Quantifying the environmental impact of the IT of Shell:

The design of key performance indicators for long term monitoring of the environmental impact of the IT within a multi-national organisation

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Preface

Legal disclaimer: This paper has been written on personal title and does not necessarily reflect the views of Shell.

In May 2008 I started my graduation internship at Shell the Hague for my study Systems Engineering, Policy Analysis and Management. Now almost ten months later, this study has come to an end. I would like to thank the members of my graduation committee for helping me during the project. Furthermore, I would like to thank especially those that have helped me and supported me throughout the project.

Delft, 16 March 2009

Executive summary

The climate on earth is changing. Scientific consensus has been reached that this is due to the increasing amount of CO2 emissions. Therefore worldwide multiple initiatives arose, which aim at reducing the amount of CO2 emissions. The IT does not get neglected and is also investigated for possible room for improvement with regard to the amount of CO2 emissions. However, before measures are put into effect that aim to reduce the environmental impact, it is wise to know the current environmental impact of the IT, for which potential progress in this regard can be monitored structurally and consistently. As such an assessment tool should be in place that can give insight into the current environmental impact of the IT within an organisation. In addition it is preferable to have the means to compare the results regarding the environmental impact over multiple organisations to get a better understanding of the relative position. From a literature study we have concluded that currently there is no encompassing assessment method for an organisation's IT. Therefore, we have developed an assessment method for an organisations IT on the basis of existing assessment tools. We have conducted this research as part of an internship within Shell.

Key performance indicators (KPIs) are chosen as main output of the assessment model. Thus the concentrates mainly on designing a number of key performance indicators (KPIs) that can serve as a benchmark for the environmental impact of the organisation's IT, with a view to utilizing the KPIs in the long run, to reduce the environmental impact of the organisation's IT. Thus, the KPIs can provide, among others, a means for assessment of the progress with regard to initiatives aimed at reducing the environmental impact of the organisation's IT. Therefore, how the KPIs should be designed and quantified is the primary subject of this study and for this purpose a design framework is composed with which the environmental impact of an organisation's IT can be assessed periodically in a consistent manner. As a result this study does not have a research question, but rather a design objective. The design objective of this study is as follows: ***The design of KPIs for assessing the environmental impact of the IT itself for Shell.***

We have chosen to approach this design study by the methodology of the metamodel. For this purpose, a first step was to define the solution space. Here, we concluded that we would limit the problem situation to the environmental impact of the IT itself only. This entails that only the direct negative effects on the environment of the production, usage and disposal of IT equipment was to be investigated. The second step was to formulate the objectives and constraints. The objectives were formulated on the basis of interviews that were conducted with the main stakeholders within Shell. The same approach was used for the formulation of the constraints. From the formulation of the objectives and the constraints, we have derived the total list of requirements. By taking the requirements as a starting point, we initiated the actual design. As it was quickly realized that the design of KPIs alone would not suffice, we started with the design of an encompassing framework. The key purpose of the framework is to provide a method to analyze the IT of a large-scale multi-national organisation for its environmental impact and to eventually deduce a number of KPIs. We have developed the framework by taking a LCA approach as the basis. Next, from the framework we eventually deduced a number of KPIs for the case of Shell.

From the research we have carried out, we can conclude that the framework can be very helpful in structuring the measurement process. The framework has a modular approach, which entails that the organisation in question has the opportunity to select elements of the IT to quantify for the purpose of the environmental assessment. However, this also comprises one of the weaknesses of the framework. As of yet, the framework does not provide a clear methodological approach for the process of selecting and quantifying KPIs for the organisation in question that effectuates the framework. Therefore, we suggest further research with regard to the design of a complementary process design, that can be used with the framework.

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1. Introduction

1.1 Background

In today's society the concept of sustainability is becoming increasingly important as the emission of green house gases globally continues to rise, altering the climate on earth and consequently reshaping the natural balance of life on earth. In addition, sustainability as a concept is becoming increasingly apparent nowadays in the academic world as well as the business environment. While some categorize sustainability as just another buzzword, large groups of academics and businesses have identified the term along with its implications as an important factor in future developments (Mebratu, 1998). However in doing so, it is important to make clear beforehand, what one means when accepting and actuating the term, as its implications can vary on the course of its dissenting definitions. The area that is covered by the concept of sustainability is wide and can reach from sustainability in one of its oldest and simplest forms, which entails the continual existence of a particular entity, to the much more encompassing concept, which is more used nowadays, involving the environment in its widest form (Robinson 2003).

The special attention for the environment arose around the early eighties. It was in this period that a great number of countries experienced one or more oil crises, demonstrating the economy's great dependency on finite fossil resources. Furthermore the Club of Rome enjoyed increasing attention worldwide, as their simulation study and scenario assessment on the future of the environment emphasized that the world's climate would see great changes and challenges in the very near future. These changes entailed that the industrial society was going to exceed most of the ecological limits within a number of decades, due to the ongoing worldwide economic growth. It were however national governments and international agencies (e.g. the FCC and the UN) that gave the stimulus to the debate at international conferences, making sustainability to the highly popular term which it is today (Mebratu 1998).

With the increase in popularity of the concept of sustainability, different definitions have also arisen. One of these definitions, which is also mostly used in today's business environment, is sustainable development (Robinson 2003). This definition acquired its popularity in a report by the Brundtland Commission, where they characterized sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland 1987). The Brundtland commission was officially formed as the World Commission on Environment and Development (WCED) by the United Nations and served as a body to address growing concerns about the accelerating deterioration of the human environment and natural resources and the consequences of that deterioration for economic and social development (Brundtland 1987). The most radical message of the Brundtland Commission's report, demonstrates the dynamic tension between poverty and environmental concerns (Robinson 2003). Along with this tension, the tension between the limitations imposed by the state of technology and the environment's ability to meet present and future needs, also plays a key role (Mebratu 1998). Shell chose to adopt the definition of the Bruntland Commission and to act accordingly (Shell 2008b).

Sustainability covers a large array of subjects, it embraces among others, biodiversity, cleaner production, pollution prevention, pollution control, and minimization of resource usage, eco-design, etc. (Glavic & Lukman 2007). However, one element that has received relatively high attention recently is global warming (Roach 2004). The debate concerning sustainable development is intertwined with the scientific debate on global warming. The latter however, has shifted in the recent years from a debate over whether or not man-made climate change is occurring, to the debate regarding what levels of green house gases (GHG) are tolerable to the environment and which actions should be taken to prevent the levels from exceeding the threshold (The Climate Group 2008). Although scientific consensus on the subject of man-made global warming has been achieved, the same cannot be said for the possible consequences of man-made global warming, or for acceptable levels of GHG emissions. According to Lord Stern (2006), economist and vice president of the world bank from 2000 to 2003, at least 5% of global gross domestic product (GDP) could be lost annually, due to manmade global warming, if adequate actions on tackling the problem are not taken in time. Therefore the initial Stern review proposed an annual investment of 1% of GDP for reducing GHG emissions to avoid the worst impacts of climate change. Lord Stern thereby based his conclusion from the data about the effects of climate change that were known at that time (2006), which were primarily from the Intergovernmental Panel on Climate Change (IPCC) (Dasgupta 2006; Carter 2006). The IPCC panel, publishes scientific reports containing facts on climate change and its effects (Intergovernmental Panel on Climate Change 1990, p. 23). However, the IPCC report of 2007 gave new insights on the potential threat of global warming, thereby stressing that the data on the threat of global warming that was published in the past should be higher (Alley 2007). Therefore Lord Stern increased the number to 2% of GDP in June 2008, due to the new information on the current trends of global warming that became available in the 2007 report of the IPCC (Jowit & Wintour 2008; Alley 2007).

The debates in the scientific world did not go unnoticed by governments and inter-governmental organisations worldwide and as a result multiple initiatives were developed that are related to sustainable development. One of these initiatives that gained massive worldwide attention, is the Kyoto Protocol. In general the Kyoto Protocol entails the obligation for a cooperating nation to reduce carbon emissions by 5,4 % relative to 1990 levels by 2012 (Grubb, Vrolijk & Brack 1999, p. 26). Since the Kyoto Protocol, many initiatives from national governments followed. The UK for example aims for a reduction in carbon emissions of 60% relative to 1990 levels by 2050 (The United Kingdom Climate Change Act 2008). Another inter-governmental organisation that developed carbon emission reduction targets is the European Union. In 2007 the European Union announced a 20% carbon emissions reduction target by 2020 compared to levels of 1990 (Viguier, Babiker & Reilly 2003). From the initiatives of governments and inter-governmental organisations mentioned above, it can be concluded that carbon emissions reductions are acquiring an ever-increasing role in the present society and is highly likely to have an important role in the business society of the future. In the near future this will include legislation targeted at businesses aiming to reduce their carbon footprint (Murray 2008).

1.2 Sustainable development and Shell

Shell is a global group of energy and petrochemical companies, which is active in more than 110 countries and territories and employs over 104 000 people worldwide (Shell 2008a). Shell explores and produces oil and gas and creates essential products from them, such as fuels and petrochemicals. Shell also has a broad portfolio of hydrogen, bio fuels, wind and solar power interests. The objectives of Shell are “to engage efficiently, responsibly and profitably in oil, oil products, gas, chemicals and other selected businesses and to participate in the search for and development of other sources of energy to meet evolving customer needs and the world’s growing demand for energy” (Shell 2008b). Shell believes that oil and gas will be integral to the global energy needs for economic development for many decades to come and thereby defines its role as, to ensure that oil and gas can be extracted and delivered profitably and in environmentally and socially responsible ways. Shell consequently aims to work closely with their customers, their partners and policymakers in order to promote more efficient and sustainable use of energy and natural resources (Shell 2007).

The commitment of Shell to sustainable development plays an integral role in the vision of Shell. As a result Shell’s approach with regard to sustainable development involves the effort to meet the energy needs of the world in economically, environmentally and socially responsible ways. The latter shows the elements of corporate social responsibility for Shell. To put the goal of sustainable development in effect, Shell has taken a multitude of initiatives. To start with, all companies and joint ventures Shell controls, must apply the Shell General Business Principles and Shell’s Health, Safety, Security and Environment (HSSE) standards. These standards include requirements for animal testing, biodiversity, managing greenhouse gas emissions, environmental management, health management, road and process safety and ship quality. Environmental and social factors play a growing role in the investment decisions and in the way Shell plans and designs major new projects. Hence, an integrated environmental and social impact assessment is required, before significant work on major projects or existing facilities commences (Shell 2008c).

Above it was mentioned that the debate concerning sustainable development is intertwined with the scientific debate on global warming. This can be explained by the fact that a key concept of sustainable development is the tension of meeting the needs of the present, without compromising the ability of future generations to meet their own needs. With the conclusions from the Stern review, which are discussed above, a new dimension to the problem unfolds. The Stern review, among others, concluded that significant investments are needed now, in order to prevent environmental damage and subsequent economic losses to occur. Therefore Shell’s commitment to sustainable development also entails the need to actively invest in reducing GHG emissions at present.

With regard to the governance of sustainable development, Shell has formed several bodies that govern the processes concerning sustainable development for the whole Shell group. One of these bodies is the Group Sustainable Development, another example of such a body is the HSSE Executive. Both bodies review environmental and social performance and set priorities, key performance indicators and targets for the future. Environmental and social performance is thereby part of the duties of every manager. Another body is the Social Responsibility Committee. This is a detached non-executive body, which reviews Shell's environmental and social performance. It assesses and advises the Board on policies and performance with respect to Shell's business principles, the Code of Conduct, HSSE and other major issues of public concern (Shell 2008c).

In order to ensure that the employees of Shell at the work floor actually maintain and respect the core values regarding sustainable development, employees are thoroughly trained on the notions of sustainable development. Moreover, internal and external audit panels assess the compliance to sustainable development. This helps Shell in acquiring understanding on the compliance on the governance of sustainable development (Shell 2008c).

1.3 Sustainability and IT

For the purpose of this study, Shell IT has chosen to focus specifically on the environmental impact of the IT within the organisation. In general, the ongoing rapid development of the IT in developing countries triggers the overall growth of IT quickly. Therefore the overall impact on the environment of IT continues to increase. According to a study carried out by Gartner, the IT industry is estimated to currently be responsible for almost 2% of global CO_2 emissions, most resulting from the power consumption of PCs, servers and cooling systems (Mingray 2007). This percentage is roughly equal to that of the aviation industry. However, this number is expected to be tree times larger by the year 2020, considering the growth of IT in primarily developing countries (The Climate Group 2008). Thus, the relatively large impact on the environment of the IT sector as a whole, created for a motive to focus on this area in particular.

Furthermore, IT plays an important role in almost every aspect of present society. This shows from the fact that the terms 'new economy', 'the knowledge economy' and 'the information society' all refer to "the increasing reliance on IT to provide services and solutions that ultimately generate wealth" (Digital Europe 2003;). Multiple studies also show that IT was the main driving force behind a major transformation in the global economy, contributing to a relatively large share of the growth in GDP since approximately 1970 (OECD 2000; Roller & Waverman 2001). Looking at IT in this perspective, compared with the definition of sustainable development, the tension between the needs of the present and the ability of future generations to meet their own needs becomes apparent. Hence, IT as a whole can be seen as a need of the present and this need of the present can potentially harm the ability of future generations to meet their own needs. In this regard it therefore is obvious to pay close attention to the possible effects of IT on the needs of future generations. This produces another rationale for focussing specifically on IT.

1.4 Problem statement

Shell takes its corporate social responsibility with regard to the concept of sustainable development seriously and therefore, among others, strives to alter its impact on the environment in a positive way. This commitment to contribute to sustainable development was done approximately a decade ago and has since led to multiple structural changes within the organisation of Shell. One of these changes that is probably most noteworthy, is the overall reduction of the number of flares, resulting in a significant reduction in Shell's emission of Green House Gases (Shell, 2007). However, there are still many opportunities left for Shell with regard to sustainable development. The IT sector for one, does not get neglected and just as every other business unit within Shell, the IT is explored for possible room for improvement with regard to sustainable development. Nonetheless, the current impact on the environment of Shell's IT is unknown. However, in order to truthfully judge in the future whether progress is made due to initiatives geared at reducing the environmental impact of Shell's IT, it is crucial to have baseline data on the environmental impact of the organisation's IT. As a result, thorough measurements on the environmental impact of Shell's IT need to be performed right now. This should ultimately lead to the goal of reducing the impact on the environment of Shell's IT in the long run.

The measurements on the environmental impact of Shell's IT have to be done in such a way that the process is controllable and repeatable over time, hence achieving the goal of annually measuring the environmental impact of Shell's IT in a consistently repeatable manner. As such an assessment tool should be in place that can give insight into the current environmental impact of the IT within the organisation. In addition it is preferable to have the means to compare the results regarding the environmental impact over multiple organisations to get a better understanding of the relative position of Shell. Although much research has already been carried out on how an organisation wide environmental footprint can be measured, the same cannot be said for measuring the environmental footprint of an organisation's IT. Unfortunately, the traditional methods for measuring the organisation's wide environmental footprint are on their own not adequate to come up with proper data on the environmental impact of the organisation's IT, as the traditional approaches mostly use the emission factor-based methodology, which estimates GHG emissions by multiplying a level of activity data (e.g., kWh of electricity consumed by a facility) by an emission factor (e.g., grams of CO2 per kWh). However, the activity data for Shell's IT is unknown, since it cannot be isolated from the company wide data, and consequently, this first has to be quantified in order to make use of existing methods.

We have conducted a literature study to conclude if an assessment tool that can give insight into the current environmental impact of the IT within an organisation is already existent and thus if this tool could be applied to Shell, so Shell could draw conclusions on the environmental impact of its IT (see appendix B). From the literature study we found several methods that could be used that could give insight into the environmental impact of an organisation. One method is to use existing hardware standards/labels as Energy Star and EPEAT. However this method only looks at the theoretical environmental impact of IT hardware and does not take the actual usage patterns into account. Another method is to make a life cycle analysis or to use a variation to the life cycle analysis, for example, the eco indicators method (Goedkoop 1999; Goedkoop 1998). However, both these methods are labour intensive to carry out. In addition, both methods are aimed at the producers of the hardware, for getting insight into the environmental impact at different phases of the product's life cycle, instead of being used as means of comparison of different hardware equipment (Goedkoop & Spriensma 2001). Other methods that exist that can give insight into the environmental impact of IT, mostly take the energy consumption as starting point and make conversions and computations from which metrics arise, for example the Power Usage Efficiency (PUE) metric (Youssif & Dollars 2008; Stanford 2008). However, if this method would be used on its own, no clear picture of the entire environmental impact can be drawn, as only the power usage is taken into account. Thus, from the literature study we can conclude that there currently is no encompassing method or tool that could be used to assess the environmental impact of an organisation's IT. Therefore, how the aforementioned goal of measuring the environmental impact of Shell's IT can be achieved, is still unclear and in this regard further research is necessary.

Numbers that quantify the overall CO2 footprint of Shell's IT can be helpful in the long run to determine the direction and amount of progress regarding the environmental impact. Yet, if these numbers could be split up in distinct parts, detailing separate aspects of the organisation's IT, clear focus areas can be characterized for future initiatives for reducing the environmental impact of the organisation's IT, which is even more helpful than gross numbers of the CO2 footprint. Key performance indicators (KPIs) that quantify the environmental impact of a certain aspect of the organisation's IT are therefore to be preferred over gross CO2 number. As these KPIs serve the purpose of measuring the progress with regard to initiatives geared at optimizing the environmental impact and providing starting points for new initiatives, they need not serve as precise measures, but rather as indications of the current environmental impact on the subject it covers. Examples of KPIs would therefore be: the total energy consumption of end user computing within the organisation, the total CO2 footprint resulting from the data centres within the organisation, or the amount of IT equipment recycled per year.

In summary, this research should concentrate mainly on designing a number of key performance indicators (KPIs) that can serve as a benchmark for the environmental impact of Shell's IT, with a view to utilizing the KPIs in the long run, to reduce the environmental impact of Shell's IT. Thus, the KPIs can provide, among others, a means for assessment of the progress with regard to initiatives aimed at reducing the environmental impact of the organisation's IT. Therefore, how the KPIs should be designed and quantified will be the primary subject of this study and for this purpose a design framework will be composed with which the environmental impact of Shell's IT can be assessed periodically in a consistent manner. The secondary subject of this study is to apply the design framework to the organisation of Shell and to actually formulate and quantify the KPIs. This study therefore has two main outcomes; the framework for designing and quantifying KPIs to assess the environmental impact of the organisation's IT and the KPIs themselves. As a result this study does not have a research question, but rather a design objective. The design objective of this study is as follows: ***The design of KPIs for assessing the environmental impact of the IT itself for Shell.***

In the next chapter the study methodology and report outline will be elaborated.

