Green information technologies and systems refer to initiatives and programs that directly or indirectly address environmental sustainability in organizations".* Cloud computing is an example of 'green information technology'. Chou and Chou (2012) have developed the Green IT value model, which is presented in Figure 11. The model contains four phases: awareness, translation, comprehension and Green IT value. Chou and Chou (2012) state that the cumulative results of the different phases should deliver Green IT value with the overarching goal of enhancing environmental sustainability. For this research, the comprehension phase is of particular interest as it entails the creation of measurements for analyzing the performance of the Green IT systems with regard to the expected results. To be able to analyze performance, approaches are needed. A comprehensive approach is provided by Uddin and Rahman (2012) who developed the 'energy efficiency and low carbon enabler green IT framework for data centers'. The framework should support organizations in implementing green IT and helps to determine and use metrics for measuring data center efficiency. A relevant phase in the framework related to measuring performance is the analysis phase, which provides steps for measuring data center performance on a regular basis. The steps to be followed are:

Figure 11: Green IT value model adapted from: Chou and Chou (2012)

- Collect data at regular time intervals.
- Perform analysis.
- Compare new with older baseline values.
- Standardize benchmark values.
- Look for greener solutions and continue greening process.

For the measurement tool, these steps of the framework of Uddin and Rahman (2012) can be seen as literal requirements that should be met by the measurement tool. They imply that the measurement tool should be aimed at collecting data at regular time intervals, should use baseline and standardized benchmark values and should look for greener solutions and continue the greening process.

Data Center Efficiency. The green IT framework of Uddin and Rahman (2012) puts a focus on the data center when it comes to implementing and analyzing Green IT. This is not a surprise, since data centers function as the backbone of cloud computing (Elgelany & Nada, 2013). On the data center level, a lot of metrics can be identified that measure the performance of the data center. In the light of this research, metrics that help to measure energy consumptions are of particular interest. To obtain an overview of the available metrics, several articles describing metrics for data center performance are analyzed. The article 'Layered Green Performance Indicators' by Kipp, Jiang, Fugini, and Salomie (2012), provided inspiration for representing metrics as displayed in Table 3. For each benchmark, the metric, level of aggregation and the source are presented. Kipp et al. (2012) have made an effort in listing relevant green performance indicators in the areas of IT resource usage, application life cycle, energy impact and the organization. The benchmarks adapted from Kipp et al. (2012) come for the larger part from the area of energy impact. For some benchmarks, further research was needed to find the right source for describing and defining the metric. Further metrics were found by using the terms 'data center metrics' and 'measuring data center performance' in Google Scholar and Scopus.

Table 3: benchmarks and their metrics for measuring data center performance

Benchmark	Metric	Level	Source
Corporate Average Data Center Efficiency (CADE)	DCE based on corporate footprint. CADE = Infrastructure utilization * Infrastructure energy efficiency * IT utilization * IT energy efficiency	Data Center	Kaplan, Forrest, and Kindler (2008)
Number of transactions/kWh	Measurement of energy consumption per computing unit for web applications	Application	Kipp et al. (2012)
Flops/kWh	Measurement of energy consumption per computing unit for simulation applications	Application	Kipp et al. (2012)
Data Center Infrastructure Efficiency (DCie)	DCie = 1 / PUE	Data Center	Joshi, Kumar, Sammakia, and Patterson (2012)
Power Usage Effectiveness (PUE)	PUE = Total facility power/IT Equipment power	Data Center	The Green Grid (2007)
Data Center Efficiency (DCE)	DCE = IT Equipment power/Total facility power	Data Center	Daim et al. (2009)
Compute Power Efficiency (CPE)	Measures the extent to which computation power is used efficiently CPE = IT Equipment Utilization / PUE or CPE = (IT Equipment Utilisation * IT Equipment Power) / Total Facility Power	Data Center	Belady and Malone (2007)
Data Centre Energy Efficiency and Productivity Index (DC-EEP Index)	IT Productivity * SI-EER	Data Center	Brill (2007)
Site Infrastructure Energy Efficiency Ratio (SI-EER)	Power to data center / IT equipment power	Data Center	Brill (2007)
Data Center Energy productivity (DCeP)	Number of bytes processed/kWh	Data Center	Anderson et al. (2008)
Data Center Performance Efficiency (DCPE)	Energy/transaction or energy per business function performed	Data Center	Azevedo (2010)
MHZ/Watt	Processor performance/energy (watts)	CPU	Schulz (2010)
Bandwidth/Watt	GBPS, TBPS or PBPS/Watts	Network	Schulz (2010)
Capacity/watt	GB, TB, PB/Watts	Storage	Schulz (2010)
IOPS/Watts	Number of I/O operations (or transactions)/energy (watts).	Storage	Schulz (2010)
Carbon Usage Effectiveness (CUE)	CUE = Total CO_2-emissions caused by the total data center energy / IT equipment energy	Data Center	Azevedo, Patterson, Pouchet, and Tipley (2010)

It is assumed that the fact that all of these benchmarks contain both an energy and performance component is not a coincidence, but based on the trade-off between energy efficiency and performance that was presented in paragraph 2.2.4. Therefore, a metric that is included in the measurement tool is likely to have a similar structure as the metrics presented in Table 3.

2.4 Sourcing theory and measuring environmental impact

In 1.3.1 the outsourcing process was presented on the basis of the model of Schniederjans et al. (2005). Within the outsourcing process two gaps related to the role of environmental performance measurements were identified. First, selecting a vendor on the basis of multiple criteria, poses the question to what extent the environmental performance of the services delivered by this vendor is included in vendor selection. Second, because the model of Schniederjans et al. (2005) implies to manage and control the outsourcing activity, the extent to which the management of environmental performance plays a role in this is also of interest. The goal of this paragraph is to address these knowledge gaps. But, before doing so, a brief background of outsourcing is provided.

2.4.1 Background of outsourcing

Leimeister et al. (2010) have made an effort in comparing cloud computing and outsourcing. They provide some relevant background information on outsourcing and state that understanding the history of outsourcing helps to grasp the evolution of cloud computing (Leimeister et al., 2010). Briefly summarized, Leimeister et al. (2010) mention the following sequence of events related to the outsourcing concept:

- In the early stages of IT outsourcing, the most important considerations were the *decisions between internal or external provisioning of IT resources* and the *subject of outsourcing*.
- Research into *motives, potential benefits and risks* helped to substantiate IT-outsourcing decisions.
- Determining the *scope of outsourcing* enabled the occurrence of total and selective outsourcing.
- Remaining questions about the effectiveness of outsourcing resulted in *backsourcing* of IT.
- Currently, the focus is mostly on the *design of the contract,* such as the service level agreement.
- Since information technology is a rapidly developing phenomenon, flexibility is necessary for managing the relationship between the service provider and the customer, requesting other mechanisms to be further investigated.

The current focus on contract design in outsourcing, could be a positive development because it emphasizes the attention for quality of services and management and control of the outsourcing activity. However, this does not necessarily mean that there is attention for the environmental performance of the cloud in this.

2.4.2 The role of environmental performance measures in vendor selection

Selecting a cloud service provider can be done through comparing the services of different cloud providers. Hussain and Hussain (2011, p. 45) state that service comparison *"is an important step towards vendor selection".* Service evaluation is not only of added value for cloud customers. It also useful for a cloud service provider for identifying those services that perform less well compared to similar services of competitors (Li, Yang, Kandula, & Zhang, 2010). Garg, Versteeg, and Buyya (2011) add to this that and mentions that it will enhance competition and help to improve the quality of their services.

However, the increasing amount of cloud services makes deciding on what services fit the requirements of a customer best, complicated (Sundareswaran, Squicciarini, & Lin, 2012). Moreover, Hussain and Hussain (2011) mention that it is not only the wide variety of providers and services, but also the different pricing schemes that lead to difficulties in evaluating the quality and costs of services. Several cloud service selection methods have been developed. With the help of several metrics, *"CloudCmp"* evaluates the impact of elastic computing, persistent storage and network services of a cloud service provider on the performance of a customer's application (Li et al., 2010). Another example is the cloud recommender system of Han, Hassan, Yoon, and Huh (2009), which helps to evaluate cloud services on the basis of network quality of services and virtual machine performance. Qu et al. (2013) mention that the focus of other cloud service selection methodologies on objective performance analysis and benchmark test lacks the inclusion of the interests of the cloud customer. Therefore, they have created a model that combines user feedback with objective performance analysis (Qu et al., 2013). The performance analysis tools used in these models, do not include measures for environmental performance, but focus for example on the speed of the CPU, service response time or network availability. Unfortunately, this means that no implications for measuring environmental performance can be derived from these models for cloud service comparison. Therefore, the next step in finding implications for measuring the environmental performance of cloud computing with the help of sourcing theory, is to turn to more generic literature on sourcing.

Molla (2008, p. 661) describes Green IT from the sourcing perspective, saying it *"implies the practice of environmentally preferable IT purchasing"*. Molla (2008) indicates several actions to be part of sustainable IT-sourcing and vendor selection, such as analyzing the environmental performance of an IT hardware supply chain and analyzing the environmental track record of -in this research- the cloud service provider. Moreover, Molla (2008) mentions the need for measuring the environmental performance of services and products involved in a sourcing decision.

So, despite environmental performance measures not being included in the analyzed cloud service comparison models, looking at sourcing IT from a green IT perspective, does mention environmental performance to be important. Going back to the knowledge gap, it can be said that there is no role for environmental performance in the process of vendor selection, because it is not included as a criterion. Therefore, no implications for measuring environmental performance can be derived from this. However, it is assumed based on the statements of Molla (2008), that the cloud customer has a certain interest in evaluating the environmental performance in the process of sourcing services and products. Moreover, as mentioned before, cloud service comparisons are also of added value for the service provider (Qu et al., 2013). For the measurement tool this means that the environmental performance output it produces, would be more useful if this output is suitable for comparing against other services to support vendor selection and service improvements. This means that comparable results should be generated by the measurement tool. More specifically, based on Molla (2008), this means that the measurement tool should facilitate vendor selection based on environmental performance.

2.4.3 The role of environmental performance in management and control of the outsourcing activity

In this paragraph the knowledge gap on the role of environmental performance in the management and control of the outsourcing activity is addressed. The customer *"expects a cost-effective, efficient and flexible delivery of IT services from their service provider, at a maximum of monetary flexibility"* (Leimeister et al., 2010, p. 6). Delivering cloud services with a guaranteed quality of services (QoS) is crucial for cloud computing to succeed (Xiong & Perros, 2009). Therefore, service level agreements are used to guarantee the provisioning of cloud services with an agreed quality of services for a certain price (Xiong & Perros, 2009). Next to that, service level agreements should also specify the consequences of any violation (Alhamad, Dillon, & Chang, 2010). Without adequate efforts to manage the negotiated service level agreement, it is of no value (Marilly, Martinot, Papini, & Goderis, 2002). Marilly et al. (2002, p. 2) mention the *"reliable measurement of the quality of services"* as one of three important requirements when taking into account customer satisfaction. Cicotti, Coppolino, Cristaldi, D'Antonio, and Romano (2012) acknowledge this requirement and state that they found evidence for the need for quality of services monitoring now, and even more in the future. Moreover, Cicotti et al. (2012, p. 15) state that *"continuous monitoring of quality of services attributes is needed to enforce service level agreements"*.

To summarize, sourced cloud services should be managed and controlled through service level agreements and these agreements should be audited in terms of adequately measuring the quality of services. For the measurement tool this implies no more than that the measurement tool should contribute positively to the enforcement of service level agreements through monitoring quality of services. However, this does not say anything about the role of environmental performance measurements. Unfortunately, the availability of literature on the content of service level agreements for cloud computing is limited. The framework of Alhamad et al. (2010) however, does provide some relevant insights. Alhamad et al. (2010) developed a conceptual service level agreement framework specifically for cloud computing. They state that it is important to allow for service level agreements with different structures to serve the variety of cloud customers. Therefore, Alhamad et al. (2010) defined different performance metrics for IaaS, PaaS and SaaS. Although the proposed performance metrics do not include any environmental performance or energy related metrics, Alhamad et al. (2010) present the following relevant requirements for performance measurement through service level agreements:

- Present the level of performance of service.
- Define ways by which the service parameters can be monitored and reported.

For the measurement tool, these requirements imply that output of the measurement tool (the result) should represent environmental performance levels as specified in service level agreements. Next to that, it should indicate how to monitor this performance level and what format the monitoring reports should have.

Cicotti et al. (2012) have developed a method for monitoring QoS in a cloud services environment. Cicotti et al. (2012) mention an important technical challenge, which increases the difficulty of measuring the quality of cloud services. This challenge lies in the fact that cloud computing infrastructure is shared and virtualized. The structure of on-premises infrastructure was known; with cloud computing, the cloud customer has no idea what the organization of the IT-infrastructure looks like (Xiong & Perros, 2009). This means that virtualization, which was presented in paragraph 2.1.3 as being a key characteristics of the cloud that enables environmental benefits, also has a downside: it complicates QoS-measurements (Xiong & Perros, 2009). For the measurement tool, this implies that the virtualized layer of cloud computing should be adequately addressed when measuring environmental performance to enable proper quality of service monitoring.

2.5 Cloud governance and measuring environmental performance

Just like sourcing theory, (cloud) governance theory also holds several implications for measuring the environmental performance of cloud computing. In paragraph 1.3.3, the definition of IT governance of Weill and Ross (2004a) indicated that it is necessary to assess how well desired outcomes are being achieved. Therefore, paragraph 2.5.1 presents insights from governance theory on the assessment of outcomes. Furthermore, in paragraph 1.3.3, certification schemes were also mentioned as a form of governance that plays a role in the cloud computing eco-system. To identify the implications of these certification schemes for the measurement tool, paragraph 2.5.2 and 2.5.3 provide implications from certification standards and certifications schemes in the coffee industry respectively.

2.5.1 Implications based on challenges in performing cloud governance

Service governance is aimed at making sure services are doing what they were designed for (Linthicum, 2009). Therefore, the performance of services must be measured to determine how well desired outcomes are being achieved. Linthicum (2009) states that performing operational monitoring can be done through placing controls on these services with the help of policies to monitor these services during runtime and that insights into these services should be completely *transparent* for the cloud customer. More specifically, Linthicum (2009) mentions that it is of utmost importance to understand what and how services need to be monitored and what level of *granularity* should be used. This means that the right level of detail on which the performance is measured, should be chosen. Determining the appropriate way of monitoring services at the right level of granularity, helps to ensure the quality of services as agreed with the customers. For the perspective of the cloud customer, Linthicum (2009) indicates that since the customer is not the owner of the services, it has to deal with the measuring services as provided by the cloud service provider and argues that the customer should take this into account when selecting a cloud service provider to make sure that it is able to measure performance based on its own needs.

2.5.2 *Implications from certification standards*

Galarraga Gallastegui (2002) mentions two functions of labels: the first function is the ability of labeling programs to enhance sustainable patterns of consumption and the second function is to stimulate stakeholders to increase the standards for products and services with regard to their environmental performance in the economy. According to De Boer (2003) labels are claims implying a product or service to have certain characteristics and these labels help to gain insight into the arguments that substantiate such a claim. De Boer (2003) identifies three levels on which labels can be issued: first party (company itself), second party (industry level) and third party (independent organization).

Related to the latter, Auld, Gulbrandsen, and McDermott (2008, p. 188) mention a certification scheme with a non-obligatory character that *"is based on third-party auditing of compliance with performance-based sustainable resource management standards developed by nonstate actors…, industry associations and social groups"*. It seems to be that such a certification scheme is the result of joint stakeholder pressures and efforts to change an industry to a more sustainable industry. For the cloud computing industry, a certification scheme specifically for cloud does not seem to exist yet. However, several standards of the International Organization for Standardization (ISO) can also be applied to cloud computing (and its environmental performance in particular). Think of ISO14000 that sets the guideline for implementing environmental management systems in organizations, the ISO50001 that provides the norm for energy management systems. ISO50001 provides relevant implications for this research:

- The energy management system prescribed by the standard follows the Plan-Do-Check-Act cycle of Deming (1982).
- The energy management system must be aimed at continuous improvement.

Due to the focus on energy consumption as the determinant of the environmental performance of the cloud, the measurement tool can also be seen as an energy management system. The ISO-standards are widely accepted and a lot of organizations are familiar with them. Therefore, it could be relevant to see how the implications based on the norm for energy management systems could be included in the measurement tool. Basically, the implications opt that the measurement tool could also follow the Deming circle and should be aimed at providing continuous improvement of the energy efficiency of cloud services.

2.5.3 *Implications from certification schemes in the coffee industry*

The coffee industry provides a relevant example as coffee is a commodity and cloud computing is often referred to as "the long-held dream of computing as a utility" (Armbrust et al., 2010, p. 50). Raynolds, Murray, and Heller (2007) studied the regulation of sustainability in the coffee industry and found that:

- The creation of certification efforts depends on the ability of non-governmental organizations to operate independently from corporates and governments.
- Instead of judging a product based on established standards, there is a shift towards evaluating the process of manufacturing products and services (Dankers, Liu, & Lawrence, 2003).

With regard to the first point, the question is to what extent non-governmental organizations and other stakeholders in and surrounding the cloud computing eco-system will start to collaborate with the goal to create certification schemes. As pressures from stakeholders are likely to increase in the future, due to ongoing and unwanted environmental impacts of business and further depletion of resources, it is likely that the intensity of governance increases. However, extensive research into the emerging of voluntary certification schemes in relation to the cloud computing eco-system is needed to be able to determine the likelihood of new governance structures arising in the future. Whether or not such a certification scheme will occur in the future, knowing the requirements for a 'good' certification scheme are helpful. Harris (2007) has made an effort into creating 'an example of sustainability certification of goods and services and lists several criteria, of which the ones relevant for measuring performance are presented here. The certification system should:

- Be based on life-cycle assessment.
- Have objective and measurable standards.

The need to consider life-cycle assessment has already been discussed in paragraph 2.3.4. In paragraph 2.4.2 it was mentioned that the measurement tool could also function as an instrument to facilitate vendor selection. This means that it should facilitate the comparison of cloud services on the basis of their environmental performance. Certification schemes have a similar function and have to be designed in such a way that they apply to a wide variety of organizations and generate reproducible results that could be checked by other stakeholders. The requirement that implies to use objective and measurable standards is one of the requirements used by Harris to evaluate independent environmental certification systems and eco-labels and is therefore expected to be important for a valuable design of a certification schemes. This implies that the measurement tool should also have objective and measurable standards.

3.

Methodology

3 METHODOLOGY

3.1 Overview of research methodology

In paragraph 1.6 the research approach and outline were presented. This paragraph presents a specification of the research approach as presented in Table 4. The following paragraphs present a more detailed description of the methodologies used in each design cycle element: requirements and assumptions (3.2), structural specifications (3.3), prototype (3.4), implementation (3.5) and evaluation (3.7).

Table 4: methodologies per sub question and element of the research approach

Design cycle element	Sub questions	Methodologies
First hunch	▪ *What is the set of goals that should be met by the measurement tool?*	See paragraph 1.4.3 for the set of goals [G].
Requirements and Assumptions	▪ *What requirements can be derived from theory on measuring the environmental impact of cloud computing in the cloud computing eco-system?*	Literature review
	▪ *What requirements can be derived from cloud service providers and cloud customers?*	Case Study
Structural specifications and structure	▪ *What does the structure of the measurement tool look like?*	IDEF0-modeling technique
Prototype	▪ *What does a prototype of the measurement tool look like?*	See description in paragraph 3.4
Implementation	▪ To what extent does the prototype fit the set of structural specifications?	Expert review using a survey
Final design	▪ *What does the final design of the measurement tool look like?*	See description in paragraph 3.6
Evaluation	▪ *To what extent is the prototype successful in measuring the environmental impact of cloud computing?*	Expert interview

With regard to the overview of the methodology as presented in Table 4, some remarks have to be made:

- The phase 'first hunch' is not discussed in this chapter, because the answer to the sub question of this phase was already answered in paragraph 1.4.3.
- Despite the recommendation of Verschuren and Hartog (2005) to do multiple iteration of this design cycle, the time frame of this graduation research project does not allow to do so. However, going back and forth between the different stages, which can also be done 'mentally' is done while performing a single walkthrough of the design cycle.
- Verschuren and Hartog (2005) emphasize on the need for evaluation after the completion of each phase. Therefore, a method for evaluating that phase is described.

3.2 Requirements and assumptions for specifying the characteristics of the measurement tool

Setting the requirements for the measurement tool consists of two parts: (1) requirements derived from theory and (2) requirements derived from practice by means of a case study. The total set of requirements is categorized into functional, non-functional and user requirements. Functional requirements describe what a system should do. Non-functional requirements do not describe what a systems should do, but *how* it will do it (Chung, Nixon, Yu, & Mylopoulos, 2000). User requirements are presented to show the requirements that are in particular important for the user of the instrument. The next paragraphs presents how requirements are derived.

3.2.1 Requirements derived from theory: literature review

Deriving requirements from theory is relevant, because (1) a variety of theoretical methods and approaches for measuring environmental performance already exists and (2) theory exists that helps to analyze the mechanisms of sourcing and governance in the cloud computing eco-system that provide implications for measuring environmental performance. The theoretical requirements are derived from the literature review that was presented in chapter 2. Existing methodologies and approaches are discussed in paragraph 2.3, sourcing theory in 2.4 and governance theory in 2.5. Throughout these paragraphs, implications for the measurement tool are provided. The requirements that are based on these requirements are listed in paragraph 6.1 together with a reference to its source.

3.2.2 Requirements derived from practice: case study

Deriving requirements from practice has two goals: (1) to include requirements resulting from analysis of the current measurement effort for measuring environmental performance of the cloud and (2) to include the requirements for the measurement tool explicitly mentioned by cloud service providers and their customers.

A multiple case study is executed that consists of interviews with cloud service providers and data collection from open source information. The case study is used to analyze the current measurement efforts for measuring environmental performance and the requirements for a new measurement tool. A total of six cases (cloud service providers) of varying size (small and large in terms of their data center floor surface and yearly revenues) and geographical orientation (national versus international) are included in the case study.

The majority of the data is gathered through semi-structured interviews. Before conducting the interview available open source information (website, white papers etcetera) of cloud service providers was analyzed. The interviews take place at the data centers of the cloud service providers. The interview starts with questions that provide generic information about the cloud service providers' characteristics, such as their customers, services, annual turnover etcetera, followed by questions to derive data center characteristics to be able to compare the cases based on their size and geographical orientation. Questions to gain insight into the current measurement process of the cloud service provider include questions about *what* is currently measured (i.e. energy consumption), *how* it is measured (i.e. with a sensor) and *why* these measurements are performed (i.e. with the goal to send an invoice to the customer). At the end of the interview, the idea of having a measurement tool for measuring the environmental performance of the cloud is challenged and the cloud service provider is asked to come up with requirements that should be met by the measurement tool.

Based on the information retrieved, the current measurement effort is evaluated on the basis of three evaluation points: (1) the current presence of a measurement effort to measure environmental impact of cloud services, (2) the support provided to this measurement effort by human and technological resources and (3) the extent to which the measurement effort is controlled by a service level agreement (see paragraph 4.4). Requirements mentioned during the interviews are combined into an overview, which can be found in paragraph 5.8. Performing this case study requires a substantiated and thorough approach, which is separately presented in chapter 4, followed by the case study results in chapter 5.

3.2.3 Evaluation of requirements and assumptions phase

The list of requirements that is derived from theory and practice, may include requirements that do not fit the scope of this research and the goal that has been set for the measurement tool. There is a chance that requirements do not fit the goal of the measurement tool. An interviewee for example, may come up with requirements that do not fit the scope of this research (think of: "it should measure the amount of waste"). In particular the set of functional requirements [R_f] should cover no more (error of commission) and no less (error of omission) than the goal that has been set (Verschuren & Hartog, 2005, p. 752). This means that each requirement has to be qualitatively assessed to see to what extent it fits the goal and the scope of this research.

The final list of requirements is the input for the structural specifications and structure of the measurement tool, for which the method is discussed in the next paragraph.

3.3 Structural specifications, assumptions and structure of the measurement tool

This paragraph presents the method for creating the structure of the measurement tool with the help of the structural specifications that are based on the list of requirements

3.3.1 Creating the structural specifications

To create structural specifications, the requirements [R] and assumptions [A] are specified or translated into characteristics, aspects or elements that the artefact should comprise of (Verschuren & Hartog, 2005). To illustrate this with an example, one could think of a relevant requirement when designing a car, such as: the car should be light. When it comes to specifications of this requirement, 'a light engine' and 'using light-weight materials' are examples of specifications. To establish such structural specifications for the measurement tool, the following steps are taken. For each requirement on the list of requirements it is determined, if the requirement:

- ..is a functional, non-functional or user requirement.
- ..needs to be further specified.
- ..should function as a specification of another requirement on the list,
- ..should be specified through formulating additional requirements.
- ..should be a specification of a higher level requirement, that is not yet on the list of requirements.

The list of structural specifications that follows from this process is used to create the *structure* of the model, for which the method is described in the next paragraph.

3.3.2 Creating the structure of the measurement tool using the IDEF0-modeling technique

As mentioned before, the measurement tool should support the cloud service provider in managing and controlling the environmental performance of the cloud. Performing management and control can be seen as an ongoing process in which performance measurements play an important role. To visualize the base structure of the measurement tool, it is visualized as a process using the IDEF0-modeling technique. IDEF0-modeling is a suitable technique for visualizing the structure of the measurement tool because "*IDEF0 can be used to analyze the functions the system performs and to record the mechanisms (means) by which these are done"* FIPS PUBS (1993, p. vii). IDEFO-modeling is based on Structured Analysis Design Technology (SADT) developed by Douglas T. Ross and Softech (FIPS PUBS, 1993). It can be seen as a diagrammatic language that should help the public to describe and understand systems (Marca & McGowan, 1987). Before explaining how the structural specifications are used to develop the structure of the measurement tool using IDEF0-modeling, the semantics of this technique are briefly discussed.

IDEF0 is an official modeling language and described by the Federal Institution of Processing Standards Publications, which is used as a guideline. One of the primary objectives of the standard is *"to provide means for completely and consistently modeling the functions (activities, actions, processes and operations) required by a system or enterprise, and the functional relationships and data (information or objects) that support the integration of those functions"* (FIPS PUBS, 1993, p.ii). As a basis, the elements displayed in Figure 12 are used. Arrows contain *arrow segments* and *arrow labels.* Examples of arrows and their labels are Input, Output, Controls and Mechanisms. The guideline says that: input

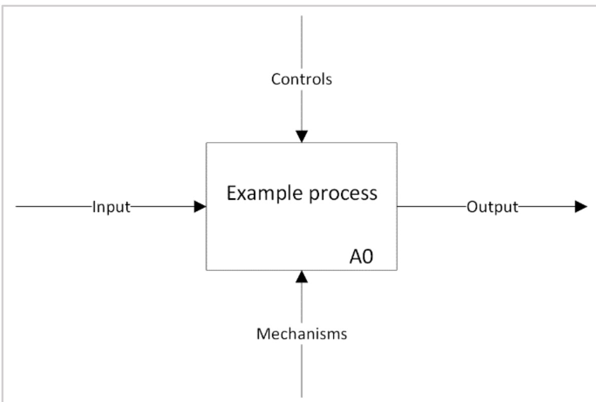


Figure 12: IDEF0-modeling basic semantics

can be seen as the data or objects that are transformed by the function into output. Output can be seen as the data or objects that are produced by a function. Controls are the conditions that are required to produce correct output. Mechanisms are the means that are used to perform a function. The rectangle that contains the *box name* 'Example process' is called a *box.* A0 represents the *box number.*

The structural specifications are categorized into functional, non-functional and user requirements. The functional requirements indicate the functions the measurement tool should be able to perform. These individual functions can be seen as the building blocks of the measurement process as a whole. Each function can be visualized as a 'box' that has a certain input and output and requires controls (conditions) and mechanisms (means) to be in place to produce the desired output. The non-functional and user requirements can be translated into input, output, controls or mechanisms. For example, a requirement could imply to use a certain metric for calculating environmental performance, which can be displayed in IDEF0 as a *control,* because it determines how the environmental performance should be calculated. There could also be requirements that do not directly imply the inclusion of a certain element in the structure, but rather set requirements to a characteristic of an element that is already part of the structure. For example, a requirement that says that measurements should be quantitative, would indicate that the metric of the previous example is a quantitative one. Following this approach, all structural specifications are translated into a visual structure of the measurement tool using IDEFO-modeling.

3.3.3 Evaluation of the structural specification stage

Evaluating this stage consists of performing two checks. The first one is checking for *structural alternatives.* This entails checking whether the specifications that have been formulated for the requirements could better be replaced by different alternatives. The second one is a check that consists of analyzing the extent to which the requirements have been properly unraveled and operationalized. If this is not done sufficiently, requirements will be further specified until the desired level of specification has been reached. The final structure of the measurement tool that is the result of this phase, is used in the next phase for designing a prototype of the measurement tool.

3.4 Designing a prototype for the measurement tool

The visualized structure (the IDEF0-model) of the measurement tool looks like a process and contains process steps that are based on the functional requirements. Each process step has a certain input, output, controls and mechanisms. These process steps should be translated into actual design constructs that fit within a prototype for the measurement tool. To do so, for each step the elements described in the IDEF0-model that are needed to perform the function of that particular process step (the input, output, controls and mechanisms) are systematically translated into design constructs. Suitable design constructs for the prototype are to be found through (1) checking whether analyzed literature or the case study results provide relevant options or through (2) searching for additional literature or other sources of information. For each design construct, a motivation for including it in the prototype design is provided.

3.5 Implementation: preliminary testing of the prototype

Verschuren and Hartog (2005) suggest to 'implement' the prototype into a situation that resembles the set of assumptions [A] to test whether the prototype is expected to perform properly in the evaluation stage. Therefore, an expert review is performed that has to goal to check to what extent the design of the prototype fits the requirements. The fit of the requirements could also be analyzed with the help of a survey among cloud service providers. This is time consuming and would merely be relevant for the requirements that were derived from cloud service providers in the first place. An expert review provides a solid alternative, because experts with different areas of expertise can be included. These areas of expertise should cover the theoretical concepts relevant for the measurement tool that have been discussed: sourcing, governance, data center and cloud computing. To cover the practical requirements, an expert that understands the cloud computing market and its stakeholders is also important. The expert review is conducted as follows.

The design of the prototype is explained to the experts followed by a small survey that presents the requirements as statements. For example: “the measurement tool uses objective and measurable standards”. The experts are asked to indicate to what extent they agree or disagree with the presented statement on a 1 to 5 Likert-scale. Motivations are asked in particular when an expert indicates to disagree with a statement. Per requirement, the extent to which it is fulfilled by the prototype is presented. The results of this expert review may require additional action. Therefore, for each result that is discussed, an action is specified. The implementation phase concludes with a set of improvements to be included in the final design of the measurement tool.

3.5.1 Evaluation of the implementation stage

Evaluation of the implementation stage consists of analyzing whether or not relevant experts with different expertise have been used together with determining if useful expertise have been overlooked.

3.6 Final Design

Based on the improvements specified in the implementation phase, the design of the prototype is changed into a final design that is ready for evaluation in the next phase. The final design is visually presented and supported by a textual explanation that describes how to use the instrument.

3.7 Evaluating the measurement tool

In this final stage, the reliability and validity of the measurement tool should be tested. Reliability can be defined as *“the extent to which an experiment, test or any measuring procedure yields the same results on repeated trials”* (Carmines & Zeller, 1979, p. 11). More specifically, the reliability of the measurement tool depends on its accuracy which is determined by the standard deviation of error. To determine the accuracy and thus the reliability of the measurement tool a calibration test with the help of data should be done. These data should at least entail the carbon footprint resulting from the energy consumption of a certain set of virtual machines means over a certain time interval. Such data is unfortunately not available at this moment, which makes it impossible to perform the desired reliability test. In paragraph 12.2.4 in chapter 12 the consequences of this are discussed.

Not as an alternative, but because data to perform a calibration test is lacking, a quantitative assessment can be done. This test is not able to assess the reliability of the measurement tool, but rather the reliability of results that it produces. The test is performed with the help of interviewing an expert. The interview consists of questions that test the extent to which the measurement tool is able to generate replicable results. More specifically, the reliability of results is analyzed through evaluating the stability, internal consistency and interrater reliability. Due to the qualitative character of this assessment, the focus is on elements in the design and content of the measurement tool of which undesired behavior can be expected. Therefore, the result of the assessment will not be solid conclusion about the reliability of the measurement tool, but rather an indication of possible weak spots in the design of the measurement tool when it comes to reliability. The interview with the expert is also used to qualitatively assess the validity of the measurement tool which is done through discussing the extent to which the measurement tool measures what it should measure: the environmental performance of cloud computing.

4.

Case study design

4 CASE STUDY DESIGN

This appendix describes the case study design. The goal of the case study is to derive practical requirements for the measurement tool through gaining insight into the current process of measuring environmental performance and user requirements. The case study is structured based on the steps for setting up a case study as described by Yin (2003) in the book "Case Study Research". Following these steps, this chapter presents the study question, motivation for choosing the case study as research method, evaluation points, interpretation of data and guidelines for interpreting the findings are presented in this chapter.

4.1 Study questions

According to Yin (2003, p.22) a study question provides *"an important clue regarding the most relevant research strategy to be used"*. The nature of the study questions as presented in this paragraph is used to provide a motivation for selecting the case study as a research method for gathering the needed data. The study questions are aimed at addressing the insights that are needed to derive requirements for the measurement tool and are formulated as:

1. How is the environmental performance of cloud computing currently measured at cloud service providers?
2. What are the requirements for a measurement tool that measures the environmental performance of cloud computing?

4.2 Motivation for choosing case study as a research method

Commonly used methods for data gathering are an experiment, survey, archival analysis, history or case study. Study question 1 is dominant in determining the research method because it represents the majority of the data that needs to be gathered. Using Table 5, which is and presents the relevant situations for choosing a certain research strategy, the case study is chosen as a research strategy for the following reasons:

- First of all, the nature of the first study question (starts with 'how') implies using an experiment, history or a case study;
- Secondly, the case study is preferred over a history as a method for the fact that there is a focus on *contemporary events*. Since *no control* is required of behavioral events, an experiment is ruled out. The case study is about assessing the process as it is, and no conditions need to be adjusted or influenced for doing so. The case study enables *"direct observation of the events being studied and interviews of the persons involved in the events"* (Yin, 2003) and that is what is ought to be done when trying to gain insights into a process.

The case study follows a holistic (see 4.3), multiple case design (see 4.5.1) and has both an explanatory and descriptive character. It is descriptive since it describes the process of measuring the environmental impact of cloud computing. It is explanatory since it also tries to explain why these processes are organized as such.

Strategy	Research question	Requires control of behavioural events?	Focuses on contemporary events?
Experiment	How, why?	Yes	Yes
Survey	Who, what, where, how many, how much?		Yes
Archival analysis	Who, what, where, how many, how much?	No	Yes/No
History	How, why?	No	No
Case study	How, why?	No	Yes

Table 5: choosing a research strategy based on study question characteristics
Adapted from: Yin (2003)

4.3 Unit of analysis and observation

This paragraph presents the units of analysis and observation which are the object of study. For this case study, the unit of analysis is a component of the cloud computing eco-system. The unit of observation provides a higher level of detail in terms of what is actually subject to observation in the case study.

4.3.1 Unit of analysis

The study questions provide directions for selecting the unit of analysis. The measurement process takes place at the cloud service provider and there is an assumed role for the cloud customer in this process (through service level agreements). Requirements need to be derived from both the cloud service provider and the cloud customer. Therefore, the unit of analysis consists of the cloud customer and the cloud service provider. As this is a single unit of analysis and the focus is on the process of measuring the environmental performance of cloud computing as a whole, the case study has a holistic character.

4.3.2 Unit of observation

Studying the unit of analysis is done through making observations. However, studying a cloud service provider and the cloud customer as a whole would yield superfluous results. Therefore, a unit of observation needs to be specified. As the data center is the backbone of the cloud and the place where the measurement process takes place, observations have to be done in the data center. More specifically, the unit of observation consists of data center employees on both operational and strategic or sales level to get a comprehensive view of the process through multiple perspectives. The contribution of the cloud customer in the unit of observation is covered through including an employee of the cloud service provider that manages customer relations or is involved in sales. More information about the method for doing observations is presented in 4.7.

4.4 Evaluation points

To provide further directions for what exactly needs to be studied to be able to answer the first study question, evaluation points are needed. The second study question, which is about gathering requirements, does not need evaluation points as requirements can be derived through asking simple questions. The first study question is aimed at analyzing the current measurement effort. Such an effort can be viewed as a process. Viewing this measurement effort from a process perspective demands to think about what elements and characteristics should be in place to perform such a process. These thought can be used to draw up the following evaluation points:

- There is a measurement effort to measure environmental performance of cloud services.
  The presence of the measurement effort can be recognized through the presence of elements that define this measurement effort.
- The measurement effort is supported by mechanisms such as human and technological resources.
  The measurement effort cannot take place without being support by human and technological resources. The kind of resources and the extent to which resources are devoted to the measurement process can provide relevant insights.
- The measurement effort is controlled by service level agreement to a certain extent.
  Since the interaction between the cloud service provider and the cloud customer is arranged through service level agreements, it is expected that the presence and influence of these service level agreements can be recognized in the measurement effort.

At the end of this chapter in paragraph 4.8.3, guidelines for interpreting the data and findings are presented.

4.5 Criteria for selecting cases for the case study

Two sets of criteria apply for selecting cases for the case study. The first set of criteria is derived from a 2x2 matrix that is used to categorize the different cases. The second set of criteria originates from the cloud computing eco-system and the evaluation points as described earlier. Before providing an overview of all criteria, the sets of criteria are briefly introduced.

4.5.1 The first set of criteria: 2x2 matrix

The case study contains multiple cases. Single cases can best be used when certain conditions apply: 1) critical test of existing theory, 2) a unique circumstance, or 3) a representative case when there is a 4) revelatory or

5) longitudinal purpose (Yin, 2003). As these conditions do not apply to this research and for the fact that the cloud computing market does not consist of one stereotype of cloud service provider and cloud customer, multiple cases are included. Different types of cloud service providers and customers, may have differing measurement efforts and requirements. To strive for a representative set of cases, cloud service providers of different size and geographical orientation are selected, which is common in the data center market and therefore a logical step to take. The size of a cloud service provider is determined by the *total data center floor surface in m^2*. More generic characteristics such as the *number of employees* and the *annual turnover* are used to check if the division of cases found on the basis of the data center floor surface is also reflected in the revenue that is generated and the amount of people at work at the cloud provider. Geographical orientation is based on data center location (Dutch or non-Dutch). There is also a desire to include both literal and theoretical replication of cases. Literal replication is achieved through including at least two cases of relatively small and large size respectively (though with opposing geographical orientation). Theoretical replication is achieved through cases being of different sizes and geographical orientations. To check and present the distribution of the cases over size and geographical orientation, the 2x2 matrix as depicted in Figure 13 was created. The x-axis represents the size of the cloud service provider and the y-axis the geographical orientation. The first set of criteria therefore consists of size (ranging from small to large) and geographical orientation (ranging from national to international).

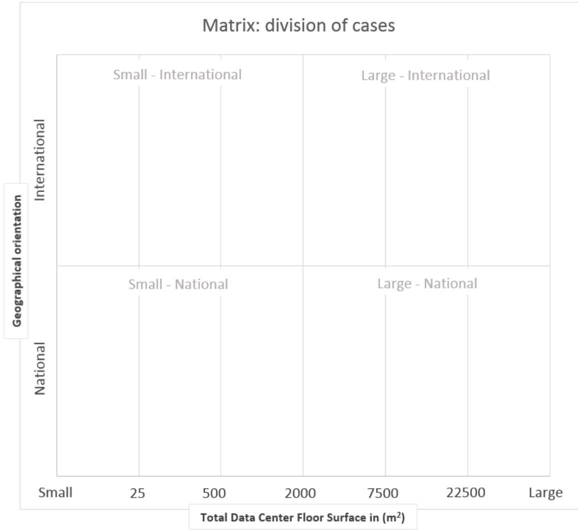


Figure 13: 2x2 matrix for the division of cases by size and geographical orientation

4.5.2 The second set of criteria: cloud computing eco-system.

Assuming that the cloud service providers in the cloud computing eco-system are interested in managing the environmental performance of their cloud services, several criteria should be met by cases that are to be included in the case study:

- The presence of efforts to increase energy efficiency, because these efforts indicate that they have a certain ability and willingness to improve the environmental performance of cloud computing.
- The level of corporate social responsibility, because it is an indicator of the importance for the cloud service provider as an organization to pay attention to the environmental.
- The presence of service level agreements, because they specify the relationship between the cloud customer and the cloud service provider and are expected to influence the measurement effort.

4.5.3 Overview of criteria

Table 7 provides an overview of the criteria of set 1 and 2 and contains a corresponding description and weight for each criterion. The weights are based on the importance of the criterion for the suitability of the case for

Size metric	Compute Space (M^2)	Matrix
Mega	≥22,501	
Massive	7,501 – 22,500	*Large*
Large	2,001 -7,500	
Medium	501 – 2000	
Small	26 – 500	*Small*
Mini	1 - 25	

Table 6: data center size (m^2)

Company category	Employees	Turnover
Micro	< 10	€≤2 m
Small	< 50	≤€10 m
Medium-sized	< 250	≤€50 m
Large	> 250	>€50 m

Table 5: company size by employees and annual turnover

the case study. Criterion 1 and 2, size and geographical orientation respectively, are considered to be of high importance as they enable literal and theoretical replication. Moreover, the better the spread of the cases over the four quadrants in the 2x2 matrix, the higher the value of the analysis is assumed to be. Table 6 is used as reference to categorize the size of a data center and shows six data center size metrics (column 1), derived from AFCOM (2014), which are combined into two size metrics in the third column to create the two quadrants of the 2x2 matrix as presented in Figure 13. Table 7 presents the guideline for interpreting the size of companies based on the number of employees and annual turnover as used by the European Union. For the third criterion, assuming that all data centers have at least some measures in place to increase the energy efficiency, the extent to which it is present is of low importance (as long as it is present of course). The fourth criterion, which is the level of corporate social responsibility, is important to the extent that it matters whether it is an important topic for the cloud service providers or not. If there is no environmental awareness at all, the case cannot be included in the case study. Therefore, the weight of criterion 4 is set to medium. For criterion 5, the weight has been set to high. This because the presence of a service level agreement is of high importance since it determines the characteristics of the interaction between the cloud service provider and the cloud customer. If such a service level agreement is not present, the case cannot be part of the case study.

Table 7: overview of criteria and their descriptions and weights

Criterion	Description	Weight
1. Size	Based on data center size (see Table 6) and number of employees and the annual turnover (see Table 7).	*High*
2. Geographical orientation	International or national, based on data center location.	*High*
3. Presence of data center efficiency efforts	Efforts to increase the energy efficiency of the data center.	*Low*
4. Level of corporate social responsibility	The value of corporate social responsibility as an indicator of the importance of environmental performance.	*Medium*
5. Presence of service level agreement	Presence of service level agreement that specifies the relationship between provider and the customer.	*High*

4.6 Selected cases for the case study

Table 8 provides an overview of cases that have been selected based on the criteria and considerations presented in the previous paragraph. For each case a description and classification is provided. In chapter 5, the case study results are presented, starting with a thorough description of the fit between the cases and the criteria to provide motivations for including these cases in the case study.

Table 8: description and classification of cases

Name	Description	Classification
Atos	Atos offers 'Canopy Cloud Services' to customers from 60 data centers in countries all over the world.	Large - international
T-Systems	T-Systems is the largest cloud provider of the world for SAP-hosting and serves large multinational companies (T-Systems, n.d.).	Large - international
kpn	KPN provides CloudNL services for which provisioning from Dutch soil is guaranteed which means that they fall under the governance of Dutch jurisdiction (KPN, n.d).	Large - national
CLOUD VPS	CloudVPS offers cloud services mainly to a large long-tail customer base. Customers can be both national and international.	Small - International
previder	Previder is a small cloud service provider located in Hengelo, the Netherlands, serving local and national customers (Previder, n.d.).	Small - national
ReasonNet	ReasonNet provides cloud services to enterprise organisations under the Dutch entity on the national level (Reasonnet, n.d.).	Small - national

4.7 Method for data collection

To be able to evaluate the measurement effort with the help of the evaluation points, data is needed. Therefore, this paragraph describes the method for data collection that is followed during the case study.

4.7.1 Interviews and open source information

A powerful way of gathering the information from the unit of observation is through interviewing. The evaluation points provide directions for the type of information that needs to be gathered. These directions are used for creating an interview protocol, which is enclosed in Appendix 13. Though all the questions in this protocol have to be answered, some of these questions can already be answered before performing the interview by examining open source information that can be found online or is provided by the cloud service providers. Based on the information retrieved prior to conducting the interview, the interview questions are adjusted, which means that questions that already have been answered are excluded.

The goal is to interview two employees of the cloud service provider of a specific case: one on the operational level and one on a higher, more strategic or sales level. This to increase the reliability of the information by correcting for the different perspectives of both employees (strategic plans being executed differently on operational level and perceptions on the operational level being framed other than its original strategic explanation). Table 9 provides an overview of the interview set-up. The aim was to perform at least 4 interviews to cover the different types of cases as presented in the 2x2 matrix (ranging from small to large and national to international), but in the end 6 of the contacted cloud service providers were willing to participate in the case study (see Table 9).

Table 9: overview of interview set-up

Interviewee	# of cases	# of employees	# interviews	Method
Cloud Service Provider	6	2	6	Interview + analysis of open source information
		Total	6	

The cloud customer is part of the unit of analysis, but not separately interviewed. Instead, the interview protocol for the cloud service provider also contains questions that need to be answered from the perspective of the cloud customer. The discussion in chapter 0 presents the consequences of not interviewing the cloud customer separately. For performing the interviews, an on-site (at a data center location), face-to-face interview is preferred. If this is not possible, Skype or a telephonic interview provide good alternatives. The interview has a semi-structured character. This means that an interview protocol is used, but there is room for a more conversational flow and additional questions to find more in-depth answers. All interviews are transcribed with the help of a transcription protocol, which is described in the next paragraph.

4.7.2 Transcription of the interviews

To be able to process the information of the interviews, the transcription template as presented in Appendix 14 is used. The following rules and guidelines shall be taken into account when making the transcriptions:

- The transcription shall be as accurate as possible. This means that the speakers' words, conversational quality and speech patterns are presented literally. Words shall be spelled correctly (despite of being pronounced incorrectly), but no grammar improvements in a sentence shall be made. Further exceptions for accuracy are made for: filler words, and acknowledgements of the interviewee's attention to the interviewer ('how interesting', 'wow').
- Interviewer and interviewee shall be noted with their initials in the transcription.
- Italicized words between parentheses () shall be used to clarify arguments if necessary or to provide additional information.

- Parentheses () are used to note audible expressions and emotions.
- Social talks that contribute to the conversational flow of the interview shall not be fully transcribed but. A short summary of the intermezzo shall be provided between parentheses ().

The official transcriptions have not been included as an appendix to this thesis, but are enclosed separately as a confidential appendix to Delft University of Technology only.

4.8 Method for data processing and interpretation

This paragraph presents the method for processing the data obtained from the interview transcriptions, which consists of the use of a code book, a method for coding the interviews and the guidelines for assessing the evaluation points.

4.8.1 Code book

As said, the interview protocol was established based on the study questions and evaluation points. The structure of the interview protocol in its turn, can be used to develop a code book. This code book is used to structure relevant information from the interview transcriptions. The code book is presented in Appendix 0 and consists of:

- (1) The characteristics of the cloud service provider, which help to determine the size and the geographical orientation of the cloud service provider.
- (2) The visited data center characteristics to be able to compare data centers of different cloud service providers.
- (3) Data center efficiency which indicates the drivers for improving data center efficiency and the value of corporate social responsibility.
- (4) Measuring data center performance, which presents the insights into the measurement process,
- (5) The implications of service level agreements.
- (6) Requirements and ideas.
- (7) Customer perspective, which presents the value of the measurement tool for the cloud customer.

4.8.2 Method for coding the interviews

All elements of the code book as presented in the previous paragraph contain sub elements. Most of these sub elements have been derived from the answers provided in the interviews. For example, if a couple of cloud service providers mentioned a driver for data center efficiency related to cost, the category 'cost driven' drivers was included as a sub element of the element 'Drivers for data center efficiency'. Small quotes of answers of the interviewees are selected and coupled to the corresponding code of a sub element into the code book. For each case, a filled-in code book is provided in Appendix 16. The number between brackets after each quote, represents the number assigned to the quotation by the software program Atlas Ti, which was used for coding the interviews. If a quote needs further explanation or interpretation in its context, the confidential appendix to this thesis can be used. This appendix contains all the coded interview transcripts in which the quotations can be traced with the help of their number. If information is derived from available open sources a letter between brackets is mentioned (i.e. (a)), that refers to this source as presented at the bottom of each code book.

4.8.3 Guidelines for assessing the evaluation points

After data is collected, the actual analysis with the help of the evaluation points should performed, for which guidelines are needed. Table 10 contains the evaluation points and the guidelines to interpret them. For the first and second evaluation point, the elements of the guideline that are presented have been established through thinking of the process of measuring performance and trying to identify characteristics and elements that should be in place to properly perform such a process. For the third evaluation point, which is about the support and control of the measurement process through service level agreements, three questions were identified. The first question is about the presence of provisions on environmental performance in service level agreements, the second question is about possible implications provisioned in service level agreements for measuring environmental performance and the third question is about implications of the service level agreements on data center efficiency efforts.

Table 10: evaluation points and their guideline for interpretation

Evaluation point	Guideline for interpretation
There is a measurement effort to measure environmental impact of the services for a specific customer.	Measurement effort is expected to contain the following elements: ▪ Environmental performance measurements follow certain steps. ▪ Environmental performance is measured using certain metrics. ▪ Environmental performance is processed into a certain format. ▪ Environmental performance can be attributed to customers. ▪ Environmental performance is measured with a certain frequency.
The measurement effort is supported and controlled by human and technological resources.	The following actions should be done: ▪ Identify controls that specify the conditions that are required to produce the desired output (FIPS PUBS, 1993). ▪ Identify mechanisms that represent the means that are needed to perform the function or process (FIPS PUBS, 1993).
The measurement effort is controlled by service level agreement to a certain extent.	The following questions should be answered: ▪ Does the service level agreement contain provisions on environmental performance levels? ▪ Does the service level agreement provide implications for measuring environmental performance? ▪ Does the service level agreement provide implications for interventions to increase data center efficiency?

4.8.4 Interpretation of results and answer to questions

As the final step in the case study method, this paragraph elaborates on providing answers to the study questions. The first study question is aimed at identifying the current effort for measuring environmental performance and is answered through presenting the gathered data from the case study cases in tables (see Appendix 15) and drawing conclusions for each evaluation point with the help of the guideline as presented in Table 10 on the basis of the interpretation of these data. The data needed to answer the second study question, consists of an overview of the requirements mentioned by the cloud service providers during the interviews bundled in a table, which can be found in paragraph 5.8.

5.
Case study results

5 CASE STUDY RESULTS

This chapter presents the case study results and consists of two parts. Paragraph 5.1 and 5.2 describe the fitness of the selected cases in the case study. The second part contains the results of the analysis of the current measurement effort of measuring environmental performance and an overview of the requirements that have been mentioned by the cloud service providers. In this chapter, a lot of data from the case study is used, which is presented in several tables in Appendix 15. Throughout this chapter, references are made to these tables.

5.1 Fitness of case study cases based on size and geographical orientation

Figure 14 presents the division of case study cases over two axes: *size* and *geographical orientation.* The goal was to include at least one case for each quadrant, which has been achieved. The x-axis represents data center size in terms of the total data center floor surface in m^2 (see 4.5.3). The data center floor surface for each case is presented in Figure 16, in which the blue bar represents the total data center floor surface of all the data centers owned or operated by the cloud service provider and the orange bar represents the floor surface of the data center that was visited for conducting the interview. As there is a wide range in size, a logarithmic scale is used to present all cases in the same figure. Based on the data in Figure 16, the order of the cases from large to small is: T-Systems, Atos, KPN, Previder and ReasonNet. The total data center floor surface of CloudVPS is classified, but based on its other characteristics it is placed in the small (only 23 employees, see Figure 15), international (see the end of this paragraph) quadrant. The y-axis presents the geographical orientation of the cases, based on data center location as presented in Figure 18. In theory a cloud service provider that provides services to Dutch customers could only be using foreign data centers and vice versa. However, it is plausible that to best serve the customer, there is a data center relatively close to these customers. Figure 18 presents the amount of Dutch and non-Dutch data centers that is owned or operated by the cloud service providers included in the case study. No distinction is made between the extent to which a cloud service provider is nationally or internationally oriented; foreign data centers indicate an international orientation and having only Dutch data centers indicates a national orientation. Based on Figure 18, this means that T-Systems and Atos are internationally oriented. Besides that, CloudVPS says to have a large long-tail customer base that is certainly not restricted to Dutch customers. They also have an English website for their international customers. Therefore, CloudVPS is also positioned as an international cloud service provider. As mentioned in paragraph 4.5.1, the size of the case study cases is further assessed using the amount of employees and the annual turnover. The results of this assessment are presented in the following paragraph.

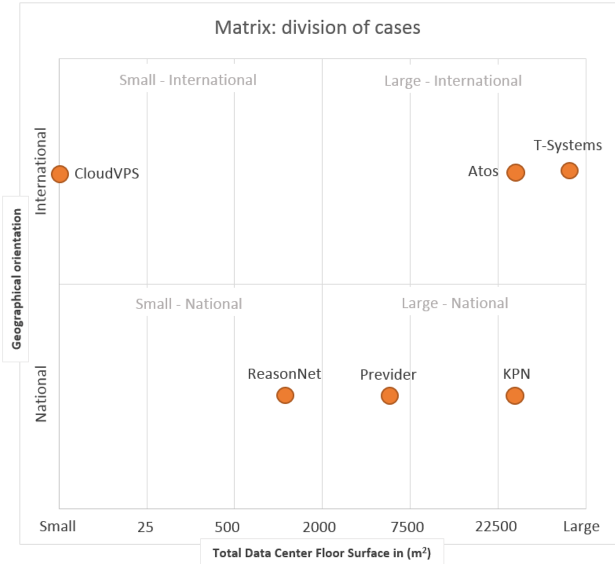


Figure 14: matrix - division of cases based on size and geographical orientation

5.1.1 The size of the cases based on the amount of employees and annual turnover

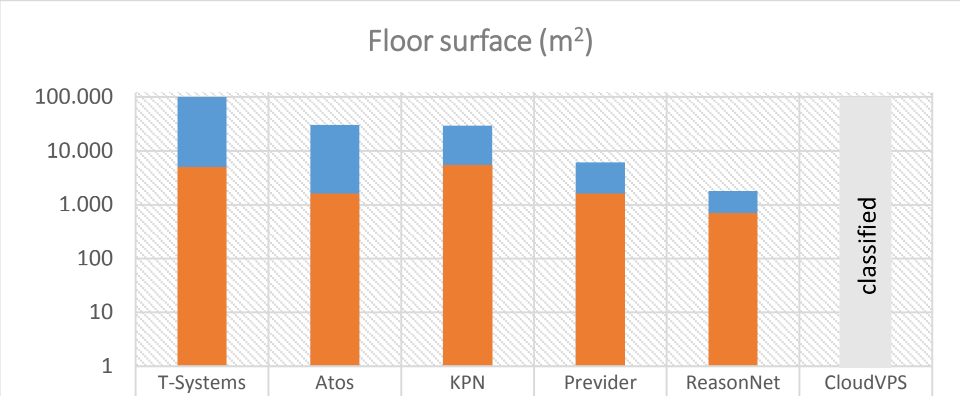
Gathering comparable data for the amount of employees and annual turnover was complicated. First of all, because the annual turnovers of Previder and CloudVPS are classified. Furthermore, large providers such as T-Systems, Atos and KPN also have other revenue models than cloud. Similar reasoning applies to the amount of employees of T-Systems, Atos and KPN: it is assumed that just a fraction of these employees have cloud related tasks. Nonetheless, annual turnover and the amount of employees are generic measures for determining the size of a company. Cloud service providers of different size are included in the case study, because they may have differing resources (money, knowledge, human resources) available. For this reason, the annual turnover and amount of employees of the cases is briefly discussed here, to see if there are any abnormalities, but no binding conclusions are made.

Figure 15 presents the amount of employees working at the cloud service providers included in the case study. Compared to the order of cases based on size, the order implied on the basis of the number of employees switches T-Systems and Atos and Previder and ReasonNet, but the differences are very small and are not expected to be of any influence.

For annual turnover, presented in Figure 17, major differences appear between the larger and smaller cloud service providers. However, taking Atos as an example, the target annual turnover for cloud is 1 billion Euro's for 2015. This still indicates a major difference compared to the smaller cloud service providers. Therefore, it is assumed that having insight into the exact annual turnover generated by cloud services for each provider, would not significantly challenge the positioning of the cases in Figure 14. The next paragraph provides a brief overview of the most important characteristics for each cloud service provider and their position on the 2x2 matrix.

5.1.2 Overview of cases and their position on the 2x2 matrix

From large to small size and from international to national geographical orientation the division of cases is as follows (see Table 23 on page 105 for data): As T-Systems serves large multinational companies with 69 data centers (of which two are located in the Netherlands) all over the world with a total data center floor surface of 100.000 m^2, almost 50.000 employees and an annual turnover of roughly 8.5 billion, it is the largest cloud service provider included in the case study. Therefore, T-Systems is placed far to the right in the large, international quadrant. Atos offers 'Canopy Cloud Services' to customers all over the world from around 60 data centers with a total data center floor surface of 30.000 m^2. The annual turnover of Atos is 8.6 billion of which about 300 million can be allocated to cloud. For these reasons Atos is placed a bit to the left of T-Systems as being a large international cloud service provider. KPN focuses on providing Dutch customers with 'CloudNL' services. KPN has 11 data centers in the Netherlands of which two are used for provisioning CloudNL. With KPN being a Dutch telecom provider and the assurance that the CloudNL services are delivered from Dutch soil and fall under Dutch jurisdiction, KPN is positioned as a large-sized national cloud service provider. When it comes to the total data center surface of 6100 m^2, spread over two data centers near Hengelo in the Netherlands, Previder is a cloud service provider of significant size, serving local to national customers in the Netherlands. However, Previder comprises of only 35 employees and is part of the parent company the Odin-group. The annual turnover of Previder, which may not be explicitly mentioned, is a fraction of the turnovers of both T-Systems and KPN. Therefore, Previder is positioned as a medium-sized national cloud service provider. ReasonNet has three relatively small data centers with a total of 1800 m^2. ReasonNet has 45 employees and doubles its cloud revenues every year. They managed to create almost 10 million of revenue in 2014 of which 4 million can be allocated to cloud services. Although growth is expected in the upcoming years, ReasonNet is currently positioned as a small national cloud service provider. CloudVPS offers cloud services mainly to a large long-tail customer base, which means that customers can be both national and international. CloudVPS does not have its own data centers, but uses two data centers of Equinix and one of EU Networks. For these reasons, CloudVPS is placed in the matrix as being a small international cloud service provider.

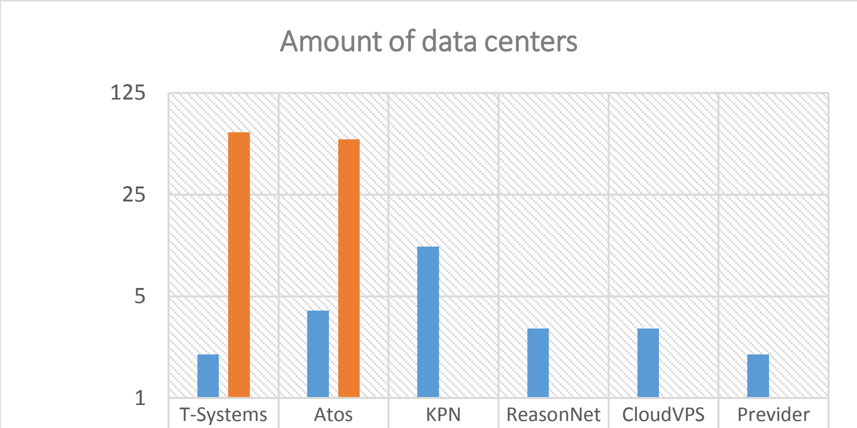


	T-Systems	Atos	KPN	Previder	ReasonNet	CloudVPS
Total	100.000	30.000	29.200	6.100	1.800	0
Visited	5000	1600	5.500	1.600	700	0

Figure 16: data center floor surface in meters squared (total and visited)
See Table 24 on page 106 for the case study data)

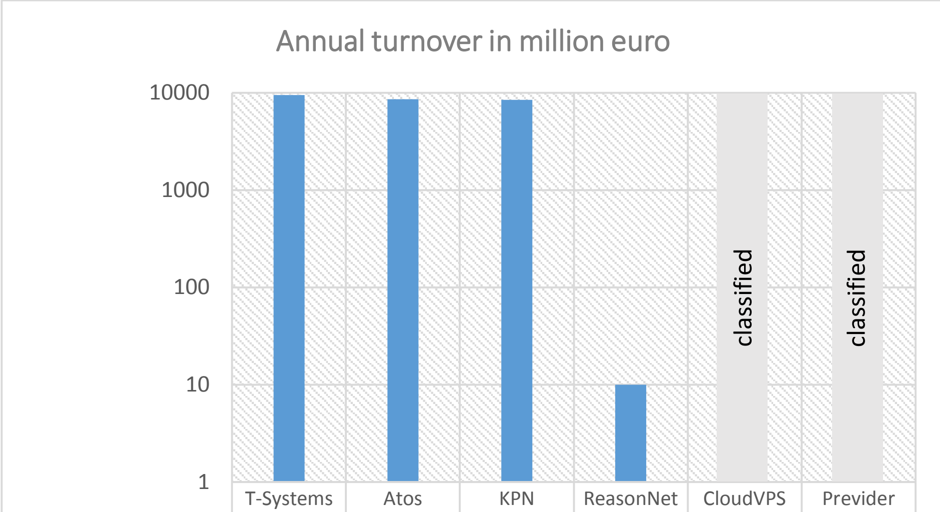
	Atos	T-Systems	KPN	ReasonNet	Previder	CloudVPS
Number of employees	76300	50000	18949	45	35	23

Figure 15: number of employees working at the cloud service provider of the case study
See Table 23 on page 105 for the case study data



	T-Systems	Atos	KPN	ReasonNet	CloudVPS	Previder
Dutch	2	4	11	3	3	2
non-Dutch	67	60	0	0	0	0

Figure 18: amount of Dutch and non-Dutch data centers operated by cloud service providers of the case study
See Table 23 on page 105 for the case study data



	T-Systems	Atos	KPN	ReasonNet	CloudVPS	Previder
Turnover in mio €	9500	8600	8472	10	0	0

Figure 17: annual turnover of the cloud service providers of the case study
See Table 23 on page 105 for the case study data

5.2 Fitness of the case study cases based on the second set of criteria

In paragraph 4.5.2 on page 35 the second set of criteria for judging the appropriateness of the cases for the case study are presented, which are: the presence of data center efforts to increase energy efficiency, the level of corporate social responsibility and the existence of service level agreements. For each criterion, the extent to which the cases fulfill the criterion is elaborated on.

5.2.1 Presence of energy efficient data center efforts

The presence of energy efficient data center efforts is assessed by analyzing the drivers for doing so and the actual interventions that are implemented by the cloud service providers. Most important findings are:

- When it comes to the drivers for dealing with data center efficiency, all cloud service providers in the case study mention a cost-related driver (see Figure 19). 4 out of 6 cloud service providers mention green thinking and governmental obligations as driver and 2 out of 6 cloud service providers mention to think of data center efficiency as being important due to questions asked by customers. All cloud service providers mentioned multiple drivers (2 or more), which indicates that data center efficiency is an important subject for the cloud service providers.

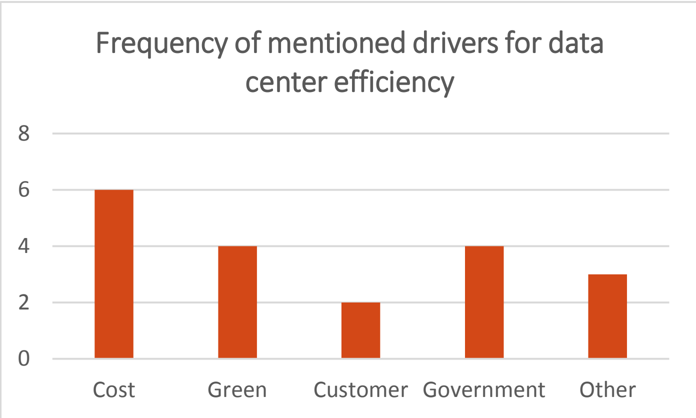


Figure 19: frequency of mentioning of drivers for data center efficiency. See Table 26 on page 108 for case study data.

- All cloud service providers mention to use hardware-related interventions for increasing efficiency, in which the acquisition of more energy efficient hardware is an important one. Besides that, in the category (auxiliary) data center systems, cloud service providers mention increasing the efficiency of their cooling systems. With regard to the data center building, 2 out of 6 cloud service providers mention that it is easier to choose a more efficient data center building when acquiring a new one compared to changing an existent configuration. 2 out of 6 cloud service providers mention to take into account the data center configuration (and for example hot spots and local load) when implementing new customers or hardware into the data center. Software measures are less present than expected (on the basis of the literature review); only 2 out of 6 cloud service providers mention to use software for increasing energy efficiency (other than the widely used hypervisor technology).

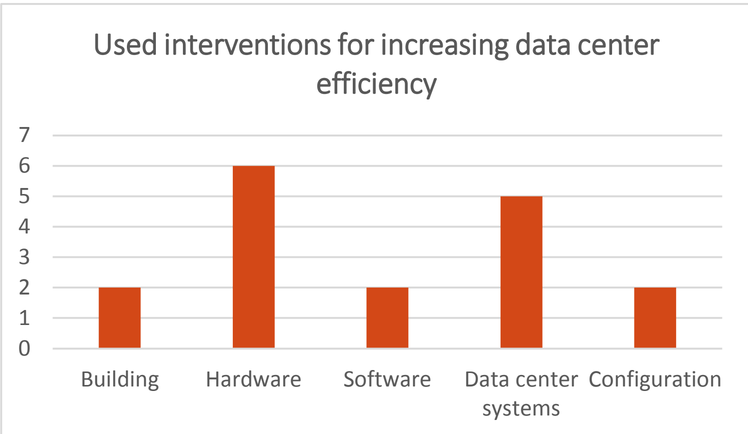


Figure 20: used interventions for increasing data center efficiency See Table 27 on page 108 for case study data.

To conclude, all cloud service providers in the case study acknowledge the presence of drivers to pay attention to data center efficiency and mention to use multiple interventions for increasing their data center efficiency. So, on the basis of this criterion, none of the cases is excluded from the case study.

5.2.2 The level of corporate social responsibility

The extent to which corporate social responsibility is present at the cloud service providers of the case study seems to differ, but there is no reason to exclude cases for this reason from the case study. This because all cases mention corporate social responsibility to present in some way as presented in Figure 22. During the interviews, the interviewees were expressing the importance of corporate social responsibility (5 out of 6). One cloud service provider mentioned to use a benchmark to receive corporate social responsibility-exposure. 5 out of 6 of the cases mentioned having certifications to be important to be able to guarantee certain characteristics and behavior of their services towards customers. 2 out of 6 cases mentioned to use their website as a source for expressing their level of corporate social responsibility, one case used corporate social responsibility-reporting and 3 out of 6 made statements about for example having the greenest data centers during the interview. From these expressions of corporate social responsibility, the certificates are of particular interest, because 5 out of 6 cloud service providers brought up certifications when asking them about corporate social responsibility. Moreover, certifications have also been examined from a theoretical point of view in chapter 2. Figure 22 presents an overview of the certifications acquired by the cloud service providers that were part of the case study. Not all of these certifications are of interest for this research: ISAE3402, ISO27001 and NEN7510 are aimed at security. Certifications that are of interest are ISO14001, which is present at the larger part of the cases in the case study, the ISO50001, which aims at dealing with energy efficiency and the BREEAM certificate (all presented in green in Figure 19). The list below provides more information on these relevant certifications.