2. Project method

We have concluded from the initial literature study that currently there is no encompassing method or tool that could be used to assess the environmental impact of an organisation's IT, therefore this tool should be designed. Nonetheless, we do not have to design this tool from the ground up. The aforementioned existing methods could be used in conjunction with each other, from which we can compose an encompassing method to assess the environmental impact of an organisation's IT in its entirety. Hence, for the purpose of this study we should focus on the design of an encompassing assessment method. There are multiple design processes that could be used for this purpose. We have chosen the method of the meta model, which is initially developed by Westerberg et al., because of its relative simplicity. Designing according to the meta model is "selecting an instance in the design space that meets the objectives and constraints" (Herder & Stikkelman 2004).

The meta model method clearly mentions a number of steps that should be carried out for reaching the end goal of a design. The different steps of the meta model and how these steps correspond to the different chapters of this report is visualized in Figure 1. The first step consists of developing the solution space. The solution space comprises the first demarcation of the study. We will deal with this step in the first part of chapter three. The solution space will be defined on the basis of the first formulation of the assignment and a literature study. The aforementioned, in combination with interviews with the problem owner, will lead to the eventual solution space, which will serve as the system demarcation for the remainder of the study. The second step is to formulate a list of requirements, objectives and constraints. We will deal with this step in the second part of chapter three. We will conclude the list of requirements, objectives and constraints, by combining the information from interviews that we have conducted, with the insights from the literature study. From the aforesaid steps, we can make a first design. We will deal with this in chapter four. The consecutive step is that of the 'test', or in other words, the validation of the model. According to Verschuren and Hartog, this is a very important step in the design cycle (Verschuren & Hartog 2005). We will deal with this step in chapter five. Two tests will be used to test the design. The first test is a feature inspection test through expert reviews. Here, the initial design will be tested for its features and as such, for its compliance with the requirements by interviewing different experts within Shell with regard to green IT and or metrics. The second test consists of a case study. We will use a case study method to test the initial design to the situation of Shell. What the purpose of the case study is and thus how we designed the case study, will also be dealt with in this chapter. The final step consists of the selection of the design. We will deal with this last step in chapter 6, where we will also present the conclusions of this study. Here, the answer to the main research question will be articulated. In addition, the theoretical contribution and the societal relevance of the project will be reviewed. Furthermore, this chapter will consist of the limitations of the study and a reflection on the project process as a whole.

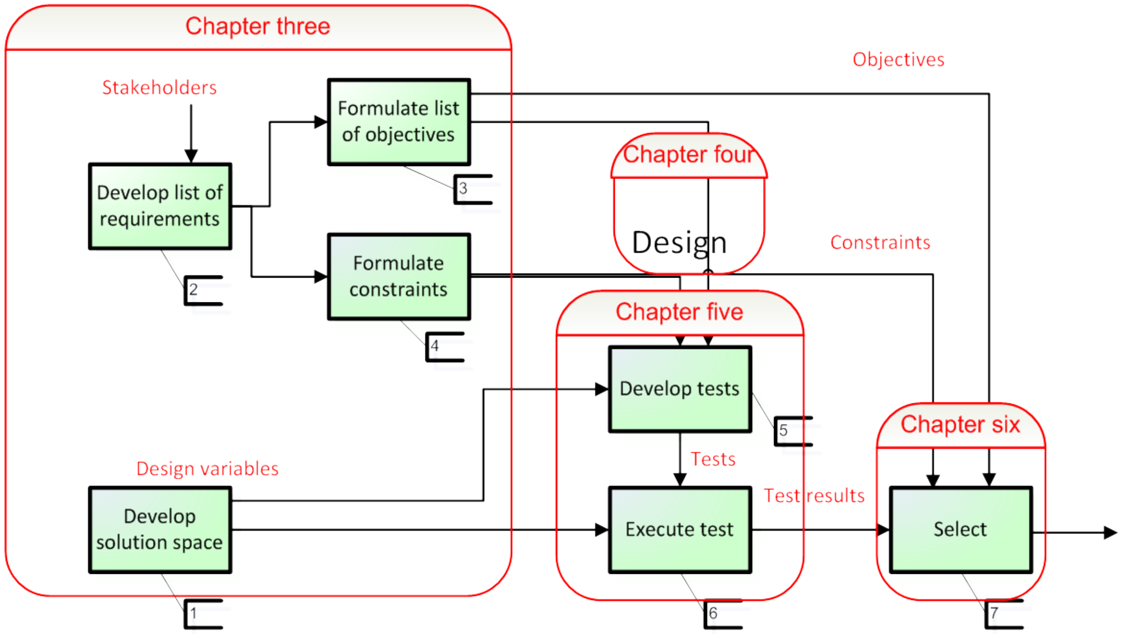

Figure 1: Metamodel for systems design (image adopted from Herder & Stikkelman 2004)

The table below shows which subjects will be dealt with in each design phase, in which chapter and with which method. The design phases result from the project proposal we have specified at the beginning of this study.

Table 1: Design phases

Design steps	Chapter	Subject	Method
Problem exploration and first demarcation	Chapter one	Introduction to the problem situation and a first demarcation	Formulation of the assignment, literature study and interviews with the problem owner.
Study methodology	Chapter two	The methodology for the study will be researched	Literature study
Demarcation and delineation	Chapter three	First demarcation of the study and formulation of requirements.	Formulation of the assignment. literature study and interviews with the problem owner.
Design of the framework	Chapter four	Design of the framework.	Synergy based on requirements and consecutive interviews.
Validation of the framework and KPIs	Chapter five	Test of the framework and practical applicability of the framework.	Expert reviewing and case study within Shell.
Selection and conclusion	Chapter six	The design objective will be discussed, the theoretical contribution and the societal relevance of the project will be reviewed and the limitations of the study and a reflection on the project as a whole will be given.	

3. Solution space, requirements and constraints

As mentioned above. A first step of the meta model is to define the solution space, as can be seen below in Figure 2. The solution space also forms the system boundaries and/or the system demarcation. We have confined the solution space by taking the project assignment as a starting point. What this entails will be discussed in paragraph 3.1. The requirements are specified by taking the objectives and constraints of the research study as a starting point. For the purpose of actually formulating the requirements, we have conducted several interviews with the project stakeholders. The overall requirements, as well as the objectives and constraints will be elaborated on in paragraph 3.2.

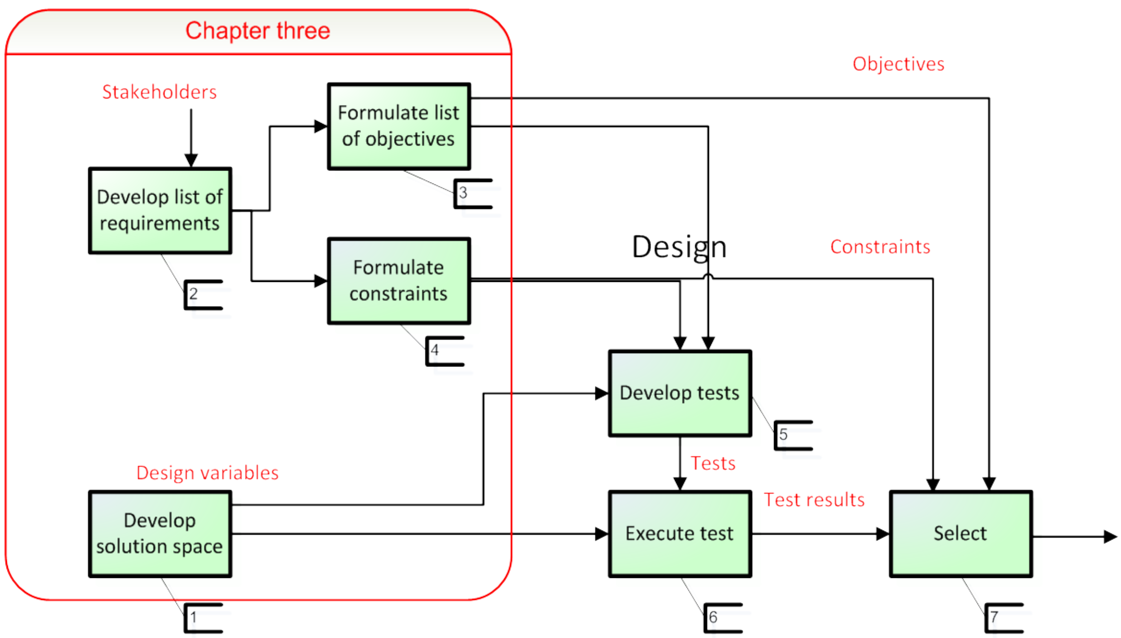

Figure 2: Metamodel chapter three

3.1 Solution space

At this point it is wise to denote that there are multiple perspectives to look at IT with regard to sustainable development. First of all, IT can be seen as the enabler of working towards sustainable development, the so-called second order effects. At the same time, IT can also be investigated on its own for room for improvement in its environmental impact, the so-called first order effects (Berkhout & Hertin 2001; The Climate Group 2008). Implications of the second order effect perspective of looking at IT could for example consist of intensifying the usage of video conferencing, thereby reducing the need to travel and consequently reducing the emissions of Green House Gases involved with travelling. Another possibility of an outcome of this perspective could be to use IT to optimize certain processes, with a view to reducing the negative environmental impact. However, if the second order effect perspective of looking at IT would be taken as point of departure, it is crucial to get a proper overview of the organisation, to carefully study where IT can be put in effect for it to reduce the company's overall environmental impact. In addition, it would be favourable to have the decision power to actually put the desired changes into effect, which can become rather cumbersome within a short timeframe in a large organisation. Nevertheless, the second order effect perspective of looking at IT is unquestionably interesting to look at for Shell for the purpose of reducing the company's negative impact on the environment. However, considering the time constraints on this study it is not viable to properly investigate the possibilities for the enabling effect of IT with regard to the environmental impact. Considering the goals mentioned in the preceding subparagraph, the focus of this study is therefore solely on the first order effects of IT.

If the focus is on the direct negative effects of the IT on the environment, it is crucial to thoroughly quantify at first what the environmental footprint of IT is. Only if these figures are known, actions that are taken to reduce the negative environmental impact of IT can be evaluated. Unfortunately, there are few generally accepted standards that exist to guide companies in the sorting, normalising and reporting of environmental data (Leahy 2007). This goes even more for IT in specific (Mingray 2007). It is therefore important that research into this subject has to be done from which a methodically applicable measurement approach can be derived. That approach should subsequently have as output a number of variables that can be easily interpretable to serve as clear measurements of the environmental impact of Shell's IT. In other words, the variables should properly assess possible changes to Shell's IT with regard to the environmental impact. These variables can be typified as environmental key performance indicators (KPIs).

The environmental key performance indicators that are to be designed for this study should be distinguished from the environmental metrics that are calculated for the purpose of benchmarking programs or cap trade schemes. For example, the Kyoto Protocol, the carbon disclosure project and the carbon commitment project, specify to a certain extent the rules for the measurement process of the environmental metrics, which consists of specific accounting and reporting requirements (Grubb Vrolijk & Bragg 1999; Carbon Disclosure Project 2005; The GHG protocol 2004). However, if the environmental metrics are for internal use only, there need not be a uniform standard for the measurement process. Nonetheless, as already mentioned in the introduction, benchmarking across multiple organisations can be a secondary goal of the KPIs. If the latter is to be carried out adequately, it then again is crucial that the same accounting methods are chosen. For example, whether partly owned facilities should be incorporated in the calculations fully or according to a certain division rule, can have a great influence on the values of the KPIs. Nonetheless, it would go beyond the scope of this research to specify into detail the accounting method for each calculation. Therefore, the GHG protocol should be used as a supplementary method next to the method that is part of this study. The GHG protocol is chosen because of the fact that this method is already a widely adopted standard for GHG accounting and reporting and because of the fact that it can be incorporated easily within another method (The GHG protocol 2004)

In summary, this study will focus specifically on the research into the current environmental impact of Shell's IT. However, the environmental impact can cover a multitude of areas and requires careful investigation in order to be quantifiable. An important step in this research will therefore be to specify a number of (KPIs). These KPIs can then be used to monitor the sustainable development of the IT within Shell on its own. If these data are known, the knowledge of the KPIs can as well be utilized to work towards reducing the environmental impact of Shell's IT. This last step, of utilizing the KPIs, is however not a subject of this study. Successful implementation of measures aimed at reducing the environmental impact of the IT requires a significant amount of time. That time is not allocated for the purpose of this study. Nonetheless this study will present a tool to assess measures that will potentially be taken in the future to reduce the environmental impact of IT and that defines the solution space of this study.

3.2 Requirements

In the introduction, the importance of paying attention to the environment was already mentioned. However, actions to reduce the negative environmental impact of the IT should not be based solely on ideologies if the actions do not make good business sense (Mingray 2007). Nonetheless, actions geared at reducing the environmental impact of an organisation's IT can have good business sense (Mingray 2007). The rationales however, may vary per organisation. This in turn, has consequences for the main focus areas for the process of measuring the current environmental impact of the organisation's IT. The attention on green IT may differ per business and can have varying underlying rationales. Hence, the approaches that are to be taken in this regard vary greatly. Therefore it is crucial to firstly identify what the focus areas for green IT are for a given organisation. For this purpose, the objectives of the metrics will first be elaborated on in subparagraph 3.2.1. We have specified this list of objectives by conducting interviews with the main project stakeholders within Shell. In subparagraph 3.2.2 the constraints on the metrics will be discussed. In subparagraph 3.2.3 the eventual list of requirements will be presented.

3.2.1 Objectives

In the introduction it is discussed why sustainable development is important for Shell. Up until now at Shell, a relatively large part of the effort to achieve the goal of sustainable development concentrates on Shell's upstream and downstream branches, which can be accounted to the fact that also these two branches contribute to a bigger part to the overall impact of Shell on the environment, than the IT within Shell. Nonetheless, in the preceding subparagraphs a number of grounds for the focus on Green IT in general are mentioned. In addition, Shell's view on corporate social responsibility was elaborated on. With the notions of sustainable development, corporate social responsibility and green IT combined, a set of concrete rationales can be articulated that outline the grounds for Shell to focus on green IT.

The grounds to focus on sustainable development in general are much more encompassing than the grounds for the focus on green IT alone. One aspect that is important for sustainable development in general, but less important for green IT, is meeting requirements of current legislation. At the present time, a great number of countries have certain legislation in place that has the goal of reducing the environmental impact at an organisation level. However national or supranational legislation aimed specifically at IT is still rather slim. Nonetheless, there are signs that this is about to change in the near future (Murray 2008).

The grounds mentioned below are characteristic for the focus on green IT for Shell and as such, not for the focus in general on sustainable development. These grounds are deduced from interviews with the initiators of green IT projects within Shell and those working on green IT projects (the grounds mentioned in this subparagraph are not in any way ordered according to importance, nor is the enumeration of grounds limitative).

Contributing to Shell's company goal of reducing its impact on the environment. As already mentioned in subparagraph 2.1.4 Shell has committed itself to the goal of operating with regard to the concept of sustainable development. Furthermore, Shell also has the target of performing top quartile in energy efficiency and CO2 emissions by 2015. Top quartile can be seen as being at least among the first 25 out of 100 competitors. As such, benchmarking should be performed for an adequate "apples to apples" comparison. Shell thereby expressed the need that the efficiency of every operation within Shell should be optimized, for reaching top quartile performance of at least two-thirds of Shell's facilities. The IT within Shell can be seen as one of these operations. Therefore also the IT within Shell should be investigated on its own, for improvement possibilities with regard to energy efficiency.

Reducing costs within Shell. By adopting cleaner IT technologies, the overall energy consumption of Shell as a whole can decrease. Moreover, altering the usage patterns of IT technology can have instantly measurable effects on the energy bill of Shell. For example, switching off certain IT equipment whenever it is not used will lead to energy consumption decreases and in turn to cost reductions. Hence costs can be reduced within the company, while at the same time the environmental impact of Shell can be diminished. This overall makes good business sense and as such is an important motive for committing to green IT.

Changing the mindset of employees of Shell. The IT within Shell is very visible to almost every employee within Shell. A relatively small percentage of Shell employees are confronted daily with oil spills or flaring of crude oil. However, a large percentage of Shell employees are making use of IT equipment daily. This equipment can range from mobile phones and desktop computers to high performance computers and notebooks. As the average employee of Shell is faced with IT almost daily, for example due to his or her desktop computer, it is rational to look at the IT sector into more detail and to explore the room for improvement in the light of sustainable development. Moreover, due to the high visibility of IT equipment within the organisation, IT has great potential to positively influence Shell's corporate image among staff.

Assuring the licence to operate in the future in certain countries. In a number of countries the regulations with regard to the environmental impact of offices are tightening. It is therefore important to diminish the overall energy consumption of offices as much as possible where feasible. The IT infrastructure provides good starting points for this purpose. In this regard it is also wise to pay attention to potential requirements that can originate from future legislation on green IT, as it is expected that in the future certain legislation will be put into effect (Murray 2008). By already looking into the possibilities of future legislation and the required changes to the organisation's IT, unnecessary costs in the future can be avoided.

Reputation management. The goal of reputation management can be subdivided between internal reputation and external reputation. Internal reputation entails the reputation of Shell amongst Shell employees. As already advocated, can green IT make a relatively big contribution on this ground, as most employees within Shell are confronted with IT almost daily. External reputation covers the reputation of Shell as a company, viewed by the outside world. As said, in this regard green IT would seem less obvious to change the image of Shell as a whole, as the IT within Shell makes up for a relatively small environmental impact, considering the overall environmental impact of Shell. Nonetheless, early signs indicate that green IT efforts indeed contribute positively to the corporate image of Shell and therefore this can also be seen as a goal to focus on green IT.

Supplier management. Supplier management entails in short, the selection of suppliers to do business with. This selection can be based on a number of criteria, for example; reputation of the supplier with regard to sustainable development and financial position of the supplier, in other words, the risk of a bankruptcy of the supplier. Also for the purpose of green IT, supplier management plays a big role. In a sense this has an overlap with reputation management in general. Nonetheless it is important enough for Shell with regard to green IT, to formulate it as a separate goal.

3.2.2 Constraints

Next to the objectives of the metrics, there are also certain constraints on the metrics. Together the objectives and the constraints make up the whole of requirements for the metrics. From the introduction it can be concluded that the current impact of IT on the environment is relatively large and is continuing to grow even larger. Where exactly this impact on the environment occurs and how the impact occurs, can however be hard to grasp at first sight as the effects of the environmental impact of IT are not nearly as visible as par example the environmental impact of the automobile industry or the aviation industry. Multiple methods exist to characterize the environmental impact of a product group. For example by use of a MET (Materials, Energy and Toxicity) matrix. Within this matrix the life cycle is divided into three phases: production, use and disposal. On the other axis the categories of environmental concern are distinguished: materials cycle, energy use and toxic emissions (van Berkel, Willems & Lafleur 1996). Within Shell the different grounds of environmental impact of the IT equipment were already categorized in a manner similar to that of the MET matrix. Below a summarization is given on the areas of environmental impact of the IT equipment, based on the grounds that were already developed within Shell by the programme manager Green IT.