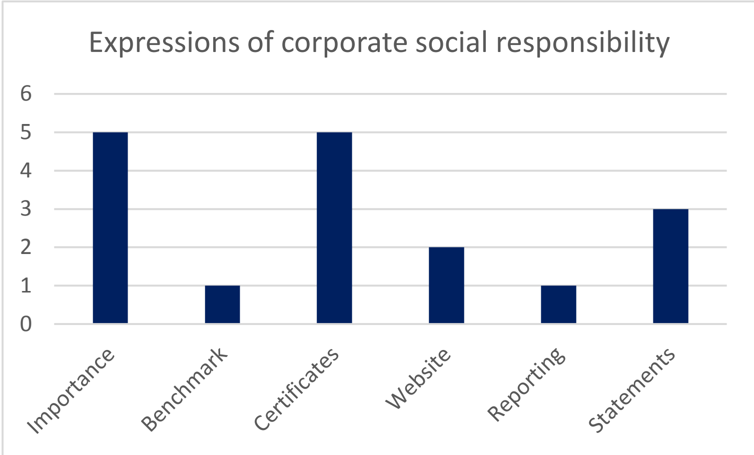


Figure 21: expressions of corporate social responsibility mentioned by
See Table 25 on page 107 for case study data.

- *ISO14001.* This is a standard that helps companies to establish and certify an environmental management system. The standard contains steps on how to set-up an environmental management of which the identification of environmental risks and how to deal with them is an important part. The presence of this certificate in particular should indicate that environmental responsibility has a certain priority in the organization as there is a certified effort to manage the quality of the environment.

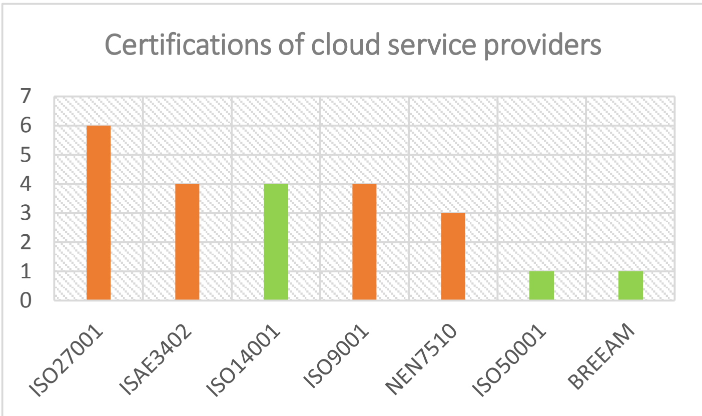


Figure 22: certifications of cloud service providers in the case study. See Table 24 on page 106 for case study data.

- *ISO50001.* This standard is extremely relevant for this research, as it specifies how to deal with an energy management system. In paragraph 2.5.2, requirements for the measurement tool were derived from this certification standard. Only one cloud service provider of the case study mentioned to have it and another one said to have the desire to obtain the certificate in the future.

- *BREEAM.* This is a method and certificate that represents the sustainability performance of a building.

5.2.3 Existence of service level agreements

All cloud service providers in the case study use service level agreements in standardized and customized form. Most service level agreements specify: the quality of services, incident management and reporting and how is dealt with service level agreement violations. Therefore, service level agreements are of utmost importance for both the cloud customer and the cloud service provider. If possible the service level agreements of a cloud service provider were downloaded or requested (if not available online) and scanned for their content. As all cases have service level agreements present, no cases are excluded from the case study based on this criterion.

5.3 Assessment of the measurement process

This part presents the analysis of the measurement processes of the cloud service providers based on the evaluation points and the guidelines for interpretation as presented in Appendix 4.8.3. For each evaluation point, the guideline for interpretation is presented follow by the actual assessment of the evaluation points.

5.3.1 Environmental performance is not explicitly measured

The analysis of the measurement processes of the cloud service providers shows that the environmental performance of cloud computing is not measured or monitored. But, energy consumption is currently measured by the cloud service providers and as the focus of this research is on the environmental impact caused by the energy consumption of cloud computing, these measurements are most relevant to assess as replacements.

Another noteworthy observation is that current measurement processes are quite generic ones, in a sense that these measurement processes apply to a variety of services, such as housing, hosting, colocation and cloud. However, the requirements for measuring the environmental performance of these services actually differ, implying more specific measurement processes.

Nonetheless, gaining insight into the current process of measuring the energy consumption of the data center services is of added value as it may provide implications in terms of requirements for measuring the energy consumption of cloud computing and thus for the measurement tool that is to be developed.

5.4 Evaluation point 1: characteristics of the measurement effort

In Table 12 the guidelines for interpreting the evaluation points were presented. To analyze the characteristics of the measurement effort, the guideline is as follows:

- There is a certain cycle or there are process steps that are followed for performing these measurements.
- Environmental performance
  - ..measurements follow a certain steps.
  - ..is measured using certain metrics.
  - ..is processed into a certain format.
  - ..measurements can be attributed to customers.
  - ..is measured with a certain frequency.

5.4.1 The steps of the measurement process

The steps of the measurement processes of the different cloud service providers show great similarity: the main processes all consists of three major steps: (1) measuring the energy consumption, (2) processing the data into some kind of software or database and (3) performing actions with the processed data. This third step can consists of several different sub processes that show similarities, but also some differences between the cloud service providers. Figure 23 provides an overview of the actions in which the measured energy consumption data is used. All cloud service providers included in the case study use the energy consumption data for performing data center management. Three cloud service providers use the data for invoicing and one cloud service provider uses the data for performing forecasting.

Data Center Management. Examples of data center management that were mentioned by the cloud service providers include rack power management and utilization management. Rack power management means that the A and B power feeds that supply power to the racks are constantly measured and compared to thresholds or trigger values to make sure that the redundant power supply system is always functioning (if feed A fails, feed B has to supply *all* power, which means that each individual feed should not exceed half of its capacity). To perform utilization management, the energy consumption data is used in combination with the amount of procured energy to determine the current utilization level (of energy). A higher utilization level, means that a larger amount of the procured energy is actually used which decreases overhead costs.

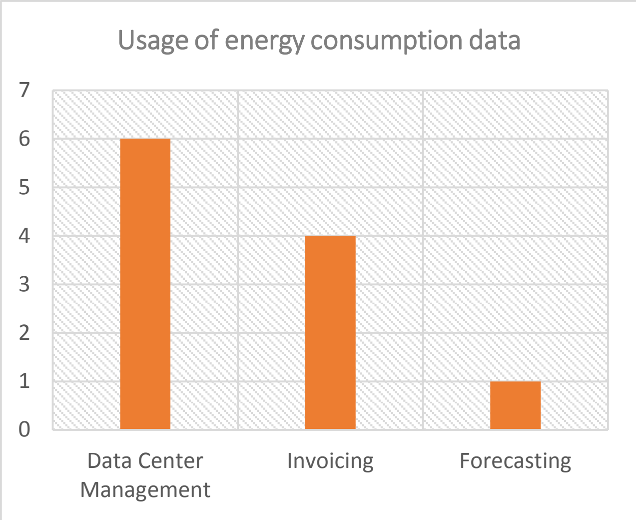


Figure 23: usage of energy consumption data by cloud service providers (see Table 27 on page 108 for data)

Invoicing. 4 out of 6 cloud service providers use the energy consumption data for invoicing; 3 of them for billing the customer and one of them for verifying the invoice it receives from the energy supplier. However, 4 out of 6 cloud service providers, charge their customers a subscription fee, which could result in them being less interested in the amount of energy that is used by a specific customer.

Forecasting. One cloud service provider, uses the energy consumption data to create forecasts of the energy supply for the upcoming months. This is done with the goal to achieve high utilization of energy and creating the desired balance between costs and income, which is done to provide as much services as possible, against the lowest cost possible.

To conclude, the use of the energy consumption data for data center management, invoicing and forecasting confirms that environmental impact is currently not being measured, but at the same time indicates that these data can be used for multiple purposes.

5.4.2 Metrics and formats used for measuring energy consumption

The data presented in this paragraph can be found in Table 27 on page 108. As environmental performance is not directly measured and the focus therefore is on the energy consumption of cloud computing, metrics used to measure energy consumption are evident: kilowatts (kW) and kilowatts per hour (kWh). In most cases, kW mostly indicates the 'installed capacity' in terms of power demand and kWh indicates the actual use of energy. Data on kW on kWh is gathered by means of sensors that are either placed directly at the A and B power feeds that power racks or at the Power Distribution Units (PDU).

Furthermore, the guideline prescribes to check what kind of models and formats are used for calculating, processing and presenting environmental performance measurements. However, since these measurements do not take place at the interviewed cloud service providers, identification of specific models was not possible. When it comes to the format in which the current measurement results are reported to customers, cloud service providers have mentioned to create reports, overviews and one cloud service provider has an online portal that provides customers with real-time insight into the power consumed.

5.4.3 *Allocating measured energy consumption to customers*

Whether or not it is possible to allocate measured energy consumption to a specific customer not only depends on the ability of the cloud service provider, but more on the necessity for the cloud service provider to do so. For example, for cloud service providers that require the customer to pay a subscription fee for the services they use, insights into the energy consumption per customer is of less added value compared to a situation in which energy consumption is directly billed to the customer. This is also related to the type of service that a customer uses. If a company uses the housing services of a cloud service provider, being billed for the used energy makes more sense compared to the situation in which a company only uses a couple of cloud servers for running the companies' corporate website. However, even though energy consumption data may not always be needed to bill the customer, some cloud service providers say that they do value these data, because it can help to gain insights into the costs for the cloud services they provide and thus in an indirect manner, for the price the end customer pays for these services.

5.4.4 *The frequency of measurements*

Insights into the frequency of measurements would be helpful to know at what time intervals environmental performance measurements and management takes place. But, as it was only possible to analyze energy consumption measurement, no relevant insights have been identified other than the fact that the sensors for measuring energy consumption measure continuously.

5.5 Evaluation point 2: the mechanisms and controls that support the measurement effort

The guideline for interpreting the evaluation points of the case study mentions that the following actions can be done to assess the presence of mechanisms and controls that support the measurement effort:

- Identify controls that specify the conditions that are required to produce the desired output (FIPS PUBS, 1993).
- Identify mechanisms that represent the means that are needed to perform the function or process (FIPS PUBS, 1993).

Controls and mechanisms are not discussed separately as they are often related to each other. Table 11 presents some examples of mechanisms and controls that support the current measurement effort at cloud service providers. The controls and mechanisms displayed in *italics* were added to illustrate the connection between mechanisms and controls. For example, cloud service providers all mentioned to use sensors for measuring the energy consumption at rack level, or at the power distribution unit. Inevitably, all of these sensors have been calibrated in a certain way, which influences the output of the energy consumption measurement. Measured energy consumption is automatically processed into software that has certain semantics, which means that it contains for example certain rules, formulas and designs that process, calculate and present the measured data into a certain format. As mentioned, the energy consumption data is currently used for processes such as data center management, forecasting and invoicing. With regard to the latter, an administrative employee may be involved in the process to check the invoices that are made to see if they contain any mistakes.

Several cloud service providers use thresholds to perform data center management. These thresholds are developed based on a cloud service providers data center configuration and experience with data center management. If the measured energy consumption data exceeds the thresholds, cloud service providers prescribe certain protocols or script that should be used by data center engineers to handle possible incidents.

Mechanisms	Control
Sensor	*Sensor calibration*
Software	*Software semantics*
Administrative employee	*Work instructions*
Data Center Engineer	Protocols
-	Tresholds

Table 11: examples of mechanisms and control in the measurement effort

The identification of these mechanisms and controls however, does not provide useful implications for a future measurement effort for measuring environmental performance. Nonetheless, there is an important control that influences the measurement effort that was not directly mentioned by the cloud service providers: the cloud configuration. Cloud service providers were also asked what kind of hardware, and servers in particular, they use for provisioning cloud services. Most cloud service providers mentioned to use servers of well-known brands such as HP or Dell (see Table 24 on page 106). But, there was one cloud service provider that said to be using Vblocks, which is an integrated cloud platform and contains computation power, storage and network and virtualization all in one platform. Using such an integrated platform for provisioning cloud services, provides advantages for performing measurements, because the architecture, structure and characteristics of these platforms are known. In such platforms, measuring on the virtualization level seems easier. Cloud service providers that do not use an integrated platform, have to build their own cloud configuration implying that the cloud service provider should connect servers placed in a certain configuration with the network, and optionally with additional storage. Besides that, the cloud service provider needs to take care of virtualization. Multiple options for doing so exist and therefore, multiple cloud configurations that differ from each other arise. These different cloud configurations make it difficult to define one single approach for measuring environmental performance on the virtualization level. Unfortunately, only one cloud service provider mentioned to use Vblocks. All the others use merely custom-built configurations which implies that the status of cloud configurations at cloud service providers may currently complicate the use and implementation of the measurement tool that is developed in this research.

5.6 Evaluation point 3: influence of service level agreement on the measurement effort

The guideline mentions the following questions to be answered to assess the influence of service level agreements on the measurement effort:

- Does the service level agreement contain provisions on environmental performance levels?
- Does the service level agreement provide implications for measuring environmental performance?
- Does the service level agreement provide implications for interventions to increase data center efficiency?

The answers to these question are as follows. In general, the service level agreements as used by the cloud service providers in the case study:

- Specify the performance of the cloud services in terms of uptime, availability, service levels (key performance indicators), incident management, compensation arrangements etcetera.
- Specify the topics that should be reported on a certain time basis to the cloud customer.

The service level agreements of the cloud service providers in the case study do not contain any clause on measuring environmental performance in particular (see Table 28 on page 108). 3 out of 6 cloud service providers in the case study, mention that service level agreements with customers limit the possibilities to experiment with or implement new interventions into the data center with the goal to increase data center efficiency, because there is fear that these interventions influence the performance delivered to customers (see Table 28 on page 108). This is the trade-off between performance and energy efficiency, which is also acknowledged in literature and described in paragraph 2.2.4. The extent to which it is possible to increase data center efficiency, limited by the agreed service levels, should be taken into account when developing a measurement tool.

5.7 Most important findings on the evaluation of the current measurement effort

The initial goal of analyzing the current effort of measuring environmental performance, was to derive requirements for the measurement tool. But, because environmental performance is currently not being explicitly measured, energy consumption measurements were taken into account as they can be used to determine the environmental performance. However, analysis of the energy consumption measurements provides findings that should be kept in mind when creating the design of the measurement tool rather than requirements that should be used to create the structure of the measurement tool in the first place. These findings are presented in this paragraph.

5.7.1 The lack of a structured approach to increase data center efficiency

Analysis of the current measurement effort shows that cloud service providers experience several pressures (or drivers) that emphasize the importance of data center efficiency (see paragraph 5.2.1). Moreover, cloud service providers implement a variety of interventions into their data centers to increase energy efficiency (see paragraph 5.2.1). But, none of the cloud service providers mentioned to use a structured, more strategic approach for dealing with the challenge of data center efficiency. This means that cloud service providers are currently implementing those interventions that have been identified as best practices or interventions that are used by competitors, instead of selecting interventions more carefully from a strategic point-of-view. So, this seems to confirm the idea that cloud service providers do not have full control of the environmental performance of their services. They do make an effort to increase the efficiency of their data centers, but lack the structured and strategic approach that is needed to support these cloud service providers in performing environmental performance management.

5.7.2 Suitability of current measurement effort for measuring the environmental performance of the cloud

Looking at the current measurement effort at cloud service providers from a cloud perspective, one could say that this current effort is immature, for a couple of reasons. First of all, energy consumption is measured at rack level or at the power distribution unit, which is too generic as measuring the environmental performance of cloud computing requires the measurement of energy consumption on the virtualization level and can preferably be allocated to specific services and customers. Moreover, the second evaluation point concluded that currently multiple cloud configurations exist that complicate measurements in the data center, because these configurations have different architectures and characteristics making it difficult to create a measurement methodology that can be used for all of these different configurations. Nonetheless, one of the cloud service providers is using Vblocks, which is an integrated and complete cloud platform and mentions that these Vblocks are able to perform energy consumption measurements on the virtualization level. Another cloud service provider mentioned to switch to using Vblocks soon. So, despite the current data center processes and capabilities currently not being optimal for measuring the environmental performance of cloud computing, it is assumed that this will change over time as data center hardware is refreshed on a regular basis and new technology becomes available.

5.7.3 Limitations to increasing data center efficiency

As explained under evaluation point 3 in paragraph 5.6, half of the interviewed cloud service providers are or feel withheld by service level agreements in increasing the energy efficiency of the data center, because this may have negative consequences for the performance delivered to customers. Despite the discussion whether or not the right choices are made on the basis of the trade-off between performance and energy efficiency, the presence of the trade-off sets boundaries to increasing data center efficiency. From the perspective of the cloud service provider, interventions to increase data center efficiency can be restricted and depended on technological development in terms of interventions that do not harm service level agreements. This could mean that cloud service providers define a target or are obliged to reach a certain target, but are not able to do so for the reasons provided. This should be taken into account when designing the measurement tool.

5.8 Overview of requirements mentioned in interviews

At the end of the interviews with the cloud service providers they were asked to mention requirements that should be met by the measurement tool. An overview of these requirements is provided in Table 12. The third column of this table, contains the quotation numbers of the quotes of the interviewees that have been used to derive the requirements. To see the full quotes, a reference is made to Appendix 16 in which a code book for each case is provided. Under point 6.1 of the code book, the quotes of the interviewees related to the requirements can be found. No requirements for KPN have been included, because no explicit requirements were mentioned during the interview. For each requirement, a short description is given. The requirement 'should deal with relativity' overlaps with the requirement 'should provide comparable results'. Because the formulation of the latter is clearer, this requirements is further taken along. In chapter 6, the requirements are presented together with the requirements derived from theory, followed by an evaluation to see if the requirements fit the goal of the measurement tool. The final set of requirements is used in chapter 7, to create the structural specifications and the structure of the measurement tool.

Table 12: description and quote number of requirements per case

Case	Requirements	Description	Quote #
T-Systems	Should be transparent	Diffuse and non-transparent measurements should be prevented.	65,66
	Should deal with relativity	It should be clear what is included in the calculation of environmental performance and what is not. Results can be reproduced by someone else.	67,68
	Should be independent of the time of measurements.	The results provided by the measurement tool should not be dependent on time.	69
	Should provide comparable results	It must be able to compare performance with peers.	70
Atos	Should contain a benchmark	Benchmarks facilitate the peer-comparison of performance.	39
	Should follow the polluter pays principle	It is of interest to charge the customer not only for the amount of energy it uses, but for the amount of pollution it causes.	45,49,50
	Should enable capacity management	Energy consumption data per customer helps to perform data center management.	51,52,53
Previder	Should appeal to customers	The value of the measurement tool should appeal to the cloud customer.	61
ReasonNet	Must be quantitative	Using qualitative measures enhances the probability of a discussion about subjective qualitative measures of environmental performance such as the used energy source.	63
	Should be granular	The measurement tool should be cloud-based, which means that measuring on the virtualization level is necessary.	44
	Should deal with relativity	It should be clear what is included in the calculation of environmental performance and what is not. Results can be reproduced by someone else.	61
CloudVPS	Should enable vendor selection	Large clients are often obliged to evaluate their suppliers. It is therefore important that the measurement tool supports the process of vendor selection.	51

6.
Requirements and Assumptions

6 REQUIREMENTS AND ASSUMPTIONS

This chapter presents the requirements and assumptions which are derived from theory and practice. To establish a multi-perspective set of requirements and assumptions, requirements and assumptions are derived from both theory and practice. In the first part of this chapter, the requirements that follow from the implications as described in the literature review (see chapter 2) are presented. The second part of this chapter, presents the requirements and assumptions that are gathered in the case study. The requirements are presented in tables. The first column presents the subject, the second column contains a reference to the paragraph of this document in which the findings and requirements are described, the third column contains the requirements and the fourth and last column the references to literature. With regard to the latter, these literary sources do not always explicitly mention these requirements for the measurement tool, but the requirements are derived from findings in these sources. Each table of requirements is followed by assumptions. At the end of this chapter, the derived requirements are evaluated to eliminate requirements that do not fit the goal that has been set for the measurement tool. The final set of requirements is used to generate structural specifications and the structure of the measurement tool in chapter 7.

6.1 Requirements and assumptions derived from theory

This paragraph presents the requirements and assumptions that can be derived from theory. In the literature review in chapter 2, theoretical insights from (1) existing methods and approaches for measuring environmental performance (see 2.3), (2) sourcing (see 2.4) and (3) governance (see 2.5) have been presented that imply requirements that should be met by the measurement tool. Table 13 presents the requirements derived from these three elements.

Table 13: requirements derived from theory per element

Subject	Ref. #	Requirements	References
Existing methods & approaches	2.3.1	The measurement tool: ▪ Should measure the economic impact of energy consumption.	e.g. Garg and Buyya (2011), Berl et al. (2010) and Sabbaghi and Vaidyanathan (2012)
	2.3.4	▪ Should measure the environmental performance of cloud computing as the carbon footprint caused by energy consumption.	-
	2.3.5	▪ Should collect data on regular time intervals. ▪ Could use benchmarks or baseline values. ▪ Should use standardized benchmark values. ▪ Should look for greener solutions and continue the greening process.	Uddin and Rahman (2012)
Sourcing	2.4.2	▪ Should facilitate environmental friendly purchasing. ▪ Should facilitate vendor selection based on environmental performance.	Molla (2008)
	2.4.3	▪ Should positively contribute to the enforcement of service level agreements.	Cicotti et al. (2012)
		▪ Should provide output suitable for functioning as a performance level in service level agreements. ▪ Should indicate how to monitor that performance level. ▪ Should indicate how to report that performance level.	Alhamad et al. (2010)
		▪ Should measure environmental performance on the virtualization level.	Xiong and Perros (2009)
Governance	*2.5.1*	▪ Should have the right level of granularity. ▪ Should be transparent.	Linthicum (2009)
	2.5.2	▪ Could follow the Plan-Do-Check-Act-Cycle of Deming (1982). ▪ Should be aimed at continuous improvement.	ISO50001
	2.5.3	▪ Should be based on life-cycle assessment. ▪ Should have objective and measurable standards.	Harris (2007)

The requirements in Table 13 assume that several conditions are present in the cloud computing eco-system. Without these assumptions being present, the requirements may be irrelevant or ignored. These assumptions are:

- It is assumed that the involved parties in the cloud computing eco-system would like to have and use a measurement tool for measuring the environmental performance of cloud computing.
- It is assumed that (in the future) the cloud customer would like to be able to include the environmental performance of cloud service in the vendor selection process.
- It is assumed that there is a need to specify environmental performance levels in service level agreements (in the future).

6.2 Requirements and assumptions derived from practice

This paragraph presents the requirements and assumptions that are derived from practice. The initial idea was to derive requirements from the analysis of the current measurement effort for measuring environmental performance and through asking cloud service providers for their requirements. But, the analysis of the energy consumption measurements did not yield requirements, but rather some findings that should be taken into account when designing the measurement tool (see paragraph 5.7). Therefore, the requirements derived from practice are limited to the requirements as mentioned by the cloud service providers at the end of the case study interviews. These requirements are displayed in Table 14 (see Table 12 for additional information).

Table 14: requirements derived from practice per element

Element	Requirements
Requirements mentioned in case study interviews	▪ Should be transparent
	▪ Should deal with relativity
	▪ Should be independent of the time of measurement
	▪ Should provide comparable results
	▪ Could use a benchmark
	▪ Should follow the polluter pays principle
	▪ Should enable capacity management
	▪ Should appeal to customers
	▪ Should measure the environmental performance quantitatively
	▪ Should have the right level of granularity
	▪ Should enable vendor selection

An important assumption to be mentioned related to these requirements is the following one. The requirements presented in Table 14 are gathered during interviews in which cloud service providers were asked to provide requirements, assuming that having a measurement would be of added value for them. So, these requirements do not undoubtedly insinuate that cloud service providers desire to have and use a measurement tool.

6.3 Evaluation of requirements and assumptions phase

The purpose of this evaluation is to eliminate requirements that do not fit the goal of the measurement tool that has been set in paragraph 1.4.3 and is formulated as:

> To facilitate the added value of *managing* the environmental performance of cloud computing by *measuring* the environmental performance of cloud computing within the boundaries of the cloud computing eco-system.

The requirements derived from theory and practice can be evaluated along this goal, to see if they fit the terms and the scoping that is implied. Only requirements for which remarks have to be made, are presented here.

- *Should measure the economic impact of the energy consumption*. Including economic impact in the measurement tool does not fit the goal, as the goal uses the term 'environmental performance' and not economic performance. However, analyzing the environmental performance of along the three dimensions of the Triple Bottom Line in paragraph 2.3.1, showed that the economic dimension should also be included, because the high costs incurred by the cloud's energy consumption are often mentioned as a similar or even bigger problem than CO_2-emissions. This could indicate that compared to the environmental dimension, the economic dimensions appeals more to some of the involved stakeholders. So, to enhance the fit between the measurement tool and the stakeholders in the cloud computing eco-system, this requirement is not eliminated from the list.
- *Requirements related to service level agreements.* In Table 13, four requirements related to service level agreements are provided under 'sourcing', that should be discussed in this evaluation:
    - Should positively contribute to the enforcement of service level agreements.
    - Should provide output suitable for functioning as a performance level in service level agreements.
    - Should indicate how to monitor that performance level.
    - Should indicate how to report that performance level.

  Service level agreements have been described as being important in the cloud computing eco-system due to its representation of the interaction between the cloud customer and the cloud service provider. Therefore, these requirements seem relevant. However, they imply that environmental performance is already, or is likely to be included in service level agreements. Analysis of service level agreements of the cloud service providers in the case study shows that it is not. Assuming that cloud service providers are soon willing to make binding agreements on environmental performance in their service level agreements is questionable and therefore more of later concern. Moreover, different cloud service providers have different service level agreements, making it difficult and undesirable to present one way of including environmental performance levels in these service level agreements. The need for including environmental performance in service level agreements, should arise *from* the market and not be *pushed* to the market. Therefore, these requirements are kept in mind when designing the measurement tool, but are eliminated from the list of requirements that should be met by the measurement tool.
- *Should follow the polluter pays principle.* This principle is for example used in environmental law to allocate responsibility of the harm done to the environment to the party that caused the damage. The added value of the measurement tool is in the potential for both cloud service providers and cloud customers to save and reduce energy costs and CO_2-emissions. Using the data provided by the measurement tool to let the stakeholders pay for their harm done to the environment, would only provide negative incentives and destroy the added value of the measurement tool. This requirement is therefore eliminated from the list of requirements.
- *Should enable capacity management.* This requirement means that cloud service providers should be able to allocate energy consumption on a more specific level to customers, with the goal to perform capacity management (some of the interviewed cloud service providers are already able to do so). In the future, performing capacity management on the basis of environmental performance may have added value, but for now, this requirement deviates too much from the goal that has been set, because it does not contribute to managing environmental performance, but to managing capacity. Therefore, it is eliminated from the list of requirements.

7. Structural Specifications and Structure

7 STRUCTURAL SPECIFICATIONS AND STRUCTURE

This chapter presents the structural specifications based on the requirements as presented in the previous chapter and the structure of the measurement tool that follows from these specifications.

7.1 Structural specifications

In chapter 6, requirements from theory and practice have been derived and evaluated, resulting in a set of requirements that should be met by the measurement tool. To turn these requirements into structural specifications that enable the creation of a visualized structure of the measurement tool, the following steps are performed. For each requirement it is determined whether it:

- ..is a functional, non-functional or user requirement.
- ..needs to be further specified.
- ..should function as a specification of another requirement on the list.
- ..should be specified through formulating additional requirements.
- ..should be a specification of a higher level requirement, that is not yet on the list of requirements.

As described in paragraph 3.3.2, categorizing the requirements into functional, non-functional and user requirements is needed to visualize the structure of the measurement tool, which is done in paragraph 8.2. To divide the requirements into functional, non-functional and user requirements, the nature of the requirement is assessed. If a requirement indicates what the measurement tool should *do,* it is a functional requirement. If a requirement indicates what the measurement tool should *be,* it is a non-functional requirement or a user requirement (these requirements specifically apply to the users of the measurement tool). This yields the structural specifications as presented in Table 15. These three types of requirements and their specifications are discussed in the following paragraphs.

7.1.1 Functional requirements

In Table 15, under functional requirements, three main functions are provided: (1) *measure* the energy consumption, (2) *translate* energy consumption into useful impacts and (3) *interpret* the meaning of these impacts. Two of these functions (the first and the third) are marked with a star, because they were added later on and were not derived from theory or practice. The functional requirement 'should translate energy consumption into useful impacts' (2) is added as a generalization of the requirements that imply to translate energy consumption into environmental (3) and economic performance (4) respectively (see Table 13 on page 53). Requirement 5 (see Table 14 on page 54), implies that the metrics used to specify environmental and economic impacts should be quantitative.

7.1.2 Non-functional requirements

The non-functional requirements describe what the measurement tool should be like and what its characteristics should be. Requirement 9 (see 'Sourcing' in Table 13 on page 53) provides a constraint towards the measurement level used by the measurement tool: it must measure on the virtualization level. Measuring on the virtualization level is of utmost importance to include the shared and virtualized resources in the measurement effort. This requirement is placed in Table 15 as a specification of requirement 8, which implies to use 'the right level of granularity'. Requirements 12 and 15 begin with 'could' instead of 'should', which means that fulfilling these requirements is optional, but are nonetheless expected to provide added value when fulfilled.

7.1.3 User requirements

The comparability of results, as mentioned in requirement 21 is very important for both cloud service providers and cloud customers, as it enables service comparison on the basis of environmental performance. The requirements 19, 20, 21 and 22 specify what comparability of results means (19) and when these comparable results are of added value for the stakeholders (20, 21 and 22). The requirements 23-26 are all marked with a star, indicating they have all been added on top of the requirements that were derived from theory and practice. These requirements were added, because the understandability of the measurement tool is assumed to be closely related to its usability. The specifications of requirement 23 were determined through asking the question: what contributes to having an understandable measurement instrument? Relevant answers included that the measurement tool should explain itself to its users (24) and should not require of knowledge from the user (25). Next to that, the user should be guided in the use of the instrument, to provide a hands-on approach for using the instrument. Requirement 27, which implies that the measurement tool should be transparent, is derived from both theory and practice. Requirements 28 and 29 were added as extra requirements to specify what transparency means for the measurement tool. If it is possible to easily trace back outputs of the measurement tool (28) to its original input and to perform transparent reporting (29), this means that the steps taken in between are transparent.

Table 15: overview of requirements categorized into functional, non-functional and user requirements

Type	Requirement	#
Functional [R_f]	The measurement tool should follow logical performance measurement process steps:	
	▪ Should measure the energy consumption of a cloud computing service*.	1
	▪ Should translate the energy consumption into useful impacts	2
	o Should measure the environmental performance of cloud computing as the carbon footprint caused by energy consumption.	3
	o Should translate energy consumption into economic performance.	4
	o Should measure the environmental performance of cloud computing quantitatively.	5
	- Should use a quantitative metric for calculating environmental and economic impact.	6
	▪ Should interpret the meaning of the resulting impacts*.	7
Non-functional [R_{nf}]	▪ Should have the right level of granularity.	8
	o Must measure energy consumption on the virtualization level (constraint).	9
	▪ Should collect data on regular time intervals.	10
	▪ Should be independent of the time of measurements.	11
	▪ Could use a benchmark or baseline value.	12
	▪ Should use standardized benchmark values.	13
	▪ Should follow the polluter pays principle.	14
	▪ Could follow the Plan-Do-Act-Cycle of Deming (1982).	15
	▪ Should be aimed at continuous improvement.	16
	▪ Should look for greener solutions and continue the greening process.	17
User [R_u]	▪ Should provide comparable results.	18
	o Should have objective and measurable standards.	19
	o Should enable environmental friendly purchasing.	20
	- Should facilitate vendor selection based on environmental performance.	21
	o Should contribute to the marketing of cloud services for cloud service providers.	22
	▪ Should be understandable*	23
	o Should be self-explanatory*.	24
	o Should not require a lot of knowledge*.	25
	o Should guide the user in using the instrument*.	26
	▪ Should be transparent	27
	o Should enable tracing back outputs to their original inputs*.	28
	o Should facilitate the transparent reporting of outputs*.	29
	▪ Should appeal to customers	30

7.2 Structure of the measurement tool

As explained in paragraph 3.3.2, IDEF0-modeling is used to visualize the structure of the measurement tool on the basis of the structural specifications. The IDEF0-model that presents the structure of the measurement tool is presented in Figure 24 and shall be built-up step by step in the following paragraphs.

7.2.1 The structure of the IDEF0-model

The functional requirements as presented in Table 15 are dominant for determining the structure of the IDEF0-model, because they represent functions that can be visualized as process steps using boxes. But, there is another dominant requirement that determines the structure of the model: requirement 15 that opts to use the Plan-Do-Check-Act cycle of Deming (1982) also known as the 'Deming-wheel'. Although using the Deming-circle is optional, it seems a very relevant option, since it is commonly accepted and used for quality management and problem solving in organizations. Moreover, according to Basu (2004), this cycle represents 'continuous improvement', which was one of the requirements (16). It is proposed to use the Observe-Plan-Do-Check-Act-cycle, because observation of the current performance is also necessary to determine whether action is needed or not. Therefore, the IDEF0-model is divided into five phases: Observe, Plan, Do, Check and Act. Table 16 presents the five phases in the first column and the steps that should be performed in each phase in the second column. The third column represents the box-number of each step as presented in Figure 24. The steps for the boxes A5, A6 and A7 follow directly from the functional requirements 1, 2 and 7 of Table 15, which is also indicate in the lower left corner of the boxes A5, A6 and A7 in Figure 24. The boxes A1 to A4, follow logically from the purpose of the phase in which these steps take place. The boxes in the IDEFO-model are connected through arrows. Output of a process steps can be used in the next (or another) phase in the process as control or input. To provide a better understanding of the IDEF0-model, the next paragraph provides a step-by-step description.

Table 16: steps per phase of the Deming Wheel and corresponding box number

Phase	Steps	#
Observe	Observe current performance	A1
Plan	Set targets	A2
	Determine how to reach targets	A3
Do	Execute plan	A4
	Measure energy consumption	A5
Check	Translate energy consumption into impacts	A6
	Interpretation of impacts	A7
Act	Go back to A1	n/a
	Go back to A3	n/a

7.2.2 Description of the IDEF0-model

Each step (or box) of the IDEF0-model can contain input, output, controls and mechanisms (see paragraph 3.3.2 for explanation on IDEF0-model semantics). The elements for each step of the model are described in this paragraph. On a regular basis, references to the requirements as presented in Table 15 are placed between brackets to show how these requirements are reflected in the IDEF0-model. In the first step (A1) and phase (Observe), the current environmental performance should be observed. The user of the instrument is expected to need some sort of motivation or reason to think of the current performance as unsatisfactory. Therefore, 'drivers' have been added as a control to this process. These drivers can be seen as perspectives that can be used by the user to evaluate the current the performance and decide that (1) action is required or that (2) no action is required.

The second phase, *Plan*, starts with setting targets. The process for target setting is controlled by the observed performance of A1, because targets are often expressed as a percentage of the current performance by which the performance should be improved. For setting targets, the user needs target setting options, because how to set a target is expected to be dependent on the purpose for which the user decided to do a walkthrough of the measurement tool. Therefore, target setting options are presented as a mechanism that supports step A2. In step A3, a plan is established that explains the interventions needed to reach the targets as specified in the previous step. These targets are presented as a control for step A3, because appropriate interventions should be selected that have the potential to reach the targets.

The third phase, *Do*, starts in step A3 with the execution of the plan of step A2, which means that the selected interventions are implemented. Input to step A3, is the energy consumption before plan execution. Through implementing the interventions, the energy consumption should change. This is visualized by the output of step A3, which is the energy consumption *after* plan execution. To gather the data that is needed to check whether or not the selected interventions have had effect, step A5 measures the energy consumption after plan execution. To be able to measure energy consumption, several controls and mechanisms are needed. First of all, a sensor is needed to measure energy consumption at a physical location in the data center (currently this is done at the server rack or power distribution unit, see 5.5). Following requirement 9, which implies to measure on the virtualization level, to achieve the right level of granularity (req. 8), hypervisor software should be used that is able to allocate energy consumption to the virtual machines. The outcome of this process is influenced by the calibration of the sensor, the metric and energy consumption model that are used to calculate energy consumption.

In the fourth phase, *Check*, the measured energy consumption of a set of virtual machines is translated (req. 2) into environmental (req. 3) and economic (req. 4) impacts in step A6. To calculate environmental and economic impact quantitative metrics (req. 5 and 6) are used. Environmental and economic impact are the output of step A6 and function as the input for step A7, in which the impacts are interpreted (req. 7). For the interpretation of the impacts, benchmarks or baseline values (req. 12 and 13) can be used. The targets as defined in step A2, are presented as controls for this step, because they should be used in these benchmarks. Both an internal and external benchmark should be included. The internal benchmark can be used to improve performance on the basis of results of the past and the external benchmark can be used to generate comparable results (req. 18) to benchmark against competitors to enable vendor selection (req. 21) and marketing of cloud services on the basis of environmental performance (req. 22). This step has 'interpreted impact' as output to which requirements 28 and 29 apply.

In the fifth and last phase, *Act*, there are two possibilities. If step A7 has provided satisfactory results, the process ends and the user can start over at step A1 directly or at a later moment in time. If step A7 has provided non-satisfactory results, the user can decide to go back to step A3, to adjust the plan and select other interventions to reach the targets that have been set.

Some final remarks with regard to the IDEF0-model are the following. Requirement 19, which implies the measurement tool include objective and measurable standards applies to: the energy consumption model in step A5, the economic and environmental metrics in step A6 and internal and external benchmarks in step A7. Taking into account this requirement in these three process steps, should contribute to the comparability of results. Another remark is that not all of the requirements of Table 15 are explicitly used in the IDEF0-model. This is explained in the next paragraph.

7.2.3 Generic requirements

Table 15 contains several requirements that do not directly apply to a certain element of the measurement tool, but rather apply to the measurement tool as a whole. These include the requirements on understandability and transparency (req. 23-29) and requirement 30 which implies that the measurement tool should appeal to the cloud customer. Requirements 15 and 16 that imply the use of the Deming-wheel and a focus on continuous improvement are embedded in the overall structure of the IDEF0-model, because the choice was made to following the Deming-wheel to determine the structure.

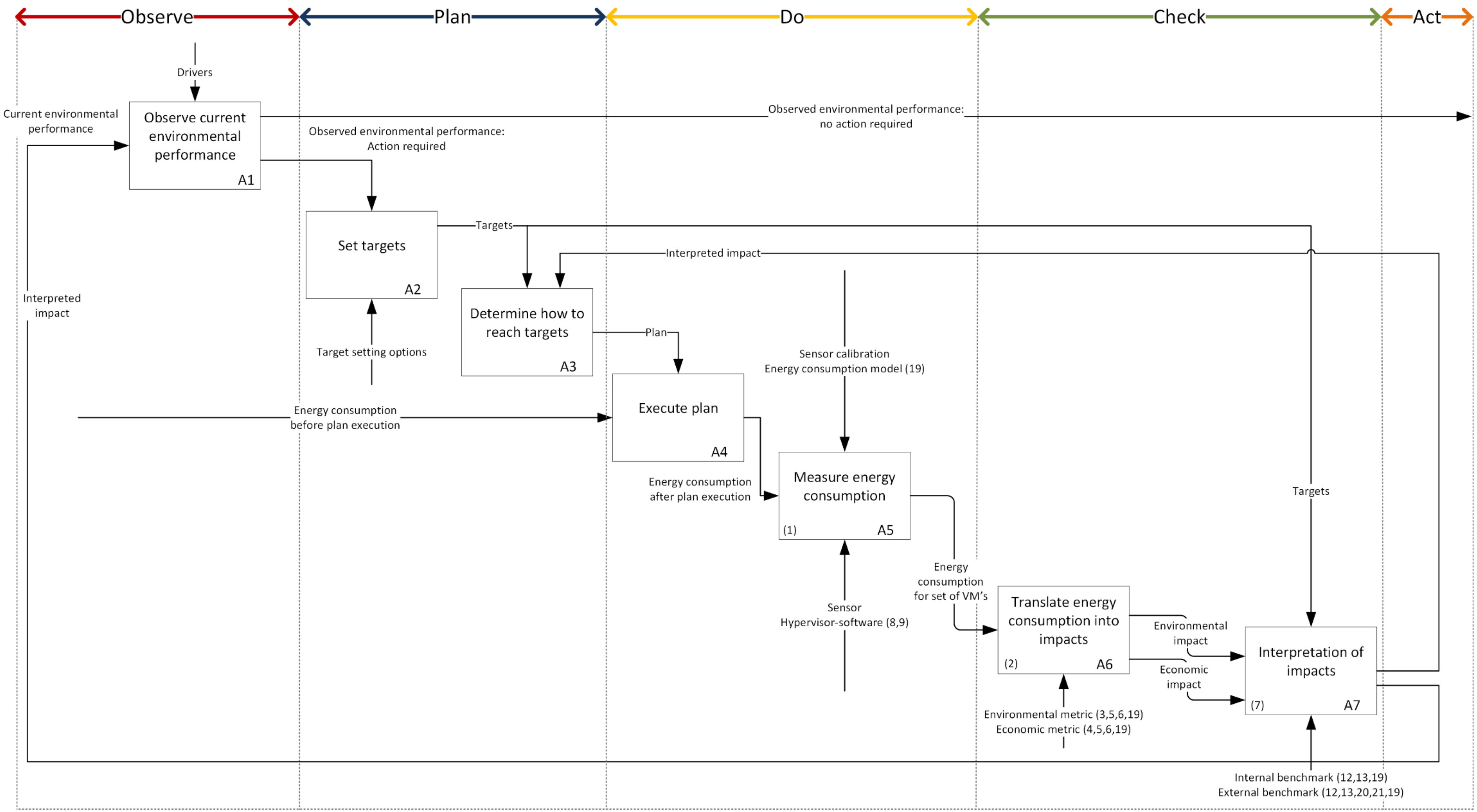


Figure 24: visualized structure of the measurement tool based on the Deming-Wheel, using IDEF0-modeling

7.3 Evaluation of structural specifications phase

As described in the Methodology in paragraph 3.3.3, this phase should be evaluated through checking for structural alternatives and checking whether or not the requirements have been unraveled to the desired level. With regard to the latter, the requirements seem to have the right level of granularity, because they enabled the creation of the visualized structure of the measurement tool. If these requirements had not been unraveled enough, it would be a difficult task to create this structure. When it comes to structural alternatives, several elements or characteristics of the model have been identified, that could be replaced by alternatives. These are the following:

- *Using the Deming-wheel*. The Deming-wheel determines the overall structure of the measurement tool. Reasons for doing include the ISO50001 for energy management systems prescribing to use the Deming-wheel for implementing an energy management system and the Deming-wheel being commonly used and acknowledged. However, relevant alternatives certainly exist. The ISO140001 for example, prescribes to use the continuous improvement cycle which contains the steps (1) commitment and policy, (2) planning, (3) implementation, (4) evaluation and (5) review (Agency, 2013). Other examples include cycles that are used for managing the performance of employees. These alternatives and the Deming-wheel have a lot in common; the steps presented in these different models are quite similar. Therefore, using an alternative for the Deming-wheel to visualize the structure of the measurement tool, would not be of significant influence.
- *Using an internal and external benchmark.* The choice was made to include both an internal and external benchmark. An alternative would be to include one and the same benchmark for evaluating both internal and external performance. However, the external benchmark needs to be standardized, to enhance the comparability of results. At the same time, this implies that the external benchmark is an abstraction of the companies' performance. Therefore, the internal benchmark can be used to provide performance insights on a higher level of granularity.

8. Prototype

8 PROTOTYPE FOR THE MEASUREMENT TOOL

This chapter describes a prototype which is built up step by step on the basis of the structure of the measurement tool (as presented in chapter 7). The seven steps as presented in Figure 24 have certain input, output, controls and mechanisms that need be replaced by actual design constructs in order to create a prototype. This is presented in paragraph 8.1, followed by a preliminary design of the measurement tool in paragraph 8.2.

8.1 Choosing design constructs for the measurement tool

This paragraph presents the design constructs for the seven steps of the measurement tool. Suitable design constructs for the prototype are to be found through (1) checking whether analyzed literature or the case study results provide relevant options or through (2) searching for additional literature or other sources of information. For each design construct, a motivation for including it in the prototype design is provided.

8.1.1 Observe phase – Step A1: observe current performance

Figure 25 presents the input, output and controls for the first step (A1), which is about observing the current environmental performance of cloud services. For the control 'drivers' a design construct should be chosen (see blue frame in Figure 25). The cloud service providers mentioned several drivers for paying attention to data center efficiency in the case study interviews. These drivers can also be used to evaluate the current environmental performance. The mentioned drivers are: costs, green thinking, customer and government (see paragraph 5.2.1). A governmental driver for example, could be a new rule or regulation that forces the cloud service provider to further improve the environmental performance of their services. But, a cloud service provider can for example also evaluate the environmental performance on the basis of the costs it incurs and the potential to reduce these costs.

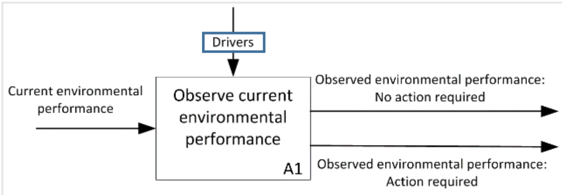


Figure 25: IDEF0-scheme for A1

8.1.2 Plan phase – Step A2: setting targets and Step A3: determine how to reach targets

Figure 26 presents the input, output, controls and mechanisms for the second (A2) and third (A3) step. The blue frames in Figure 26 indicate the elements for which a design construct should be chosen. For step A2, the mechanism 'target setting options' needs to be defined. Targets need to have a reference situation, which can be provided in the first place by benchmarks. Benchmarking can be done internally or externally (2005). Internal benchmarking is defined by O'Dell and Essaides (1998) as *"the process of identifying, sharing, and using the knowledge and practices inside one's own organization".* External benchmarking is aimed at comparing the performance of the organization with similar other organizations. Next to that, targets can also be set on the basis of strategic objectives that are derived from the company's strategy. Another option is to use forecasting and trend analysis to estimate targets for the future. So, the target setting option to include in the measurement tool are:

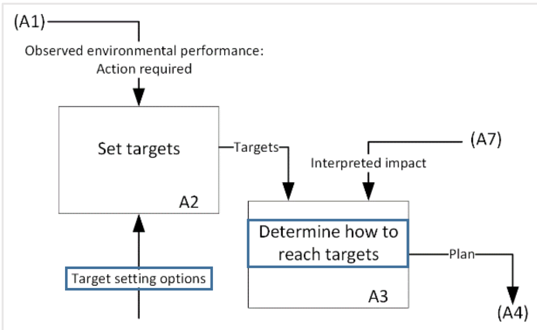


Figure 26: IDEFO-scheme for A2 and A3

- Internal benchmarking
- External benchmarking
- Strategic objectives
- Trend analysis and forecasting

For step A3, interventions should be specified that could be implemented by cloud service providers to reach the targets that have been set. In paragraph 2.2 the data center energy systems and categories of interventions for increasing energy efficiency were presented. The focus of this research is not on providing detailed interventions. Therefore, categories of interventions are described in which cloud service providers can look for those interventions that suit their targets. The categories and examples of interventions are presented in Table 17.

Table 17: categories of interventions and examples

Category	Example
Hardware	Purchasing new, more energy efficient hardware.
Software	Use software for load balancing.
Auxiliary equipment	Optimize cooling efficiency.
Data center configuration	Strategic placement of servers in the data center to prevent hotspots.

8.1.3 Do phase – Step A4: execute plan and Step A5: measure energy consumption

Figure 27 presents the input, output, controls and mechanisms for step A4 and A5 in the 'Do'-phase. For A4, no design constructs need to be chosen as step A3 resulted in a plan, which should be executed in this step. There are no other elements that should be specified for this step. For step A5, design constructs need to be determined for the energy consumption model, sensor, hypervisor-software and 'energy consumption for a set of virtual machines'. An energy consumption model is needed to be able to measure the energy consumption in step A5. A variety of models for conventional server energy consumption exists in literature (e.g. Chen et al., 2005; Elnozahy, Kistler, & Rajamony, 2003; Lewis, Ghosh, & Tzeng, 2008). Throughout the years, research into energy consumption modeling of virtual machines has also been done (e.g. Bohra & Chaudhary, 2010b; Kansal, Zhao, Liu, Kothari, & Bhattacharya, 2010; Stoess, Lang, & Bellosa, 2007). Selecting one of these energy consumption models for use in the measurement tool, should be substantiated through extensively testing the accuracy and reliability of these models when used in the measurement tool. This does not fit the scope of this research. Another, but weaker option for selecting an energy consumption model, would be performing an extensive literature review on these models, to see what model seems to have the best theoretical fit with the goal of the measurement tool. But again, such research deviates too much from the scope of this research and would be very time consuming. Therefore, the following is assumed. In paragraph 5.7.2, Vblocks were discussed, which are integrated cloud platforms. One of the interviewees mentioned that the technology of these Vblocks, allows to measure energy consumption at the physical server and allocate energy consumption not only to virtual machines running on this physical server, but also to the level of virtual resources, such as CPU, memory and storage. The hypervisor-software 'VMWare' uses a certain algorithm to do so. It is not about using that specific algorithm, but rather the assumption that cloud technology will be ready in the near future for easily measuring the energy consumption of virtual machines and its resources. So, for the energy consumption model, sensor, hypervisor-software and 'energy consumption for a set of virtual machines' this implies the following:

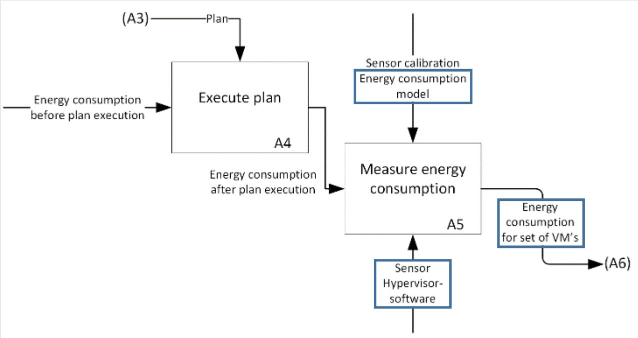


Figure 27: IDEF0-scheme of A4 and A5

- Energy consumption model: it is assumed that energy can be measured at a physical server and allocated to virtual machines and their virtual resources.
- Sensor: a sensor is needed to measure energy consumption at the physical server.
- Hypervisor-software: is needed for virtualization and allocation of energy consumption to virtual machines and virtual resources.
- Energy consumption for a set of virtual machines: can be retrieved from the hypervisor-software.

8.1.4 Check phase – Step A6: translate into impacts and Step A7: interpretation of impacts

Figure 28 presents the input, output, controls and mechanisms for the check phase, which consists of step A6, translating energy consumption into useful impacts and step A7, the interpretation of these impacts. As indicated with blue frames in Figure 28, for an environmental and economic metric need to be designed for step A6 and an internal and external benchmark should be developed for step A7.

8.1.4.1 Designing an environmental and economic metric

The environmental and economic metrics should translate the energy consumption of a set of virtual machines into environmental and economic impact respectively. Important to mention is that the 'set' of virtual machines of which the energy consumption is measured depends on the purpose of the user that is using the measurement tool. Examples of different purposes can be measuring the impact of a specific cloud service, of a specific customer or the cloud system of a provider as a whole. These different purposes require energy consumption data of different sets of virtual machines. To express the environmental impact caused by the energy consumption of virtual machines, carbon footprint should be used (see requirement 3 in Table 15 on page 58). To determine the CO_2-emissions caused by the energy consumption of an x-amount of virtual machines, a parameter α (that represents the amount of CO_2-emissions generated per kWh) is multiplied with the sum of kWh consumed by the x-amount of virtual machines. See equation (1).

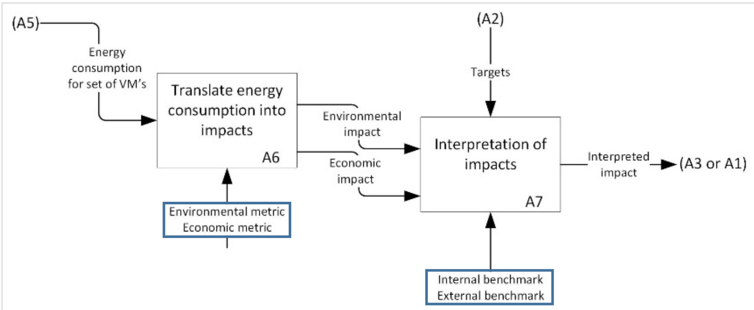


Figure 28: IDEF0-scheme for A6 and A7

$$(1)\ CF_{set} = \sum_{i=1}^{x} VM_{ei} * \alpha$$

with:
$CF_{set} = carbon\ footprint\ of\ a\ set\ of\ VM's$
$e = energy\ consumption\ in\ kWh$
$VM = Virtual\ Machine$
$\alpha\ = gram\ CO_2\ per\ kWh$

As mentioned in paragraph 8.1.3, it is assumed that energy consumption can also be allocated to virtual resources such as the CPU, memory and storage used by a virtual machine. This also means that the carbon footprint can be determined on the resource level. This is valuable, because it provides insight into the origin of the overall carbon footprint of the set of virtual machines. A high carbon footprint for CPU for example, may indicate that CPU-power is not allocated efficiently. To present the carbon footprint of the virtual CPU, memory and storage, the equations (2), (3) and (4) have been derived from equation (1).

$$(2)\ CF_{CPU} = \sum_{i=1}^{x} vCPU_{ei} * \alpha$$

$$(3)\ CF_{mem} = \sum_{i=1}^{x} vMEM_{ei} * \alpha$$

$$(4)\ CF_{stor} = \sum_{i=1}^{x} vSTOR_{ei} * \alpha$$

with:
$CF = carbon\ footprint$
$e = energy\ consumption\ in\ kWh$
$vCPU = Virtual\ CPU$
$vMEM = \ Virtual\ Memory$
$vSTOR\ = Virtual\ Storage$
$\alpha\ = gram\ CO_2\ per\ kWh$

For parameter α, a conversion table is needed that specifies the amount of CO_2-emissions that are generated for a particular source of energy. This because cloud service providers do not all use the same energy source. Therefore, the conversion table of the Dutch CO_2-prestation ladder can be used. This ladder is used by clients in tender procedures to award discounts to bidding organizations that make an effort to minimize their CO_2-emissions. The conversion table used in this mechanism is presented in Table 18.

To translate the energy consumption into economic impact, the cost model as described by Patel and Shah (2005) can be used. This model is presented in equation (5) in which the power consumed by hardware is multiplied with the market energy price to which the result of multiplying K1 with the costs for the consumed power by hardware is added. K1 one is a power burdening factor to take into account amortization and maintenance of the power delivery system. Further research should indicate whether or not including such a burdening factor would be of added value for the measurement tool. For now, the focus is only on the cost incurred for the consumed energy based on the market price (see blue frame in (5)). Therefore, the economic impact of the energy consumption of a set of virtual machines can be formulated as in equation (6).

Table 18: CO_2-emissions per energy source adapted from: SKAO (2014)

CO_2-emissions per energy source		gr CO_2/kWh
Grey	After 2010	455
Green	Wind	15
	Water	15
	Solar	80
	Landfill gas	80

$$(5)\ \mathrm{Cost}_{\mathrm{power}} = \boxed{\mathrm{U}_{\$\mathrm{grid}} * \mathrm{P}_{\mathrm{consumedhardware}}} + \mathrm{K}_1 * \ \mathrm{U}_{\$\mathrm{grid}} * \mathrm{P}_{\mathrm{consumedhardware}}$$

$$(6)\ E_{cost} = \sum_{i=1}^{x} VM_{ei} * \beta$$

with:
$E_{cost} = energy\ costs\ in$ €
$e = energy\ consumption\ in\ kWh$
$VM = Virtual\ Machine$
$\beta\ =$ € $(euro)\ per\ kWh$

For the cloud customer, the same equation applies, but with a parameter for the price of one kWh consumed energy that is determined by the cloud service provider. This is done to prevent claims from the customer towards the cloud service provider about how much the customer should pay for its energy. It is the cloud service provider that sets the price for the cloud services. Economic impact can also be determined on the level of the virtual resources. This yields the equations as presented in (7), (8) and (9).

$$(7)\ E_{costCPU} = \sum_{i=1}^{x} vCPU_{ei} * \beta$$

$$(8)\ E_{costMEM} = \sum_{i=1}^{x} vMEM_{ei} * \beta$$

$$(9)\ E_{costSTOR} = \sum_{i=1}^{x} vSTOR_{ei} * \beta$$

with:
$E_{cost} = energy\ costs\ in$ €
$vCPU = Virtual\ CPU$
$vMEM = Virtual\ Memory$
$vSTOR = Virtual\ Storage$
$e = energy\ consumption\ in\ kWh$
$\beta\ =$ € $(euro)\ per\ kWh$

8.1.4.2 Developing internal and external benchmarks

Benchmarks are needed for making results comparable, which leads to enhanced value for both the cloud service provider and the cloud customer. The introduced metrics for environmental and economic impact, only have an absolute meaning. For example, if customer A has a footprint of 700 kg of CO_2 in February compared to 600 kg of CO_2 in January, customer A notices an increased environmental performance. However, when comparing two different cloud service providers, these absolute figures are not sufficient, as they do not specify the size of the load that was processed. This emphasizes the need for a *standardized benchmark.* Analysis of existing metrics for measuring data center efficiency in paragraph 2.3.5, showed that all metrics contain an energy component and a performance component, for example: GB/Watt, in which GB stands for the amount of Gigabytes that have been processed with 1 Watt of energy. A new metric with similar characteristics can be introduced to enable the comparability of the carbon footprint of services of different cloud service providers: the carbon footprint per 1 unit of Gigahertz (for CPU efficiency), Mb (for memory efficiency) and Gigabyte (for storage efficiency). This metric is presented for CPU, memory and storage in the equations (10), (11) and (12). To be able to calculate the values of this metric, the hypervisor-software should also measure the amount of Ghz, Mb and GB and energy consumed by the virtual resources.

(10) $$CF_{Ghz} = \frac{\sum_{i=1}^{x} vCPU_{ci}}{\sum_{i=1}^{x} vCPU_{gi}}$$

$CF = carbon\ footprint$
$vCPU = Virtual\ CPU$
$g = consumed\ Gigahertz$
$c = carbon\ footprint$

(11) $$CF_{Mb} = \frac{\sum_{i=1}^{x} vMEM_{ci}}{\sum_{i=1}^{x} vMEM_{mbi}}$$

$CF = carbon\ footprint$
$vMEM = Virtual\ Memory$
$mb = consumed\ megabyte$
$c = carbon\ footprint$

(12) $$CF_{GB} = \frac{\sum_{i=1}^{x} vSTOR_{ci}}{\sum_{i=1}^{x} vSTOR_{gbi}}$$

$CF = carbon\ footprint$
$vSTOR = Virtual\ Storage$
$gb = consumed\ gb$
$c = carbon\ footprint$

Next step is to introduce two benchmarks: an internal benchmark and an external benchmark.

- Internal benchmark: calculate the deviation in terms of percentage between the total carbon footprint of the virtual machines (equation 13 and 14) and the carbon footprint allocated to virtual machine resources (equation 15 and 16) for two similar time intervals:

(13) $$1 - \frac{CF_{set}t}{CF_{set}(t-1)}$$

$with:$
$For\ t \le t-1$
$CF_{set} = carbon\ footprint\ of\ a\ set\ of\ VM's$
$t = time\ interval$

(14) $$\frac{CF_{set}t}{CF_{set}(t-1)} - 1$$

$with:$
$For\ t \ge t-1$
$CF_{set} = carbon\ footprint\ of\ a\ set\ of\ VM's$
$t = time\ interval$

(15) $$1 - \frac{CF_{vRES}t}{CF_{vRES}(t-1)}$$

$with:$
$For\ t \le t-1$
CF_{vRES}
$= carbon\ footprint\ of\ CPU, memory\ or\ storage$
$t = time\ interval$

(16) $$\frac{CF_{vRES}t}{CF_{vRES}(t-1)} - 1$$

$with:$
$For\ t \ge t-1$
CF_{vRES}
$= carbon\ footprint\ of\ CPU, memory\ or\ storage$
$t = time\ interval$

The time interval in the equations 10 to 13 can be chosen by the user of the measurement tool. Logical options seem to be for example a comparison with the previous month, the same month a year ago and the deviation from the target that has been set. Moreover, the equations for internally benchmarking the economic impact are exactly the same, except for CF_{set} and CF_{vRES} being replaced by their corresponding value for energy costs (E_{cost}).

- External benchmark: calculate the deviation in terms of percentage between the carbon footprint per Ghz, Mb and GB of cloud service provider A, compared to cloud service provider B as presented in equations 17 and 18. These equations use externally benchmarking the CPU as an example. For memory and storage, similar equations apply. Of the benchmark data it should be known to what time interval it applies and at what time the data was created.

(17) $$1 - \frac{CF_{Ghz}at}{CF_{Ghz}bt}$$

$with:$
$For\ a \le b$
$CF_{Ghz} = carbon\ footprint\ per\ GHz$
$a = cloud\ service\ provider\ A$
$b = cloud\ service\ provider\ B$
$t = time\ interval$

(18) $$\frac{CF_{Ghz}at}{CF_{Ghz}bt} - 1$$

$with:$
$For\ a \ge b$
$CF_{Ghz} = carbon\ footprint\ per\ GHz$
$a = cloud\ service\ provider\ A$
$b = cloud\ service\ provider\ B$
$t = time\ interval$

8.2 Preliminary design of the prototype

The choices for the design constructs as presented in the previous paragraph allow to create a preliminary design of the measurement tool, which can be seen as a specification of the structure of the measurement tool which was presented in Figure 24 on page 61. The steps as presented in this structure are also present in the preliminary design as shown in Figure 29, but steps A2 and A3, which are target setting and determine how to reach those targets respectively, have been merged into one step in the preliminary design: Determine and implement interventions to reach targets. This was done to keep the content of the steps on the same level. Every step of the measurement tool is connected to a rectangle of the same color as the step it is connected to. These rectangles visualize the design constructs that were chosen in the previous paragraph. In this paragraph, no detailed description of the design is provided, because this preliminary design is first assessed on the extent to which it fits the set of requirements in chapter 9. The final design, which is presented in chapter 10 contains a thorough description of each step.

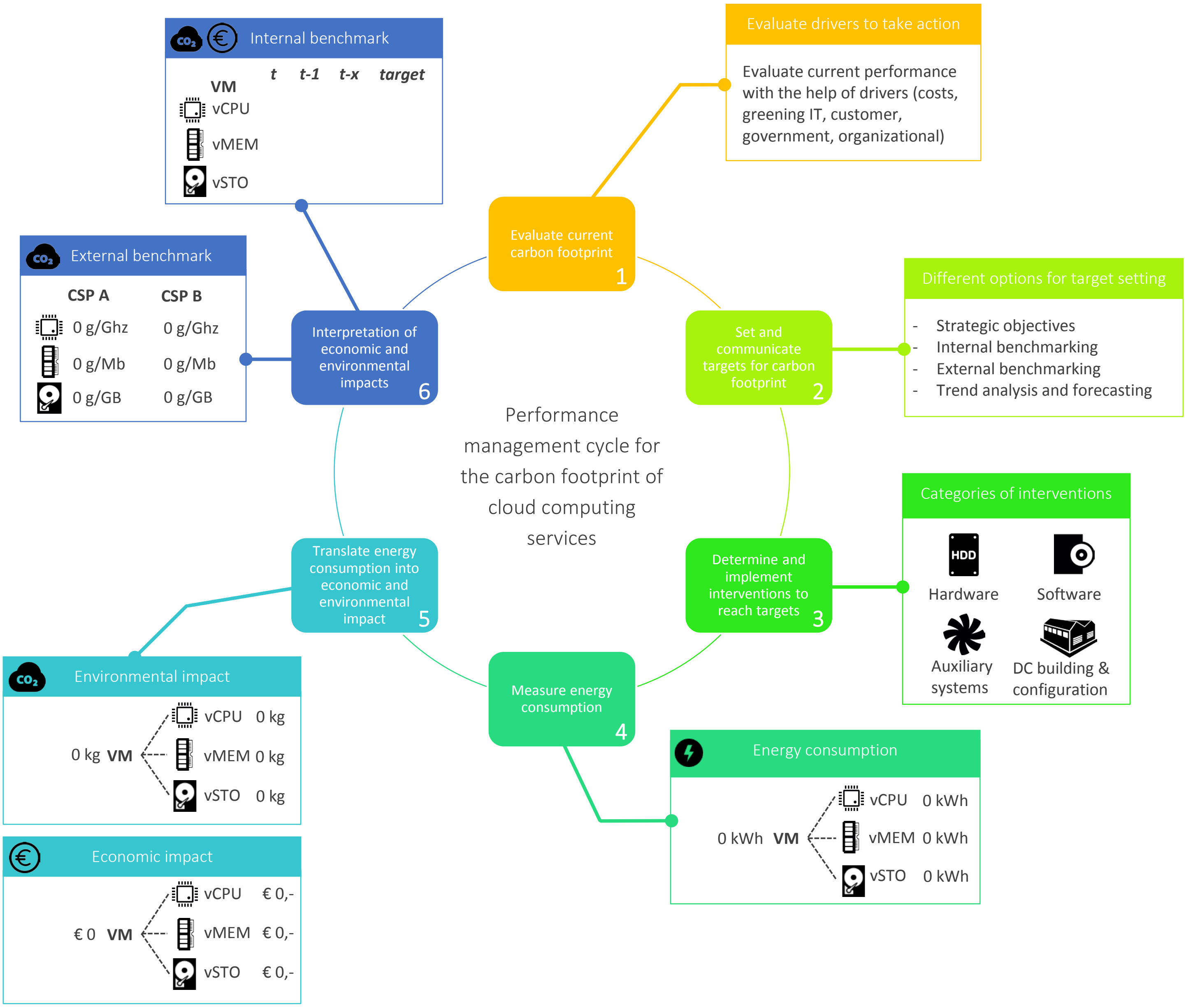


Figure 29: design of the prototype of the measurement tool

9. Implementation

9 IMPLEMENTATION OF THE MEASUREMENT TOOL

This chapter presents the findings from implementing the measurement tool in the context of the cloud computing eco-system, which means that the extent to which the prototype fits the structural specifications is evaluated by using expert reviews.

9.1 Set-up of the expert review

Five experts with different areas of expertise participated in the expert review. The experts were introduced to the subject of this research by means of a small presentation, followed by an explanation on the preliminary design of the measurement too. Next, statements based on the requirements were presented to the experts with the question to indicate on a 1 to 5 Likert-scale to what extent they agreed or disagreed with that particular statement. A score of 5 means that they strongly agree with the statement and a score of 1 means that they strongly disagree. The results of this review can be found in Table 21. The following areas of expertise and organizations were involved in the expert review (see Table 19).

Table 19: expert number, areas of expertise and organizations included in the expert review

Expert number	Area of expertise	Organization(s)
1	IT Outsourcing	KPMG, TU Delft
2	Data center organization, configuration and optimization	Royal Haskoning/DHV
3	Data center auditing	KPMG
4	Sustainability	TU Delft
5	Data center sustainability	Freelance IT professional

9.2 Results of the expert review

A total of 22 statements regarding the fit between the preliminary design and the requirements was evaluated of which 20 statements were evaluated using a Likert-scale and 2 statements were presented as yes-or-no questions. So, 20 statements were quantitatively evaluated by five experts, which yields a total of (20 statements * 5 experts) 100 data points. Figure 30 presents the frequency of scores given by the experts in the expert review. The circle diagrams show that 80 (in green) of the 100 data points are a 4 (55 times, yellow) or a 5 (25 times, dark blue). The other 20 data points consists of 15 times a 3, 4 times a 2 and there is one occurrence of a 1. Next to that, 8 of the 20 quantitatively tested statements do not receive any scores lower than 4. Overall, this seems a satisfactory result, but at the same time, there are still 12 statements that receive a score of 3 or lower from one or more of the experts. Therefore, statements that score on average lower than 4 are discussed here. If necessary, an action to deal with a certain finding is provided. Actions also include improvements of the design of the prototype, which are presented in the last paragraph of this chapter.

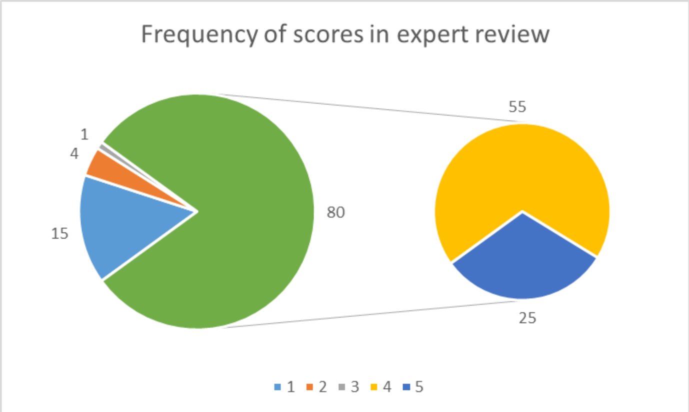


Figure 30: frequency of scores in expert review

The first yes-or-no question asks experts to what extent the measurement tool succeeds in measuring the energy consumption of cloud computing. Three of the five experts indicate that the measurement tool does not fully succeed in measuring the energy consumption of cloud computing, which is mainly due to the scope of this research. For example, experts mention that cooling should be taken into account. This can be corrected through for example multiplying the energy consumption with a factor that resembles the PUE of the data center. These comments, which are actually about the scoping of this research are important and therefore more thoroughly discussed in the discussion in paragraph 12.2.1.