- Direct pollution of air water and land from the manufacturing, transport, use and disposal of IT equipment.
- GHG emissions resulting from manufacturing, use (power) and disposal of IT equipment and GHG emissions from transport and travel of IT equipment
- Use of hazardous, non-degradable and finite materials at the manufacturing- and disposal phase of IT equipment.

From the summary above we can conclude that a distinction on the general environmental impact of IT can be made on three grounds. The first ground is the direct pollution. This entails the immediately visible impact on the environment. In the case of the manufacturing of the IT equipment, this can be the air pollution from factories, producing IT equipment, but also earlier in the product life cycle, the ground pollution and potential sound pollution from the mining of raw materials. The direct pollution from the use of IT equipment is as already mentioned less apparent. Nonetheless, direct pollution due to the usage of IT equipment can manifest for example when printing from a laser printer, as this emits ultra fine particles (Morawska et al. 2008; He, Morawska & Taplin 2007; Schripp et al. 2008)

The second ground for the general impact of IT on the environment, is the GHG emissions resulting from the manufacturing, use and disposal of IT equipment and the transport and travel. Before the IT equipment will be put to use, in for example an office building, it first has to be produced from raw material and then transported to its destination. In the production phase a relatively large part of energy is needed to make the equipment. According to some, more energy is consumed at the production phase of IT equipment than at the usage phase of the same equipment (Costanza 1980; Brown & Herendreen 1996). The energy that is required for the production of the IT equipment is in most cases derived from fossil fuels and therefore accountable for the emission of GHGs. Next to the GHG resulting from the production of IT equipment, GHG emissions result from the transport of IT equipment, for example from the production facility to the retailer or from the retailer to the end user. Whether this transport is by boat, plain, train or truck, GHGs are highly likely to be emitted. GHG emissions resulting from the usage of IT equipment are due to the energy requirements of the IT equipment and as long as the energy that powers the devices does not solely result from renewable sources, GHGs are emitted. Finally, at the disposal phase GHGs are likely to be emitted whenever the equipment is disassembled with use of energy consuming machinery for recycling or refurbishment.

The third ground for the general environmental impact of IT, is the use of hazardous, non-degradable and finite materials at the manufacturing- and disposal phase of IT equipment. For specific IT equipment, hazardous material is used, such as lead, cadmium, mercury and chromium (Hazardous waste directory 2008). These materials can have a harmful impact on the environment at the disposal phase of the IT equipment, if they are not to be taken care of properly. Furthermore, considering scarce resources, with an average worker printing about 1000 pages per month, water and wood required for the paper is consumed in large amounts too.

Considering the three grounds discussed, it should be concluded that whenever an organisation wants to improve its environmental impact of the IT, it should focus on more than for example the power consumption of the equipment alone. The three grounds where the environmental impact of the IT can occur, should be kept in mind whenever thorough measures are to be taken with regard to the environmental impact of an organisation's IT. This also goes for the organisation that is looking into green IT largely from a reputational point of view, as a focus on decreasing energy use alone for example, could easily be characterized by others as a cost reduction initiative, rather than a serious green IT initiative. The grounds for the environmental impact make up an important constraint for the design of the metrics.

3.2.3 Total list of requirements on the set of KPIs

From the objectives and constraints we discussed in the preceding subparagraphs, we have made an initial list of requirements for the design of KPIs. For the design of the framework, these requirements are the key input. The requirements are categorized into functional and non-functional requirements. The functional requirements articulate the things the framework has to do and the non-functional requirements articulate the qualities that the framework should have. The functional and non-functional requirements are summarized in table 2. A textual explanation of each requirement is given thereafter.

Table 2: functional and non-functional requirements on the total of KPIs

	Functional requirements
1	As a whole, the KPIs should reflect the environmental impact of IT
2	As a whole, the KPIs should reflect the objectives of the organisation effectuating a green IT policy (e.g. in Shell's case; reduce environmental impact, reduce costs, change the mindset of employees, ensuring the license to operate, reputation management and supplier management)
3	The measurement of a KPI should be repeatable
4	A KPI should be consistently measurable
5	A KPI has to measure only those things that the organisation can influence
6	A KPI should only focus on those areas of the IT where a potential difference will lead to measurable changes
	Non-functional requirements
1	A KPI should be able to measure aspects of the functional areas of the IT individually (e.g. data centre computing, end user computing, printing, etc.)
2	There should be a KPI that takes changes to the organisation into account
3	There should be a KPI that takes changes to the organisation's environment into account
4	A KPI should preferably provide benchmarking opportunities
5	A KPI should be quantifiable within the organisation within a reasonable timeframe
6	A KPI should be quantifiable within the organisation within a reasonable amount of effort
7	There should preferably be a combination of leading and lagging KPIs

Due to the fact that the framework and the corresponding KPIs are designed within a Shell environment, the requirements are relatively specific for Shell. Nonetheless the framework is purposely made from a generic perspective, to enable the usage in other large-scale multi-national organisations. Having a generic framework will ease the adoptability of the framework across multiple organisations and as such provide opportunities for benchmarking. By benchmarking, the relative position of one organisation in comparison to other organisations can be concluded, which is valuable knowledge in the today's business society (Voss, Allstrom & Blackmon 2007). Therefore, a **KPI should preferably provide benchmarking opportunities.** Benchmarking however, is not the main focus of the framework. The main focus of the framework is long-term, repeatable and consistent monitoring of the environmental impact of a large scale multi-national organisation's IT, through KPIs. The framework provides a method to analyze the IT of a large scale multi-national organisation for its environmental impact and to eventually deduce a number of KPIs. From this, several requirements derive. First of all, **as a whole, the KPIs should reflect the environmental impact of IT.** Second of all, **the measurement of a KPI should be repeatable.** Third of all, **a KPI should be consistently measurable.** By annually or quarterly measuring the KPIs, the progress of the organisation with regard to green IT can be monitored. Only if this monitoring is carried out in a consistent and just manner, conclusions can be drawn on the effectiveness of measures that are taken with regard to green IT. This is not only important for those in the organisation who are directly involved and responsible for the progress in green IT, but also for the upper management, where high level budgetary decisions are taken, as these decisions can now be based on the basis of successes or losses in the past.

Next to the fact that as a whole, the KPIs should reflect the environmental impact of IT, as a whole the KPIs should also reflect the other objectives of the organisation effectuating a green IT policy. In subparagraph 3.1.2 it was already mentioned that contributing to the goal of reducing the environmental impact is only one of Shell's goals for effectuating a green IT policy. The other goals are: reduce costs, change the mindset of employees, ensure the license to operate, reputation management and supplier management. As a result, the KPIs that are to be developed should also address these objectives. As the objectives for a green IT policy may vary per organisation, the organisation's specific objectives are not translated to requirements, since this would hamper the general cross business applicability of the framework to a large extent. As a solution, we chose to adopt the more general and organisation independent requirement: **as a whole, the KPIs should reflect the objectives of the organisation effectuating a green IT policy.** Nonetheless, for the purpose of this study, the objectives for Shell are taken as a starting point and as such also have an influence on the eventual characteristics of the framework in general and the KPIs specifically. Whether the objectives of Shell can be aligned with the objectives of other organisations will be briefly evaluated in chapter six.

It is important that the KPIs focus only on those areas where the organisation can make a difference. If this is not the case, the effort of quantifying the KPIs would prove futile. However, this restriction should not be interpreted too narrowly, as an organisation can also make a difference in certain areas where it does not have a direct influence. In such a case the organisation could make a difference by imposing pressure on the third party that indeed has direct influence. For example, for a certain organisation the supplies for printing are delivered by a specialized printer company through a service contract and as such a third party makes the decision on the types of supplies to use within the organisation. However, by incorporating provisions on the supplies to use within the SLAs, the organisation can have an influence on which types of supplies to use for printing purposes. The notion of influencing is therefore important to this regard. As a result, the corresponding requirement is as follows: **A KPI has to measure only those things that the organisation can influence.**

Next to the requirement that the KPIs should only focus on the areas where the organisation can make a difference, there also should be a requirement entailing that **the KPIs should only focus on the areas of the IT where a potential difference will lead to (relatively) significant changes that are measurable**. This however, is difficult to conclude with enough precision beforehand. Nonetheless, by simply estimating its size within the organisation and multiplying it by its theoretical environmental impact, an estimation of the impact of each area of the IT can be made. For example, within a certain organisation it may be fruitless to design and quantify a KPI for 'data centre computing', if the organisation only has a handful of servers scattered throughout the office location and there is absolutely no possibility to change the amount of data servers or to incorporate other measures that could reduce the environmental impact of the data centre computing. On the other hand, if an organisation for example has to print a relatively high amount of paper considering its core business, it is wise to incorporate one or more KPIs that asses the amount of prints within the company, whereas for an organisation that prints a relatively small amount and again, there is no possibility of changing the latter, this may be pointless. From this, another closely related requirement derives; **A KPI should be able to measure aspects of the functional areas of the IT individually (e.g. data centre computing, end user computing, printing, etc.).**

Since the main focus of the framework is long-term, repeatable and consistent monitoring of the environmental impact of a large scale multi-national organisation's IT, through KPIs, it is important that the KPIs take changes to the organisation into account and changes to the organisation's environment. For example, if an organisation decides to outsource a large part of their IT, we can speak of a change to the organisation. A change in the organisation's environment can for example be the overall growth of the use of IT, something that is expected to occur in the future (The Climate Group 2008). The KPIs should be robust enough to deal with these changes and still provide consistent and comparable results. There are basically two methods to deal with the aforementioned changes; rebase lining and normalization (Hayard et al. 2007). Either of these methods should be incorporated to one or more of the KPIs. This leads to the following two requirements: **There should be a KPI that takes changes to the organisation into account** and t**here should be a KPI that takes changes to the organisation's environment into account.**

No strict top down or bottom up approach is chosen for the design of possible KPIs. Yet, the KPIs are a trade off between what is necessary to include as a KPI for the assessment of the environmental impact of the organisation's IT and what is feasible to conclude for each part of the IT. The feasibility requirement can be split up into two individual requirements. First of all, it should be feasible to measure a certain part of the organisation's IT within a reasonable time frame with a reasonable amount of effort. Second of all, it should be feasible to design KPIs that require relatively little information from other (sensitive) business operations, as this can highly complicate and delay the process of designing KPIs. Thus, the KPIs should be as narrowly defined as possible thereby paying respect to the most important aspects. Concerning the latter, it would for example be beneficial for the management of the organisation to make a conversion of environmental KPIs to financial KPIs, or at least to incorporate environmental KPIs in financial reporting procedures. By doing this, it can among others be concluded which areas of the IT should be focussed on to achieve the most reductions of the environmental impact of the IT with the least amount of money. However, to facilitate these trade-offs properly, information is needed on budgetary decision and this information should be translated properly to the KPIs (Leahy 2007). This would acquire significantly more time, since information from the business is needed and this information should in turn be interpreted and transformed to the KPIs properly. From the feasibility implications two requirements result, they are as follows: **A KPI should be quantifiable within the organisation within a reasonable timeframe** and a **KPI should be quantifiable within the organisation within a reasonable amount of effort**.

The environmental KPIs can be grouped into two categories, 'lagging' and 'leading'. Lagging indicators are also known as result indicators and are focused on measuring certain parts at certain moments of time from which a change in any direction of the KPI can be concluded. Therefore, lagging indicators can only be validated retrospectively. Leading indicators on the other hand measure internal practices or efforts, for example company policies, which are expected to improve performance. The purpose of leading indicators is less to measure results, but aimed more on encouraging certain actions (Leahy 2007). Since it is important that the key performance indicators serve the goal of working towards a decrease of the environmental impact of the IT, it is wise to incorporate both leading and lagging indicators (Mingray 2007). Hence, **there should preferably be a combination of leading and lagging KPIs.** Lagging indicators can be helpful in the long term to consciously monitor whether improvements related to actions geared at reducing the environmental impact of IT have been achieved. Whereas leading indicators can give clear indications on the measures that could be taken to reduce the environmental impact of the IT. However, it is important that the leading indicators in question actually monitor the elements that are required to be monitored (Banerjee & Marcelino 2006; Moore & Shiskin 1967). In this situation it entails that the leading indicators have good forecasting properties for the environmental impact and thereby concentrate not solely on peaks and troughs. In addition, the leading indicator should anticipate peaks and troughs in the environmental impact systematically, possibly with a rather constant lead-time.

4. Design of the green IT framework

For the next phase of this study, an initial design of a framework will be made on the basis of the requirements that derived from the preceding chapter. The key purpose of the framework is to provide a method to analyze the IT of a large scale multi-national organisation for its environmental impact and to eventually deduce a number of KPIs. The framework therefore specifies the possible KPIs and the method to assess them. Firstly, the core of the framework itself will be presented and how the framework acquired its form in paragraph 4.1. Secondly, in paragraph 4.2, the framework will be elaborated on in depth, for which we will discuss each element of the framework individually.

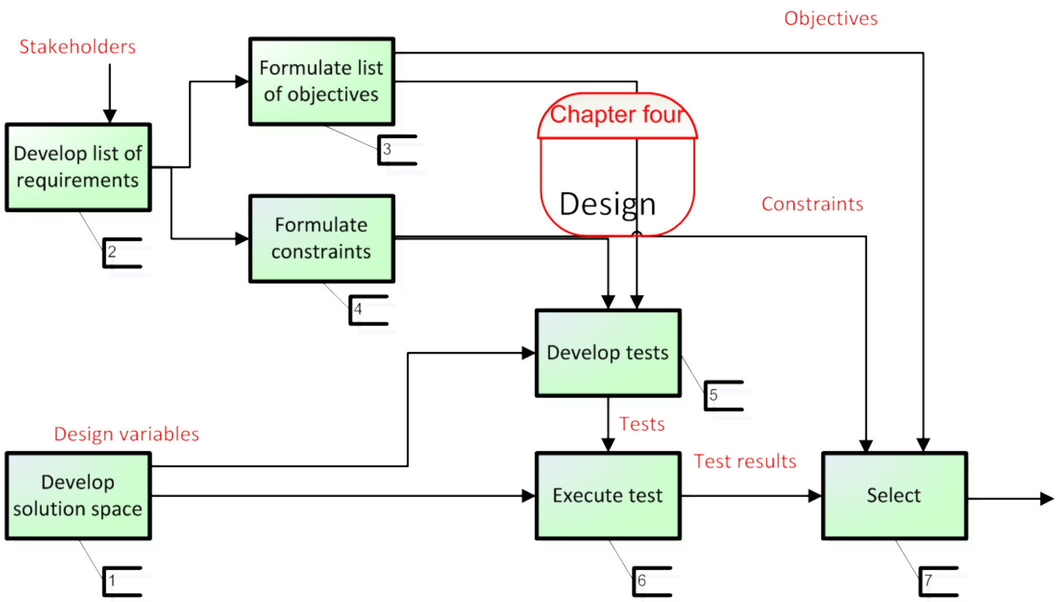

Figure 3: Metamodel chapter four

4.1 Introduction to the framework

The reasons for focussing on green IT for any given organisation are already discussed in the preceding chapters. Thereby it was also concluded that a decent measurement procedure should be in place, so the progress with regard to green IT can be measured. The measurement procedure, which consists of the design and quantification of KPIs that assess the environmental impact of an organisation's IT, will be articulated in the form of a framework. That framework will be presented in this chapter. We have designed the framework on the basis of the requirements, objectives and constraints, which are presented in the preceding chapter. Nonetheless, before the core of the framework is presented, the way in which the framework acquired its eventual appearance will be discussed. Therefore, in paragraph 4.1.1 the foundation of the framework, which is the environmental life cycle of the IT industry, will be elaborated. In subparagraph 4.1.2 the framework itself will be presented.

4.1.1 Environmental life cycle for the IT industry

From subparagraph 3.2.2, where the different grounds of environmental impact of the IT industry are mentioned, it can be concluded that the impact on the environment of IT itself is apparent at every stage of the life cycle of IT equipment. This is again summarized below:

- Direct pollution of air, water and land from the manufacturing, transport, use and disposal of IT equipment.
- GHG emissions resulting from manufacturing, use (power) and disposal of IT equipment and GHG emissions from transport and travel of IT equipment
- Use of hazardous, non-degradable and finite materials at the manufacturing- and disposal phase of IT equipment.

The grounds that are presented relate clearly that the environmental impact of IT occurs at every stage of the life cycle (e.g. manufacturing, transport, use and disposal). Furthermore, the grounds show that a distinction can be made on the type of environmental impact of the IT (e.g. direct pollution of air water and land, GHG emissions and use of hazardous, non-degradable and finite materials). Therefore the environmental life cycle of the IT industry is interesting to look into. A life cycle analysis (LCA) based focus also derives from the ISO 14042 standard, where an environmental LCA is recommended for the assessment of the environmental impact of a product (Hertwich & Pease 1998). A visualization of the environmental life cycle of IT is given below.

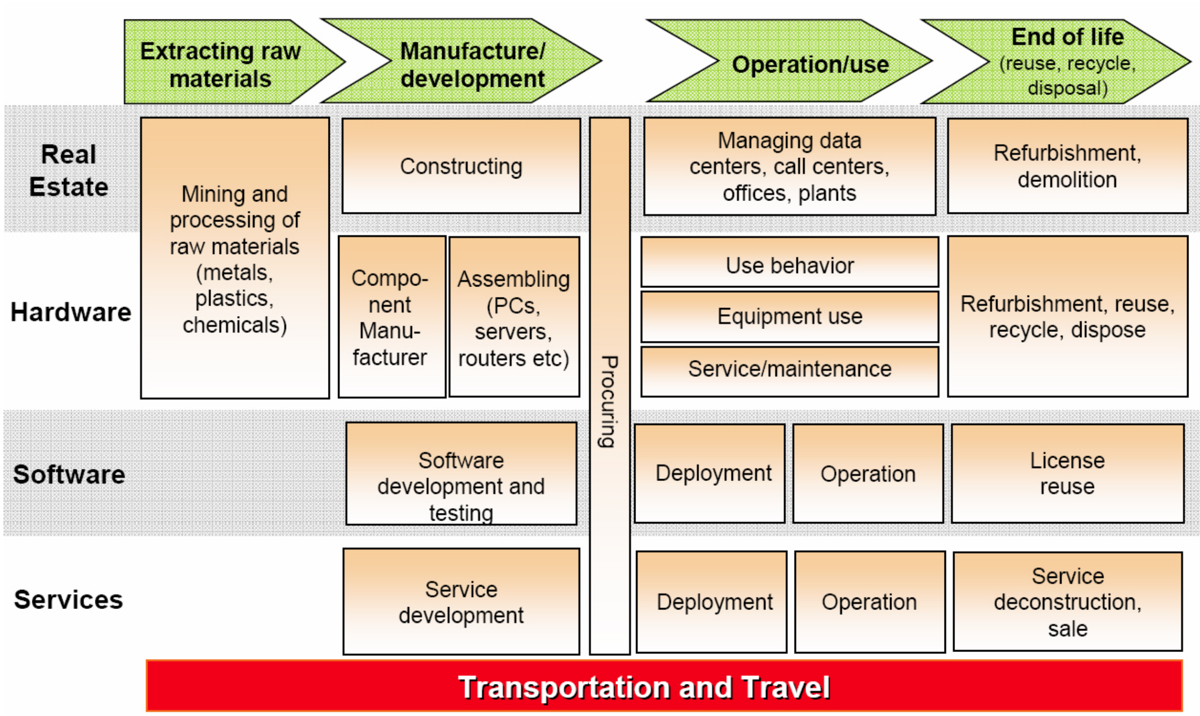

Figure 4: environmental life cycle of the IT industry (visualization adopted from Gartner)

If this environmental life cycle of IT is studied in more detail, it can also be concluded that the level of the environmental impact of IT equipment varies along that life cycle. However, actions aimed at reducing the environmental impact of IT, are not for every organisation at every level of the environmental life cycle achievable to put into effect. For example, a company that produces IT equipment can indeed make a difference in the first part of the environmental life cycle for the IT equipment, whereas a company that only uses IT equipment, will not have that ability. Since the framework is not intended solely for IT producing companies, but rather for non-IT producing organisations, the product centric environmental life cycle for IT equipment shall not provide favourable results for the foundation of the framework. The environmental life cycle is therefore adjusted, so it is confined to the organisational boundaries of a non-IT producing organisation. The 'cradle to grave approach' that is reminiscent of the environmental life cycle is therefore replaced by 'an organisation's entry to organisation's exit approach'. As a result, the following building blocks are to be omitted: "mining and processing of raw materials" and "component manufacturing". Both are areas where a non-IT producing organisation will not be actively involved. Another variation to the environmental life cycle that should be made, entails that the hardware element is taken as chief perspective. This choice is made, considering the fact that most results with regard to reducing the environmental impact can be made the fastest on the hardware level, as the effort to quantify the environmental impact of software and services would be much more laborious. Thus, according to functional requirement 4 - A KPI should only focus on those areas of the IT where a potential difference will lead to measurable changes – in combination with non-functional requirements 5 and 6 - A KPI should be quantifiable within the organisation within a reasonable timeframe and a reasonable amount of effort – the framework will have a hardware centric focus. This is demonstrated in the visualization below.

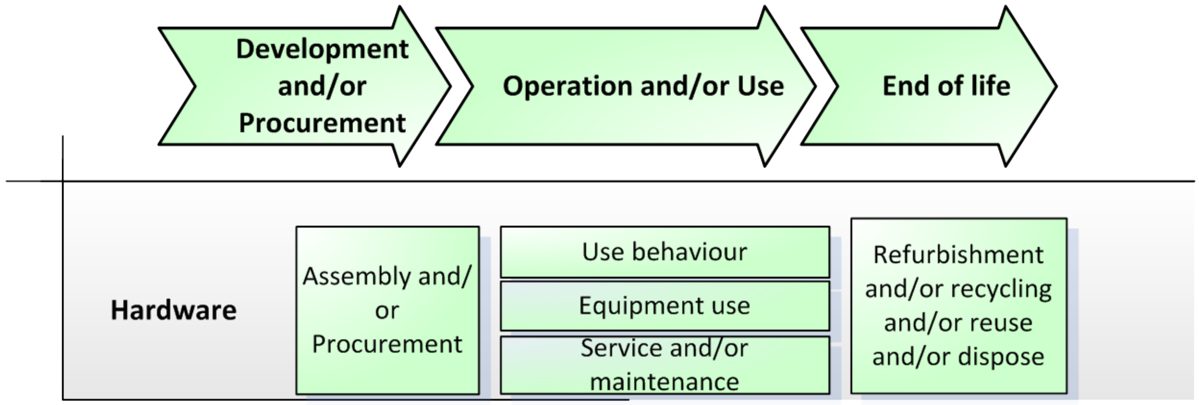

Figure 5: Environmental life cycle of IT for a non-IT producing organisation (adopted from: Gartner)

Given the hardware centric focus of the framework, it could be assumed that the framework deals solely with the IT equipment itself. However, within an organisation, the manner in which the employees are using the IT can have huge effects on the environmental footprint of an organisation's IT as well. Therefore usage patterns are also taken into consideration within the framework (more on this in subparagraphs 4.1.6 till 4.1.9). Furthermore, from the visualization it can be concluded that a factor such as transport is not explicitly taken into account within the framework. Still, it can also be subject to assessment through the embodied energy module (more on this in subparagraph 4.1.3).

4.1.2 From environmental LCA to the framework

The three areas of environmental impact of IT which are first mentioned in paragraph 3.2.2, are taken as the foundation for the design of the framework. In turn, those three areas are transformed to the environmental life cycle of IT for a non-IT producing organisation. The latter, in combination with the requirements for the KPIs, which are discussed in paragraph 3.2, shape the framework. In addition, there are requirements and preferences regarding the design of the KPIs, which determine the eventual framework's layout. The core of the framework, which is deduced from the aforementioned, is visualized at first for the purpose of clarity below in Figure 6.

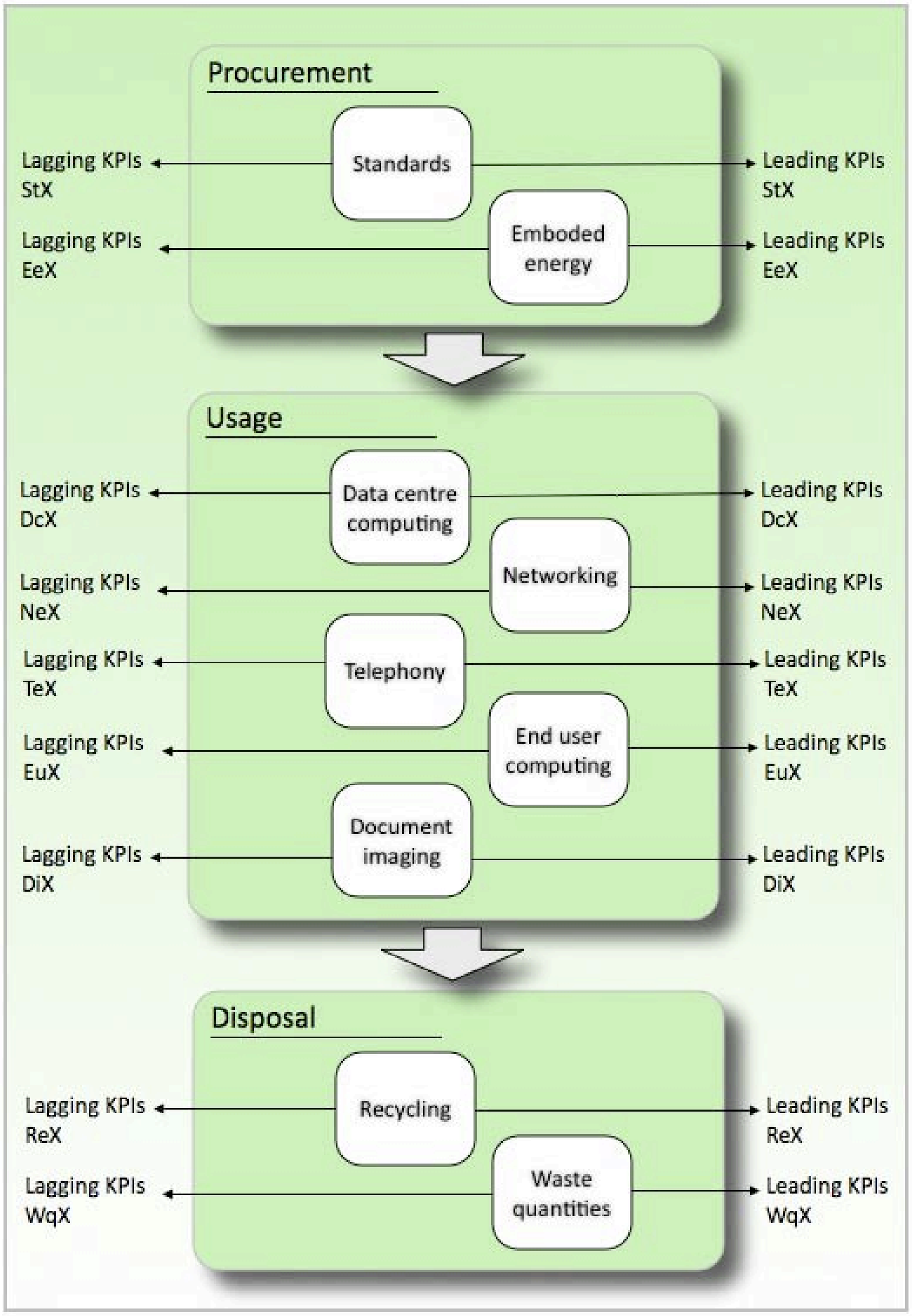

Figure 6: Core of the framework

The three large green boxes represent the building blocks. The nine smaller white boxes represent the modules. The modules and its KPIs will be elaborated on individually in paragraph. 4.2. At first in this paragraph, the requirements and preferences for the design of the KPIs are discussed, which elucidates the definitive shape of the framework.

As already mentioned, the KPIs that are to be designed and quantified serve two main purposes. Firstly, long term repeatable and consistent monitoring of the environmental impact of a large-scale multi-national organisation's IT. Secondly, benchmarking the environmental impact of the organisation's IT relative to other organisations. However, these two purposes can conflict with each other, since for the purpose of benchmarking it is important that there are clear rules on the accounting and reporting procedures to create a level ground, whereas the latter is not required for the purpose of internal monitoring. By indeed incorporating strict rules within the framework on the accounting and reporting procedures, the adoptability and general applicability of the framework would suffer. In addition, since the primary goal of the framework is consistent and internal monitoring and the secondary goal benchmarking, the choice is therefore made not to impose strict accounting and reporting requirements within the framework. As a result the framework will offer the choice between multiple measurement and reporting methods and does not specify a definitive list of KPIs, nor a definitive list of measurement methods. Hereby it is acknowledged that this is disadvantageous for the benchmarking opportunities of the framework. However, the benefit of benchmarking does not outweigh the strict requirements that otherwise would have to be imposed on the accounting and reporting procedures. Furthermore, benchmarking across businesses will still be possible if enough details are reported with regard to the measurement processes.

For adequate decisions to be taken on the basis of the KPIs that derive from the framework, it is necessary for the KPIs to focus on the areas of IT that are most important for the organisation. This rationale results from functional requirement 4; 'A KPI should only focus on those areas of the IT where a potential difference will lead to (relatively) significant changes'. These areas can be important due to the fact that they are highly visible (for example end user computing), or due to the fact that they account for the largest part of the environmental impact of the organisation's IT (for example data centres). In the visualization below (Figure 7) it is demonstrated to what extent each individual piece of IT contributes to the overall environmental impact of IT for the business environment in general. The visualization gives a break up in percentages for the business environment in its entirety. However, as already said, it is well imaginable that the diagram takes on a completely different shape for a specific organisation and as such, the conclusions to draw from functional requirement 4 will be completely different, which leads to different KPIs.

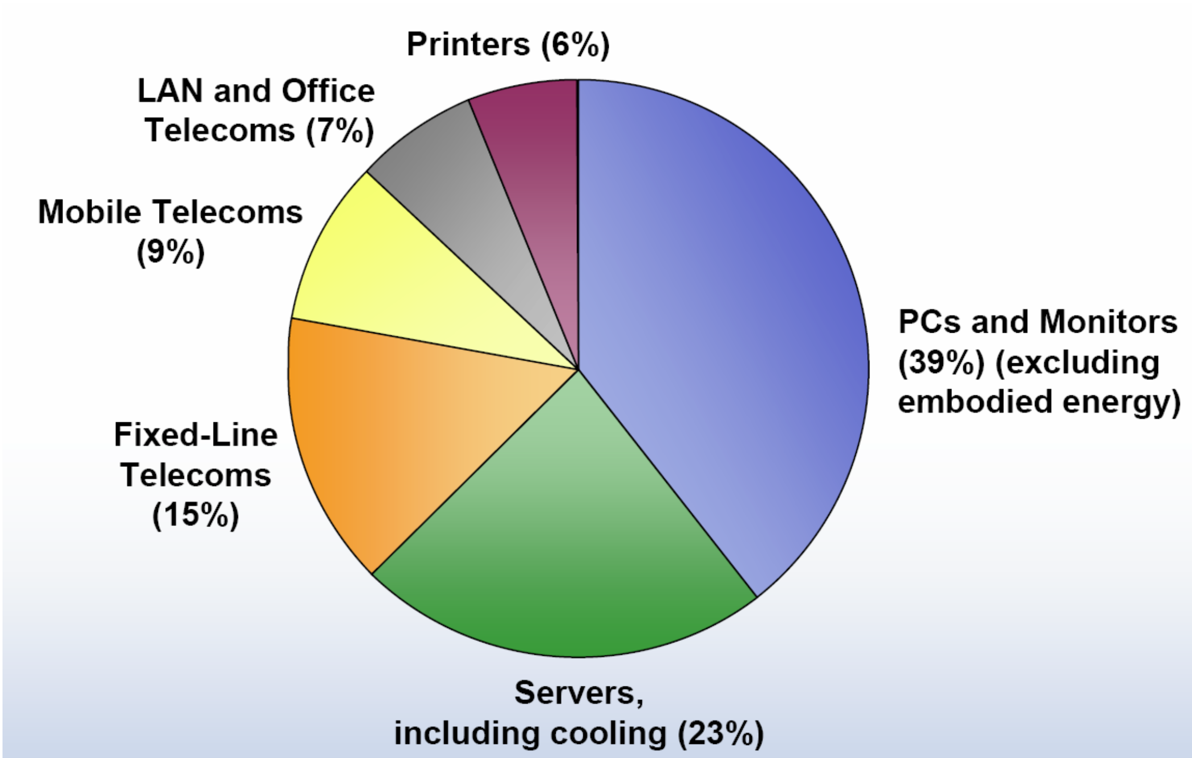

Figure 7: contribution of IT areas to overall environmental impact of IT (source: Gartner)

From the diagram it can be concluded that the main areas that require focus for the business environment in general are: PCs and monitors, servers and cooling and telecoms. Although data centre computing has received the most attention with regard to green IT, the other areas should not be neglected. However, tackling the problem in the other areas is a more difficult challenge because of the behavioural issues that are involved in decreasing the environmental impact in this area, compared to data centre computing where there is a concentration of devices that are power-inefficient and where there is the opportunity to remove significant visible costs (Mingray, 2007).

Non-functional requirement 7 states: "There should preferably be a combination of leading and lagging KPIs". The implication of this requirement is explicitly made within the visualization of the framework by incorporating two output arrows for each module. One output arrow stands for the leading indicators for each module and the other output arrow represents the lagging indicators for each module. This entails that for each module separate leading as well as lagging indicators should be designed and quantified. By specifying both types of KPIs on a module level, the scope of measurement is confined, which has two main benefits. Firstly, the measurement process itself is confined to only the module in question itself, which makes the measuring itself less troublesome. Secondly, the level of detail is higher by specifying both types of KPIs on a module level, which also gives clearer focal points for eventual initiatives aimed at improving the environmental impact. The leading indicators for each module are designed differently than the lagging indicators. The lagging indicators are designed by combining insight from scientific literature, with business literature and interviews. Information on leading indicators however, is very scarce and as a result, we could not derive sufficient information from the literature alone. To cope with this problem, we have decided to organize and conduct a workshop. The main exercise of the workshop was hereby to have brainstorm sessions in several small groups to come up with leading Key Performance Indicators (KPIs) to be used in the assessment of the environmental impact of Shell's IT. The process that was followed for the workshop, details of who the participants were and the results from the workshop, can be read in appendix C.

Functional requirements 4 and 5 - "A KPI has to measure only those things that the organisation can influence" and "A KPI should only focus on those areas of the IT where a potential difference will lead to measurable changes" – necessitate the possibility to specify per organisation which KPIs are to be designed and also what the focus areas for the design of KPIs are. Thus, since the focus areas can differ per organisation, the framework has a modular design to enable the choice for the focus area of the IT. This entails that the framework consists of nine independent modules, from which the KPIs can derive. The choice for the modular design of the framework is also made from a feasibility perspective, which derives from non-functional requirements 5 and 6; 'A KPI should be quantifiable within the organisation within a reasonable amount of time and effort'. It will depend per organisation what information is available for the measurements processes and how much time there is available to carry out the measurement processes. Due to the modular design, certain aspects of the organisation's IT can be neglected at one time (for example because of lack of data), but can be measured for the organisation at another point in time (for example when more information becomes available).

Non-functional requirement 1 states: "A KPI should be able to measure aspects of the functional areas of the IT individually". This creates another reason why a modular design of the framework is chosen. The modular design also ensures that double counting of information is restricted to a minimum. This should be distinguished from redundancy in KPIs, as double counting between KPIs entails that certain information is accounted for multiple times and that as such the results of certain KPIs are distorted. Whereas redundancy in KPIs entails that certain parameters are comparable, but nonetheless they are not one-for-one mutually exchangeable. For the framework this means that different redundant KPIs can be specified per module, but that the redundancy in KPIs should not reach beyond one certain module. For example, within the telephony module, everything concerning telephony could be measured by means of multiple KPIs. However, it should not be the case that KPIs are designed that incorporate the energy usage of certain parts of telephony, in for example, the networking module.

It was already mentioned that for the choice of KPIs, feasibility played a role. Thus, the same can be said for the choice of the modules within the framework. The nine modules that are part of the framework are not only chosen because these modules are important to include in the assessment, but also because of the fact that for these modules it is feasible to derive adequate KPIs. The latter is thus a combination of the functional requirements 5 'a KPI should only focus on those areas of the IT where a potential difference will lead to measurable changes' and again non-functional requirements 5 and 6. One module that in theory could be part of the framework, but does not belong to the framework because of feasibility motives, is the module for employees. In theory it could be possible to conclude the environmental impact of each employee working for the IT department of the organisation. However, this would be too difficult to measure within a reasonable timeframe with a reasonable amount of effort, since this would require a great number of extra calculations. Factors that should also be taken into account in such a case are for example: traffic distance per employee, working hours, working behaviour, etc. Considering the complexity of gathering all the required data, it is preferred to not measure this element, because of feasibility motives. Nonetheless, the implications of staff attitude and staff policies, could be incorporated in the framework as a leading indicator within one of the modules (more on this in paragraph 3.2.).