For item B1 (see Table 21), the extent to which the design succeeds in determining the environmental impact, is scored with a 3 by two experts. One of these two experts comments that using a parameter which indicates the amount of CO_2-emissions per kWh to calculate the carbon footprint may be invalid, because of the mechanism of 'merit order' in the energy market. Merit order means that energy supplier determine the energy mix on the basis of the price for provisioning a kWh from different energy sources and the demand for energy. So, if cloud service providers want to use the conversion table as presented in 8.1.4, they should exactly now the energy mix they receive from their supplier over a certain period in time, which is expected to be complicated. Therefore, the expert opts to base the economic impact on the market price for one ton of CO_2-emissions as used in the emission trading scheme of the European Union. This market is currently not stimulating green improvement, due to a large surplus of emission rights, which results in a very low market price for one metric ton of CO_2-emissions. The other expert argues that the amount of CO_2-emissions may be dependent on the location of the data center and thought that the carbon footprint is presented as an average over time, but is however an accumulated value. The consequences of the negligence of the merit order mechanism are further discussed in the discussion in paragraph 12.2.3.

For item e.1, one expert gives a 3 as a score arguing that the measurement tool succeeds in involving the right elements on the system level, but fails to fully grasp the business process level, as the supply chain of a cloud service comprises of more than only this part of the process in the data center. But again, this is the result of the scoping of this research, which is further discussed in paragraph 12.2.1 of the discussion.

For item F, which is about the extent to which the design motivates the user to collect data on regular time intervals, one expert scored a 3 and another expert scored a 2. With regard to the latter, the expert says that the measurement tool does suggest to collect data on regular time intervals, due to the formulas it uses and its design, but this is not explicit enough. The expert opts to present the steps of the measurement tool as time steps (t1, t2,..,t6). The other expert advises to improve the design on this point through including arrows in the design to visualize the necessity of repeating the measurement process within a certain time interval. These findings are taken into account as improvements and are further specified in 9.3.

Item G is about the extent to which the output of the measurement tool is independent of the time of measurement. Three experts have comments on the fit of the design with this requirement and provide scores of 3, 2 and 1 respectively. The internal benchmark that is included in the design of the measurement tool, does not take into account changing customer demand. But, when for example comparing the results of February with January, customer demand must also be taken into account. Therefore, the experts advise to include a correction for customer demand. This correction is described in 9.3 and included in the final design of the measurement tool.

For item K, the average is below 4, due to a score of 3 given by one expert. This score was given for the reason that the measurement tool presents categories of interventions that do not directly contribute to the energy that is consumed by hardware. These categories are auxiliary equipment and data center building and configuration. Therefore, the preliminary design should be improved by taking away these two categories.

Item L consists of three sub requirements or statements. As can be seen in Table 21, experts five consistently scored a 3 for these requirements and provided the following reason. Under item b.1, the merit order was discussed. The expert implies that not taking into account the merit order mechanisms may harm the objectivity and measurability of results, making it difficult to use these results to facilitate vendor selection and the marketing of cloud services.

Item l.1 is about the objectivity and measurability of the standards used in the measurement tool. One of the experts scores this statement with a 2, with the substantiation that the extent to which these standards are objective is questionable. He argues that cloud service providers may be tempted to alter data in their favor and set the norm in such a way that it is beneficial for their own company. The expert agrees that the standards should be objective, but states that this will only be achieved through an independent organization that audits the results of the cloud service providers. The need for an auditing is discussed in the discussion in paragraph 12.5.1.

For item l.2, one expert that scored this statement with a 3, commented that vendor selection is never solely based on environmental performance. After a pre-selection of several cloud service providers based on other factors, environmental performance may be a factor that comes in second or third place for evaluating a cloud service provider.

For item l.3, one expert that scored this statement with a 3, argues that the customer currently does not value environmental performance in its decision for a cloud service provider. Therefore, the extent to which the output of the measurement tool contributes to the marketing of cloud services seems questionable.

For item m.2, one expert that scored this statement with a 3, indicates that the measurement tool itself may not require a lot of knowledge, but effectively implementing the tool requires knowledge on organizations and processes.

For item m.3, one expert that scored this statement with a 3, has the opinion that the measurement tool does not explicitly guides the user, but acknowledges that the design is still a theoretical model instead of a hands-on approach for cloud service providers which can directly be implemented and used.

For item n.1, two experts have provided a score lower than 3. One of the experts mentions the tendency of organizations to adjust data into their favor. The other expert mentions that the output can only be traced back by the cloud service provider. To enable the customer for doing this, more information should be provided together with the output scores, such as the used coefficient for calculating CO_2-emissions, the used energy price etcetera, but this is more relevant when translating this design of the measurement tool into software that can be implemented by cloud service providers.

For item O, one of the experts made the remark that the measurement tool not only appeals to cloud customers, but also the customers that want to acquire regular data center services or data center operators for example.

To summarize, the findings that need further action are presented in Table 20. A distinction is made between problems that can directly be solved through embedding a solution in the final design of the measurement tool and larger, more complex problems, which may require additional research or discussion. The third column of Table 20 shows the items of the expert review that are affected by the presented problems. The direct improvements are further specified in paragraph 9.3. The other findings are further discussed in chapter 0, which is the discussion.

Table 20: overview of most important findings of expert review that require action

Type	Finding	Item #
Direct improvement	1. Extend the design with visualizations that emphasize the focus on continuous improvement.	F
	2. Include a correction for customer demand in the internal benchmark.	G
	3. Remove categories ‘auxiliary systems’ and ‘data center building and configuration’ from categories of interventions.	K
Additional research/discussion	4. Experts mentioned limitations that are the result of the scoping of this research.	A
	5. The measurement tool ignores the merit order mechanism that is used in the energy market to determine the energy mix.	B1, L
	6. There is a need for an independent auditing party to prevent strategic behaviour in the use of the measurement tool.	L1

9.3 Improvements to include in the final design on the basis of the expert review

Table 20 presents three improvements to be made for creating the final design of the measurement tool. These improvements are further described here to enable implementation of these improvements in the final design, which is presented in the next chapter.

- *Extend the design with visualizations that emphasize the focus on continuous improvement.* Adding several elements to the design of the measurement tool are expected to emphasize the focus on continuous improvement. First of all, arrows should be added between each step to enhance the idea that the measurement tool is a repeatable cycle and that one step is followed by another step. Second, the steps included in the design should be labeled with a marker (t_1, t_2, t_3) that defines the moment in the process these steps are executed.
- *Include a correction for customer demand in the internal benchmark*. As explained, the internal benchmark does currently not take into account the customer demand, because it compares absolute values of carbon footprint for a set of virtual machines and its virtual resources of two similar time intervals. However, the customer demand may change over time. If the amount of customers and services delivered to customers increase, more virtual machines and virtual resources may be allocated, resulting in a higher carbon footprint. Therefore, to correct for customer demand, the measurement tool should also present the carbon footprint as an average per virtual machine that was allocated.
- *Remove categories 'auxiliary systems' and 'data center building and configuration' from categories of interventions.* Currently, four categories of interventions are included in the design of the measurement: (1) hardware, (2) software, (3) auxiliary systems and (4) data center building and configuration. Experts in the expert review indicated that categories 3 and 4 do not directly contribute to increasing the energy efficiency of IT resources. Therefore, these categories should be deleted from the model.

Table 21: results of expert review

#	Requirements	Expert number	1	2	3	4	5	
A	Does the measurement tool succeed in measuring the energy consumption of cloud computing?		Yes	Other	Other	Yes	Other	Average
B	Should translate energy consumption into useful impacts.							
b.1	..succeeds in determining the environmental impact.		4	4	4	3	3	3,60
b.2	..succeeds in determining the economic impact.		4	4	4	4	4	4,00
C	Does the measurement tool use a quantitative metric for the environmental and economic impact?		Yes	Yes	Yes	Yes	Yes	n/a
D	Provides sufficient ways to interpret the environmental and economic impact.		5	4	4	4	4	4,20
E	The measurement tool should have the right level of granularity.							
e.1	*..succeeds in using the right measurement level*		4	4	3	4	4	3,80
e.2	*..succeeds in measuring on the virtualization level.*		5	4	4	5	4	4,50
F	The measurement tool collects data on regular time intervals.		5	4	3	2	5	3,50
G	The output of the measurement tool is independent of the time of measurements.		4	3	2	1	4	2,50
H	Indicating carbon footprint per Ghz, Mb and Gb is a strong standardized benchmark.		5	4	4	5	5	4,50
I	The Deming-circle can be clearly recognized in the steps of the measurement tool.		4	4	4	4	5	4,00
J	The measurement tool is aimed at continuous improvement		5	4	4	4	5	4,25
K	Succeeds in looking for greener solutions.		3	4	4	4	4	3,80
L	The measurement tool should provide comparable results.							
l.1	*..the output of the measurement tool is objective and measurable.*		5	2	4	4	3	3,60
l.2	*..facilitates vendor selection based on environmental performance.*		5	3	4	4	3	3,80
l.3	*..contributes to the marketing of cloud services for cloud service providers.*		3	4	4	5	3	3,80
M	The measurement tool should be understandable.							
m.1	*..is self-explanatory.*		5	4	4	4	5	4,40
m.2	*..does not require a lot of knowledge.*		5	3	4	4	4	4,00
m.3	*..guides the user in using the instrument.*		5	4	3	5	5	4,40
N	The measurement tool should be transparent.							
n.1	*..enables tracing back outputs to their original inputs.*		5	3	2	5	5	4,00
n.2	*..facilitates the transparent reporting of results.*		4	4	4	5	4	4,20
O	The measurement tool appeals to cloud customers.		3	4	4	5	4	4,00

In Table 21 the results of the expert review are presented. Scores lower than 4 have been formatted with a red fill and dark red text. Averages lower than 4 have been formatted with a yellow fill with dark yellow text. These colors indicate that an expert has a remark regarding the extent to which the design of the prototype fits a particular requirement. Therefore, the scores and averages lower than 4 have been discussed in paragraph 9.2.

9.4 Evaluation of the implementation phase

The experts used in the expert review cover the most relevant areas of expertise needed to evaluate the set of requirements that should be met by the measurement tool: (1) IT outsourcing (2) data center organization, configuration and optimization, (3) data center auditing (4) sustainability, (5) data center sustainability. Nonetheless, several areas of expertise can be identified, that could be of added value for performing the expert reviews more thoroughly. This does not suggest that the performed expert review is insufficient, but rather that additional reviews can be done, when other researchers desire to do so. The most relevant areas of expertise that could provide additional insights are:

- *Cloud computing expert.* The experts involved in the expert review were quite familiar with the concept of cloud computing. Nonetheless, a cloud computing expert that has extensive knowledge on virtualization, hypervisor-software and the behavior of cloud services, could provide additional insights. In particular, the insights of this expert into the energy consumption measurements on the virtualization level would be helpful.
- *Performance management expert*. An expert that has experience in projects about quality improvement within organization and is familiar with quality improvement techniques, may have a different and useful perspective on the measurement tool. Such an expert is expected to be more focused on the functioning of the measurement tool as a whole for performance management.
- *Governance expert*. In a later stadium, involving a governance expert would be helpful. Such an expert could evaluate the measurement tool on its ability to function within organizations (internal governance) and as tool for comparison between organizations (external governance).

10.

Final design

10 FINAL DESIGN OF THE MEASUREMENT TOOL

This chapter presents the final design of the measurement tool, in which the improvements as presented in 9.3 have been included: the categories of interventions in step 3 have been limited to ‘hardware’ and ‘software’, arrows and time labels (e.g. T_1) have been added to the cycle and the internal benchmark has been adjusted and now also includes the carbon footprint and costs *per virtual machine* (see step 6, Internal benchmark, next to ‘VM’) This is done to provide an extra layer of interpretation that compensates for changing customer demand over time. Figure 31 presents the final design of the measurement tool, followed by a description of each step in the subsequent paragraphs of this chapter.

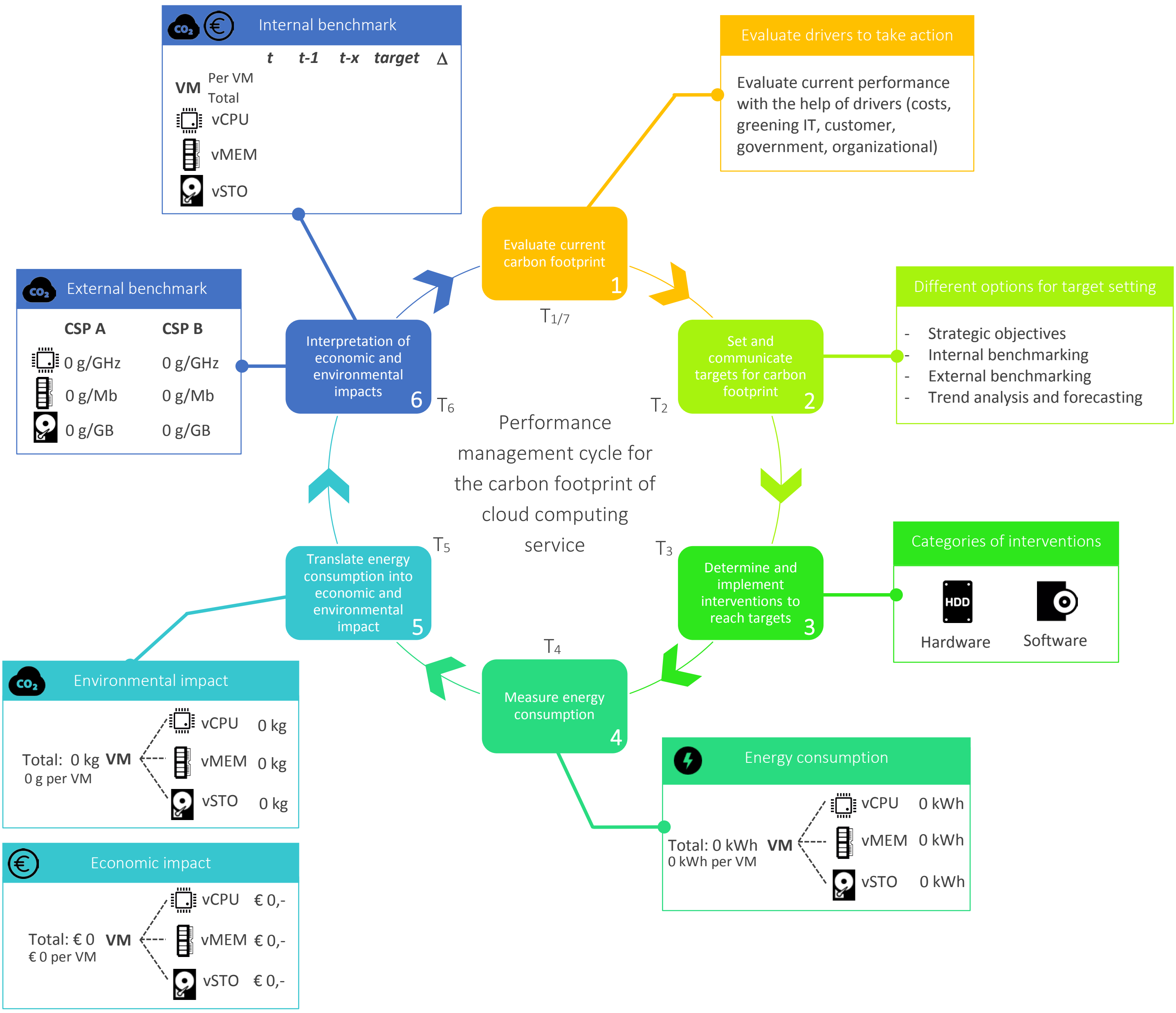


Figure 31: final design of the measurement tool

10.1.1 Step 1: evaluate current carbon footprint

The output of the previous iteration (T_7) of the performance management cycle is evaluated in this step, using drivers based on different perspectives. The user is advised to evaluate the current performance from the perspective of costs, greening IT, customer, government and the organization. Table 22 presents examples of evaluation points per driver. An example of the way these evaluation points can be used is the following. For the driver 'customer', the user could evaluate the extent to which customers are demanding greener products in sales conversations for example. If the conclusion of the evaluation is that the current environ-mental performance should be improved, the user advances to step 2. If not, the performance should be evaluated again at a later moment in time.

Table 22: drivers and examples of evaluation points

Driver	Examples of evaluation points
Costs	Tenability of current energy costs.
Greening IT	Potential of new, greener technology.
Customer	Customer push for greener products.
Government	Rules and regulations on sustainability.
Organizational	Corporate strategy for sustainability.

10.1.2 Step 2: set and communicate targets for the carbon footprint

In this step the user should set targets. Different options for setting targets for the carbon footprint are available and include the use of strategic objectives, internal benchmarking, external benchmarking and trend analysis and forecasting. The user can choose to set absolute values as targets for example: a maximum of 600 kg CO_2 in the month February. But, the target may also be expressed as a percentage by which current performance should be improved. Which option to choose, or which options to combine, may be decided by the user as long as the target is specified in an amount of Euro's or kilograms CO_2 for a specific group of virtual machine and/or virtual machine resources (CPU, memory and storage). These targets should be used in step 6 for performing the internal benchmark.

10.1.3 Step 3: determine and implement interventions to reach new targets

In this step, the user should select interventions that can be used to reach the targets and include these in an implementation plan. The next step is to execute the implementation plan. Examples of interventions include investing in energy efficient hardware, implementing dynamic voltage scaling of CPU's, software interventions to enable load balancing and tools for optimizing virtualization (Jing et al., 2013). The extent to which the cloud customer is able to implement interventions for increasing the energy efficiency depends, but one could think of consolidating the need for storage or CPU-power, by optimizing the processes at the customer-side.

10.1.4 Step 4: measure energy consumption of cloud service

The user should retrieve the needed energy consumption data from the hypervisor-software. To do so, the user needs to provide two inputs:

- The time interval over which energy consumption data needs to be gathered (e.g. February or 2015).
- The set of virtual machines of which the energy consumption data is needed. This could be a set that is used for the provisioning of a specific service, a set that is used for provisioning services for a specific customer or all the virtual machines used by the cloud service provider.

The outputted energy consumption data provided by the hypervisor-software should be presented as displayed in the connected rectangle to step 4 in Figure 31, which means that the total amount of kWh consumed by the set of virtual machines, the average amount of consumed kWh per virtual machine and the total amount of consumed kWh for CPU, memory and storage should be presented.

10.1.5 Step 5: translate energy consumption into economic and environmental impact

In this step, the raw energy consumption data of step 4 is translated to environmental and economic impact, using several equations. These equations are presented in chapter 8.1.4. The following steps should be taken:

- Calculate equation 1 (see paragraph 8.1.4) to determine the total carbon footprint of the set of virtual machines.

- Calculate equations 2, 3 and 4 (see paragraph 8.1.4) to determine the total carbon footprint allocated to the CPU, memory and storage resources.
- Calculate equation 6 (see paragraph 8.1.4) to determine the energy costs incurred by the energy consumption of the set of virtual machines.
- Calculate equations 7, 8 and 9 (see paragraph 8.1.4) to determine the energy costs incurred by the energy consumption, allocated to CPU, memory and storage resources.

The calculated carbon footprints and energy costs should be visually represented as in the two rectangles connected to step 5 in Figure 31 for environmental and economic impact respectively.

10.1.6 Step 6: interpretation of economic and environmental performance

To be able to interpret the environmental and economic impacts of the previous step, two benchmarks are provided:

- Internal benchmark: calculate equations 13, 14, 15 and 16 (see paragraph 8.1.4) to benchmark the carbon footprint of the virtual machines and the virtual machine resources of the current time period with data from other relevant time intervals and/or the target that has been set in step 2. To correct for changing demand, the benchmark also contains the amount of CO_2-emissions and costs as an average per virtual machine.
- External benchmark: calculate equations 17 and 18 (see paragraph 8.1.4) to benchmark the carbon footprint per unit of measurement (i.e. grams of CO_2/GHz) per type of virtual resource (CPU, memory and storage). To be able to calculate the equations 17 and 18, equations 10, 11 and 12 need to be calculated first to calculate the CO_2/GHZ, Mb and GB for each individual cloud service provider included in the benchmark. To do so, the amount of Gigahertz, Megabytes and Gigabytes consumed by the CPU's, memory and storage units of the virtual machines respectively for the same time interval as used for retrieving the energy consumption data must be retrieved from the hypervisor-software.

11. Evaluation

11 EVALUATING THE MEASUREMENT TOOL

The evaluation of the measurement tool consists of a qualitative reliability test and a face validity test which was performed with an expert of KPMG in the research field of data center efficiency. As described in 3.7, doing a calibration test to determine the accuracy and the reliability of the measurement tool is not possible, due to the lack of data to perform such a test. This is further discussed in paragraph 12.2.4 of the discussion. The reliability of results and the validity of the measurement tool have been qualitatively assessed with the help of expert prof.dr. E.J.J (Erik) Beulen, who is Director at KPMG at the department of Shared Services and Outsourcing, and professor in the area of Global Sourcing at Tilburg University. Beulen has been working on a research to identify the value of energy efficiency for customers in outsourcings decisions. His expertise in this area, combined with his experiences obtained at working for KPMG, make him a great candidate for performing the reliability and face validity test.

11.1 Assessing the reliability of results of the measurement tool

The reliability of results of the measurement tool has been evaluated through assessing its *stability, internal consistency* and the *interrater reliability*, with the help of the following three questions and answers:

- *Stability.* If the measurement tool is used at two different points in time (i.e. January and February), what can you say about the stability of the results? Stability is closely related to the scale of operations. An example is mentioned of a large IT-service provider with a data center that is only partially filled. This is expected to yield less stable results, compared to a situation in which this data center is completely filled. When operating on a large scale, deviations in customer demand, are expected to 'level-out' in the output of the measurement tool in the final step. External factors, over which cloud service providers have no control, may influence the stability of the measurement tool. Beulen mentions that the influence of different seasons is limited and acceptable. But, busy periods, such as the gift shopping period for Christmas, may affect the stability of the measurement tool. To cover for this, Beulen advises to include a prolonged time interval of one year. It is expected that a year is sufficient, as each year for example contains the different seasons and busy holiday periods.
- *Internal consistency.* What can you say about the internal consistency of the measurement tool? In other words: are there any inconsistencies? The measurement tool seems to follow a logical cycle of steps. At first sight, the measurement tool contains no inconsistencies. Further testing the measurement tool in practice, may help to identify possible inconsistencies.
- *Interrater reliability.* If the measurement tool is used by different users (i.e. cloud service providers or cloud customers), what can you say about the reliability of the results? The measurement tool itself does not seem to contain loopholes or elements that invoke wrong behavior of its users. This means that if measurements are not performed correctly or if unreliable results are provided the cause is more likely to be manipulation of the model. Benchmarking implies the use of 'large numbers'. This implies that, when including the results of a large number of cloud service providers in a benchmark, differences are not likely to stand-out. Beulen illustrates this with an example. A lease-car company could for example provide a monthly indication of the 'greenness' of your driving behavior. Benchmarking your driving behavior against a large group of other car users is expected to provide relatively stable results. A significant change in driving behavior may have a large impact for you as a user, but as large numbers are included in the benchmark, other colleagues may also have improved their behavior, leading to a similar score. This indicates that the measurement tool may be sensitive for strategic behavior, which could harm the reliability of the results.

  Another important remark to interrater reliability is, again, the influence of the scale of operations. A small data center that only hosts a few customers is more likely to negatively affect the interrater reliability than a large scale data center. For example, the owner of the small data center, may choose a time interval for measurement in which a couple of his customers temporarily switched off their equipment for performing a hardware refresh for example. This phenomenon is more likely to occur within a short time interval. This again, pleads for a time interval of a year.

11.2 Testing the validity of the measurement tool

The validity of the measurement tool was tested with the help of a face validity test that consisted of asking the following question to mister Beulen: to what extent does the measurement tool measure what it was designed for: the environmental performance of cloud computing?

First of all, the environmental performance of cloud computing is more than just the energy consumption of the cloud services. Think of cooling water for example. The focus on energy consumption is a focus on the 'use' dimension, which is one of the multiple dimensions to the environmental performance of the cloud. This is however not a limitation of this research, but rather a scope that is defined. However, within the focus on the use dimension, the total energy consumption of the cloud is more than the energy consumed by the IT-hardware. Indicating that the cloud has a higher energy consumption than currently measured with the measurement tool.

Zooming in on the 'use'-dimension of the cloud, Beulen mentions the influence of the application that is running on the hardware resources of which the energy consumption is measured. A server that is for example used for hosting a SAP-application that has a high workload demands more from the hardware resources than running a simple website on this server. The footprint of the server that runs SAP, is likely to be worse than the server that runs the website. However, comparing the SAP-server with another SAP-server, could theoretically show that the carbon footprint of the SAP-server of the example is not that negative at all, taking into account the intensity of the application that is run on the server. This is an example which indicates that further refinement of the measurement tool is necessary. An option to correct for this, is through including multiple benchmarks. According to Beulen this is however expected to be a complicated and undesirable task.

11.3 Concluding remarks on the reliability of results and validity of the measurement tool

The qualitative assessment of the reliability of results of the measurement tool, indicates certain external factors of which it is assumed that they influence the reliability of the results, that cannot be controlled through the design of the measurement tool: the extent to which the data center is 'filled' (with equipment), the scale of operations and the occurrence of strategic behavior (assuming that the measurement tool does not invoke such behavior).

Qualitatively assessing the validity of the measurement tool indicates that there is a need to further refine the measurement tool to for example account for different workloads demanded by applications. Next to that, measuring the environmental performance of cloud computing is more than just energy consumption. Therefore, future research should be done to build a more comprehensive approach for managing the environmental performance of cloud computing.

Most important finding on the basis of the qualitative assessments of the reliability of results and validity of the measurement tool is the identification of uncertainties (the external factors, the influence of different workloads) that may influence the reliability and validity of the measurement tool. The exact influence of these uncertainties is yet unknown and therefore emphasizes the need to perform additional reliability and validity tests. This is further described in paragraph 12.4.1 as a recommendation.

12.

Conclusion
Discussion
Recommendations

12 CONCLUSIONS, DISCUSSION AND RECOMMENDATIONS

12.1 Final conclusions

The final conclusions consist of the answer to the main research question, followed by an elaboration on the scientific and practical value of the measurement tool that has been developed.

12.1.1 Answer to the main research question

Despite the cloud's potential for its customers to realize significant energy savings and cost reductions compared to their on-premises infrastructure, the exploding demand for cloud computing services drives enormous energy consumption and CO_2-emissions in cloud computing data centers. This intensification of cloud data centers challenges the potential of cloud computing and specifically puts the overall environmental performance of cloud computing services under pressure. To be able to manage and control the environmental performance of the cloud, this research aimed at developing a measurement tool that is able to do so. Therefore, the following research question needed to be answered:

What requirements should a tool meet to support the management of the environmental performance of cloud computing and to be of added value for the involved stakeholders?

The deliverable of this research is a set of requirements, which has been translated into a design for the measurement tool. To derive these requirements and to develop this design, the Design Oriented Approach of Verschuren and Hartog (2005) was used. The result is a performance measurement tool based on the Deming Circle for quality management. The measurement tool (see Figure 31 on page 78) contains six steps to guide the user in managing the cloud's environmental and economic impacts in terms of the carbon footprint and energy costs respectively: (1) evaluate current performance, (2) set targets, (3) determine and execute plan to reach targets, (4) measure energy consumption, (5) translate energy consumption into environmental and economic impact and (6) interpret these impacts. The core of the measurement tool lies in the steps 4, 5 and 6, because these steps contribute the most to the added value of the measurement tool (see paragraph 12.1.2 and 12.1.3). Step 4 prescribes how to measure the energy consumption of a set of virtual machines and its virtual resources: CPU, memory and storage. Step 5 translates the energy consumption data of step 4 into environmental impact (in terms of CO_2-emissions) and economic impact (in terms of energy costs based on the energy market price). Step 6 prescribes a two-dimensional interpretation of the environmental and economic impact resulting from step 5, using an internal and external benchmark. The output of step 6, is at the same time the input for step 1, to aim at continuous improvement. The external benchmark includes a standardized metric to enable comparison on environmental performance between different cloud service providers, which is useful for the cloud customer in the process of vender selection, but also for the cloud service providers for improvement and benchmarking of their services. The following paragraphs discuss the scientific and practical value of this design for a measurement tool that measures the environmental performance of cloud computing.

12.1.2 Scientific value

Measuring environmental performance is not a new concept, but considering environmental performance on the level of cloud computing services and including multiple stakeholders is a new way of looking at the environmental problems caused by IT. Energy consumption measurements as currently performed by cloud service providers, also provide insight into environmental performance, but in a secondary and indirect manner. The measurement tool as presented in this research, adds value to these energy consumption measurements, through translating the energy consumption data into economic and environmental impacts to consider environmental performance directly. The majority of the available research into green cloud computing and data center efficiency focuses on very specific solutions, which as a result often lack applicability to the variety of cloud service providers and cloud services. The measurement tool however, does not focus on a single solution, but provides a structural and guided approach for managing the environmental performance of cloud computing services in general. More specifically, the design of the measurement tool brings together several relevant equations, metrics and management steps to aim at continuous improvement. In particular, the introduced metric in the external benchmark is of added value, which can be used to express the carbon footprint per unit of performance, for the virtual resources CPU, memory and storage (e.g. CO_2/Ghz). This metric is a new standardized benchmark, which presents the carbon footprint relative to the performance that was delivered. Since no similar previous work has been done, the results of this research are expected to have an agenda setting function, within the related scientific fields. Whether others praise or criticize the measurement tool, it is expected that the conversation about this measurement tool motivates to perform further research into this subject.

12.1.3 Practical value

Currently, empirical research shows that cloud service providers seem to 'randomly' implement available best practices to increase the energy efficiency of their data centers, instead of these interventions being part of a well-considered strategy. The measurement tool provides a new, structured 'philosophy' for managing the environmental performance of the cloud data center. Implementing the measurement tool into the cloud service provider organization, is expected to result in two advantages. First of all, the measurement tool, provides the user control over environmental performance, which makes it easier to safeguard a certain quality of services towards customers in terms of environmental performance. Secondly, the external standardized benchmark allows to compare services against competitors. This may help the cloud service provider to improve their services and set targets based on this benchmark. The cloud customer, may also benefit from this external benchmark, given the assumption that the environmental performance of a cloud service becomes increasingly important in the process of vendor selection.

12.2 Discussion and reflection

This paragraph presents a discussion of limitations of this research followed by a reflection on the used research method.

12.2.1 Limitations of the narrow scope

Due to the narrow scope of this research, the designed measurement tool only applies to a small part of the cloud computing life-cycle, despite a comprehensive view of the life-cycle being necessary for considering the cloud's environmental performance. As a consequence, impacts of hardware manufacturing, data center waste, inefficient cooling systems and network infrastructure are not taken into account. In particular the impact of network infrastructure is important, because the use of cloud services implies an increase in network traffic compared to an on-premises setting. Taking the energy consumption of network infrastructure into account is necessary, but very complex and time consuming to research. Experts included in the expert review advised to broaden the scope to also including the energy consumption needed for cooling. The need for doing so is acknowledged, but there is no suitable ready-to-use solution. A possibility would be to multiply the energy consumption of hardware with the Power Usage Efficiency (PUE) value, but since PUE measurements are by far not objective and measurable, this could harm the quality of the measurement tool. Despite the need to broaden the scope of the measurement tool in future research, the narrow scope chosen for this research was (1) relevant, because the energy consumption of IT resources accounts for a major part of the environmental impact of the cloud and (2) manageable, given the lack of previous work and the time frame of the graduation project.

12.2.2 Limitations of the design of the measurement tool

Four limitations related to the design of the measurement tool have been identified. First of all, the presented design of the measurement tool is only one of multiple (perhaps better) ways to translate the structure of the measurement tool as presented in Figure 24 on page 61, to an actual design. Therefore, it must be emphasized that this research presents the measurement tool as a minimum viable product, that shows the core functions a measurement tool for measuring environmental performance must have, rather than as the ultimate design.

Secondly, one of the experts included in the expert review remarked that, from a philosophic point of view, introducing this measurement tool could lead to a situation in which cloud service providers look at the environmental performance problem with blinkers on: they use the measurement tool and thereby expect to have environmental performance management covered. However, they should actually stay open-minded and also search for solutions outside the scope of the measurement tool. This is not a problem that only applies to this measurement tool, but it is rather inherent to developing a measurement methodology.

Third, economic impact is currently calculated based on the energy market price while using the price of CO_2-emissions at the emissions trading market would be a more desirable solution, because this would directly represent the economic impact of CO_2-emissions, instead of the economic impact of energy consumption. However, the emissions trading market is not functioning as it should: there is a large surplus of CO_2-emissions with the result that the price of a metric ton of CO_2-emissions is currently only a couple of Euro's. This implies that in case this market starts to function better in the future, the economic impact should be determined with the help of a parameter that represents the price of one metric ton of CO_2-emissions on the emission trading market instead of the market price of one kWh of energy.

Fourth, calculating environmental impact in terms of CO_2-emissions is based on a conversion table that specifies the amount of CO_2-emissions generated for using one kWh of a certain energy source. One of the experts of the expert review argues that the merit order mechanism is neglected in these environmental performance calculations. Merit order is used in the energy market to determine the energy mix that is most profitable, given a certain demand. As this merit order is dynamic and changes over time, the energy mix provided to customers, also differs over time. This makes it difficult to calculate CO_2-emissions with the help of parameters that are based on the type of energy source that is used. It is questionable to what extent it is possible to take into account the merit order mechanism. However, more simple solutions would be using averages. Starting point should be consistency, to make sure each cloud service provider does it the same way.

12.2.3 Limitations of the metrics used in the measurement tool

The measurement tool uses a standardized benchmark that presents the carbon footprint per Gigahertz (for the virtual CPU), per Gigabyte (for the virtual storage) and per megabyte (for the virtual memory).. This should help the customer in selecting a cloud service provider that has the carbon footprint that it desires. However, an important motivation for customers to migrate their IT to the cloud is when it is clear that this provides major benefits compared to managing their own, on-premises IT-infrastructure. This opts for the possibility to benchmark the environmental performance of a cloud service provider against the current setting of the customer. This is expected to be a complicated and fuzzy task, because the IT-systems of these customers are likely to be old, complex and difficult to manage, which also indicates that it may be difficult to determine where and what to measure to determine its environmental performance.