As already discussed, the environmental life cycle approach forms the basis of the framework. This is incorporated in the framework by the categorization of the modules, seeing as the nine modules are categorized on the basis of the three building blocks of the framework: procurement, usage and disposal. The building blocks group the separate modules together. Since each building block focuses on a separate part of the environmental life cycle, the KPIs that can be deduced from every building block have a different focus. Even though the modular design of the framework acknowledges the possibility of excluding certain modules for the analysis, a preferable outcome of an environmental analysis on the basis of the framework would include KPIs of every building block, since only in that case is the whole environmental life cycle taken into account.

As already mentioned each module has one or more KPI as output. Since the main goal of the KPIs, and the framework in general, is long term repeatable and consistent monitoring of the environmental impact of a large scale multi-national organisation's IT, it is important that the KPIs can be normalized for changes in the organisation or the environment, or provide another way to adequately compare the data of the past with the present, in the circumstance of major changes within the organisation itself or the organisation's environment. An example of a change in the organisation, is a merger or an outsourcing of the entire IT or a certain part of the IT. A change in the organisation's environment can for example be the overall growth of the use of IT, something that is expected to occur in the future (The climate group 2008). There are basically two methods to deal with the aforementioned changes; rebase lining and normalization (Hayward 2007). With rebase lining the data that is measured is calculated and in turn adjusted to a base situation, this is also the method that is proposed by the GHG protocol (The Green House Gas protocol 2004). With normalization, the value that is measured is expressed relative to some measure of output (Dunn & Knight 2005). Thus the metric that serves as an output is composed on the basis of a numerator and a denominator. For example, total power consumption per employee. The method that is chosen for this framework to deal with the changes in the organisation and/or the organisation's environment, is not to rebase line the KPIs each time they are measured, but to normalize the KPIs by including for each module at least one KPI that shows the efficiency in such a way that it is independent of the number of installed units, for example, a KPI that relates the output in KWH to an employee. This choice is made first of all because the inclusion of a rebase lining method that uses a base situation would require more effort each time the KPIs will be designed, since the conversion will have to take place in the base situation. Secondly, the chosen method of normalization provides better opportunities for benchmarking, which is the secondary goal of the framework, in comparison to the method of rebase lining of the KPIs, as the rebase lined data would be organisation specific after a longer period of time and thus not straightforwardly comparable with other organisations, whereas normalized data can indeed be one-on-one comparable between different organisations (Dunn & Knight 2005).

4.2 Modules of the framework

The modules of the framework are the main focus areas for the actual measuring process if the framework is applied. The nine modules of the framework each concentrate on a different area of an organisation's IT and as a result, the measurement process for quantifying the KPIs varies per module. In addition, since each module has different characteristics, the number of KPIs that should be derived per module varies. In this paragraph, each of the nine modules will be discussed individually, from subparagraph 4.2.1 to subparagraph 4.2.9. Hereby the measurement process and the potential KPIs will be elaborated per module. In the final subparagraph, 4.2.10, the possible KPIs and measurement processes for each module are summarized by means of a diagram. Also for each module, the leading KPIs will be discussed next to the lagging KPIs. The leading KPIs derive from the workshop that was given at Shell. Since the leading KPIs are solely suggested KPIs and are as such not studied into detail, the measurement process will not be discussed for these KPIs.

For each module, multiple potential KPIs will be elaborated at first. Then, from the gross list of KPIs, a subset will be presented as 'suggested KPIs'. The gross list of KPIs was formed by the literature study and on the basis of interviews with multiple experts within Shell. Subsequently, a selection of this gross list of KPIs is made, based on the opinions of the experts on the respective modules, thereby taking feasibility of the required measurements into account. The process of selecting the 'suggested KPIs' from the gross list of KPIs was carried out in parallel to the case study (more on this in paragraph 5.3). Yet, for the purpose of the selection of suggested KPIs, the experts of the respective modules were asked questions on the importance of the relevant KPIs, next to questions on the feasibility of measuring the KPIs within Shell. In addition, the result from the workshop that was aimed at designing leading indicators was added to the list of suggested KPIs. However, as said before, these leading KPIs are less funded on literature than the lagging indicators and therefore are not definitive and as such subject for further research. Below, the design process of the KPIs is visualized.

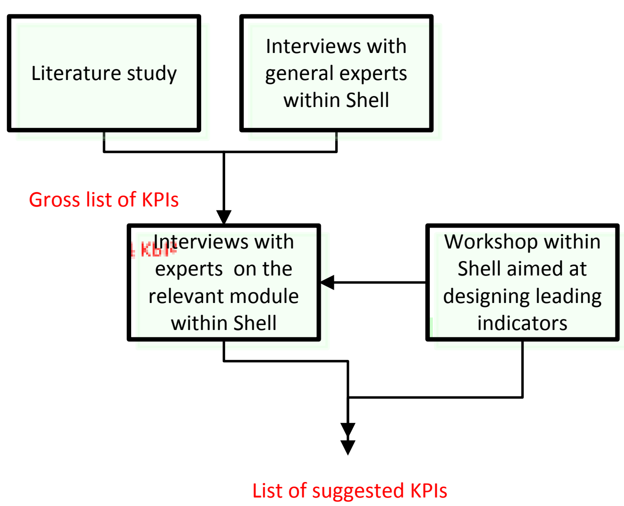

Figure 8: Design of KPIs

4.2.1 Standards

This module is part of the procurement phase. The procurement phase is an important phase to look into for a non-IT producing organisation if it aims to reduce its environmental impact, since a non-IT producing organisation cannot make a difference in the first phases of the life cycle (e.g. extracting raw materials, manufacturing, developing, etc.). A non-IT producing organisation can however make a judgement on the type of equipment they procure and whom they procure from, with regard to the environmental impact of that equipment. In paragraph 2.1.4 the existence of voluntary environmental performance labels and declarations of IT equipment has already been pointed out. These standards can be used by an organisation to determine what type of equipment to procure. However there is a multitude of standards in existence that aim to have the same goal, but each have their positives and negatives. It is first important to point out which standards are helpful to look into and which are not.

Within Europe there are multiple standards available for the producers of IT equipment to assess the environmental impact of its products. The International Organisation for Standardization (ISO) has categorized the different voluntary standards into three broad types of labels. Type I (ISO 14024) consists of a voluntary, multiple criteria-based, third party program that awards a license that authorises the use of environmental labels on products, based on life cycle considerations. Type II (ISO 14021) consists of informative environmental self-declaration claims. The third type consists of environmental product declarations, but is not widely in use as of yet (November 2008) (Jonbrink & Amen 2007). Although the different types of voluntary agreements have different origins, their meaning and use can be the same for the consumer, which is to acquire immediate insight into the environmental friendliness of the product. For this purpose, it is essential that the label for environmental friendliness is awarded on sufficient grounds and in a just manner. Examples of standards that satisfy these criteria are: Energy Star, TCO, the Flower, the Swan, the Blue Angel and EPEAT.

Energy Star is a labelling scheme for computers, laptops and monitors introduced by the US Environmental Protection Agency (EPA) in 1992 (Energy Star n.d.). Of all labelling schemes, Energy Star has the best market coverage for computers (Meier 2003; Wiel, McGregorry & Herrington 2003). The European Energy Star programme today qualifies 268 PC models (Jonsbrink & Amen 2006). The TCO labelling does not only cover environmental issues, but also addresses other issues regarding the work environment, such as image quality, noise and electromagnetic emissions. Currently (November 2008), about 50 % of all computer displays in the world are TCO-labelled (about 3500 models). About 20% of computers are TCO-labelled (TCO n.d.). The flower is an eco label from the European Union and is to a large extent comparable with the aforementioned labels. Nonetheless, today no IT equipment has yet been labelled with this standard (Jonbrink & Amen 2007; The EU eco label n.d.). The Swan and the Blue Angel are comparable national initiatives of respectively Norway and Germany (Svanen n.d.; Der Blaue Engel n.d.). Finally, EPEAT is a system where manufacturers add their products to the registry by declaring that the products meet specific individual criteria of IEEE 1680. As with Energy Star and other voluntary declaration labels, there is no verification of this declaration at the time the product is registered, but manufacturers must be able upon request to produce the supporting evidence for product declarations spelled out in the IEEE standard (EPEAT n.d.).

From the aforementioned labels, only the use of Energy Star and TCO are widespread and to a lesser extent EPEAT (Jonbrink & Amen 2007). Considering the first functional requirement regarding the consistency of measurements, it is advised to only focus on labels that are in relatively widespread use. If this is not the case, then it could easily be falsely concluded that progress with regard to the procurement of IT equipment has been reached, whereas this is not in actuality the case, but rather the equipment database of the label has been expanded. As such, it is not recommended to monitor the less used environmental labels: the Flower, the Swan or the Blue Angel. Thus, the standards to incorporate in the measurements are preferably: Energy Star, TCO and EPEAT. Nonetheless, for each organisation another selection of standards can be made if this better suits the organisation. It is for example imaginable that a certain organisation has specialized equipment that does not use the common standards as energy star and TCO, but that other standards are used which serve a similar purpose. These specialized standards can in that case be used as a substitute for the preferred standards.

Next to the voluntary standards that were discussed above, there are also standards that derive from existing mandatory law. The two most important standards in this regard derive from directives of the European Commission. These are the Waste for Electric and Electronic Equipment (WEEE) directive and the Restriction of Hazardous Substances (RoHS) directive. If an electronic device complies with the WEEE standard it entails in short that the separate collection for disposal of the electronic equipment should be taken care of by the manufacturer, or that the manufacturer takes care of this task in another manner and that as such the electronic equipment does not get disposed as municipal waste (EU 2003). Furthermore, the manufacturer should facilitate the possibilities of reuse and recycling of the equipment as much as possible (Stevels 2003; Gottberg et al. 2006). The ROHS standard implies that the equipment does not contain lead, mercury, cadmium, hexavelent chromium, polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE) (EU 2003; Cussack & Perret 2006). Both standards are compulsory for all member states of the European Union. Hence, no electronic equipment may be produced or imported that is not in line with one of the two standards. However, in most countries outside the European Union such strict environmental requirements are not imposed. Therefore, the compliance ratio to one of the two EU standards can be helpful to incorporate if an organisation has much of its activities outside the European Union. At the same time it should be kept in mind that if an organisation has much of its operations in the nations of the European Union, the compliance to either of these standards is probably higher than if they would have most of their operations outside the European Union. This however, should not be a problem as the WEEE and ROHS standards are also used outside the European Union and also similar standards are in use in other countries, that can be used as a substitute (Hicks, Dietmar & Eugster 2005).

Until this point, we have only discussed environmental standards that focus mainly on the environmental impact of the IT equipment when in use and standards that focus on the use of hazardous and non-degradable materials at the manufacturing and disposal phase of IT equipment. However, as argued in paragraph 2.1.3, the environmental impact of the IT encompasses more than this. For example, the direct pollution of air, water and land from the manufacturing, transport, use and disposal of IT equipment cannot be assessed by one of the aforementioned standards. One of the methods to actually assess this, is by carefully selecting the supplier and thereby paying respect to, for example; the necessary transport distance for the IT equipment and the manufacturing process of the IT equipment. However, for these areas, no unified standards have yet been defined. Therefore, this cannot be part of this module of the framework at this time. Nonetheless, if in the future standards are developed that focus on these areas, they could and should be incorporated in the assessment process for this module. Another possibility to cope with the problem is to assign a separate module for supplier management. However, for the design of the framework the choice was made to focus on embodied energy instead, as with this module clear numbers can be given on the amount of energy that is required for the manufacturing and transport of the equipment.

Possible KPIs

The manner in which the incorporation of standards in the procurement phase should be quantified, can also vary per organisation. One method would be to define a ratio of the total equipment complying with one of the three standards against the total of equipment procured in that period, which is for example a year. A variation can be to define a ratio of the total equipment complying with all three of the standards against the total of equipment procured in that period. In this regard, the organisation that effectuates the framework, should make a choice on how high they want to set their 'standards KPI'. Since compliance to EPEAT gold stands for the most environmental friendly IT equipment in comparison to the aforementioned standards, a KPI where the ratio to compliance to EPEAT gold would be measured, will have the highest level of environmental friendliness, whereas a ratio of compliance with energy star would have the lowest level.

As already pointed out, multiple variations are possible for this KPI, depending on the level of environmental friendliness an organisation wants to achieve and the type of IT equipment an organisation procures. The choice for the focus on the types of standards should therefore be made by the organisation that effectuates the framework. Nonetheless, examples of KPIs for this module can be given. They are as follows:

- Percentage of IT equipment procured in one year, complying with any environmental standard
- Percentage of IT equipment procured in one year, complying with EPEAT Gold
- Percentage of IT equipment procured in one year, complying with at least EPEAT Silver
- Percentage of IT equipment procured in one year, complying with one of the TCO standards
- Percentage of IT equipment procured in one year, complying with the WEEE directive
- Percentage of IT equipment procured in one year, complying with the ROHS directive.
- Percentage of IT equipment procured in one year, complying with Energy Star standard
- Percentage of IT equipment procured in one year, complying with either Energy Star, TCO or EPEAT

As the KPIs define percentages, it is important to pay careful attention to what should serve as the total from which the percentage should derive. One possibility is to quantify a percentage from the total of IT equipment procured. The danger from doing so however, lies in the fact that standards are not awarded in the same way for every type of IT equipment,. For networking equipment for example, the granting of standards is less wide spread (Jonbrink & Amen 2007). So if an organisation procures a relatively high number of network equipment in a certain period, the output of the KPI would be lowered falsely. A solution is therefore to only specify this KPI for a certain group of IT equipment where the granting of standards is indeed wide spread and to consistently focus on this group alone for designing the KPIs (for example desktop computing and servers alone). Another solution is to specify one percentage per narrowly demarcated group of IT equipment, so multiple percentages and as a result multiple KPIs result from this module. Examples of KPIs in this case are:

- Percentage of desktops and notebooks procured in one year, complying with EPEAT Gold
- Percentage of servers procured in one year, complying with Energy Star standard
- Percentage of monitors procured in one year, complying with TCO'03

In appendix B it is investigated how each different standard measures the environmental impact differently. Herein in it concluded, that between the different standards, there is a relatively large overlap of measurement points. The elements of the TCO standard for example, are also covered by the EPEAT gold standard. Therefore, quantifying both the TCO and EPEAT gold standard would be a pointless effort. Since EPEAT gold covers more elements than TCO, it is recommended that EPEAT gold is taken as preferable KPI. It is purposely chosen to focus on standards specifically for the procurement phase and not also on the numbers specified by the manufacturer concerning usage power, standby power, etc. as these numbers tend to be rather inconsistent between different manufacturers (Jonbrink & Amen 2007). The standards however are measured and monitored by a third party and they use the same consistent measurement procedure for each piece of equipment. Therefore it is more valid to compare the results on the basis of standards, than on the basis of manufacturer data, as manufacturers obviously tend to specify these numbers as low as possible.

Also two leading indicators are suggested for this module. The leading indicators originate from the workshop that was held at Shell, which focuses on the design of leading KPIs (appendix C). The purpose of leading indicators is less to measure results, but aimed more on encouraging certain actions (Leahy 2007). As already advocated, it is wise to incorporate both leading and lagging indicators, since it is essential that the key performance indicators serve the goal of working towards a decrease of the environmental impact of the IT. The leading indicators give clear steering abilities in this regard. The first leading indicator is percentage of outstanding orders complying with the Energy Star standard. With this leading KPI, an actual number can give insight into the compliance with the Energy Star standard. In this case, the Energy Star standard is taken as primary standard, yet other standards could also be used for this KPI. Since this KPI gives insight into the number of outstanding orders, as opposed to the number of procured equipment over a preceding time frame, this is a leading KPI. Therefore, this KPI can be used directly to change the behaviour of, for starters, the procurement department. A second leading KPI that is suggested for this module is, importance of environmental criteria in the procurement process. This KPI gives insight into the importance of environmental criteria for the procurement of IT equipment. A simple rationale is the foundation for this KPI. Namely, the more important environmental criteria are in the procurement process, the more environmentally friendly the procured equipment will be. In order to effectively utilize this KPI however, it is important that there is consensus concerning the terms 'importance' and 'environmental criteria'. 'Importance', in the KPI definition, is the factor that should be quantified and therefore this is also the term that should be specified carefully. Secondly, it is important to adequately demarcate the term ‘environmental criteria’. What some may consider an environmental criterion could for others be simply an economic criterion. An example in this regard is the criterion of power consumption in the procurement process. It is suggested therefore, to incorporate the same standards as environmental criteria for the KPI as with the other KPIs of this module.

The suggested KPI for this module are summarized as follows:

1. Percentage of IT equipment procured in one year, complying with the WEEE directive
2. Percentage of IT equipment procured in one year, complying with the ROHS directive
3. Percentage of IT equipment procured in one year, complying with the Energy Star standard
4. Percentage of desktops and notebooks procured in one year, complying with EPEAT Gold
5. Percentage of outstanding orders complying with the Energy Star standard (leading)
6. Importance of environmental criteria in the procurement process (leading)

Measurement process

One method to measure this KPI is to look at the track records of the procurement department. From that data it can be deduced what the total of procured IT equipment was for a given period and which equipment it was. By looking into the procured equipment, it can then be concluded with which standards the IT equipment complies. The suppliers of the IT equipment can aid in the latter, by providing the relevant information if necessary. Another method is to include criteria as compliance to standards within the track record of the procurement department to easily conclude the percentages. In this way, one aspect of the measurement process gets allocated to the procurement phase. This could have an added benefit that the procurement department pays more attention to the standards and acts accordingly.

For this module it is also important that there is a clear definition of the equipment that is subject to assessment, as this can easily have many interpretations. For example, ‘IT equipment’ can only involve desktops, notebooks and monitor, but also the aforementioned equipment plus mobile phones, printers, beamers, toner, etc. Therefore, whenever the term ‘IT equipment’ or ‘equipment’ is used, it is advised to clearly and explicitly specify what is meant with the terms. By explicitly specifying the usage of the term ‘IT equipment’ also the scope of the measuring process can be defined. As discussed above, a distinction within ‘IT equipment’ can be made on the basis of different types of IT equipment, for example; monitors or computer mice. Also, in this case it is important to explicitly define the scope of the equipment, as the category computer mice could concern solely computer mice, but also for example trackballs and pen tablets. Thus, a carefully chosen and explicitly articulated definition of the equipment that is under review is crucial. Considering the general applicability feature of this framework, no definition or demarcation of the equipment that should be incorporated in the measurement process will be given, as restraints on the measurement process and/or the needs and goals of different organisations should determine the scope of the measurements. This stresses the importance of a careful articulation of the scope of the terms even more.