With regard to using 'Gigahertz' to express the performance of a CPU, the following remark has to be made. Besides a certain clock speed expressed in Gigahertz, CPU's have an Instruction-per-Cycle (IPC) value which indicates the amount of instructions that can be executed per cycle. The IPC-value of CPU's used by cloud service providers has not been taken into account which means that the carbon footprint per Gigahertz should possibly be corrected on the basis of the IPC-value. This means that an additional step should be included in the measurement tool that benchmarks the performance of each CPU used. However, as this comprises complex, technical tests, this is not yet included in this research.

12.2.4 Limitations to the reliability and validity of the measurement tool

Due to the lack of data for performing (1) a calibration test to determine the reliability and (2) a validation test to determine the validity of the measurement, only qualitative assessment on the reliability of results and validity were done. These qualitative assessments however, have not provided results with which the reliability and validity of the measurement tool can be determined. These results rather emphasize that tests on the basis of data need to be performed, as several uncertainties have been identified that challenge the reliability and validity of the measurement tool. Therefore, a first step should be to make an effort to acquire a suitable data set. The recommendation in paragraph 12.4.1 further elaborates on this.

12.2.5 The applicability of the measurement tool

The applicability of the measurement tool is expected to be dependent on the maturity of the environmental performance management effort of a cloud service provider. A cloud service provider that is experienced in environmental performance management may be reluctant to use the measurement tool, as they have developed their own best practices throughout the years. However, empirical research showed that none of the six cloud service providers has processes in place to measure environmental performance. Cloud service providers did mention to already use interventions to increase data center efficiency, which is also an important step in the measurement tool. But, since the measurement tool presents categories of interventions instead of prescribing what interventions to use, the expectation is that the measurement tool provides added value for most cloud service providers as it helps them to use interventions in a more structured manner. Above all, cloud service provider should have a certain willingness in terms of time and resources to devote to the implementation of the measurement tool in their organization.

The applicability of the measurement tool does not only depend on the cloud service providers. Other key stakeholders may have an important role in the extent to which the measurement tool receives stakeholder support. Environmental organizations are an example of key stakeholders. If they are skeptic about the measurement tool and spread their opinion, this may influence the willingness of cloud service providers to use it. This because these environmental organizations are expected to have authority in the market as customers often value their opinion. Therefore, when the measurement tool is implemented in practice, a strategy to deal with the key stakeholders is needed.

12.2.6 Implementation of the measurement tool

The implementation of the measurement tool has received no attention in this research, despite being important for its success in practice. Governance issues need to be solved before being able to implement the measurement tool in practice. Therefore, this paragraph elaborates on the need for internal and external governance and the related challenges.

Internal governance implies a correct division of roles, responsibilities and accountability. For the measurement tool, broadly speaking, this means that an administrator or owner needs to be pointed that manages the measurement process and is able to guide the other employees. He or she has to make sure that sufficient training is provided, that the involved people stay motivated and that necessary information is shared and communicated to the team. Data center employees should be trained for performing additional tasks related to measuring equipment and hypervisor-software. The account managers, who manage customer relations, should be able to explain the figures on environmental performance of the cloud that are presented and they should be aware of what the cloud service provider has done, and will do in the future, to increase the environmental performance of their cloud services. The marketing department of the cloud service providers, should think of campaigns and channels in which the environmental performance of cloud computing can be used as a marketing tool. This all sounds quite straightforward, but the expectation is that realizing what is suggested here or other similar internal governance structures, is in fact difficult. A reason for this is the fact that environmental performance is currently not a priority of cloud service providers, which makes it is questionable to what extent the cloud service providers are willing to allocate money and human resources to this process and the measurement tool. To overcome this problem, further research is suggested into internal governance structures used for the implementation of similar standards, methodologies and certifications. This is described in paragraph 12.5.1.

External governance entails auditing the efforts of the cloud service providers and the use of an independent third party organization for performing the benchmark as described in the measurement tool. Performing audits on a regular basis helps to detect and prevent strategic behavior and manipulation of data. Moreover, it enhances the comparability of results and helps to maintain objective and measurable standards. Besides the need for auditing, there is also a need for an independent organization that facilitates the benchmarking of the carbon footprint of different cloud service providers. The cloud service providers need each other's data, which can best be arranged by an independent party. Next to that, letting the cloud service providers individually perform these benchmarks may incur strategic behavior as they may choose to benchmark only against a selection of competitors or against a certain time interval in their favor. To set-up such a benchmarking system, research into best practices into other industries need to be performed to derive how such a system can be organized for the cloud computing market. Paragraph 12.5.1 further describes the future research recommendation related to governance.

12.3 Reflection on the research method

The Design Oriented Approach as described by Verschuren and Hartog (2005) was used for developing a design for the measurement tool. Several findings can be presented that reflect some positive points and some limitations of using the research method as described:

- Including a step to evaluate the results of each phase seemed a bit exaggerated in the first place, but turned out to be very helpful. These evaluation steps forced me to take another look at the results of a specific phase, but with another purpose such excluding requirements that do not fit the scope of the research or elements of the conceptual model that can be replaced by alternative means that better fit the design of the measurement tool.
- In the approach for the case study, the cloud customer is explicitly mentioned as being part of the unit of observation, but has not been personally interviewed. In the first place the interview plan also include interviewing the cloud customer, but arranging these interviews turned out to be difficult. This because the cloud service providers said to be able to cover the part of the cloud customer themselves or preferred not to set-up the interview with their customers, which makes sense. It is however unclear to what extent this influences the result of this research. It may be assumed that interviewing the cloud customer personally would have enable more thorough requirements from their side.
- The Design Oriented Approach is, as the name says, focused at designing something: a prototype. The research methods and the steps it contains support the researcher thoroughly in developing a prototype. However, the focus on the design of the prototype perhaps results in governance issues, which have been presented in paragraph 12.2.6.

12.4 Generic recommendations

This paragraph presents a generic recommendation, which it is the next important step to follow this research. Next to that, recommendations specifically for KPMG are also presented.

12.4.1 Assessing the reliability and validity of the measurement tool

Paragraph 12.2.4 presented the limitations to the reliability and validity of the measurement tool, which have not been properly assessed due to a lack of data and time. However, analyzing the reliability and validity of the measurement tool is evidently needed from a scientific point of view, but also from a more practical point of view as an unreliable and non-valid instrument is of no use for cloud service providers. The problem related to the lack of data is not easily solved, but several steps could be taken to make an effort. First of all, it is advised to collect energy consumption data of a set of virtual machines over a time interval of one year from multiple cloud service providers. Based on these energy consumption data, cloud service provider should also specify the costs they paid for that particular amount of energy. This way, the reliability of the economic impact calculation can be determined, since the data can be compared to the results presented by the measurement tool for economic impact. Moreover, this analysis could also provide insight into the reliability of the energy consumption calculation in the measurement tool, as it is directly linked to economic impact. Secondly, it is advised to search for carbon footprint data that can be used. A possible way for doing so, may be trying to reproduce statements (of cloud service providers and as mentioned in literature) that mention an X-amount of CO_2-emissions that was incurred by an X-amount of energy needed for powering a cloud data center. Unravelling these statements may provide data that can be used to test the reliability of the environmental impact calculations of the measurement tool.

12.4.2 Recommendations to KPMG

The recommendations of KPMG are threefold and are presented in this paragraph in chronological order. Initially, KPMG would be a suitable party for performing implementation support and checks. This means that KPMG could help organizations to set-up the necessary internal governance structure for implementation of the measurement tool or could perform a check, or pre-audit to determine the extent to which the organization would be ready for auditing.

Due to performing the implementation support and checks, the knowledge on best practices for implementation of KPMG increases. This knowledge could be used to develop and license software that helps organizations to use and govern the measurement instrument.

These different options can be combined together with other relevant options into a 'Green Data Center Proposition'. This should be a shared proposition between the departments CIO Advisory (for providing guidance of the governance processes and implementation), Technology Advisory (for advice on interventions that should be selected) and Sustainability (for using their knowledge on achieving corporate sustainability).

12.5 Future research recommendations

To further enable insights into the environmental performance of cloud computing, additional research needs to be done. Several topics that need to be investigated are presented here.

12.5.1 Analyzing internal and external governance structures

As described in paragraph 12.2.6, no attention was paid to internal and external governance structures needed for implementation of the measurement tool. Some ideas for setting up these governance structures were presented, but knowledge on how to define and implement these structures is lacking. Internal and external governance structures used for the implementation of similar methodologies, certifications and standards should be analyzed. Preferably, structures are analyzed that had to deal with the problem of the technology that needs to be implemented, not being commonly accepted and desired yet. A relevant starting point for this research, could be analyzing the implementation of the standards of the International Organization for Standardization (ISO) into the market, since the standards provided by this organization are often widely used and implemented.

12.5.2 Investigating the environmental impact of the full cloud life-cycle

The focus only on the energy consumption of the hardware resources in the data center used for provisioning the cloud services, was mentioned as a limitation to this research. Therefore, additional research on how to include other elements of the cloud computing life-cycle in the measurement tool is needed. Based on expert opinions in the expert review, it is advised to start with including the energy consumption of cooling equipment as it is a major contributor to the cloud's energy consumption. The challenge would be to define a way in which cooling energy consumption can be included, while maintaining comparability and objectivity of results.

12.5.3 Allocation of responsibilities for environmental performance and the creation of a sense of urgency

When outsourcing IT, cloud customers still want to have control of the services they use, but at the same time these customers are transferring risks and responsibilities to the cloud service provider. The question therefore is to what extent the cloud customer cares or feels responsible for the environmental performance of the cloud services they use. Their ability to improve the efficiency of these services is limited and they have little control over what happens in the data centers. For the cloud service provider, setting up the right governance structure for integrating the measurement tool into the organization is a challenge. For both the cloud customer and the cloud service provider it holds that insights into how responsibilities should be divided them and within their organization are needed.

References

REFERENCES

2nd Watch. (2014). Public Cloud Workloads Gain Steam According to Latest 2nd Watch Survey. Retrieved 3-3, 2015, from http://www.marketwired.com/press-release/public-cloud-workloads-gain-steam-according-to-latest-2nd-watch-survey-1976058.htm

AFCOM. (2014). Data Center Size and Density. *White paper*.

Agency, E. P. (2013). EMS under ISO14001. Retrieved 16th of April, 2015, from http://www.epa.gov/ems/#iso14001

Alger, D. (2009). *Grow a greener data center*: Pearson Education.

Alhamad, M., Dillon, T., & Chang, E. (2010). *Conceptual SLA framework for cloud computing.* Paper presented at the Digital Ecosystems and Technologies (DEST), 2010 4th IEEE International Conference.

Anderson, D., Morris, P., Cader, T., Rawson, A., Darby, T., Rawson, F., . . . Simonelli, J. (2008). A framework for data center energy productivity. *White paper, 13*.

Armbrust, M., Fox, A., Griffith, R., Joseph, A. D., Katz, R., Konwinski, A., . . . Stoica, I. (2010). A view of cloud computing. *Communications of the ACM, 53*(4), 50-58.

Arnold, U. (2000). New dimensions of outsourcing: a combination of transaction cost economics and the core competencies concept. *European Journal of Purchasing & Supply Management, 6*(1), 23-29.

Auld, G., Gulbrandsen, L. H., & McDermott, C. L. (2008). Certification schemes and the impacts on forests and forestry. *Annual review of environment and resources, 33*(1), 187.

Azevedo, D. (2010). Harmonizing Global Metrics for Data Center Energy Efficiency. Retrieved 9-12-2014, 2014, from http://eeglobalforum.org/10/workshop_presentations/dan_azevedo_info_comm.pdf

Azevedo, D., Patterson, S. M., Pouchet, J., & Tipley, R. (2010). Carbon Usage Effectiveness (CUE): A Green Grid Data Center Sustainability Metric. *White paper, 32*.

Basu, R. (2004). *Implementing quality: A practical guide to tools and techniques: Enabling the power of operational excellence*: Cengage Learning EMEA.

Belady, C. L., & Malone, C. G. (2007). *Metrics and an infrastructure model to evaluate data center efficiency.* Paper presented at the ASME 2007 InterPACK Conference collocated with the ASME/JSME 2007 Thermal Engineering Heat Transfer Summer Conference.

Beloglazov, A., & Buyya, R. (2010a). *Energy efficient allocation of virtual machines in cloud data centers.* Paper presented at the 2010 10th IEEE/ACM International Conference on Cluster, Cloud and Grid Computing (CCGrid).

Beloglazov, A., & Buyya, R. (2010b). *Energy efficient resource management in virtualized cloud data centers.* Paper presented at the Proceedings of the 2010 10th IEEE/ACM International Conference on Cluster, Cloud and Grid Computing.

Beloglazov, A., Buyya, R., Lee, Y. C., & Zomaya, A. (2011). A taxonomy and survey of energy-efficient data centers and cloud computing systems. *Advances in Computers, 82*(2), 47-111.

Berl, A., Gelenbe, E., Di Girolamo, M., Giuliani, G., De Meer, H., Dang, M. Q., & Pentikousis, K. (2010). Energy-Efficient Cloud Computing. *The Computer Journal, 53*(7), 1045-1051. doi: 10.1093/comjnl/bxp080

Bohra, A. E., & Chaudhary, V. (2010a). *VMeter: Power modelling for virtualized clouds.* Paper presented at the Parallel & Distributed Processing, Workshops and Phd Forum (IPDPSW), 2010 IEEE International Symposium.

Bohra, A. E., & Chaudhary, V. (2010b). *VMeter: Power modelling for virtualized clouds.* Paper presented at the Parallel & Distributed Processing, Workshops and Phd Forum (IPDPSW), 2010 IEEE International Symposium.

Brill, K. G. (2007). Data center energy efficiency and productivity: Santa Fe, NM: The Uptime Institute. www. uptimeinstitute. org/symp_pdf/(TUI3004C) DataCenterEnergyEfficiency. pdf.

Broadbent, M., & Weill, P. (1997). Management by maxim: how business and IT managers can create IT infrastructures. *Sloan management review, 38*, 77-92.

Buyya, R., Beloglazov, A., & Abawajy, J. (2010). Energy-efficient management of data center resources for cloud computing: A vision, architectural elements, and open challenges. *arXiv preprint arXiv:1006.0308*.

Buyya, R., Yeo, C. S., Venugopal, S., Broberg, J., & Brandic, I. (2009). Cloud computing and emerging IT platforms: Vision, hype, and reality for delivering computing as the 5th utility. *Future Generation Computer Systems, 25*(6), 599-616.
Carmines, E. G., & Zeller, R. A. (1979). *Reliability and validity assessment* (Vol. 17): Sage publications.
Chen, Y., Das, A., Qin, W., Sivasubramaniam, A., Wang, Q., & Gautam, N. (2005). *Managing server energy and operational costs in hosting centers.* Paper presented at the ACM SIGMETRICS Performance Evaluation Review.
Choi, K., Soma, R., & Pedram, M. (2005). Fine-grained dynamic voltage and frequency scaling for precise energy and performance tradeoff based on the ratio of off-chip access to on-chip computation times. *Computer-Aided Design of Integrated Circuits and Systems, IEEE Transactions on, 24*(1), 18-28.
Chou, D. C., & Chou, A. Y. (2012). Awareness of Green IT and its value model. *Computer Standards & Interfaces, 34*(5), 447-451.
Chung, L., Nixon, B., Yu, E., & Mylopoulos, J. (2000). Non-functional requirements. *Software Engineering*.
Cicotti, G., Coppolino, L., Cristaldi, R., D'Antonio, S., & Romano, L. (2012). *QoS monitoring in a cloud services environment: the SRT-15 approach.* Paper presented at the Euro-Par 2011: Parallel Processing Workshops.
Cisco. (2014). Cisco Global Cloud Index: Forecast and Methodology, 2013-2018. Retrieved March 3rd, 2015, from http://www.cisco.com/c/en/us/solutions/collateral/service-provider/global-cloud-index-gci/Cloud_Index_White_Paper.pdf
Clemons, E. K., & Chen, Y. (2011). *Making the decision to contract for cloud services: managing the risk of an extreme form of IT outsourcing.* Paper presented at the System Sciences (HICSS), 2011 44th Hawaii International Conference.
Daim, T., Justice, J., Krampits, M., Letts, M., Subramanian, G., & Thirumalai, M. (2009). Data center metrics: An energy efficiency model for information technology managers. *Management of Environmental Quality: An International Journal, 20*(6), 712-731.
Dankers, C., Liu, P., & Lawrence, T. (2003). *Environmental and social standards, certification and labelling for cash crops* (Vol. 2): Food & Agriculture Org.
Dao, V., Langella, I., & Carbo, J. (2011). From green to sustainability: Information Technology and an integrated sustainability framework. *The Journal of Strategic Information Systems, 20*(1), 63-79.
De Boer, J. (2003). Sustainability labelling schemes: the logic of their claims and their functions for stakeholders. *Business Strategy and the Environment, 12*(4), 254-264.
Deming, W. E. (1982). *Quality, productivity, and competitive position*: Massachusetts Institute of Technology Center for Advanced En.
Dikaiakos, M. D., Katsaros, D., Mehra, P., Pallis, G., & Vakali, A. (2009). Cloud computing: Distributed internet computing for IT and scientific research. *Internet Computing, IEEE, 13*(5), 10-13.
Dillon, T., Wu, C., & Chang, E. (2010). *Cloud computing: issues and challenges.* Paper presented at the Advanced Information Networking and Applications (AINA), 2010 24th IEEE International Conference.
Elgelany, A., & Nada, N. (2013). Energy Efficiency for Data Center and Cloud Computing: A Literature Review. *Energy, 3*(1).
Elkington, J. (2004). Enter the triple bottom line. *The triple bottom line: Does it all add up*, 1-16.
Elnozahy, M., Kistler, M., & Rajamony, R. (2003). Energy-efficient server clusters *Power-Aware Computer Systems* (pp. 179-197): Springer.
EPA. (2009). EPA ENERGY STAR program requirements for computer systems - draft 4. Washington, DC: Environmental Protection Agency.
Fifka, M. S., & Drabble, M. (2012). Focus and standardization of sustainability reporting–a comparative study of the United Kingdom and Finland. *Business Strategy and the Environment, 21*(7), 455-474.
FIPS PUBS. (1993). 183 (1984)."Integration definition for Function Modeling (IDEF0)". Federal Information Processing Standards, United States National Institute of Standards and Technology (NIST). *Computer Systems laboratory, Gaithersburg*.
Foster, I., Zhao, Y., Raicu, I., & Lu, S. (2008). *Cloud computing and grid computing 360-degree compared.* Paper presented at the Grid Computing Environments Workshop, 2008. GCE'08.

Fujitsu. (n.d). Practical methods for improving ICT sustainability. Retrieved 8th of April, 2015, from http://www.sustainability-perspectives.com/article/practical-methods-for-improving-ict-sustainability/

Galarraga Gallastegui, I. (2002). The use of eco-labels: A review of the literature. *European Environment, 12*(6), 316-331.

Garg, S. K., & Buyya, R. (2011). Green cloud computing and environmental sustainability. *Harnessing Green IT: Principles and Practices (2020)*, 315-340.

Garg, S. K., Versteeg, S., & Buyya, R. (2011). *Smicloud: A framework for comparing and ranking cloud services.* Paper presented at the Utility and Cloud Computing (UCC), 2011 Fourth IEEE International Conference.

Global e-Sustainability Initiative and the Boston Consulting Group Inc. (2012). GeSI SMARTer 2020: The Role of ICT in Driving a Sustainable Future.

Global Reporting Initiative. (2013). G4 Sustainability Reporting Guidelines - Reporting Principles and Standard Disclosures. Retrieved 8-12-2014, 2014, from https://www.globalreporting.org/resourcelibrary/GRIG4-Part1-Reporting-Principles-and-Standard-Disclosures.pdf

Gong, C., Liu, J., Zhang, Q., Chen, H., & Gong, Z. (2010). *The characteristics of cloud computing.* Paper presented at the Parallel Processing Workshops (ICPPW), 2010 39th International Conference on.

Grobauer, B., Walloschek, T., & Stocker, E. (2011). Understanding cloud computing vulnerabilities. *Security & privacy, IEEE, 9*(2), 50-57.

Grossman, R. L. (2009). The case for cloud computing. *IT professional, 11*(2), 23-27.

Han, S.-M., Hassan, M. M., Yoon, C.-W., & Huh, E.-N. (2009). *Efficient service recommendation system for cloud computing market.* Paper presented at the Proceedings of the 2nd international conference on interaction sciences: information technology, culture and human.

Harris, S. M. (2007). Green Tick™: an example of sustainability certification of goods and services. *Management of Environmental Quality: An International Journal, 18*(2), 167-178. doi: doi:10.1108/14777830710725830

Harvard Business Review Analytic Services. (2011). How the Cloud Looks from the Top: Achieving Competitive Advantage In the Age of Cloud Computing. Retrieved 8th of April, 2015, from https://hbr.org/resources/pdfs/tools/16700_HBR_Microsoft%20Report_LONG_webview.pdf

Hertwich, E. G., & Peters, G. P. (2009). Carbon footprint of nations: A global, trade-linked analysis. *Environmental science & technology, 43*(16), 6414-6420.

Hussain, F. K., & Hussain, O. K. (2011). *Towards multi-criteria cloud service selection.* Paper presented at the Innovative Mobile and Internet Services in Ubiquitous Computing (IMIS), 2011 Fifth International Conference.

Ilinitch, A. Y., Soderstrom, N. S., & Thomas, T. E. (1999). Measuring corporate environmental performance. *Journal of Accounting and Public Policy, 17*(4), 383-408.

Jadeja, Y., & Modi, K. (2012). *Cloud computing-concepts, architecture and challenges.* Paper presented at the Computing, Electronics and Electrical Technologies (ICCEET), 2012 International Conference on.

Jenkin, T. A., Webster, J., & McShane, L. (2011). An agenda for 'Green'information technology and systems research. *Information and Organization, 21*(1), 17-40.

Jing, S.-Y., Ali, S., She, K., & Zhong, Y. (2013). State-of-the-art research study for green cloud computing. *The Journal of Supercomputing, 65*(1), 445-468.

Joshi, Y., Kumar, P., Sammakia, B., & Patterson, M. (2012). *Energy Efficient Thermal Management of Data Centers*: Springer.

Kansal, A., Zhao, F., Liu, J., Kothari, N., & Bhattacharya, A. A. (2010). *Virtual machine power metering and provisioning.* Paper presented at the Proceedings of the 1st ACM symposium on Cloud computing.

Kaplan, J. M., Forrest, W., & Kindler, N. (2008). Revolutionizing data center energy efficiency: Technical report, McKinsey & Company.

Katsikas, S. K., Gritzalis, S., Karyda, M., Mitrou, E., & Quirchmayr, G. (2006). A framework for outsourcing IS/IT security services. *Information Management & Computer Security, 14*(5), 403-416.

Kipp, A., Jiang, T., Fugini, M., & Salomie, I. (2012). Layered green performance indicators. *Future Generation Computer Systems, 28*(2), 478-489.
Kolk, A. (2004). A decade of sustainability reporting: developments and significance. *International Journal of Environment and Sustainable Development, 3*(1), 51-64.
Kolk, A. (2008). Sustainability, accountability and corporate governance: exploring multinationals' reporting practices. *Business Strategy and the Environment, 17*(1), 1-15.
KPN. (n.d). Cloud NL Volledig Nederlandse datacentra. Retrieved 5th of December, 2014, from http://www.kpn.com/zakelijk/grootzakelijk/it/cloud/cloudnl.htm
Lamb, J. P. (2009). *The greening of IT: how companies can make a difference for the environment*: IBM Press/Pearson.
Lavallée, B. (2014). Undertaking the Challenge to Reduce the Data Center Carbon Footprint. Retrieved 25th of March, 2015, from http://www.datacenterknowledge.com/archives/2014/12/17/undertaking-challenge-reduce-data-center-carbon-footprint/
Leavitt, N. (2009). Is cloud computing really ready for prime time? *Computer, 42*(1), 15-20.
Leimeister, S., Böhm, M., Riedl, C., & Krcmar, H. (2010). The business perspective of cloud computing: actors, roles and value networks.
Lewis, A. W., Ghosh, S., & Tzeng, N.-F. (2008). Run-time Energy Consumption Estimation Based on Workload in Server Systems. *HotPower, 8*, 17-21.
Li, A., Yang, X., Kandula, S., & Zhang, M. (2010). *CloudCmp: comparing public cloud providers.* Paper presented at the Proceedings of the 10th ACM SIGCOMM conference on Internet measurement.
Linthicum, D. S. (2009). *Cloud computing and SOA convergence in your enterprise: a step-by-step guide*: Pearson Education.
Marca, D. A., & McGowan, C. L. (1987). *SADT: structured analysis and design technique*: McGraw-Hill, Inc.
Marilly, E., Martinot, O., Papini, H., & Goderis, D. (2002). *Service level agreements: a main challenge for next generation networks.* Paper presented at the Universal Multiservice Networks, 2002. ECUMN 2002.
Market Research Media. (2014). Global Cloud Computing Market Forecast. Retrieved March 3rd, 2015, from http://www.marketresearchmedia.com/?p=839
Marston, S., Li, Z., Bandyopadhyay, S., Zhang, J., & Ghalsasi, A. (2011). Cloud computing—The business perspective. *Decision Support Systems, 51*(1), 176-189.
Mell, P., & Grance, T. (2009). The NIST definition of cloud computing. *National Institute of Standards and Technology, 53*(6), 50.
Molla, A. (2008). GITAM: A Model for the Adoption of Green IT. *ACIS 2008 Proceedings*, 64.
Montiel, I., & Delgado-Ceballos, J. (2014). Defining and Measuring Corporate Sustainability: Are We There Yet? *Organization and Environment, 27*(2), 113-139.
Moogk, D. R. (2012). Minimum viable product and the importance of experimentation in technology startups. *Technology Innovation Management Review, 2*(3).
MSCI. (2014a). MSCI ESG Environmental Indexes. Retrieved 8-12-2014, 2014, from http://www.msci.com/products/indexes/esg/environmental/
MSCI. (2014b). MSCI Global Low Carbon Target Indexes Methodology. Retrieved 6th of April, 2015, from http://www.msci.com/eqb/methodology/meth_docs/MSCI_Low_Carbon_Target_Indexes_Methodology.pdf
Niemann, J., Brown, K., & Avelar, V. (2011). Impact of hot and cold aisle containment on data center temperature and efficiency. *Schneider Electric Data Center Science Center, White Paper, 135*, 1-14.
O'Dell, C. S., & Essaides, N. (1998). *If only we knew what we know: The transfer of internal knowledge and best practice*: Simon and Schuster.
Pallis, G. (2010). Cloud Computing: the new frontier of internet computing. *IEEE Internet Computing 2010, [14:5:5562494:70-73]*.
Pandey, D., Agrawal, M., & Pandey, J. S. (2011). Carbon footprint: current methods of estimation. *Environmental monitoring and assessment, 178*(1-4), 135-160.
Patel, C. D., & Shah, A. J. (2005). Cost model for planning, development and operation of a data center.
Previder. (n.d.). Klantcases van Previder. Retrieved 1st of November, 2014, from http://www.previder.nl/Over_Previder/Klanten_Testimonials

Pu, X., Liu, L., Mei, Y., Sivathanu, S., Koh, Y., & Pu, C. (2010). *Understanding performance interference of i/o workload in virtualized cloud environments.* Paper presented at the Cloud Computing (CLOUD), 2010 IEEE 3rd International Conference.

Qu, L., Wang, Y., & Orgun, M. A. (2013). *Cloud service selection based on the aggregation of user feedback and quantitative performance assessment.* Paper presented at the Services Computing (SCC), 2013 IEEE International Conference on.

Raynolds, L. T., Murray, D., & Heller, A. (2007). Regulating sustainability in the coffee sector: A comparative analysis of third-party environmental and social certification initiatives. *Agriculture and Human Values, 24*(2), 147-163.

Reasonnet. (n.d.). 10 Reasons why we are the Masters of the Dutch Cloud. Retrieved 10th of January, 2014, from http://reasonnet.com/nl

Ries, E. (2014). Minimum viable product: a guide. *Startup Lessons Learned*.

Sabbaghi, A., & Vaidyanathan, G. (2012). Green information technology and sustainability: A Conceptual taxonomy. *Issue, 2*, 26-32.

Sadashiv, N., & Kumar, S. D. (2011). *Cluster, grid and cloud computing: A detailed comparison.* Paper presented at the Computer Science & Education (ICCSE), 2011 6th International Conference on.

Schniederjans, M. J., Schniederjans, A. M., & Schniederjans, D. G. (2005). *Outsourcing and insourcing in an international context*: ME Sharpe.

Schulz, G. (2010). *The green and virtual data center*: CRC Press.

SKAO. (2014, 4th of April, 2014). Handboek CO2-prestatieladder 2.2. Retrieved 15th of April, 2015, from http://co2-prestatieladder.nl/images/cms/20140404_Handboek_CO_2_Prestatieladder_2_2.pdf

Stoess, J., Lang, C., & Bellosa, F. (2007). *Energy Management for Hypervisor-Based Virtual Machines.* Paper presented at the USENIX Annual Technical Conference.

Sundareswaran, S., Squicciarini, A., & Lin, D. (2012). *A brokerage-based approach for cloud service selection.* Paper presented at the Cloud Computing (CLOUD), 2012 IEEE 5th International Conference on.

T-Systems. (n.d.). *Sap uit een private cloud.* Retrieved 12th of December, 2014, from http://www.t-systems.nl/diensten-oplossingen/cloud-computing/392544

The Green Grid. (2007). Data Center Power Efficiency Metrics: PUE and DCiE. Retrieved 9-12-2014, 2014, from http://www.thegreengrid.org/en/Global/Content/white-papers/The-Green-Grid-Data-Center-Power-Efficiency-Metrics-PUE-and-DCiE

The National Academies Press. (2005). *Measuring Performance and Benchmarking Project Management at the Department of Energy*. Washington, DC: The National Academies Press.

Uddin, M., & Rahman, A. A. (2012). Energy efficiency and low carbon enabler green IT framework for data centers considering green metrics. *Renewable and Sustainable Energy Reviews, 16*(6), 4078-4094.

Vaquero, L. M., Rodero-Merino, L., Caceres, J., & Lindner, M. (2008). A break in the clouds: towards a cloud definition. *ACM SIGCOMM Computer Communication Review, 39*(1), 50-55.

Verschuren, P., & Hartog, R. (2005). Evaluation in design-oriented research. *Quality and Quantity, 39*(6), 733-762.

Vink, E. T., Rabago, K. R., Glassner, D. A., & Gruber, P. R. (2003). Applications of life cycle assessment to NatureWorks™ polylactide (PLA) production. *Polymer Degradation and stability, 80*(3), 403-419.

VMWare. (n.d.). Virtualization Defined [Online image]. Retrieved March 4th, 2015, from http://www.vmware.com/virtualization/virtualization-basics/how-virtualization-works

Wadhwa, V., & Ravindran, A. R. (2007). Vendor selection in outsourcing. *Computers & operations research, 34*(12), 3725-3737.

Webb, M. (2008). SMART 2020: Enabling the low carbon economy in the information age. *The Climate Group. London, 1*(1), 1-1.

Weber, C. A., & Current, J. R. (1993). A multiobjective approach to vendor selection. *European Journal of Operational Research, 68*(2), 173-184.

Weill, P., & Ross, J. W. (2004a). IT governance on one page.

Weill, P., & Ross, J. W. (2004b). *IT governance: How top performers manage IT decision rights for superior results*: Harvard Business Press.

Wiedmann, T., & Minx, J. (2008). A definition of 'carbon footprint'. *Ecological economics research trends, 1*, 1-11.

Xiong, K., & Perros, H. (2009). *Service performance and analysis in cloud computing.* Paper presented at the Services-I, 2009 World Conference.

Yin, R. (2003). Case study research: Design and methods. *Sage Publications, Inc, 5*, 11.

Youseff, L., Butrico, M., & Da Silva, D. (2008). *Toward a unified ontology of cloud computing.* Paper presented at the Grid Computing Environments Workshop, 2008. GCE'08.

Zhang, Q., Cheng, L., & Boutaba, R. (2010). Cloud computing: state-of-the-art and research challenges. *Journal of internet services and applications, 1*(1), 7-18.

Appendices

CONTENT OF APPENDICES

13 APPENDIX INTERVIEW PROTOCOL CLOUD SERVICE PROVIDERS

This appendix provides the interview protocol for performing interviews as part of the case study. Up-front analysis of open source information is done to gather information on a case up-front that does not require to be asked during an interview. This saves time and gives the interviewee the idea that the interviewer is well prepared. The protocol consists of two parts. The first part is focused on the cloud service provider and the second part contains question about the cloud customer.

13.1 Interview protocol

The interview protocol consist of an introduction and five parts containing questions about the company, general question on data center efficiency, measuring data center performance, the relationship with the customer and additional question regarding the measurement tool itself. In each part, several main questions shall be asked supported by shadow or backup questions (indented bullets), to derive the desired level of detail.

13.1.1 Introduction of interviewer

The interview starts with a short introduction of the interviewer, the purpose of the research and this interview.

13.1.2 Cloud Service Provider Characteristics

Let's start with some generic information.

- Can you give me some examples of the type of customers that your company serves?
    - Think of size: employee/turnover.
    - Segment: dotcom companies, industry, banking etc.
- What are the motivations of your customers for acquiring cloud services?
- What type of cloud services do you offer?
- How many employees work for this company?
- What is the annual turnover of this company?
- How many data centers do you own or operate?
    - Within the Netherlands;
    - Outside the Netherlands.

13.1.3 Data Center Characteristics

- What is the total data center floor surface that your company uses or owns?
- What is the year of construction or operation of this data center?
- What is the Tier-classification of this data center?
- What is the floor surface of this data center?
- What kind of hardware is used for provisioning the cloud services?
- What kind of software is used for provisioning the cloud services?
- What kind of virtualization technology is used for provisioning the cloud services?
- What kind of energy supply is used to power the data center?
- What certifications are in possession of the cloud service provider?
- What is the PUE of this data center?
- What kind of cooling system is used in this data center?

13.1.4 Data center efficiency

This part contains some general questions about data center efficiency and why it is, or why it is not important for your company and to what extent it is embedded in the data center.

- To what extent is the efficiency of the data center an ongoing challenge?