4.2.2 Embodied energy

Embodied energy is the energy required directly and indirectly to manufacture products (Treloar 1998). This can be seen as an accounting methodology with the goal of quantifying the total amount of energy that was necessary to acquire the end result of the product in question. In order to quantify this number, different steps of the product life cycle should be investigated, including the raw material extraction-, refining-, transport-, manufacturing-, assembly- and installation phase. In addition, the final phases of the product life cycle should also be accounted for, including disassembly, deconstruction and/or decomposition. There are different methodologies to quantify the embodied energy. One of these methodologies is that of 'process analyses', for this methodology the energy embodied in a product is traced upstream by examining the inputs to each preceding process towards raw materials. Unsurprisingly, this methodology can lead to serious feasibility problems, as it is extremely difficult to quantify the amount of energy as input for every step of the product life cycle. Another major embodied energy analysis methodology, is the 'input-output analysis', this comprises the use of national statistics combined with product specific conversions, in order to quantify the total amount of embodied energy of a certain product (Treloar 1998). This method makes use of many assumptions and generalizations and therefore this method produces unreliable results if inadequate effort is spent on the computation processes (Lenzen 2002).

However, as of yet there is no consensus in either the scientific world or the business environment on which methodology to use for quantifying the amount of embodied energy. Therefore the numbers for embodied energy for IT equipment vary greatly per manufacturer (Mingray 2008). This would have large consequences for the consistency of data, if an organisation would switch between IT equipment manufacturers and as such has to rely on other calculations for the embodied energy. Therefore, the embodied energy module of the framework is at present not properly incorporated in the framework and it is advised to leave embodied energy out of the scope of the framework until there is more consensus on the methodology for quantifying the amount of embodied energy. Because of the fact that embodied energy is indeed an important factor to look into, as it makes up for a relatively large part of the environmental impact of IT, the embodied energy module is still a part of the framework. It however cannot be quantified adequately at present and until more consensus on the methodology is achieved, it cannot be defined consistently as KPI.

Therefore, for this module there are no KPIs suggested.

4.2.3 Data centre computing

The data centre computing module belongs to the usage phase of the framework. So for this module, only the environmental impact resulting from the usage of a data centre will be quantified by means of KPIs. However, this is a more encompassing task than it might seem at first sight, since a data centre houses more than only the data servers themselves. For example, the cooling for the data servers is a crucial element of data centre computing. Data centres are characterized by very high energy utilization intensities and the internal heat load of the servers creates a nearly constant demand for air conditioning to maintain equipment within a narrow range of temperature and humidity, which is necessary for proper operation (U. S. Environmental Protection Agency Combined Heat and Power Partnership 2007). Accordingly, data centres have much higher energy utilization intensities, approximately 20 to 100 watts per square foot, compared to typical commercial buildings, which average at 2 Watts per square foot (Energy Information Administration 2007).

The equipment contained in a data centre can be divided into two main categories: infrastructure equipment and Information Technology (IT) equipment. The first category includes the equipment for conditioning and distributing electrical power (e.g. transformers, switch gear, uninterruptible power supplies, power distribution units, circuit breakers, and distribution wiring), as well as equipment used to remove waste heat from the data centre (e.g. Computer Room Air Conditioners [CRA Cs], Computer Room Air Handlers, Direct Expansion (DX) coolers, chillers and pumps for circulating chilled water, and cooling towers). IT equipment includes the servers that run the operating system and application software that produce the primary work product of the data center along with support hardware such as storage devices and networking equipment (The Green Grid 2008).

Since there are multiple ways to look at data centre computing, it is wise to give a clear definition of data centre computing as it is used for this module. For example, data centre computing can be approached by looking solely at the servers at a data centre. On the other hand, data centre computing can be approached by taking the whole data centre as a starting point, thereby including all infrastructure equipment from the data centre, the IT equipment from the data centre and the network elements necessary to connect the data centres to the office environment. By taking the functional and non-functional design criteria for the KPIs as point of departure, the definition of data centre computing for this module fits in the midst of the two types of definitions given above. Data centre computing for this module involves all equipment that is situated at a data centre, thus including all infrastructure equipment and IT equipment. However, the network necessary to connect the data warehouse to the office environment is not included. The functional design criterion that justifies the latter is: 'A KPI has to measure only those things that the organisation can adjust'. The network itself which is used to connect the data warehouse to the office environment is in most cases not owned or managed by the same organisation that uses the data centre. As a result, there is little to no influence on the type of network to be used and as such it is not worthwhile measuring these data. On the other hand, the same functional design criterion used for the aforementioned rationale, justifies the decision to incorporate the cooling and network equipment in the definition. The cooling and network equipment is in a large number of cases either property of the same organisation that uses and manages the data centre and otherwise, the organisation that only uses the data centre can have influence on the type of equipment that should be used for this purpose.

Possible KPIs

From the aforementioned it can be concluded that each aspect of data centre computing has a certain impact on the environment and as such it would be inadequate to focus on the servers within a data centre alone. Hence, the building itself including lighting and cooling, would not exist if there were not a need for the servers. Therefore multiple KPIs should be designed for this module to properly quantify the environmental impact of data centre computing. These KPIs should give insight in total power consumption of the data centre as a whole, but also the efficiencies within the data centre, as for the latter much improvement can still be achieved with regard to the environment (Hird 2008, p. 89).

The first KPI for this module is the total facility power. This is the total of power that the data centre facility uses. By including this KPI, the cooling, lighting and other overhead of the facility is also measured. This KPI can be measured in KWhs. In addition, by multiplying the total energy consumption with numbers on the energy mix, a transformation to kilograms of CO2 is made. The same procedure is used for the standard CO2 calculations that are based on the GHG protocol (Shires & Loughran 2004). However, the total facility power KPI and the CO2e KPI do not take the overall growth of the IT into account. Therefore more KPIs that focus on efficiency should be quantified, these are: power usage efficiency (PUE) and data center infrastructure efficiency (DCiE). These KPIs can be computed as follows:

$$PUE = \frac{\text{Total facility power}}{\text{IT equipment power}}$$

$$DCiE = \frac{1}{\text{PUE}} = \frac{IT\ equipment\ power}{Total\ facility\ power} \times 100\%$$

While both of these metrics are essentially the same, they can be used both to illustrate the energy allocation in the data centre differently. For example, if a PUE is determined to be 3.0, it indicates that the data centre demand is three times greater than the energy necessary to power the IT equipment. Additionally, the ratio can be used as a multiplier for calculating the real impact of the system's power demands. For example, if a server demands 500 watts and the PUE for the data centre is 3.0, then the power from the utility grid needed to deliver 500 watts to the server is 1500 watts. The DCiE serves more of a communication purpose, taking the PUE as base value. For example, a DCiE value of 33%, which is equivalent to a PUE of 3.0, suggests that the IT equipment consumes 33% of the power in the data centre and that as such, in theory, 66% of the energy is going to waste (Youssif & Dollars 2008; The Green Grid 2007).

In addition, it is preferable to show the relation between the organisation's size and the power usage from the data centre. This so called normalization requirement, results from non-functional requirements two, three and four, which entail respectively that there should be a KPI that takes changes to the organisation into account, there should be a KPI that takes changes to the organisation's environment into account and that the KPI should provide benchmarking opportunities. A KPI that should be incorporated that takes the normalization into account, is a KPI that relates the total power usage of the data centre to the number of employees within the company. It is debatable whether there also should be a KPI that relates the total power usage of the data centre to the revenue of the company. Incorporating the latter has the benefit of providing yet another normalized KPI, thereby enhancing among other things the benchmarking opportunities of the model. On the other hand, is it questionable whether a ratio to the total revenue is wise to incorporate, as it is extremely difficult to align the scope of the total energy usage with the total revenue. As a result, the KPI does not give a good representation of the actual output. In other words, no proper conclusions can be drawn on the basis of that KPI. Therefore it is advised not to incorporate a KPI that is normalized to revenue. Nonetheless, there are other normalized KPIs that can be designed, these KPIs focus on the utilization of the data centre. These are: data centre productivity (DCP) and compute power efficiency (CPE) (Malone & Belady 2007; The Green Grid 2007). These KPIs can be computed as follows:

$$\text{CPE} = \frac{\text{IT equipment utilization} \times \text{IT equipment power}}{\text{Total facility power}}$$

$$\text{DCP} = \frac{\text{Useful work}}{\text{Total facility power}}$$

Both formulae have some interesting features, they are unit-less and as such provide easy benchmarking opportunities between multiple data centres. Moreover, the ultimate goal of the metrics is clear, to reach the highest possible number. However, both metrics pose a serious difficulty. Namely, it is nearly impossible to adequately measure the utilization or the amount of useful work within a data centre. A possibility to quantify the utilization, in the case of the CPE metric, is to monitor the CPU utilization of the servers. However, if the CPU utilization would be used as a proxy for measuring the IT equipment utilization, the CPU overhead would not be accounted for. Furthermore, if some type of CPU-speed stepping would be used for power management purposes of the CPU, the measurements will be drastically skewed (The Green Grid 2008). In the case of the DCP KPI, it will prove even more troublesome to get a proper quantification of 'useful work'. Therefore it is suggested to only specify the CPE or DCP if there are means in place to adequately quantify each variable of the formula. Based on interviews we have conducted within Shell, we can conclude that this is not the case in most organisations nowadays and therefore the CPE and DCP are not part of the list of suggested KPIs.

For this module, again two leading KPIs are suggested that originate from the workshop (see appendix C). The first leading KPI is; there a policy in place aimed at reducing the energy consumption of the data centre? This leading KPI is rather straightforward in the sense that the answer could be either 'yes' or 'no'. Nonetheless, it is important to demarcate what is meant with 'a policy to reduce the energy consumption'. In a way, this leading indicator is similar to the leading indicator from the standards module, which quantifies the importance of environmental criteria in the procurement process. Again, here it is important to carefully specify when it is considered a policy and when it is indeed aimed at reducing the energy consumption of the data centre. Thus these elements need to be specified beforehand, by the organisation that aims to utilize this leading KPI. A second leading KPI is; virtualization of the data centre. The underlying rationale for this KPI is, the more virtualization is used within the data centre, the better use is made of the power consumption management within a data centre. Virtualization, entails that data centre servers are used to operate processes in parallel, for which more efficient use will be made of the available hardware in the data centre. For this leading KPI, it has to be specified by the company that will effectuate this KPI, how they aim to quantify the element of virtualization.

The suggested KPIs for this module are as follows:

1. Total power consumption
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area in
5. Is there a policy in place aimed at reducing the energy consumption of the data centre? (leading)
6. Virtualization of the data centre (leading)

Measurement process

The total power consumption of the facility can be measured by interpreting the data from the meter of the facility. This KPI is therefore relatively easy to quantify. However, this holds only true if the data centre is in a separate building with its own energy meter. If the data centre is in a shared building, the task of quantifying the total power requirement is less easy. One method to quantify this KPI in this situation, is to subtract the power necessary for the office environment, from the total power consumed in the building. In this situation, the data centre administrator would have to measure or estimate the amount of power being consumed by the non-data centre offices, which in the case of an estimate, will obviously introduce some error into the calculations. Furthermore, if the CO2 values of the total facility power are to be calculated, it is necessary to acquire the correct numbers on the energy mix. For example, if renewables are used as the sole energy source for the data centre, the corresponding CO2 value would be nil. The GHG protocol has provided a number of tools with which the CO2 values can be computed, thereby taking the energy mix of separate countries into account.

For the potential other KPIs of this module, PUE and DCiE, the power consumption of the IT equipment itself has to be measured. This can be done by taking the data on power usage from the manufacturer as starting point and computing the total number, or by actually monitoring the power usage of the equipment with power monitors and similar equipment. This should be measured after all power conversion, switching, and conditioning is completed and before the IT equipment itself. The most likely measurement point would be at the output of the computer room power distribution units (PDUs). This measurement should represent the total power delivered to the racks in the data centre (The Green Grid 2007). This method would provide better data if it is carried out thoroughly than the method of computing the whole number. Nonetheless, it is a rather laborious task and requires as such considerable time investments. Therefore again, the organisation that effectuates the framework should make a trade-off for the measurement process for this KPI. Hence, the PUE and DCiE are not incorporated in the list of suggested KPIs.

4.2.4 End user computing

Whereas data centre computing concentrates on the computers that form the backbone of most modern organisation's computer networks, end user computing constitutes the forefront of the computer network for most of the organisation's employees. Thus, end user computing comprises the computing equipment the employees within the organisation use for their daily work. Desktop computers, monitors, thin clients and notebooks therefore belong to this module. This module can be considered as the most important module of the framework, since the visibility of the equipment that belongs to this module is very high and at the same time, the overall environmental impact of the equipment that belongs to this module is relatively the highest (39%, see Figure 7). However, the effort to properly design and quantify adequate KPIs to assess the elements of this module can also be considered the biggest. Unlike the situation of data centre computing, the equipment is in most situations not confined to one location that allows for measuring the power usage from the meter. In reality, the equipment is scattered throughout the offices and thus the power usage of the total equipment cannot be concluded from the power meter.

Since end user computing equipment is part of the office environment, elements such as illumination and cooling of the building, should not be accounted for the quantification of KPIs for this module. In the case of illumination of the building this is obvious, as illumination would also be necessary in more or less the same quantity in the situation that an office building has a large amount of end user computing equipment or in the case that the office building has no end user computing equipment. However, exactly the same cannot be said about the cooling of the building. In certain buildings, the air-conditioning in a building has to work harder to cool the waste heat from the end user computing equipment within the building. Therefore, extra energy is needed for the cooling of the building, due to end user computing. However, this is only the case if the office is in a location where the outside temperature is higher than the required office temperature and consequently air-conditioning within the building is required. In the case of an office building where the outside temperature is lower than the required inside temperature, the end user computing equipment aids in the process of heating the office building. In such a case, less energy is required from the central heating of the building. For that reason, it seems unproductive to quantify the exact amounts of waste heat and accordingly the extra energy requirements for the cooling of the building. The latter would only be valuable if it concerns an organisation with office buildings solely in a warm climate, where the air conditioning is required year round.

Possible KPIs

Before the discussion will take place on the measurement processes of the KPIs, it should be discussed which KPIs should be measured. Just as with the data centre module, it is helpful to design and quantify a KPI that gives insight in the total power consumption. This could be articulated in KWhs. Along with the total power usage for end user computing, it is helpful and at the same time a relatively small effort to quantify the amount of CO_2 in Kgs. Nevertheless, the aforementioned two KPIs do not take potential future changes to the organisation or the organisation's environment into account and therefore one or more other KPIs should be developed for this module. One possibility is to relate one of the two aforesaid KPIs to the number of employees and/or the total floor area. As already mentioned in the preceding paragraph, in theory it is possible to incorporate a KPI that is normalized to revenue. However, such a KPI would be too much of an effort to specify adequately, because of potential differences in scope of the numerator and denominator of the KPI. An alternative is therefore to normalize to total floor area. Again, in practice it can become difficult to align the scope of the total floor area with the numerator. Nonetheless this is a more feasible task, than in the case of normalization to revenue. Another possibility is to normalize, by relating the total numbers on power usage and/or CO2 to the amount of IT equipment, from which an average per piece of IT equipment derives. For the KPIs of this module it is possible to make a distinction on the type of equipment or to make KPIs for the whole of end user computing equipment. For example, separate KPIs on total power usage, amount of CO2 and power usage per employee can be formulated for desktops, notebooks and monitors individually or the same KPIs can be designed for the total of end user IT equipment. The choice for the latter can be based on the preferences of those aiming to utilize the KPIs and/or the feasibility with regard to the process of quantifying the KPIs.

The suggested leading KPIs for this module are: 'Is there a policy in place aimed at switching of the equipment at night?' and 'Awareness of the employees with green IT'. The first leading indicator is very similar to the leading indicator of the data centre module aimed at the policy with regard to energy consumption management. Here again, this KPI could be quantified by simply specifying whether the policy is in place or not. The underlying rationale for this KPI is that if there is a policy in place, there will be compliance with the policy and as such the power consumption of end user computing equipment will be lower. However, it cannot be guaranteed that if there is a policy in place, there will actually be compliance with the policy. This could be subject for further research, wherein the correlation between the policy and lower energy consumption could be investigated. The second leading KPI, deserves a similar side note. For this KPI, it is assumed that if the employee is more aware with green IT, he or she will also act more environmentally friendly. However, again, this assumption should be tested and as such could be subject for further research.

The suggested KPIs for this module are:

1. Total power consumption
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area
5. Is there a policy in place aimed at switching of the equipment at night? (leading)
6. Awareness of the employees with green IT (leading)

Measurement process

As already pointed out, the measuring process for this module is less straightforward than for the data centre computing module, since no data on the power consumption of the end user computing equipment can be derived from the building's power meter. A solution is therefore to make calculations on the basis of usage patterns, multiplied with the numbers on power consumption of the IT equipment. Therefore the usage patterns of the equipment have to be measured first. This can be done in multiple ways. One possibility is through user surveys. In this case every employee that makes use of end user computing specifies when he or she uses the equipment and when he or she turns off the equipment. Another possibility is to carry out a field survey, where one monitors the behaviour of the employees considering the usage of IT equipment. A third possibility is to make use of a certain network tool that remotely monitors when specific pieces of IT equipment are switched on and when they are switched off. The last mentioned solution has the benefit that it is less labour intensive and, depending on the tool, possibly also more accurate than the other measurement possibilities.

Once the usage pattern is known, the numbers on the power usage of the IT equipment have to be specified. This also can be done in numerous ways. The first method is to simply use the numbers that are specified by the manufacturer of the IT equipment. However, these numbers can in certain occasions be incorrect compared to the real life situation, as the numbers of the manufacturer are mostly only specified for idle load situations. Therefore it is preferable to actually measure the power usage of the IT equipment in question with a power meter, whereby the power usage of the equipment is measured in different states (e.g. off, on and standby). The measurement process should thereby preferably be carried out according to a known standard of measuring the power usage of electronic equipment, for example the energy measurement method designed by Energy Star, as this gives a clear method for measuring the power usage in a consistent manner (Energy Star n.d.; Meier 2003) Nevertheless, the latter can be laborious to carry out if the amount of different end user computing equipment is high. Therefore also in this regard a trade off has to be made between accuracy and effort, by the organisation that effectuates the framework.

Finally, the organisation that is going to effectuate the framework should choose if the measurements for this module are to be carried out in its entirety, or that a sample of certain parts of the organisation will be taken and that the result at its turn are extrapolated to calculate the whole for the organisation. Off course, by extrapolating the sample to calculate the whole, the measurement error increases. Nonetheless, for some organisations it may be infeasible to measure a usage pattern for the whole organisation. If the method of extrapolation is chosen, it is important that the sample group is representative for the whole of the organisation. In addition it may be beneficial to validate the representativeness of the sample group with a second sample group.

4.2.5 Telephony

Telephony is by some seen as an important part of IT and others characterize telephony as a separate communication medium that should not be categorized to IT. Accordingly, whether telephony will be subject for assessment, is a choice that should be made by the organisation that aims on designing the environmental KPIs by using the framework. Motivations for this choice can be based on the size of telephony within the organisation. If the number of telephony equipment within the company is relatively small, there can be a motive to not incorporate KPIs on telephony considering functional requirement 4 - A KPI should only focus on those areas of the IT where a potential difference will lead to (relatively) significant changes - (Clevers & Verweij 2007). While an average piece of end user computing equipment uses somewhere between 50 and 300 W of power when in use, an average telephone uses somewhere between 1 and 8 W, whether in use or in standby (Clevers & Verweij 2007; Rosen, Meier & Zandelin 2007). Therefore the total power consumption could be low if the number of telephones within the organisation is also low. This statement may contradict with the message from Figure 7, where it is visualized that fixed line telephony accounts for 15% to the overall environmental impact of IT. However, the calculation of the latter includes the environmental impact of the whole telephony infrastructure and that number is multiple times higher than the telephony equipment that is required within an organisation alone. Furthermore if the number of telephones is relatively high, the overall environmental impact of telephony can also be high considering the fact that the equipment consumes energy continually. Therefore, if an organisation's IT department does have control over the telephony within the organisation, it may be beneficial to also design KPIs on telephony. In the end, the choice of incorporating the telephony module, is one that should be made by the organisation that effectuates the framework. This framework does provide the guideline for assessing telephony within the company and therefore it is important to look into the difference between traditional telephony and IP telephony.

An increasing number of organisations is making the switch from traditional telephony to IP telephony (Jiang et al. 2001) This switchover is often initiated considering the benefits of IP telephony over traditional telephony, as lower costs and easier expandability (Jiang et al. 2001). IP telephony has these advantages since it can use the company's intranet and/or the Internet instead of a separate network which traditional telephony requires (Jiang et al. 2001). In view of that, a crucial choice for this module, is whether IP telephony should be part of the telephony module, or that it should belong to the networking module. Incorporating IP telephony into the networking module has its benefits and disadvantages. One benefit of including IP telephony into the networking module is that the same measurement process can be used for both, which is IP scanning. IP telephony largely uses the same network and networking equipment as the IT equipment of the networking module. As a result, if IP scanning will be used as measurement method for the networking module, the danger of double counting is high if the elements of IP telephony are to be measured and reported separately for another module and this conflicts with non-functional requirement 1 – A KPI should be able to measure aspects of the functional areas of the IT individually. However, a disadvantage of incorporating IP telephony into the networking module is that whenever the division between traditional telephony and IP telephony changes, a movement between modules occurs. For example, if an organisation decides on switching a large part of their traditional telephony to IP telephony, the numbers on the KPIs of the telephony module will diminish, whereas the numbers on the KPIs of the networking module will increase. This is unfavourable for proper periodical comparisons of the KPIs. Another disadvantage of incorporating IP telephony into the networking module, is that the KPIs for the telephony module will not represent the actual situation within the organisation, since a portion of telephony, namely the IP telephony part, is accounted for at the networking module. Thus, in such a situation the numbers of the KPIs of the telephony module do not represent all telephony equipment, but only the traditional telephony equipment. This is adverse for the communicative value of the KPIs.

Although the measurement process will be more troublesome and labour intensive if IP telephony will be part of the telephony module instead of the networking module, this is nevertheless preferred considering the functional requirements on the KPIs. The first two functional requirements state that the KPIs should be repeatable and consistently measurable, as already discussed, will this be very difficult if IP telephony is part of the networking module and the division of traditional telephony opposed to IP telephony changes. In combination with non-functional requirement 2 – A KPI takes changes to the organisation into account – incorporating IP telephony into the telephony module is clearly preferred.

Before the measurement process is dealt with for this module, it is important to know what there is to measure. It was already concluded that IP telephony should be included in this module.

Therefore, simply all telephones within the organisation can and should be part of this module. Furthermore, should all supporting equipment for telephony be part of this module. In the case of traditional telephony, these are the Private Automatic Branche eXchange (PABX) devices and the wires themselves. In the case of IP telephony, the situation is largely analogous, with the difference that special VOIP PABXs are necessary (Jiang et al. 2001). By stating that all supporting equipment should be used, it is not intended to also measure the elements of the telephony- and or IP network that are not owned or controlled by the organisation. The elements outside the organisation (e.g. glass fibre, copper wires, satellites and switches) are property of the network company and considering functional requirement 3 - A KPI has to measure only those things that the organisation can influence – should not be subject for analysis.

Mobile telephony has not been discussed yet. Whether mobile telephony should be part of the assessment, is another choice to make. Even more so than fixed line telephony, which was discussed above, the environmental impact of mobile telephony within an organisation is relatively small (Clevers & Verweij 2007; Rosen, Meier & Zandelin 2007). Again, the largest environmental impact is made at the infrastructure level, which is beyond the scope of measurement for most organisations, since the network operators control this infrastructure. One area where mobile telephony differs from fixed line telephony is that the energy consumption is battery based and that the charging of the battery often takes place outside the office environment. In view of the aforesaid, the question might arise whether numbers on the energy consumption of mobile telephony should be specified. However, there is no functional or non-functional requirement that entails that the power consumption should take place at the property of the organisation. Although functional requirement 3 states, "a KPI has to measure only those things that the organisation can influence", this does not demand that the actual energy utilization takes place at the expense of the organisation. Therefore, also mobile telephony could be taken into account, if an organisation decides to design KPIs for the telephony module. Another aspect that should be kept in mind is that the energy consumption per mobile device can vary to a great extent and this may trouble the measurement process for the total energy consumption of mobile telephony greatly. The latter may justify the rationale to not incorporate mobile telephony in the measuring process, considering non-functional requirements 5 and 6 that see on the feasibility of the measurement process.

Possible KPIs

The KPIs that should be designed for this module do not differ in essence from the KPIs of the other modules. Similar to the other modules of the 'use phase' of the framework, it is useful to design and quantify a KPI that gives insight in the total power consumption. Again, this could be articulated in kWhs. Along with the total power usage for end user computing, it is helpful and at the same time a relatively small effort to quantify the amount of CO_2 in Kgs. As the aforementioned two KPIs do not take potential future changes to the organisation or the organisation's environment into account, one or more other KPIs should be developed for this module that are normalized. For this purpose, one of the two aforesaid KPIs could be related to the number of employees and/or the total floor area within the organisation.

For this module, also one leading KPI is suggested. This KPI originates from an interview with the expert on telephony within Shell. The leading KPI is; Use of fixed line telephony opposed to e-mail and/or mobile telephony. The underlying rationale for this KPI is that for fixed line telephony the power consumption is relatively constant, whereas for the other means of communication, this is not the case (Clevers & Verweij 2004). As already mentioned, mobile phones consume more power once they are used for voice communication than when they are in standby mode. The same is the case for e-mail usage, if a PC is idle, the power consumption is lower than when the PC is being used. Therefore, from an energy consumption point of view, it is more efficient to use the fixed line telephony network than other means of communication.

The suggested KPIs for this module can be summarized as follows:

1. Total power consumption
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area
5. Use of fixed line telephony opposed to e-mail and/or mobile telephony (leading)

Measurement process

The measurement process of the telephony module has one big advantage over the measurement process for the end user computing module. That is, that no usage patterns have to be specified. Unlike computing equipment, the energy requirements of the fixed line telephones do not vary much between standby and usage (Rosen, Meier & Zandelin 2007). Therefore it does not justify the effort to analyse and specify usage patterns for telephony. As a result the energy consumption of fixed line telephones can be computed by multiplying the number of phones with the average power consumption of a phone. The number on the average consumption of a phone can be acquired by either taking the number specified by the manufacturer as starting point, or by measuring the power consumption with a power meter according to the Energy Star standard of measuring power usage. The number on the total amount of phones within the company can be obtained by looking at the total of phone numbers in use within the company, or by examining the track record of the procurement department for fixed line telephones.

Next to the fixed line telephones, the energy consumption of the PABXs should be measured. As these devices are in most cases always on, this number can be computed in the same fashion as for the telephones. Again, the average consumption of a phone can be acquired by either taking the number specified by the manufacturer as starting point, or by measuring the power consumption with a power meter, again complying with the Energy Star method of measuring power usage. The number on the total amount of PABXs within the organisation can be obtained by interviewing someone who has a gross overview of the telephony network within the company, or by examining the track record of the procurement department for PABXs.

Although no exact numbers can be given, it is expected that the surplus of environmental impact resulting from the extra stress on the IP network is minimal (Jiang 2001). Therefore, considering the danger of measuring the wrong information if the numbers of IP telephony are to be calculated separately, it is advised to solely calculate the energy consumption of the IP telephones and therefore to neglect the extra stress IP telephony puts on the company's IP network. The latter can be justified on the grounds of functional requirements 4: "a KPI should only focus on those areas of the IT where a potential difference will lead to (relatively) significant changes". The calculations for the environmental impact of the IP telephones can be done on the same manner as for the traditional fixed line telephones.

A final element that should be measured for this module is mobile telephony. As already discussed, the power consumption of mobile telephony varies significantly between different mobile devices. This troubles the measurement process, as ideally the power consumption for each individual device should be calculated. However, it is also possible to take an average for the power consumption of the devices and to base the total power consumption for mobile telephony on the multiplication of the average. The remainder of the measurement process for mobile telephony can be exactly the same as for the fixed line telephones and will therefore not be elaborated.

4.2.6 Networking

In almost every large scale multinational organisation there are one or more networks within the company, to facilitate, among other things, communication between the employees (Varshney et al. 2002). Although the exact topology of the network differs largely per organisation, the basic lay out of a network consists mostly of routers and switches and of course the network cables. It is important to clearly specify at first what is included in the networking module, since the interpretation of the scope may vary. For the purpose of the module, networking consists not of data centres etc., as these are already covered with another module. The elements that are indeed covered by this module are the pieces of networking equipment itself, such as routers, switches, transceiver modules, etc. The scope for this module is defined largely on the basis of feasibility, according to non functional requirements 5 and 6. Cisco Internet Business Solution Group has made this scope definition in a project they carried out for Shell, in order to compute the network energy and carbon footprint. In this project, they explicitly excluded from the measurements, parts with resistance only, as networking cables.

Possible KPIs

The KPIs for this module also derive from the work that was carried out by Cisco. They chose to focus on energy consumption of the equipment. As such, the KPIs that should be designed for this module do not differ in essence from the KPIs of the other modules. Along with the total power consumption for networking equipment, Cisco chose to quantify the amount of CO2 in Kgs. Nonetheless, as the aforementioned two KPIs do not take potential future changes to the organisation or the organisation's environment into account, one or more other KPIs should be developed for this module that are normalized. For this purpose, one of the two aforesaid KPIs could be related to the number of employees and/or the total floor area within the organisation. Other KPIs that were suggested to quantify were power consumption per Gbps and power consumption per port. However, the latter two KPIs are as of yet, infeasible to quantify in a reasonable amount of time with a reasonable amount of effort.

The suggested KPIs for this module are:

1. Total power consumption
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area

Measurement process

Unlike with the telephony module, the networking equipment does have a variable power consumption according to the usage load. Depending on the networking equipment's level of advance with regard to power consumption management, the power usage could be from 10% to 50% lower than under full load. Therefore, for the measurement process of this module, the choice should be made to either incorporate usage patterns, or to base the calculations on a predefined utilisation factor. The latter method was chosen by Cisco, considering the difficulties with defining adequate usage patterns for the networking equipment. The utilisation factor was defined by Cisco by estimating the number of hours per day that the equipment would operate as 'in use' and as 'idle'. Secondly, it was estimated how much less the power consumption would be in percentages, whenever the equipment is in 'idle' mode, as opposed to 'in use' mode. By taking the utilisation factor as starting point, multiplications can be made with the number of equipment.

4.2.7 Document imaging

This module focuses on printing devices, scanners, copiers, faxing machines and multifunctionals. In short, everywhere within the organisation where there is an interaction between digital documents and paper. This module is of great importance for an organisation that aims to reduce its environmental impact, as the visibility of printing is high and therefore the associations of printing and environmental impact among employees is also high. The latter can be explained by the fact that unlike with the modules discussed above, there is a direct noticeable effect, with regard to the environmental impact, of the printing request, which is paper and ink that is consumed for the prints. Consequently, for this module not only the power consumption of the equipment should be analysed but also the use of paper, ink and toner.

Possible KPIs

To a large extent the same KPIs can be specified for this module as for the other modules, which are: a KPI on the total power consumption, a KPI on the CO2 footprint and a KPI that relates the aforementioned KPIs to the number of employees or the total floor area. However, this only covers just the printing equipment and not the printing supplies such as paper, ink and toner. Therefore, KPIs on the printing supplies are necessary as well. In an ideal situation, the exact numbers on all the supplies would be measured and then related to the number of employees within the company. However, it is well imaginable that these numbers cannot be quantified exactly. In such a case, an alternative KPI can be used to gain insight on these numbers, which is the number of employees per printer. The number of employees per printer can serve as a proxy for the aforementioned KPIs, since if the number of employees per printer is low, the amount of printers would be higher and as such also the total power consumption of the printing equipment would be higher. In such a case, the amount of prints is highly likely to be higher as well, for which the total number of paper and ink/toner usage will be higher. However, if the KPI only specifies the number of employees per printer, no harsh conclusions can be drawn on the amount of prints. Therefore, it is preferred to quantify all of the aforementioned KPIs where possible. In such a situation, the last mentioned KPI could also serve as a validation of the other KPIs.

In addition to the lagging KPIs, two leading KPIs can be suggested. Both originate from the workshop (appendix C). The first leading KPI is 'Awareness of employee on the amount of prints. This KPI should measure how aware a given employee is with the number of prints he or she makes. By confronting the employee with the amount of prints, he or she could acquire more insight in the environmental impact of his or her behaviour. A method to make the employee more aware of the amount of prints, is by building a printing dashboard, where an employee could acquire insight dynamically into the number of prints. An underlying assumption for this KPI is that when the employees are more aware of the amount of prints, they will print less. Again, this assumption should be tested and this could be subject for further research. The second leading KPI for this module is 'Ease of changing printing settings'. From the workshop it was concluded that in a large number of cases, the printing settings were suboptimal (appendix C). This entails that multiple printing requests were necessary at times. This problem could be taken care of easily, by prompting the printing settings to the user every time he or she does a printing request. Hence, the ease of changing the printing settings could lead to a lower number of prints in total. Again, this assumption has to be tested, which could be subject for further research.

The suggested KPIs for this module can be summarized as follows:

1. Total power consumption of document imaging equipment
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area
5. Number of employees per printer
6. Number of pages printed per year per employee
7. Awareness of employee on the amount of prints (dashboard) (leading)
8. Ease of changing printing settings (leading)

Measurement process

Whether all KPIs are to be measured, or solely the KPI that specifies the total number of employees per printer, it is essential that the number of printers within the company is known. This can, in the case of a small office, be measured by either actually counting all the printing equipment within the building. Another possibility is to use a method of IP scanning, similar to the method for detecting end user computing equipment. However, this will only generate valid results if all the printing equipment is connected to the company network and can be recognized as such. A third method is to extract the information from the asset management system within the company.

If the KPIs chosen are to quantify the actual power usage of the equipment, this needs to be measured as well. One possibility is to use the results from the IP scan and measure as such when the equipment is switched on and when it is on standby. This is however only possible if the scanning method can provide such data. In other cases it is possible to investigate within the organisation what the schedules are of the printing devices, to conclude if the printing devices will be switched on and off automatically and when this occurs. This information should then be used to compute the total power consumption by multiplying the usage pattern with the numbers specified by the manufacturer or with the numbers measured with a power meter, again measured according to the Energy Star standard. If the total power consumption is known, the CO2 value can be calculated in the same fashion as for the other modules.

Finally, the numbers on paper use and ink/toner use should be known. One method to quantify these numbers is to simply look into the track records of the procurement department and conclude what the consumption of printing paper and ink/toner was. If this however is not possible for any reason, it can also be possible to derive the numbers from the printers themselves. Some printing equipment keeps track of the total number of prints and ink consumed. This method however, has the disadvantage that there is a risk of neglecting certain printing equipment, which can lead to lower than actual numbers. Therefore the method of concluding from the track records of the procurement department is generally preferred.

4.2.8 Waste quantities

While the preceding five modules were part of the usage phase of the framework. The next two modules that will be dealt with are part of the disposal segment of the framework. As elaborated in paragraph 2.1.3, this the general impact on the environment of the IT, implies more than the effects of the power requirements of the IT equipment alone. Therefore, it is also important to look into the disposal segment of the framework, as this aims to address the direct pollution of air, water and land from the disposal of IT equipment and the GHG emissions resulting from the disposal of IT equipment.

Firstly, the waste quantities module will be discussed. This module has one lagging KPI, which is the waste quantity itself. Nonetheless, this KPI is not as straightforward as it sounds. At first, it is important to specify what exactly is meant with waste. Secondly, it is important to scope the types of waste. With regard to the former, it has to be decided at which moment in time a product is considered ‘waste’. For some organisations, this is whenever the product gets disposed of through a contract with the disposal company. Other companies however, have a policy where equipment is considered waste after the equipment type has reached a certain life time (Kelly 1993). The definition of waste is therefore not strict and has to be made by the company that aims to quantify this module. Another problem they then have to deal with, is as already mentioned, the scoping of the types of equipment. One suggestion is to include the same equipment as the modules that are chosen to include in the usage phase of the framework. Thus, if for example only the end user computing module and the telephony module are included, then also the equipment of only these two modules could be included for the waste quantities module. This however may contradict with functional requirement 4 – A KPI should be consistently measureable -, as the modular design of the framework enabled the periodic selection of modules to include. This would hamper the consistent comparison of the KPIs of the waste quantities module. For example, if in a given year an organisation incorporates only two modules and the next year it incorporates four, the scope of the waste quantities module would be bigger and as such incomparable to preceding measurement. Therefore, it is not recommended to base the scoping for this module on other modules. An alternative to scope this module, is by clearly investigating at first which waste could be measured and then to stay with this group of waste for a number of years (e.g. 5 years) and potentially evaluate the group after this period for incorporating other types of waste. By doing this, the KPIs of this module would be consistently comparable for fixed periods.

Possible KPIs

The first KPI of this module is the total amount of IT equipment disposed per year. In other words, the waste quantity itself. As already mentioned is it important to make some clear definitions around this KPI. A second KPI for this module is a leading KPI that derives from the workshop (see appendix C). This KPI is: Is there an internal company wide policy in place for green disposal? With this KPI, an immediate conclusion can be drawn on the effort of an organisation with regard to the disposal of IT equipment. However, as with all the other suggested leading indicators, is it important that there will be consensus on the interpretation of the KPI. Elements within this KPI that are open for debate, are whether the initiative can be considered a policy, whether it can be considered companywide and whether it can be considered green disposal. These questions are all subject for further research and can only be answered once more information from more organisations is available.

The suggested KPIs for this module are:

1. Total amount of IT equipment disposed
2. Is there an internal company wide policy in place for green disposal? (leading)

Measurement process

It was already mentioned that the scope of the measurement for this module may vary. The bigger the scope the more effort in quantifying the KPIs when taking the same measurement process. Hence, the scope also determines the measurement process. Suggested measurement processes are to make estimations on the amount of waste based on either data from a company's asset centre or from the track records of the disposal department, or the compute the data on the basis of the average life span of the equipment within the company.