- What is the basis of this challenge for the company?
    - What is the role of cost reduction in this challenge?
    - What is the role of decreasing the environmental impact in this challenge?
- To what extent does your company value corporate social responsibility?
    - How does that effect the ongoing challenge of data center efficiency?

13.1.5 Measuring data center performance

I would like to have some insights in the current process of measuring performance in the data center. I am explicitly curious about measurements of energy consumption or other measurements related to environmental impact.

- What does the process of provisioning a service from your data center look like?
    - Think of the steps of the process, such as: customer sends request, processed by network etc.
- What kind of interventions are implemented to increase the efficiency of the data center?
    - You said intervention X, Y, Z.
        - Why these interventions?
        - Why are they important?
    - What is the effectiveness of these interventions?
- Can you tell me about measurements that are performed in the data center to measure performance?
    - What do they measure?
    - Why are these measurements performed?
- Can you tell me more about those measurements that specifically measure environmental impact or for example energy consumption?
    - What level of detail is used in these measurements?
        - Measure energy per chip, per server cluster, whole rack etc.
    - What aspects of energy consumption are measured?
        - What about energy consumption of hardware?
        - What about energy consumption of cooling?
        - What about energy consumption of the network?
        - What about energy consumption of lightning and other secondary systems?
- Can you describe the metrics related to environmental performance that are measured?
    - Can you give examples?
    - What do these metrics represent and why are they important?
    - How did you decide to use these metrics?
    - What kind of unit is used to express the metric?
    - What is the frequency of measurement?
- Can you describe the process of measuring a metric (using an example of the previous question)?
    - Can you describe the steps of the measurement process?
        - What is the starting point of the process?
        - What is the result of the process?
        - What steps are necessary to produce the results?
    - What kind of resources are used to support the process?
        - Think of human and technological resources.
- How are results reported?
    - What kind of format is used?
    - How and where are these results saved?

- What is the follow-up on these measurements?
    - Is there some kind of internal feedback?
    - Are the results reported to the client?
- To what extent is it possible to attribute measurements and/or results to a specific customer? Or a specific customer segment?

-- SECOND PART OF INTERVIEW---

13.1.6 Relationship with the customer

The operations in the data center are organized in such a way that delivering services of a certain quality to your cloud customers is made possible. The details about the provisioning of these services are often captured in a service level agreement. With the following questions, I would like to gain some insight into the influence of the client, for example through service level agreements, on the operations in the data center.

- What does the service level agreement with the client look like?
    - Is environmental performance provisioned in these service level agreements?
- Can you define the quality of services (QoS) that is offered?
    - Think of reliability, up-time, maintenance, pricing model, PUE, sustainability.
- What implications to these agreements have on the data center level?
    - Does it affect the allocation of resources?
    - Does it influence the interventions that are taken?
    - Does it influence the way things are measured in the data center?

13.1.7 Requirements and ideas for a new measurement tool

My goal is to develop a measurement tool. These last questions have to goal to gather some input on the look and feel and content of such an instrument.

- When you think about a tool that can be used to express the environmental performance of cloud computing:
    - What kind of requirements can you think?
        - What should the tool be able to do/measure?
        - What should it be like?
    - What does it look like?
    - Is this a quantitative tool or a qualitative tool?
    - What kind of metrics are included?
- Is there anything else you would like to add?

13.1.8 Requirements and ideas for the new measurement tool

Similar to the previous question, but this time from the perspective of the cloud customer.

- When you think of the perspective of the customer:
    - What kind of requirements are important for the customer?
    - What does it look like?
    - Is this a quantitative tool or a qualitative tool?
    - What kind of metrics are included?
- Is there anything else you would like to add?

14 APPENDIX TRANSCRIPTION TEMPLATE

This appendix presents the template, which is used to create transcription of the case study interviews.

Interview with [Name of Interviewee]
on the process of measuring environmental performance of data centers

Date	
Location	
Length	
Interviewee	
Interviewer	
Transcriber	
[XX]	Interviewee initials
KS	Interviewer initials

15 APPENDIX OF CASE STUDY DATA

This appendix presents an overview of the data obtained in the case study which is used for the motivations for including the selected cases in the case study (see paragraph 5.1) and analyzing the measurement process (see paragraph 5.3). Each table contains a short description and refers to the parts in these report in which the data is used. The numbers used in the tables, correspond with the numbers used in the code books as presented in Appendix 16. This way, the used source of information can be retrieved by the reader if he or she desires to do so.

15.1 The characteristics of the cloud service providers in the case study

The data in Table 23 is used to determine the size and the geographical orientation of the case study cases as presented in paragraph 5.1. To locate the sources of these data points, the individual code books of each case can be used through checking the entry at the corresponding number. This yields a small text fragment obtained during an interview with the cloud service provider or a reference to an open source of information.

Table 23: cloud service provider characteristics

1.	Cloud Service Provider Characteristics						
#	Description	T-Systems	Atos	KPN	Previder	ReasonNet	CloudVPS
1.2	Customer size and type	Large multinationals	Large enterprises and multinationals	Top-100 customers	Local to national customers	Hybrid customers: system integrators and enterprises	Long-tail and medium-small enterprises
1.4	Type of cloud services	Business applications on private or public cloud platform.	Canopy Cloud: flexible services for critical business applications (e)	CloudNL (Office, Sharepoint, Lync)	Managed cloud services	Infrastructure-as-a-Service	Virtual cloud and infrastructure
1.5	Amount of employees	50.000	76.300	18.949	35	45	23
1.6	Annual turnover	9.500	8.600*	8.472	Classified	< 10	Classified
1.7	Amount of DC's in the NL	2	4	11**	2	3	3
1.8	Amount of DC's outside the NL	67	60	0	0	0	0

*of which about 300 million can be allocated to cloud services

**CloudNL-services are only delivered from two of these data centers

15.2 Visited Data Center Characteristics

Table 24 presents an overview of the data characteristics of the data centers owned or operated by the cloud service providers. 2.1 presents the total data center floor surface of *all* data centers of the cloud service provider and 2.2 – 2.11 specifically present the characteristics of the data center that was visited for conducting the interview. Not all data is explicitly used in this thesis. The total data center floor surface and the data center floor surface are used in paragraph 5.1 and the data on certifications is used in paragraph 5.2.2. Code books of each case should be checked to obtain the source of information.

Table 24: characteristics of the data centers that have been visited for the case study

2.	Visited Data Center Characteristics						
#	Description	T-Systems	Atos	KPN	Previder	ReasonNet	CloudVPS
2.1	Total DC floor surface (m^2)	100.000	30.000	29.200	13.500	1.800	Classified
2.2	Year of construction	2000	2007	2007	2010	2009	2012
2.3	Tier classification	3	3 (rated)	Unknown	3+	2+	3+
2.4	Data Center Floor Surface (m^2)	5.000	1.600	4.500	4.500	700	Classified
2.5	Type of hardware	Variety	Dell	Variety	Dell	Vblocks	Variety
2.6	Type of software	Variety	VMWare	Windows	VMWare	VMWare	Windows
			Hyper-V	Linux			Linux
2.7	Virtualization technology	VMWare	VMWare	VMWare	VMWare	VMWare	Hyper-V
		Hyper-V	Hyper-V	Hyper-V			Xen
				KVM			
				OVM			
				Xen			
2.8	Type of energy supply	Renewable	Renewable	Renewable	Renewable	Renewable	Unknown
2.9	Certifications	ISO14001	ISO14001	ISO14001	ISO14001	ISO27001	ISO14001
		ISO9001	ISO27001	ISO9001	ISO9001		ISO50001
		ISO27001	ISAE3402	ISO27001	NEN7510		ISO9001
		ISAE3402		ISAE3402	NEN7510		ISO27001
				NEN7510			ISAE3402
							NEN7510
2.10	PUE	1.8	1.43	Unknown	1.25	1.29	1.19
2.11	Cooling	Water cooling	Air cooling	Water cooling	Air cooling	Air cooling	Air Cooling

15.3 Data on Data Center Efficiency, the Measurement Process and service level agreements

The following tables present the data on data center efficiency, the measurement process and service level agreements. A green checkmark means that a certain statement has been made by the interviewee(s) that indicates the presence of a characteristic or element. A red cross means that no statements have been made that fall into that category. In each table, a column that presents the frequency of positive checkmarks is included.

15.3.1 Data on Data Center Efficiency

Table 25 presents the drivers for data center efficiency as mentioned by the cloud service providers of the case study. A green checkmark means that a certain statement has been made by the interviewee(s) that indicates the presence of a certain driver category or element that indicates the presence of corporate social responsibility (corporate social responsibility). A red cross means that no statements have been made that fall into that category. For drivers of Data Center Efficiency, a categorization is made into drivers related to cost, green thinking, customer, government and other. The presence of corporate social responsibility may be recognized at a cloud service provider through statements that emphasize on the importance of corporate social responsibility, benchmarks that are performed by cloud service providers to express their level of corporate social responsibility, the certifications related to corporate social responsibility in possession of the cloud service provider, expressions of corporate social responsibility on the corporate website, efforts for reporting on corporate social responsibility and statements made related to corporate social responsibility.

Table 25: drivers for data center efficiency and presence of corporate social responsibility

3.	Data Center Efficiency							
#	Description							
3.1	Drivers for DCE	T-Systems	Atos	KPN	Provider	ReasonNet	CloudVPS	Total
3.1.1	*Cost*	✓	✓	✓	✓	✓	✓	**6**
3.1.2	*Green thinking*	✗	✓	✓	✓	✗	✓	**4**
3.1.3	*Customer*	✗	✓	✗	✗	✓	✗	**2**
3.1.4	*Government*	✓	✓	✗	✓	✓	✗	**4**
3.1.5	*Other*	✗	✓	✗	✓	✗	✓	**3**
3.2	Presence of corporate social responsibility							
3.2.1	*Importance*	✓	✓	✓	✗	✓	✓	**5**
3.2.2	*Benchmark*	✗	✓	✗	✗	✗	✗	**1**
3.2.3	*Certificates*	✓	✗	✓	✓	✓	✓	**5**
3.2.4	*Website*	✗	✗	✗	✓	✗	✓	**2**
3.2.5	*Reporting*	✓	✗	✗	✗	✗	✗	**1**
3.2.6	*Statements*	✓	✗	✗	✓	✓	✗	**3**

15.3.2 Data on Data Center Performance

Table 27 presents the categories of intervetions used by cloud service providers for increasing data center efficiency. These categories are: building, hardware, software, data center systems and configuration. Table 27 also presents the way measurements are currently performed in the data center of a cloud service provider. The first possibility is measuring energy consumption at the level of the server rack, which means the power feeds to a server rack are directly measured. Measuring energy consumption can also be done at the level of the Power Distribution Unit.

Table 26: interventions to increase data center efficiency and measurements for environmental impact

4.	Measuring Data Center Performance							
#	Description	Cases						
4.2	DCE Interventions	T-Systems	Atos	KPN	Previder	ReasonNet	CloudVPS	Total
4.2.1	*Building*	✗	✗	✗	✗	✓	✓	**2**
4.2.2	*Hardware*	✓	✓	✓	✓	✓	✓	**6**
4.2.3	*Software*	✗	✗	✓	✓	✗	✗	**2**
4.2.4	*Data Center Systems*	✓	✓	✗	✓	✓	✓	**5**
4.2.5	*Configuration*	✗	✗	✗	✓	✗	✓	**2**
4.3	Measurements for measuring environmental impact or energy consumption							
4.3.1	*Rack-level*	✗	✓	✓	✓	✓	✓	**5**
4.3.2	*PDU-level*	✓	✓	✗	✗	✗	✗	**2**

Table 27: data on the measurement process at cloud service providers

4.4	Measurement process							
#	Description	T-Systems	Atos	KPN	Previder	ReasonNet	CloudVPS	Total
4.4.1	*Metrics*	kWh/kW	kW	N/A	kWh	kWh	N/A	N/A
4.4.2	*Models/steps*							
4.4.21	DCM	✓	✓	✓	✓	✓	✓	**6**
4.4.22	Invoicing	✓	✗	✗	✓	✓	✓	**4**
4.4.23	Forecasting	✓	✗	✗	✗	✗	✗	**1**
4.4.24	Follow-up	✓	✗	✓	✓	✓	✓	**5**
4.4.3	*Format*	reports	reports	N/A	online portal, reports	N/A	N/A	**N/A**
4.4.4	*Attribution to specific customer*							
4.4.4.1	Subscription fee	✗	✓	✓	✓	✗	✓	**4**
4.4.4.2	Pay per use	✓	✗	✗	✗	✓	✗	**2**
4.4.5	*Frequency*	*Not relevant as measuring energy consumption is inherently continuous.*						

Table 28: implications of service level agreements

5.	Implications of service level agreement							
#	Description	T-Systems	Atos	KPN	Previder	ReasonNet	CloudVPS	Total
5.1	Presence of environmental performance in quality of services	✗	✗	✗	✗	✗	✗	**0**
5.2	Implications of SLA for measuring environmental performance	✗	✗	✗	✗	✗	✗	**0**
5.3	Implications of service level agreement for DCE	✓	✗	✗	✓	✗	✓	**3**

15.3.3 Data on the measurement process at cloud service providers

Table 27 presents the data on the measurement processes at the cloud service providers of the case study. It indicates the metrics used for expressing the energy consumption that is measured. For possible steps that can be part of the measurement process, a distinction is made between Data Center Management (DCM), invoicing, forecasting and follow-up actions. The format in which results of the measurement process are presented is indicated for each case. The table also shows the way customer pays for the services of the cloud service provider: a subscription fee or on a pay-per-use basis. Frequency was originally part of the code book, with the goal to gain insight in the time intervals used for determining environmental performance. However, since only energy consumption is measured, frequency is irrelevant due to the fact that energy consumption is constantly measured through sensors.

15.3.4 Data on the implications of service level agreements

Table 28 presents an overview of the implications of service level agreements through presenting the presence of environmental performance levels in the specification of the quality of services, the implications of the service level agreement on measuring environmental performance (i.e. the measurement tool prescribes how to measure and report on environmental performance) and the implications of service level agreements on implementing measures to improve the efficiency of the data center.

16 APPENDIX CODE BOOKS

In 0 a description of the code book is given followed by a filled-in code book for each case of the case study.

16.1 Description of the code book

Code	*Title*	*Description*
1.	**Cloud Service Provider Characteristics**	Provides information that helps to determine company characteristics
1.1	Customer examples	Examples of customers that are served by the company
1.2	Customer size and type	Insights into the size of the customers that are served by the company
1.3	Customer motivation for acquiring cloud services	Different motivations are possible for acquiring cloud services
1.3.1	*Company image/qualifications*	The image and/or qualifications of the company appeal to the customer
1.3.2	*Cloud characteristics*	The perceived benefits of the cloud due to its characteristics
1.3.3	*Cost reductions*	The possibility to reduce IT-cost by acquiring cloud services
1.3.4	*Green thinking*	The possibility to reduce the footprint of IT
1.4	Type of cloud services	Cloud Services that are offered to customers
1.5	Amount of employees	Indicates the amount of employees that work at the cloud service provider
1.6	Annual turnover	Turnover generated by the cloud service provider
1.7	Amount of DC's in the NL	n/a
1.8	Amount of DC's outside the NL	n/a
2.	**Visited Data Center Characteristics**	
2.1	Total Data center Floor Surface	Floor Surface of all data center space managed/owned by cloud service provider
2.2	Year of construction/operation of DC	n/a
2.3	Tier classification	Tier classification of the DC (can be official or non-official)
2.4	Data Center Floor Surface	Floor Surface of the data center that is managed by the cloud service provider
2.5	Type of hardware	Hardware used for provisioning cloud services
2.6	Type of software	Software used for provisioning cloud services
2.7	Type of virtualization technology	Virtualization technology used for cloud services
2.8	Type of energy supply	Type of energy supply that delivers energy to the DC
2.9	Certifications	Certifications that apply to the DC
2.10	PUE	The Power Usage Efficiency of the DC
2.11	Cooling	The cooling system that is uses in the data cetner
3.	**Data Center Efficiency**	
3.1	Drivers for Data Center Efficiency	Drivers mentioned by cloud service providers to pay attention to DCE
3.1.1	*Cost driven*	Cost as a driver for making an effort to increase data center efficiency
3.1.2	*Green thinking driven*	The idea to reduce the impact on the environment
3.1.3	*Customer driven*	Customers demands to increase data center efficiency
3.1.4	*Government driven*	Government implies rules and regulations for the efficiency of a data center
3.1.5.	*Other*	n/a
3.2	Presence of Corporate Social Responsibility	The role of Corporate Social Responsibility at the cloud service provider
3.2.1	*Importance*	The extent to which CSR is important for the cloud service provider
3.2.2	*CSR initiatives*	The engagement of the cloud service provider in initiatives related to CSR
3.2.3	*Certificates*	ISO-certifications or others that are an indicator of the presence of CSR
3.2.4	*Website*	Exposure on the corporate website involving CSR
3.2.5	*Reporting*	Reporting about CSR prestations
3.2.6	*Statements*	Statements made about the cloud service provider's CSR
4.	**Measuring Data Center Performance**	
4.1	Process of provisioning cloud services	Indicates the way cloud services are provisioned in the DC
4.1.1	*Internet*	Cloud services are accessed through the internet
4.1.2	*Direct connections*	Cloud services are accessed through a direct connection
4.2	Measures to increase DCE	Provides insight into the measures that are implemented in the DC to improve DCE
4.2.1	*Building*	Increasing the efficiency of data center building
4.2.2	*Hardware*	Increasing the efficiency of the hardware used for provisioning the cloud services
4.2.3	*Software*	Increasing the efficiency of the software used for provisioning the cloud services
4.2.4	*Data Center Systems*	Increasing the efficiency of data center systems such as cooling and lightning
4.2.5	*Configuration*	Increasing the efficiency of the configuration of cloud services in the data center
4.3	Measurements for measuring environmental impact or energy consumption	Indicates the measurements currently in place to measure environmental impact or energy consumption
4.3.1	*Rack-level*	Sensor at server rack for measuring energy consumption
4.3.2	*PDU-level*	Sensor at Power Distribution Unit for measuring energy consumption
4.4	Measurement process	
4.4.1	*Metrics used for measurements*	Indicates the corresponding metrics to the measurements described in 4.3 and 4.4
4.4.2	*Models/steps*	Description of the process of measuring performance
4.4.21	Data Center Management	Data center management includes for example power management and incident management
4.4.22	Invoicing	Measured data is used for invoicing
4.4.23	Forecasting	Measure data is used for forecasting
4.4.24	Follow-up	Measured data is used for follow-up actions
4.4.3	*Format*	Describes the way results from the measurement process are reported
4.4.4	*Attribution to specific customer*	The extent to which it is possible to attribute measurement to specific customers
4.4.4.1	Subscription fee	The cloud customer pays a fee each months which is determined with a certain formula
4.4.4.2	Pay per use	The cloud customer pays for its actual use of the cloud services
4.4.5	*Frequency*	The frequency of the measurement effort
5.	**Implications of Service Level Agreement**	
5.1	Presence of environmental performance in service level agreement	Provisions on environmental performance in service level agreements
5.2	Implications of SLA for measuring environmental performance	Describes the influence of the SLA on the way performance is measured in the DC
5.3	Implications of SLA for data center efficiency	Describes the influence of the SLA on the way that is dealt with DCE
6.	**Requirements and ideas**	
6.1	Requirements	Requirements that should be met by the measurement tool
6.2	Ideas	Ideas for the content of the measurement tool
7.	**Customer perspective**	
7.1	Value of the measurement tool for the customer	n/a

16.2 Code book of Atos

Code	*Title*	*Quotations*
1.	**Cloud Service Provider Characteristics**	
1.1	**Customer examples**	Unknown
1.2	**Customer size and type**	Large enterprises and multinationals
1.3	**Customer motivation for acquiring cloud services**	
1.3.1	*Company image/qualifications*	Indien Atos niet beschikt over certificering zie je dat bedrijven letterlijk opstappen of besluiten om geen klant te worden (3)
1.3.2	*Cloud characteristics*	-
1.3.3	*Cost reductions*	Kostenbesparing is de hoofdmoot voor klanten om clouddiensten af te nemen (54)
1.3.4	*Green thinking*	Met betrekking tot environmental impact, gaat het om de manier waarop Atos in de pers komt (55)
1.4	**Type of cloud services**	flexible services for critical business applications (c)
1.5	**Amount of employees**	
1.6	**Annual turnover**	8600 miljoen (b) Atos streeft naar een omzet van één miljard eind 2015 (d)
1.7	**Amount of DC's in the NL**	4 data centers in NL: Amsterdam 1, Eindhoven 2, Best 1 (a)
1.8	**Amount of DC's outside the NL**	About 60 in the rest of the world (consolidation program)(a)
2.	**Visited Data Center Characteristics**	
2.1	**Total Data center Floor Surface**	30000 m^2 (a)
2.2	**Year of construction/operation of DC**	Hurk: 2007 en Best: 2009 (2)
2.3	**Tier classification**	rated 3 (3)
2.4	**Data Center Floor Surface**	1600 m^2 (a)
2.5	**Type of hardware**	Dell (46), Morgen pakken wij HP (47)
2.6	**Type of software**	Zie 2.7
2.7	**Type of virtualization technology**	VMWare en Hyper-V (a)
2.8	**Type of energy supply**	100% groene stroom. Europeesche Wind voor 100% van het geleverde volume (a)
2.9	**Certifications**	ISO27001, ISAE3402, ISO14001 (a)
2.10	**PUE**	Juli 2014 highest 1,57 december 2014 lowest 1,29. Gemiddeld: 1.43 (a)
2.11	**Cooling**	cold air containment (a)
3.	**Data Center Efficiency**	
3.1	**Drivers for Data Center Efficiency**	
3.1.1	*Cost driven*	binnen een jaar moet ie zijn eigen terugverdiend hebben (16)
3.1.2	*Green thinking driven*	Atos wil gewoon, die wil 14001-certificaat (26)
3.1.3	*Customer driven*	Atos, hoe zorg je er nou voor dat jij, als leverancier van mij, zo weinig mogelijk energie verbruikt in je data center (41)
3.1.4	*Government driven*	Je bent verplicht als onderneming maatregelen te doen en als ze binnen vijf jaar terugbetalen (17), als je dus meedoet aan dat meerjarenakkoord dan krijg je ook bijvoorbeeld korting op je tarief van je elektriciteit (18)
3.1.5	*Other*	vanuit global (12), de opdracht gekregen om vijf procent per jaar aan je PUE te doen (13), in 2020 of 2030, moeten we 20% of 30% halen ten opzichte van..() (15)
3.2	**Presence of Corporate Social Responsibility**	
3.2.1	*Importance*	als je daar op sustainability zoekt bij Atos, want het is een key-ding bij Atos (9), te boek staan ook als een bedrijf wat het milieu hoog in zijn vaandel heeft staan (27), we willen een groen bedrijf zijn (28)
3.2.2	*CSR initiatives*	hoe hoger dat je scoorde, hoe meer dat je van je, bieding, af mocht doen (11)
3.2.3	*Certificates*	-
3.2.4	*Website*	-
3.2.5	*Reporting*	-
4.	**Measuring Data Center Performance**	
4.1	**Process of provisioning cloud services**	
4.1.1	*Internet*	-
4.1.2	*Direct connections*	-
4.2	**Measures to increase DCE**	
4.2.1	*Building*	-
4.2.2	*Hardware*	set points verleggen (22), Temperatuur (23), afspraken met de leverancier (38)
4.2.3	*Software*	als je kijkt naar maatregelen dus op softwaregebied dat je bijvoorbeeld load balancing gaat doen of dat je servers gaat uitzetten 's nachts dat is niet echt aan de orde? (19), Nog niet. Er lopen wel wat vragen, wat initiatieven, maar nog niet concreet (20), pijlen gaan richten op de softwareleveranciers (48)
4.2.4	*Data Center Systems*	1000W per vierkante meter (4), vaak de beperking nu (5), cold air containment (24)
4.2.5	*Configuration*	-
4.3	**Measurements for measuring environmental impact or energy consumption**	
4.3.1	*Rack-level*	In Best hebben jullie dus die metertjes per rack (32)
4.3.2	*PDU-level*	Power Distribution Unit (29), je hebt 400 Volt en 30 Volt (30)
4.4	**Measurement process**	
4.4.1	*Metrics used for measurements*	kilowatts (36)
4.4.2	*Models/steps*	
4.4.21	Data Center Management	koeling te managen (33), hoeveelheid energie (34)
4.4.22	Invoicing	-
4.4.23	Forecasting	-
4.4.24	Follow-up	-
4.4.3	*Format*	rapportages (35)
4.4.4	*Attribution to specific customer*	
4.4.4.1	*Subscription fee*	Maal een factor en een bedrag en dat is wat ze aangerekend krijgen (31)
4.4.4.2	*Pay per use*	-
4.4.5	*Frequency*	-
5.	**Implications of Service Level Agreement**	
5.1	**Presence of environmental performance in Quality of Services**	Klanten kijken eigenlijk naar alles, om op die manier de juiste afweging en keuze te kunnen maken (56), De QoS die door Atos geboden wordt, verschilt niet echt ten opzichte van concurrentie (57)
5.2	**Implications of SLA for measuring environmental performance**	-
5.3	**Implications of SLA for data center efficiency**	We laten niet na om maatregelen te nemen die als general practice, best practices in de wereld bekend zijn (21)
6.	**Requirements and ideas**	
6.1	**Requirements**	Ten opzichte van wat (39), zowel in kosten als in besparingen? (44), Ja (45), naar een klant ook daadwerkelijk verbruik kan gaan aanrekenen (49), de vervuiler betaalt (50), klant zit altijd wel aan zijn top (51), capaciteitsmanagement (52), waar wordt nou de grootste energie verbruikt (53)
6.2	**Ideas**	programmeren (40), schakelt die apparaten uit (42), het enige knopje, waar de klant dan ook echt mee kan draaien (43)
7.	**Customer perspective**	
7.1	**Value of the measurement tool for the**	-

(a) Confidential Appendix - paragraph 2.3
(b) http://atos.net/content/dam/global/reports-2013/en/annual-report-2013.html#a-1
(c) http://canopy-cloud.com/
(d) Telephone conversation with interviewee

16.3 Code book of T-Systems

Code	Title	Quotations
1.	**Cloud Service Provider Characteristics**	
1.1	**Customer examples**	Large multinationals (4,5,6,7,8)
1.2	**Customer size and type**	schaalgrootte (1), Grote outsource-contracten (2), 70 miljoen-plus dollar/euro deals (3)
1.3	Customer motivation for acquiring cloud services	
1.3.1	*Company image/qualifications*	heel stabiel als een enorme grote installed base voor hele grote instanties en bedrijven (73), T-Systems is een hele early cloud provider en er zit ook heel veel stappen worden daarin gemaakt. Maar wel tegemoetkomend aan de requirements van de klant (74)
1.3.2	*Cloud characteristics*	Beheer dat wil men consolideren. T-Systems heeft daar global de footprint voor. (72)
1.3.3	*Cost reductions*	Het is kostenbesparing, want daaruit ontstaat meestal de vraag naar outsourcing (71)
1.3.4	*Green thinking*	-
1.4	**Type of cloud services**	Business applications on private or public cloud platform.
1.5	**Amount of employees**	50000 (a)
1.6	**Annual turnover**	9500 million (a)
1.7	**Amount of DC's in the NL**	2
1.8	**Amount of DC's outside the NL**	67 (69 in totaal)
2.	**Visited Data Center Characteristics**	
2.1	**Total Data center Floor Surface**	rond de 100.000 m2 in totaal (14)
2.2	**Year of construction/operation of DC**	2000 (b)
2.3	**Tier classification**	3 (minimum)(c)
2.4	**Data Center Floor Surface**	28.000 m2 (12), Voor T-Systems is dat zo'n 5000 m2 (13)
2.5	**Type of hardware**	Er zijn niet echt dingen, behalve dan mainframe, dat wij hier niet doen (17)
2.6	**Type of software**	Zie 2.6.
2.7	**Type of virtualization technology**	VMware (18), Hyper-V kijken we ook naar (19)
2.8	**Type of energy supply**	100% groene stroom (21)
2.9	**Certifications**	ISO9001, ISO14001, ISO27001, ISAE3402, AMS-IX (b)
2.10	**PUE**	overall is het 1,8 (16)
2.11	**Cooling**	Chilled water cooling (a)
3.	**Data Center Efficiency**	
3.1	**Drivers for Data Center Efficiency**	
3.1.1	*Cost driven*	bereid om kostenbesparend mee te werken aan welke groene inzet dan ook (20), moet natuurlijk wel een financiële business case opleveren. (24)
3.1.2	*Green thinking driven*	-
3.1.3	*Customer driven*	-
3.1.4	*Government driven*	verplichting naar de gemeente Amsterdam (25), PUE hebben, onder 2 (26), CO2-afspraken die gelden tot 2020 of 2025. Dat ze op 20% minder zouden zitten dan op een bepaalde startdatum (27), Voor alle partijen is het belangrijk, maar tot een bepaalde mate. Uiteindelijk zie je dat IT-budgetten bij klanten zwaar onder druk staan en dan is het altijd de kostenreductie die prevaleert en zeker in deze tijd. (28)
3.1.5.	*Other*	-
3.2	**Presence of Corporate Social Responsibility**	
3.2.1	*Importance*	Is het onderscheidend? Ik vraag het me af. Het is meer de norm. Het is meer de commodity dat je het doet (31)
3.2.2	*CSR initiatives*	-
3.2.3	*Certificates*	En die vraagt ook naar dit soort certificaten elk jaar en dat wordt wel op centraal niveau allemaal gebundeld (30b)
3.2.4	*Website*	-
3.2.5	*Reporting*	corporate social responsibility (29), vraagt ook aan ons altijd elke maand alle getallen op van hoeveel hebben we verbruikt (30a)
4.	**Measuring Data Center Performance**	
4.1	**Process of provisioning cloud services**	
4.1.1	*Internet*	internetverbinding (32)
4.1.2	*Direct connections*	Point-to-point gewoon echt fysieke verbindingen (33)
4.2	**Measures to increase DCE**	
4.2.1	*Building*	-
4.2.2	*Hardware*	zo hoog mogelijke utilization (34), in een asset refresh programma zullen ze ook letten op deze consumptie (35)
4.2.3	*Software*	Software niet zo heel veel. Tenzij je kijkt naar virtualisatie enzo waardoor je minder hardware nodig hebt uiteindelijk in totaal (36)
4.2.4	*Data Center Systems*	containment (22), waardoor we minder cooling nodig hebben en dus eigenlijk de PUE verlagen (23)
4.2.5	*Configuration*	-
4.3	**Measurements for measuring environmental impact or energy consumption**	
4.3.1	*Rack-level*	-
4.3.2	*PDU-level*	elke week, krijg ik totalen van PDU's, dus power distribution units, dus dat is met kWh of kW. En elke maand krijg ik de kWh per ruimte. (40)
4.4	**Measurement process**	
4.4.1	*Metrics used for measurements*	Maandelijks over kWh en wekelijks over kW (41)
4.4.2	*Models/steps*	
4.4.21	Data Center Management	power management op wekelijks niveau (42)
4.4.22	Invoicing	maandelijks vanwege de invoicing (43)
4.4.23	Forecasting	forecast (47)
4.4.24	Follow-up	uitbreiden of juist moet inkrimpen, consolideren (46)
4.4.3	*Format*	overzichten (44), trend, overzicht (45)
4.4.4	*Attribution to specific customer*	
4.4.4.1	Subscription fee	-
4.4.4.2	Pay per use	fixed fee (50), wat op het apparaat staat (51)
4.4.5	*Frequency*	-
5.	**Implications of Service Level Agreement**	
5.1	**Presence of environmental performance in Quality of Services**	Je ziet steeds meer de trend dat voor nieuwe contracten we naar standaard SLA's gaan. Zeker voor grotere contracten. (55), soms is dat natuurlijk absoluut niet mogelijk (56), trade-off: hoeveel procent kun je standaard leveren en hoeveel niet (57), Ja, er is sowieso in de kern is er vooral de zero outage mentaliteit. (58), Nee, niet dat ik weet. Daar zijn geen KPI's met de klant voor afgesproken. (64)
5.2	**Implications of SLA for measuring environmental performance**	Plus dat op elk incident, welke gradatie dan ook, de hoeveelheid en de frequentie, staat gewoon een penalty (61), En die liggen wel vast in de SLA (62), SLA reporting, die is uiterst belangrijk. Daar staat niet alleen in wat er gebeurt is, maar ook in welke categorie een bepaald probleem dat zich heeft voorgedaan..() (63)
5.3	**Implications of SLA for data center efficiency**	Aan de andere kant moet je ook realistisch zijn soms heb je een passive stand-by, dat gebeurt ook nog wel eens. Als een klant dat per se wil hebben, dan zal het een soort step-out zijn, ja dan utilization is nul-komma-nul op die stand-by (37), daar zie je dus business continuity en dat kost geld (38), enorm strikt change management politiek (59), risico-mitigatie ten top (60)
6.	**Requirements and ideas**	
6.1	**Requirements**	andere reporting, die heel diffuus kan zijn, dat moet je dus voorkomen (65), Storage wordt heel vaak niet zo transparant gerapporteerd als dat we denken. (66), dat je de relativiteit van al die metingen laat zien (67), als je bij ons, als er negen uitkomt, en je gaat naar de buren, en je meet hetzelfde, dan moet daar ook negen uitkomen als ze dezelfde volumes hebben (68), Het is in principe tijdsonafhankelijk. (69), Opdat je het echt vergelijkbaar kan maken. (70)
6.2	**Ideas**	Slices en een bepaalde verhouding tussen CPU-power, RAM-geheugen en storage. En daar zit ook een stukje data center capaciteit, zit daarin verrekend (52), voor je interne sturing is het altijd wel handig om te weten, dat is een ander verhaal. In onze dingen naar de klanten, is dat ondergeschikt (53), Housing, ja daar kan ik me voorstellen dat dat een verrekeneenheid is. Voor hosting, nee. (54)
7.	**Customer perspective**	
7.1	**Value of the measurement tool for the customer**	Hij schat zijn kansen natuurlijk dan ook in. Want als hij dat ook gaat gebruiken, kan je weer gaan vergelijken en wat ga je daar weer mee bereiken, of wat wil je daarmee bereiken? (75), Hoe generiek gaat het dan worden dat je het ook werkelijk kan gebruiken? (76), Het mooiste zou zijn als je zo'n zelfde omgeving in een klassieke oplossing kan meten dat je kan zien waar je winst zit. (77)

(a) http://www.t-systems.com/about-t-systems/company-profile/764104

(b) http://www.globalswitch.com/media/67984/global-switch-technical-specification-amsterdam.pdf

(c) http://www.globalswitch.nl/infrastructuur/

16.4 Code book of KPN

Code	*Title*	*Quotations*
1.	**Cloud Service Provider Characteristics**	
1.1	**Customer examples**	-
1.2	**Customer size and type**	Ja, dat zijn externe klanten en echt grote top-100 klanten zeg maar die hier allemaal draaien. Dat is echt verbazingwekkend wat hier allemaal draait. Die kan ik niet allemaal noemen. (56)
1.3	**Customer motivation for acquiring cloud services**	
1.3.1	*Company image/qualifications*	hechten aan de extra security, privacy (15), gecertificeerd zijn voor financiële sector, voor de zorg en voor de overheid (16)
1.3.2	*Cloud characteristics*	voordeel van de cloud willen (14), time-to-market (54)
1.3.3	*Cost reductions*	-
1.3.4	*Green thinking*	-
1.4	**Type of cloud services**	CloudNL office, Sharepoint en Lync (55)
1.5	**Amount of employees**	18949 (a)
1.6	**Annual turnover**	8472 (b)
1.7	**Amount of DC's in the NL**	11 (c)
1.8	**Amount of DC's outside the NL**	0
2.	**Visited Data Center Characteristics**	
2.1	**Total Data center Floor Surface**	29200 m^2
2.2	**Year of construction/operation of DC**	2007 (e)
2.3	**Tier classification**	Unknown
2.4	**Data Center Floor Surface**	45 zei hij net ja. (1)
2.5	**Type of hardware**	-
2.6	**Type of software**	twee stacks: (2), Windows (3), Linux (4)
2.7	**Type of virtualization technology**	We draaien VMWare en Hyper-V (5), KVM (7), OVM (8), Xen (10)
2.8	**Type of energy supply**	100% groene stroom (13)
2.9	**Certifications**	ISO27001, ISO9001, ISO14001, NEN7510, ISAE3402 (d)
2.10	**PUE**	Unknown
2.11	**Cooling**	water (11), koeltorens (12)
3.	**Data Center Efficiency**	
3.1	**Drivers for Data Center Efficiency**	
3.1.1	*Cost driven*	daardoor kan je je TCO ook gigantisch verlagen (22), en je footprint ook (23), Consolideren (24)
3.1.2	*Green thinking driven*	en je footprint ook (23)
3.1.3	*Customer driven*	-
3.1.4	*Government driven*	-
3.1.5.	*Other*	-
3.2	**Presence of Corporate Social Responsibility**	
3.2.1	Importance	je ziet wel in toenemende mate dat wij aanbestedingen, in die uitvragen, waarin je dus ook je corporate social responsibility moet invullen (41)
3.2.2	CSR initiatives	-
3.2.3	Certificates	daar hebben we wel de nodige certificaten (42)
3.2.4	Website	-
3.2.5	Reporting	-
3.2.6	Statements	-
4.	**Measuring Data Center Performance**	
4.1	**Process of provisioning cloud services**	
4.1.1	*Internet*	-
4.1.2	*Direct connections*	-
4.2	Measures to increase DCE	
4.2.1	*Building*	-
4.2.2	*Hardware*	CPU's zo efficiënt mogelijk inkopen (17), stroomverbruik van bijvoorbeeld switches, dan kijken we echt naar (18), één van de selectiecriteria (19), rationaliseren en opruimen van oude platforms (20)
4.2.3	*Software*	We hebben daar ook wel tooling voor aangeschaft als bedrijf. Waar automatisch op de achtergrond die VM's balanceert, VMTurbo, gebruiken we nog niet echt overal. Ligt een beetje aan de soort omgeving (25), herdistribueren van workloads (26), We hebben maps van de zalen, laten we dan maken, dan zie je de hotspots. (27)
4.2.4	*Data Center Systems*	-
4.2.5	*Configuration*	-
4.3	**Measurements for measuring environmental impact or energy consumption**	
4.3.1	*Rack-level*	real-time (28), van elke kast (29), wat het stroomverbruik is op A en op B-zijde (30)
4.3.2	*PDU-level*	-
4.4	**Measurement process**	
4.4.1	*Metrics used for measurements*	-
4.4.2	*Models/steps*	
4.4.21	Data Center Management	En dan zien we gewoon live wat er gebeurt (31), we meten honderden dingen tegelijk (32)
4.4.22	Invoicing	-
4.4.23	Forecasting	-
4.4.24	Follow-up	tresholds (33), alarmering een melding (34), daar hebben we dan een soort script voor (35)
4.4.3	*Format*	-
4.4.4	*Attribution to specific customer*	
4.4.4.1	Subscription fee	als je dus de CloudNL propositie afneemt dan betaal je gewoon een service fee per maand en als je hier zelf je eigen spullen hebt staan, Rackspace, maar dan betaal je meer voor je stroom en wat andere zaken toch? (36), Cloud is pay per day en voor service management betaal je een maandelijkse fee (f)
4.4.4.2	Pay per use	-
4.4.5	*Frequency*	-
5.	**Implications of Service Level Agreement**	
5.1	**Presence of environmental performance in Quality of Services**	standaard SLA (38), Dat gaat bij ons niet zozeer om kwaliteit, maar meer om up-time. De negens zeg maar. Wij specificeren niet de temperatuur, weet ik veel wat, want weet je, daar ziet de klant-as niks van. (39), reactiesnelheid (57)
5.2	**Implications of SLA for measuring environmental performance**	Dat zal je bij ons niet zien in een SLA (40)
5.3	**Implications of SLA for data center efficiency**	server geeft zoveel rekenkracht (47), slag te halen is in hoe efficiënt zo'n applicatie nou omgaat met de CPU's (48), dienstontwikkeling gebeurt wel in een andere unit (58), wij zijn wat dat betreft geen startup (59)
6.	**Requirements and ideas**	
6.1	**Requirements**	-
6.2	**Ideas**	carbon footprint (45), maatstaf, waarbij je kan uitdrukken hoe groen jouw CPU-cycle in de cloud is (46), We hebben wel een tool hiervoor, we hebben net een tool geïntroduceerd, Cloud Cruiser heet ie. Die kan bijvoorbeeld die CPU cycles heel goed meten. Niet dat het een rekeneenheid is die wij gebruiken, maar je kan het wel meten al. (49), juist op machine-niveau (50), efficiency per virtuele CPU. Dan zou je niet de fysieke, maar de virtuele CPU pakken (51), Zelfde geldt voor storage, maar ik weet niet zo goed wat je daar nou voor rekeneenheid... (52), Dan krijg je Watt per Gigabyte of zo. Is, waarom niet? (53)
7.	**Customer perspective**	
7.1	**Value of the measurement tool for the**	-

(a) http://corporate.kpn.com/het-bedrijf/veelgestelde-vragen.htm
(b) http://corporate.kpn.com/pers/persberichten/kpn-resultaten-2013.htm
(c) http://www.kpn.com/itsolutions/datacenters.htm
(d) http://www.kpn.com/zakelijk/grootzakelijk/it/datacenters/colocation.htm
(e) http://www.datacentrumgids.nl/nederland/kpn-cybercenter-aalsmeer/details/faciliteiten
(f) answer provided through e-mail.

16.5 Code book of Previder

Code	*Title*	*Quotations*
1.	**Cloud Service Provider Characteristics**	
1.1	**Customer examples**	Drie-O, Reggefiber, Ordina (a)
1.2	**Customer size and type**	Ja, als je het over wat wij noemen grote klanten hebt, dan moet je denken aan een 80-100. (6)
1.3	**Customer motivation for acquiring cloud services**	
1.3.1	*Company image/qualifications*	nooit de garanties en de SLA's kunt geven dan als je het in een data center draait (2), Kostenbesparing. Soms. Kwaliteitsbesparing. Altijd. Bijna altijd. Er zijn weinig bedrijven die het zo voor elkaar hebben. En wat je natuurlijk ook ziet is dat de kennis die we hier hebben vele malen groter is als de systeembeheerder die al tien jaar..() (64)
1.3.2	*Cloud characteristics*	-
1.3.3	*Cost reductions*	Kosten besparen wordt wel vaak aangedragen als een van de belangrijkste zaken, maar is vaak maar de vraag of dat zo is (1)
1.3.4	*Green thinking*	-
1.4	**Type of cloud services**	alles wat managed is (7), Volledig voor de klant draaien. (8), er zijn twee modellen (23), je kunt resources afnemen (24), Dat is een smaak (25), De andere smaak die wij hebben is dat wij iets meer gaan doen en dan neemt de klant een virtual af bijvoorbeeld met Linux erop met Apache erop, die kunnen wij tot op dat niveau ook managen (26)
1.5	**Amount of employees**	Previder is 35 fte. Onderdeel uitmakend van de Odin-groep, zo'n 300 fte. (3)
1.6	**Annual turnover**	ordergrootte 10 tot 11 miljoen (4)
1.7	**Amount of DC's in the NL**	2 (c)
1.8	**Amount of DC's outside the NL**	0
2.	**Visited Data Center Characteristics**	
2.1	**Total Data center Floor Surface**	13500 m^2 (c)
2.2	**Year of construction/operation of DC**	dit data center is in 2010 gebouwd? (9), Ja. (10)
2.3	**Tier classification**	Tier 3+ (c)
2.4	**Data Center Floor Surface**	4500 m^2 (c)
2.5	**Type of hardware**	Dell (d)
2.6	**Type of software**	VMWare (d)
2.7	**Type of virtualization technology**	VMWare (63)
2.8	**Type of energy supply**	100% groene stroom
2.9	**Certifications**	ISO27001, ISO14001, ISO19001, NEN7510 (b)
2.10	**PUE**	1,25 (c)
2.11	**Cooling**	Closed cold corridors (15)
3.	**Data Center Efficiency**	
3.1	**Drivers for Data Center Efficiency**	
3.1.1	*Cost driven*	Stroom is gewoon onze grootste kostenpost, dat zijn onze hoogste kosten. Dus als we daar op kunnen besparen, ja dat is zeer welkom (18)
3.1.2	*Green thinking driven*	Groen imago is ook heel belangrijk (18a)
3.1.3	*Customer driven*	-
3.1.4	*Government driven*	Er is geen aanbesteding waar er niet naar gevraagd wordt (18b)
3.1.5	*Other*	Het is een aantal racks. Als je zalen vol hebt dan wordt het een heel ander verhaal. (35)
3.2	**Presence of Corporate Social Responsibility**	
3.2.1	*Importance*	-
3.2.2	*CSR initiatives*	-
3.2.3	*Certificates*	BREEAM certificering (20)
3.2.4	*Website*	de website (19)
3.2.5	*Reporting*	-
3.2.6	*Statements*	groenste data centers van Nederland (21), groene inrichting (22)
4.	**Measuring Data Center Performance**	
4.1	**Process of provisioning cloud services**	
4.1.1	*Internet*	Die bereik je gewoon via het internet, via Amsterdam en dan via zeg maar, de PDC hier. (27), Ja. (28)
4.1.2	*Direct connections*	-
4.2	**Measures to increase DCE**	
4.2.1	*Building*	-
4.2.2	*Hardware*	processoren met die low-voltage dingen, die processoren gaan steeds minder stroom verbruiken (57)
4.2.3	*Software*	Dat gaat automatisch (32), Je hebt daar ook een DRS onder draaien dat is Dynamic Resource Scheduling. Die kijkt wat handig is. (33)
4.2.4	*Data Center Systems*	temperatuur (69), racks die minder koeling nodig hebben, zorg je dat er iets minder gekoeld wordt (70)
4.2.5	*Configuration*	voor de Power Usage Efficiency heb je een bepaalde basis nodig (67), Zodat je genoeg vulling hebt per zaal, om in ieder geval daar goed mee te draaien (68), door daar inderdaad in te gaan regelen, en ook hot spots een beetje te plaatsen op zaal (71)
4.3	**Measurements for measuring environmental impact or energy consumption**	
4.3.1	*Rack-level*	Stroomverbruik wordt sowieso per rack gemeten. (4.3.1), Wij meten, wij hebben in beide data centers automatische metingen per rack. (17), twee feeds (36)
4.3.2	*PDU-level*	-
4.4	**Measurement process**	
4.4.1	*Metrics used for measurements*	Dus die betaalt per kWh. (39), PUE (59)
4.4.2	*Models/steps*	
4.4.21	Data Center Management	operationeel beheer (50), Continue monitoring (51)
4.4.22	Invoicing	direct aan de klant wordt doorberekend (38)
4.4.23	Forecasting	-
4.4.24	Follow-up	digitaal uitlezen (48), controleslag (56)
4.4.3	*Format*	real-time inzichtelijk (40), gepresenteerd in een mooie portal (49), online portal (52), grafiekjes (53), real-time overzichten en je hebt een maandoverzicht dat is een .pdf die er uiteindelijk in komt te staan, waar het totaal staat en daar staat in kWh is dat gemeten. Dus die vindt hij (de klant) ook terug op zijn factuur. (54), In een Service Management rapportage heb je KPI's (65)
4.4.4	*Attribution to specific customer*	
4.4.4.1	Subscription fee	Ja, in cloud servers zit die stroomprijs al verwerkt. En we kunnen ook niet per cloud server nu zien wat er gebruikt wordt. (41)
4.4.4.2	Pay per use	-
4.4.5	*Frequency*	doorlopend proces (45), een vijf-minuten-gemiddelde (46), we hoeven er niks aan te doen en de metingen lopen constant door (47)
5.	**Implications of Service Level Agreement**	
5.1	**Presence of environmental performance in Quality of Services**	-
5.2	**Implications of SLA for measuring environmental performance**	van een aantal klanten is daar ook wel energie bij, mee gemoeid. Kijk, klanten die rackspace afnemen, die willen dat natuurlijk zien en ook trends zien en daar adviezen over hebben (58)
5.3	**Implications of SLA for data center efficiency**	Dat doen we bewust niet. (30), En je krijgt, of we zagen rare dingen als we dat wel deden. Je hebt toch wel continuïteit waarvoor je wel moet staan. Dus op dit moment hebben wij daar geen automatisch mechanisme in die servers uit gaat zetten. (31), Dat is bij ons op dit moment het (er wordt nadruk op dit woord gelegd) punt. (34)
6.	**Requirements and ideas**	
6.1	**Requirements**	iets op je voordeur zou kunnen plakken (61)
6.2	**Ideas**	En je kunt het ook wel terugrekenen naar die CPU-cycle, maar ja je moet wat slimmigheid daarin..() (60)
7.	**Customer perspective**	
7.1	**Value of the measurement tool for the customer**	iets op je voordeur zou kunnen plakken (61), Consumenten zullen vaak terugvertalen naar hoe ze het thuis kennen. Op de wasmachine, de labels, A,B,C,D, als je het iets in die geest..() (62)

(a) http://www.previder.nl/Over_Previder/Klanten_Testimonials
(b) http://www.previder.nl/Datacenters
(c) http://www.previder.nl/Portals/0/docs/pdf%20commercieel/DA022v2_Specsheet_Datacenters.pdf
(d) http://www.previder.nl/Cloud_Hosting

16.6 Code book of ReasonNet

Code	*Title*	*Quotations*
1.	**Cloud Service Provider Characteristics**	
1.1	**Customer examples**	PinkElephant, QWise (3)
1.2	**Customer size and type**	Reasonnet levert 100% indirect (1), system integrator market (2), enterprise-organsaties (4), Meer dan 80% van onze klanten is hybride. (6), tot 2000 werkplekken (9)
1.3	**Customer motivation for acquiring cloud services**	
1.3.1	*Company image/qualifications*	hybride vorm, dat geeft de beste business resultaten voor de business case van de klant (7), lossen echt een business probleem op (68), maken zo'n organisatie wendbaar (69), gevoel van maatwerk (71)
1.3.2	*Cloud characteristics*	dat stukje flexibiliteit dat ze nodig hebben om snel te kunnen schakelen, elastisch te worden, dat vinden ze bij ons (8), pay-per-use model (70)
1.3.3	*Cost reductions*	-
1.3.4	*Green thinking*	-
1.4	**Type of cloud services**	platte data center diensten, platte IaaS-diensten en daar bovenop, we hebben wel een werkplek-stack, een werkplekproduct (5)
1.5	**Amount of employees**	We zitten op dit moment op 45 man (10)
1.6	**Annual turnover**	ReasonNet doet net iets minder dan 10 miljoen. (11), Onze cloudomzet verdubbelt jaar na jaar. (12), We zaten in 2011 op 500.000 euro, toen werd het 1 miljoen, toen werd het 2 miljoen, 4 miljoen..() (13)
1.7	**Amount of DC's in the NL**	Gyrocenter 1 (14), Gyrocenter 2 (15), DC3 in Almere (17)
1.8	**Amount of DC's outside the NL**	0
2.	**Visited Data Center Characteristics**	
2.1	**Total Data center Floor Surface**	in totaal hebben we 1800 (21)
2.2	**Year of construction/operation of DC**	2009 (16)
2.3	**Tier classification**	Dit is een Tier 2+ data center. (19)
2.4	**Data Center Floor Surface**	dit data center is 700 m2. Iets groter. (22)
2.5	**Type of hardware**	Wij hebben een strategische keus gemaakt om alles met de VCE Alliance te doen. Dus dat is, de term VCE staat voor Virtual Computing Environment. (27), VBlocks (28), En daar zit dus Cisco Compute in, EMC storage, Cisco Networking (29)
2.6	**Type of software**	Zie 2.7
2.7	**Type of virtualization technology**	VMWare virtualisatie (30)
2.8	**Type of energy supply**	Groene stroom. (31)
2.9	**Certifications**	ISO27001. Re-audit is gepland voor 2013-standaard. (32), We hebben ambities, maar ambities voor ISO20000, ISAE 3402 (33), Cisco Powered (34), EMC heeft ons in het velocity-programma opgenomen. (35)
2.10	**PUE**	tussen de 1.28 en 1.30 (23)
2.11	**Cooling**	DX managed cooling (24), air cooling. (25), cold corridors. Cooling alleys. (26)
3.	**Data Center Efficiency**	
3.1	**Drivers for Data Center Efficiency**	
3.1.1	*Cost driven*	zoveel mogelijk diensten kunnen bieden tegen zo min mogelijke kosten (36)
3.1.2	*Green thinking driven*	-
3.1.3	*Customer driven*	Wij zien in aanvragen die we krijgen dat klanten erom vragen (64)
3.1.4	*Government driven*	En weet je, het is ook een vereiste van de gemeente bijvoorbeeld, die heeft bepaalde zaken die..() (37), MJAP-plan (40)
3.1.5.	*Other*	-
3.2	**Presence of Corporate Social Responsibility**	
3.2.1	*Importance*	geen marketingpraatje, doen echt ons best om maximaal energie-efficiënt te zijn en bij de juiste leveranciers dat in te kopen (65)
3.2.2	*CSR initiatives*	-
3.2.3	*Certificates*	geen certificatenhandel (66)
3.2.4	*Website*	-
3.2.5	*Reporting*	-
3.2.6	*Statements*	We hebben echt groene stroom (67)
4.	**Measuring Data Center Performance**	
4.1	**Process of provisioning cloud services**	
4.1.1	*Internet*	We koppelen op het netwerk, volgen we een Noordring en een Zuidring rond Amsterdam, waarbij we aansluiten op GlobalSwitch en Nikhef, dat zijn de locaties waar we de carriers oppikken zoals Cogent, Tata level 3 en waar we ook op de AMS-IX uitbreken. (18)
4.1.2	*Direct connections*	-
4.2	**Measures to increase DCE**	
4.2.1	*Building*	bouw van het data center (39), technische ruimtes heel compact ontwerpen (41)
4.2.2	*Hardware*	VBlock is zo ontworpen dat ie continu zoekt naar energiebesparingsmogelijkheden (43)
4.2.3	*Software*	geen mogelijkheid voor ons om work loads te verplaatsen omdat de stroom ergens voordeliger is (42)
4.2.4	*Data Center Systems*	hoe je met je air flow bezig gaat op zalen (38)
4.2.5	*Configuration*	-
4.3	**Measurements for measuring environmental impact or energy consumption**	
4.3.1	*Rack-level*	De zaalverdelers vanwaar uiteindelijk een A en B feed en die worden echt gemeten. Dus echt op rack niveau. (48)
4.3.2	*PDU-level*	-
4.4	**Measurement process**	
4.4.1	*Metrics used for measurements*	kWh (47)
4.4.2	*Models/steps*	
4.4.21	Data Center Management	data center management systeem (50), tresholds instellen (56)
4.4.22	Invoicing	billing naar de klanten (49)
4.4.23	Forecasting	-
4.4.24	Follow-up	als dat inderdaad piekt dan wordt dat gecheckt (53), Excel, met daarin automatische kleuring (54), Er wordt wel gealarmeerd (55)
4.4.3	*Format*	-
4.4.4	*Attribution to specific customer*	
4.4.4.1	*Subscription fee*	-
4.4.4.2	*Pay per use*	de klanten betalen dat allemaal per kWh (46)
4.4.5	*Frequency*	En dat wordt constant gemeten neem ik aan? (51), Ja. (52)
5.	**Implications of Service Level Agreement**	
5.1	**Presence of environmental performance in Quality of Services**	Onze uptime van 99.98 en onze gemeten uptime van 100% is voldoende vertrouwen voor de klant. (20), Helemaal gestandaardiseerd. (72), Gewoon heel hoog Service Level Agreement, een hele hoge service. Het feit dat we ze met architectuur helpen, dat we ze met on-boarding helpen, dat we ze met migratie helpen. (73), exit strategie. Daar zijn we ook heel duidelijk over. (74)
5.2	**Implications of SLA for measuring environmental performance**	-
5.3	**Implications of SLA for data center efficiency**	de applicaties die wij draaien voor onze klant, dat zijn applicaties die er echt toe doen. Die moeten beschikbaar zijn, er moet een hoge performance zijn, die moeten always on, daar is bijna geen ruimte voor experimenteren (75), Dat geldt voor ons ook denk ik. Behalve voor ons eigen cloudplatform. Daar neemt de klant een dienst af. (76), En als dat VBlock op 25 graden zou kunnen functioneren dan zouden we dat bij wijze van spreken kunnen doen. (77)
6.	**Requirements and ideas**	
6.1	**Requirements**	granulairder maken (44), dat er een nieuwe metric komt, die meer cloudgebaseerd is en die op basis van inderdaad het aantal CPU-cycles, of het aantal misschien als dat makkelijker meetbaar is, het aantal werkplekken wat je bedient (45), er moet eenduidigheid bestaan over hoe komt die waarde tot stand en welke formule daarvoor gebruikt wordt (61), kwantitatief maken, omdat dat is echt de enige manier dat je niet in eindeloze ruzies terechtkomt (63)
6.2	**Ideas**	op het cloudplatform gaan we wel een stuk verder. Daar hebben we meer metrics waar wij in de praktijk nu niks mee doen, maar wij weten wat de stroomconsumptie van ons VBlock is (57), En die kunnen we zelfs uitsplitsen op het niveau van de virtuele machine, dus binnen de virtualisatie stack (58), vijf metrics die belangrijk zijn (78), CPU, Memory, Storage, Firewalls. Dit vormen samen de resources die de klant heeft en dan bepaalt de klant zelf hoe die die resources weer in virtuele resources..() (79), We weten wat de CPU, of wat de consumptie is van het hele platform en we kunnen dat uitsplitsen op niveau van CPU, memory, storage, network (80)
7.	**Customer perspective**	
7.1	**Value of the measurement tool for the customer**	de klant moet het kunnen snappen en kunnen vergelijken (59), het moet een gestandaardiseerde wijze van meten (60), aan de klant moet je in een instructiefilmpje van drie minuten kunnen uitleggen: dit is de meetwaarde, zo meten we hem, zo zit ie in elkaar en dit betekent het voor jou (62)

16.7 Code book of CloudVPS

Code	Title	Quotations
1.	**Cloud Service Provider Characteristics**	
1.1	**Customer examples**	*Irrelevant, since they serve a large long-tail of customers.*
1.2	**Customer size and type**	twee soorten klanten (1), hele grote long-tail (2), mensen die een servertje nodig hebben om, of om mee te spelen, of voor zichzelf, of omdat het een klein bedrijfje is waar de website op draait (4), Aan de andere kant hebben we bedrijven die een hele online presence
1.3	**Customer motivation for acquiring cloud services**	
1.3.1	*Company image/qualifications*	dat certificering telkens belangrijker wordt in de race om de klant (7), afvalcriterium in het offertestadium beschouwd (8)
1.3.2	*Cloud characteristics*	flexibiliteit (48), Ze kunnen er snel bij, ze kunnen er ook snel weer vanaf (49)
1.3.3	*Cost reductions*	-
1.3.4	*Green thinking*	-
1.4	**Type of cloud services**	binnen onze gevirtualiseerde infrastructuur, bouwen ze hun eigen virtuele platform (6), virtuele infrastructuur leveren in de vorm van virtuele servers (3)
1.5	**Amount of employees**	Op dit moment 20 en vanaf 1 maart, 23 (12)
1.6	**Annual turnover**	e-mail
1.7	**Amount of DC's in the NL**	3 (Equinix AM1, EU Networks Amsterdam, Equinix AM3) (a)
1.8	**Amount of DC's outside the NL**	0
2.	**Visited Data Center Characteristics**	
2.1	**Total Data center Floor Surface**	Not disclosed, classified.
2.2	**Year of construction/operation of DC**	AM1: 2007 (b), AM3: 2012 (c), EU Networks: onbekend
2.3	**Tier classification**	Tier 3+
2.4	**Data Center Floor Surface**	Not disclosed, classified.
2.5	**Type of hardware**	Alle topmerken (e)
2.6	**Type of software**	Windows, Linux (e)
2.7	**Type of virtualization technology**	Hyper-V, Xen (e)
2.8	**Type of energy supply**	Unknown
2.9	**Certifications**	ISO9001, ISO27001, NEN7510, ISO14001, ISO50001, ISAE3402 (c)
2.10	**PUE**	1.19 (value AM3 is designed for)(d)
2.11	**Cooling**	Air cooling (geothermal)(c)
3.	**Data Center Efficiency**	
3.1	**Drivers for Data Center Efficiency**	
3.1.1	*Cost driven*	misschien ook nog een incentive voor jullie om zelf dus het stroomverbruik zo laag mogelijk te houden omdat je die standaardprijs al krijgt, dus hoe meer je op die stroom kan besparen, hoe meer je daarop kan verdienen eigenlijk? (38), Ja dat klopt. Zolang het niet ten koste van de performance gaat is dat precies wat we doen (39)
3.1.2	*Green thinking driven*	in tweede instantie zijn er inderdaad nu ook al klanten die in het kader van goed ondernemerschap en maatschappelijk verantwoord ondernemen, vragen stellen over hoe groen die dingen zijn (9)
3.1.3	*Customer driven*	
3.1.4	*Government driven*	
3.1.5	*Other*	niet zozeer gericht op het verhogen van de energy efficiency, maar eerder gericht op het verhogen van de efficiency van het vloeroppervlak (13)
3.2	**Presence of Corporate Social Responsibility**	
3.2.1	*Importance*	We sponsoren bijvoorbeeld ook een sportvereniging (15), maatschappelijke verantwoordelijkheid die we daarin nemen is dat we een goede leverancier willen zijn (16), Dat gaat iets verder dan alleen groen zijn (14)
3.2.2	*CSR initiatives*	-
3.2.3	*Certificates*	ISO50001 voor energiemanagementsystemen (11)
3.2.4	*Website*	eigen pagina die uitlegt hoe groen een virtual machine is (10)
3.2.5	*Reporting*	-
3.2.6	*Statements*	-
4.	**Measuring Data Center Performance**	
4.1	**Process of provisioning cloud services**	
4.1.1	*Internet*	merendeel van de klanten dat bestelt bij ons online een server en krijgt deze ook online aangeleverd (18)
4.1.2	*Direct connections*	deel van die klanten heeft wat complexere vragen (19)
4.2	**Measures to increase DCE**	
4.2.1	*Building*	daarom zijn we ook toen Equinix AM3 werd opgeleverd een van de eerste klanten geweest die zeiden van nou, doe ons daar ook ruimte (17), Ik denk dat het makkelijker is voor een data center om een nieuw data center te bouwen en dan te zeggen: dit is de nieuwe standaard, dan het wijzigen van een bestaande set-up (20)
4.2.2	*Hardware*	utilization-rate te optimaliseren (26)
4.2.3	*Software*	-
4.2.4	*Data Center Systems*	cold corridor systeem (28)
4.2.5	*Configuration*	systeembelasting kunnen balanceren (27)
4.3	**Measurements for measuring environmental impact or energy consumption**	
4.3.1	*Rack-level*	Per rack (30), meten we uiteraard ook stroomverbruik (29)
4.3.2	*PDU-level*	-
4.4	**Measurement process**	
4.4.1	*Metrics used for measurements*	-
4.4.2	*Models/steps*	
4.4.21	Data Center Management	om te zorgen dat we niet boven de maximum, de grens van die feed uitkomen (33), triggers (34), monitoringssysteem (35)
4.4.22	Invoicing	rekening van onze leverancier (31), matchen met onze gegevens (32)
4.4.23	Forecasting	-
4.4.24	Follow-up	Corrective Actions Procedure (36)
4.4.3	*Format*	-
4.4.4	*Attribution to specific customer*	
4.4.4.1	Subscription fee	zit allemaal in de kostprijs van de virtual machines zelf verrekend (37)
4.4.4.2	Pay per use	-
4.4.5	*Frequency*	-

5.	**Implications of Service Level Agreement**	
5.1	**Presence of environmental performance in Quality of Services**	zoveel mogelijk te standaardiseren (41), virtual machine is per tijdseenheid zoveel beschikbaar (42), extra monitoring (43)
5.2	**Implications of SLA for measuring environmental performance**	-
5.3	**Implications of SLA for data center efficiency**	manier van stroomtoevoer in het data center werd veranderd en dat is een proces geweest wat uiteindelijk 1,5 jaar heeft geduurd (21), uiteindelijk gaat om systemen die 24/7 moeten draaien (22), data center zelf is daar ook wel terughoudend in (23), als het bij dit data center niet goed gaat, dan uiteindelijk zullen klanten naar een data center gaan waar ze wel weten waar ze aan toe zijn (24), Dat doen wij niet en dat kunnen wij ook niet en dat heeft alles te maken met het feit dat we afspraken hebben gemaakt met onze klanten over wat die klanten individueel allemaal geleverd krijgen (25), op het moment dat we de bios instellen voor maximum performance per Watt, dan zien we de totale performance van heel zo'n cluster, zien we ook echt gewoon achteruit gaan (40)
6.	**Requirements and ideas**	
6.1	**Requirements**	verplicht vanuit de diverse standaarden om hun leveranciers te evalueren (51)
6.2	**Ideas**	aan het eind van de dag worden al die machientjes automatisch weer afgesloten en opgeruimd, zodat ze 's avonds daar niet voor betalen (44), algemeen rapport uit te kunnen, of op te kunnen stellen over hoe groen CloudVPS als bedrijf werkt (50)
7.	**Customer perspective**	
7.1	**Value of the measurement tool for the customer**	Maar omdat wij die energieprijs nu verdisconteerd hebben in de prijs per virtual machine als het ware, of de uurprijs van een..() (45), klanten zijn wel geïnteresseerd in het besparen van geld dus als ze een computer uitzetten die ze niet nodig hebben uitzetten, dan besparen ze daar geld mee (46), driver daarvoor niet specifiek de energieprijs, die ze moeten betalen, maar de kostprijs van de servers, van de infrastructuur die ze gebruiken (47)

(a) http://www.cloudvps.nl/cloud-servers/netwerk-datacenters

(b) http://www.equinix.nl/resources/data-sheets/ibx-tech-specs/am1/

(c) http://www.equinix.nl/resources/data-sheets/ibx-tech-specs/am3/

(d) http://www.equinix.com/company/news-and-events/press-releases/equinix-wins-2014-international-datacentre-and-cloud-award-for-environmental-sustainability/

(e) Telephone conversation with Peter Arkesteijn, accountmanager at CloudVPS on February 23rd, 2015

17 APPENDIX OVERVIEW OF GLOBAL REPORTING INITIATIVE GUIDELINE

This appendix presents an overview of the measures 'energy' and 'emissions' as presented in the guideline of the Global Reporting Initiative (GRI). Only guidelines and description that are relevant for the scope of this research are presented. More detailed information can be found in *Reporting Principles and Standard Disclosures* (Global Reporting Initiative, 2013) and the corresponding implementation manual.

Measure	Guideline	Description
Energy	Energy consumption within the organization G4-EN3	▪ Report in joules, watt-hours or multiples, the total electricity, Heating and Cooling consumption. ▪ Report total energy consumption in joules or multiples. ▪ Report standards methodologies and assumptions used.
	Energy intensity G4-EN5	▪ Report the energy intensity ratio ▪ Report the organization-specific metric chosen to calculate ratio. ▪ Report the types of energy included in the intensity ratio.
	Reduction of energy consumption G4-EN6	▪ Report the amount of reductions in energy consumption achieved. ▪ Report the types of energy included in the reductions.
	Reduction of energy consumption of products and services G4-EN7	▪ Report the reductions in the energy requirements of sold products and services.
Emissions	Direct Greenhouse Gas Emissions	▪ Report gross direct (Scope 1) GHG emissions in metric tons of CO2 equivalent, independent of any GHG trades, such as purchases, sales, or transfers of offsets or allowances. ▪ Report the chosen base year, the rationale for choosing the base year, emissions in the base year, and the ▪ Context for any significant changes in emissions that triggered recalculations of base year emissions. ▪ Report standards, methodologies, and assumptions used.
	Energy Indirect Greenhouse Gas Emissions	▪ Report gross energy indirect (Scope 2) GHG emissions in metric tons of CO2 equivalent, independent of any GHG trades, such as purchases, sales, or transfers of offsets or allowances. ▪ Report the chosen base year, the rationale for choosing the base year, emissions in the base year, and the context for any significant changes in emissions that triggered recalculations of base year emissions. ▪ Report standards, methodologies, and assumptions used.
	Greenhouse Gas Emissions Intensity	▪ Report the GHG emissions intensity ratio. ▪ Report the organization-specific metric (the ratio denominator) chosen to calculate the ratio.
	Reduction of Greenhouse Gas Emissions	▪ Report the amount of GHG emissions reductions achieved as a direct result of initiatives to reduce emissions, in metric tons of CO_2 equivalent. ▪ Report the chosen base year or baseline and the rationale for choosing it. ▪ Report standards, methodologies, and assumptions used.