4.2.9 Recycling

With the waste quantities module, the amount of waste is the key metric. The underlying rationale there is, the less waste an organisation produces, the more environmentally friendly that organisation operates. Nevertheless, the manner in which an organisation deals with its waste, also determines the environmental friendliness of the company. Disposal of IT equipment can be categorized into several categories. The first category is that of landfill. Landfill is the oldest form of waste treatment and entails the dumping of the equipment on specially designated sites (Grenchus, Keene & Nobs 1997). A second category is that of recycling. Recycling involves processing used materials into new products in order to prevent among others the waste of potentially useful materials and reduces water pollution by reducing the need for "conventional" waste disposal as landfill (Kopacek & Kopacek 1999). A third category is that of reuse. With reuse, the IT equipment gets only a slight update or alteration and then will be reused by another customer. In the case of computers or laptops, frequently the hard drive will be wiped for its data too (Grenchus, Keene & Nobs 1997).

When the different methods of disposal are put in order, according to the level of environmental impact, landfill would be first, as this is the least environmental friendly option, followed by recycling at second and reuse as last (Grenchus, Keene & Nobs 1997; Kopacek & Kopacek 1999; Jung & Bartel 1999). Thus, the higher the percentage of recycling and reuse of disposal as opposed to landfill, the more environmentally friendly an organisation operates.

Possible KPIs

The KPI for this module derives from the fact that recycling and reuse of IT equipment is more environmentally friendly than landfill of IT equipment. The suggested KPI is thus, 'Percentage of disposed equipment that gets recycled or reused'. With this KPI, the same should be said about the scoping of the KPI, as with the waste quantities module. Hence, here too, it is up to the organisation that effectuates the framework to decide which IT equipment to include in the measurements. Furthermore is it also possible to specify not only the percentage of landfill, opposed to the other methods of disposal, but also to specify each percentage individually. The latter would provide more insight in the different methods of disposal and since reuse is the most environmentally friendly out of all options, more could be done to optimize this percentage.

Two leading KPIs can also be specified for this module. Both originate from the workshop (appendix C). The first leading indicator is on first sight very similar to the suggested lagging indicator. However, 'Percentage of contracts with recycle companies' does not measure the actual percentage of equipment that will be recycled, but it gives a quantification of the number of contracts with recycle companies, relative to the total amount of disposal contracts. This KPI is suggested, since it could require a huge effort to quantify the lagging KPI of this module, whereas quantifying the percentage of contracts would require less of an effort and could provide similar insights. However, as with the other leading indicators of this framework, the underlying assumption, in this case that a higher percentage of contracts with recycle companies would lead to a higher percentage of actual equipment that will be recycled and as such will lead to a lower environmental impact, should be tested. A second leading indicator that is suggested is; 'Innovativeness of recycle companies'. Once the equipment gets disposed of and sent to the recycling company, it is their duty to take care of the waste and to recycle it properly. However, different recycling companies recycle differently and as such the environmental impact of recycling varies per recycling company (Cui & Forssberg 2003). Thus, the amount of innovativeness of the recycling company also determines the amount of environmental impact. For the organisation that is willing to effectuate a green IT policy there could therefore also be an opportunity with regard to the selection of recycling companies.

The suggested KPIs for this module are:

1. Percentage of disposed equipment that gets recycled or reused
2. Percentage of contracts with recycle companies relative to the total amount of disposal contracts (leading)
3. Innovativeness of recycle companies (leading)

Measurement process

Again, since the scope of the measurements for this module can vary, so too can the measurement process vary. Similar to the waste quantities module, suggested measurement processes are to use the information from a company's asset centre, or from the track records of the disposal department. Here however, the contracts with the disposal companies would provide the most crucial information.

4.2.10 Summary of KPIs

Below a summary is given of all the possible KPIs for each independent module.

Table 3: Initial list of KPIs

Standards module:
1. Percentage of IT equipment procured in one year, complying with the WEEE directive
2. Percentage of IT equipment procured in one year, complying with the ROHS directive
3. Percentage of IT equipment procured in one year, complying with the Energy Star standard
4. Percentage of desktops and notebooks procured in one year, complying with EPEAT Gold
5. Percentage of outstanding orders complying with the Energy Star standard (leading)
6. Importance of environmental criteria in the procurement process (leading)
Embodied energy:
0. None
Data centre computing
1. Total power consumption
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area in
5. Is there a policy in place aimed at reducing the energy consumption of the data centre? (leading)
6. Virtualization of the data centre (leading)
End user computing
1. Total power consumption
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area
5. Is there a policy in place aimed at switching of the equipment at night? (leading)
6. Awareness of the employees with green IT (leading)
Telephony
1. Total power consumption

2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area
5. Use of fixed line telephony opposed to e-mail and/or mobile telephony (leading)
Networking
1. Total power consumption
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area
5. Power consumption per Gbps
6. Power consumption per port
7. Usage of wireless rather than a wired network (leading)
Document imaging
1. Total power consumption of document imaging equipment
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area
5. Number of employees per printer
6. Number of pages printed per year per employee
7. Awareness of employee on the amount of prints (dashboard) (leading)
8. Ease of changing printing settings (leading)
Waste quantities
1. Total amount of IT equipment disposed
2. Is there an internal company wide policy in place for green disposal? (leading)
Recycling
1. Percentage of disposed equipment that gets recycled or reused
2. Percentage of contracts with recycle companies (leading)
3. Innovativeness of recycle companies (leading)

5. Tests of the framework

We have arrived at the validation phase for this study (see Figure 8). With the validation of the framework, it can be determined to what degree the framework is an accurate representation for the real world usage of the model (Sornette et al. 2007). Furthermore, the validation can also serve the purpose of testing the requirements for the design and to what extent the requirements fit the actual design (Leitte & Freeman 1991). According to Verschuren and Hartog, a designer must be very critical of his own work, entailing that respect will be paid to the future user and the stakeholders. Therefore it is important that the artefact which is designed, satisfies a set of design criteria (Verschuren & Hartog 2005). Verschuren en Hartog make a distinction between different types of evaluation. The first distinction is between plan, process and product evaluation. Each of these, see a different phase of the design. A second distinction is between summative and formative evaluation. Summative evaluation entails the evaluation by stakeholders, whereas formative evaluation is carried out solely by the designer. A third distinction in evaluation, is between ex ante and ex post evaluation. Ex ante evaluation is evaluation before an activity has started, or before the aim of this activity is realised or put into practice. Ex post evaluation is evaluation after the construction has been finished or the result of a stage has been realised or brought to practice. The fourth and final distinction in evaluation methods, is that between goal based and goal free evaluation. With goal based evaluation, the goal of the design is taken as the starting point for the evaluation, where this is not important with goal free evaluation.

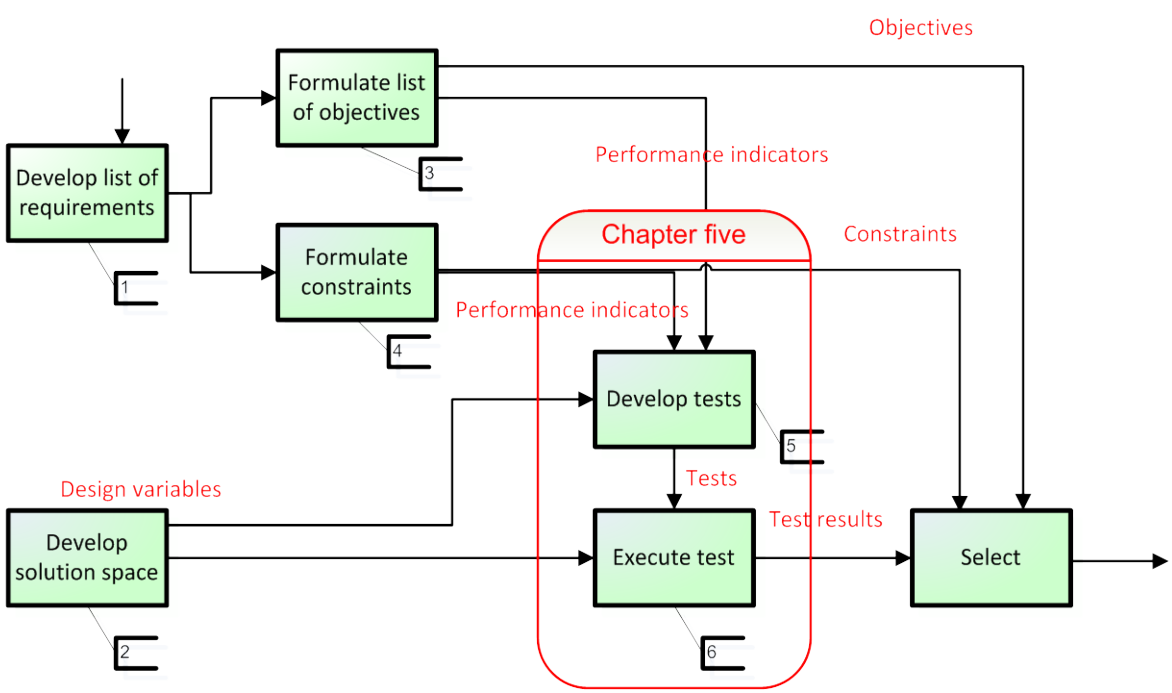

Figure 9: Metamodel chapter five

In this chapter, the framework will be evaluated by paying respect to the different methods of evaluation that are discussed by Verschuren and Hartog. In this chapter, the focus will be on ex post evaluation as this chapter sees on a clear phase of validation. Nonetheless, ex ante evaluation has been carried out throughout the whole process of designing the framework and its KPIs. This shows from the multitude of interviews that were conducted as part of the earlier phases. Yet, also within this chapter, different evaluation techniques will be used. At first, the framework will be tested on the basis of expert reviewing within Shell. This is done to test the fit of the framework with the initial requirement and to test in brief the reliability of the framework. This can be characterized as summative evaluation goal based evaluation. Secondly, the framework and its KPIs are tested through a case study, where the KPIs are quantified within Shell. This second test gives more insight into the verifiability and applicability of the framework. The test on the basis of the expert reviewing will be discussed in paragraph 5.1. The case study will be elaborated in paragraph 5.2. Finally, in paragraph 5.3, the framework and the KPIs as a whole will be tested structurally on their design criteria, which are the requirements that are formulated at first in paragraph 3.2.3. How the different tests relate to each other and what the output of each consecutive test is, is visualised below in Figure 9.

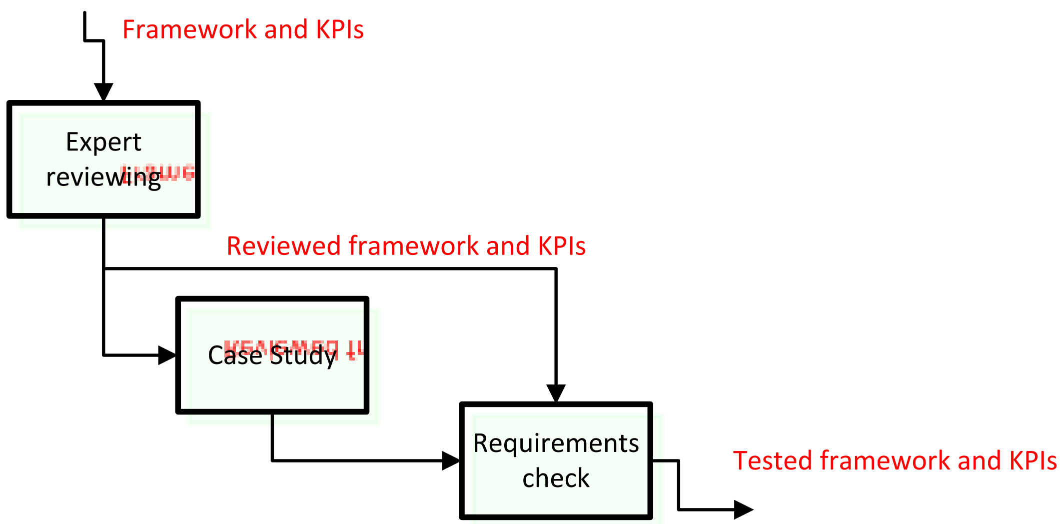

Figure 10: Validation process and steps

5.1 Expert reviewing

As mentioned, the expert reviewing serves the purpose of testing the fit of the framework with the initial requirement and also as a test of the framework's reliability. The composition of the expert reviewing panel will be mentioned at first in subparagraph 5.2.1. Secondly, in subparagraph 5.2.2, the expert reviewing methodology will be described. In subparagraph 5.2.3 the results from the expert reviewing will be elaborated. In paragraph 5.2.4 the conclusions of the expert reviewing will be presented, where we will also discuss what implications the expert review has on the framework and its KPIs.

5.1.1 Composition of expert reviewing panel

For the expert reviewing of the framework and the KPIs, three experts within Shell were consulted. Two of these experts were experienced in the design and quantification of environmental metrics for Shell. The third expert was more experienced with regard to green IT in general and the implications of reducing the environmental impact of IT. With the composition of the expert panel, the knowledge with regard to the adequate design of metrics could be combined with the knowledge with regard to green IT in general.

For the purpose of the design of the KPIs for each independent module, an expert on that module was consulted for an interview, with the purpose of acquiring information that could be used for the design and quantification of the KPIs. It was deliberately chosen not to also consult these experts, for the expert reviewing. Hence, dissimilar experts were chosen for the validation of the framework, than for the design of the framework. This choice was made, as the experts that were consulted for the first in time, were also asked to suggest improvements on the KPIs and to reflect and give their opinion on the definition of the KPIs. As such, these experts are partly responsible for the definition of the KPIs and therefore it would not be just to consult them again for the purpose of the expert review.

5.1.2 Expert reviewing method

For the purpose of the expert reviewing, the experts were presented a pre-read with, among other things, a description of the model. The pre-read is described in appendix D. Within the pre-read, the purpose of the expert review is outlined. Hence, for each expert it was made clear beforehand what the goal of the expert review was and as such what the focus of the interview would be. Secondly, the term environmental impact is elaborated on in more detail. This is done to guarantee that all the respondents have the same understanding of the term environmental impact, since this is an important point of the validation. After the description of environmental impact, an introduction to the framework is given. To not overly lengthen the page count of the pre-read, the introduction to the model is purposely made very brief. In this introduction only the core concepts of the framework are explained. As such it is not elaborated how the framework acquired its shape and why certain choices in the design process were made. Nonetheless, it is mentioned that the framework consists of several modules and the modular approach of the framework aids with the feasibility constraints of the measurement process. After the presentation of the framework and the framework visualization, the set of KPIs for Shell is given. Herein, the different KPIs are categorized per module. As the final part of the pre-read, the questions for the expert review are presented.

In the e-mail that was sent along with the pre-read, it was mentioned that the questions were only given to indicate what the respondent could expect, but that it was not necessary for the respondent to answer the questions in depth. Furthermore, it was mentioned that the respondents are supposed to answer each question on a three point ordinal scale which ranges from ‘sufficient’ to ‘insufficient’, with ‘partly sufficient’ as the mid-value. An ordinal scale is wise to incorporate in expert reviews, as this scale is easy to understand and interpret, since it requires the respondent to express their opinion in either a positive or a negative mark.

The questions for the expert review are based on three different criteria that were defined beforehand. Multiple authors recommend to define the criteria for the validation beforehand (Stufflebeam 2004; Holsapple & Joshi 2001). We follow Huizer for the formulation of these criteria (Huizer 2008). These criteria are as follows: completeness, correctness, relevance and usability. From these four criteria, one criterion was excluded from the expert review, as that criterion will be tested in depth at the phase of the case study. That criterion is that of correctness. The other criteria and their implications are discussed below.

Completeness: It is important that the framework indeed cover the main objectives. Therefore within framework design, the articulation of requirements and the test of the fit of the framework with the requirements, is an important one. In this case, the framework serves the purpose of providing a method to analyze the IT of a large-scale multi-national organisation for its environmental impact and to eventually deduce a number of KPIs. Herein, environmental impact is an important element. Therefore the questions concentrate on the implications of environmental impact in particular.

Relevance: During the design of the framework, it was mentioned in interviews with several experts, that it is important that only relevant KPIs are incorporated in the final list of KPIs. Too great a number of KPIs would potentially lead to interpretation problems and would require too much of an effort to quantify. Hence, according to these experts, the support from upper management would decrease in the case of a large set of KPIs. Therefore it is important that the list of KPIs focus only on the core concerns. This may contrast with the notions of completeness, as in order for the KPIs to be complete, they will have to suffice to all the requirements, which include all the objectives for Shell. Thus, the design of KPIs can be seen as a balancing act. Whether this balancing act is carried out adequately, should be concluded on the basis of the criterion 'relevance'.

Usability: The framework and the KPIs that derive from the framework is not a goal in itself, the KPIs need to be utilized to contribute to the goals of the green IT policy. These goals are: reduce the environmental impact of IT. reduce costs, change the mindset of employees, ensure the license to operate, reputation management and supplier management (for a more elaborate discussion of these goals, see paragraph X). With the criterion for usability, it will be investigated whether the KPI can indeed contribute to these goals.

The different questions that derive from the three aforementioned criteria are summarized below.

Completeness:

1. To what extent do the three grounds of environmental impact cover the whole of the environmental impact of IT?
2. To what extent do the KPIs as a whole cover the whole of the environmental impact?
3. To what extent do the different areas of the IT (modules) cover the total IT within Shell?

Relevance:

4. To what extent is there a redundancy of KPIs?

Usability:

5. To what extent can the KPIs be utilized to reduce the overall environmental impact on the long term?
6. To what extent can the KPIs be utilized for the purpose of the other objectives (reduce costs, change mindset of employees, license to operate, reputation management, supplier management)

As said, the respondents were asked to answer these questions on a three point ordinal scale. Before the interview commenced, we explained the respondents the process of the interview. Furthermore, we deliberately pointed out that the respondent is not supposed to confine his or her answer to the three point scale, but to give a motivation for the choice and to, where possible, give suggestions for improvement. The duration of each interview was approximately one hour. The results of the expert review will be discussed in the next subparagraph.

5.1.3 Expert reviewing results

The complete list of answers of each expert, per question, is given in appendix D. In this paragraph, only the most important conclusions of the expert reviewing will be presented. The result will be given per criterion and is shown in table 4 in subparagraph 5.1.4. How the results led to alterations to the design will also be discussed in the next subparagraph.

Completeness: With regard to the completeness criterion, all respondents responded with either sufficient or partly sufficient on the corresponding questions. One respondent mentioned that the list of KPIs could be considered to be too complete, entailing that the number of KPIs in general is too large. This point will be handled in greater depth with the next criterion, relevance. Another point that was raised, is why exactly these specific grounds of environmental impact were chosen (see appendix D) and why not, for example also grounds that focus on health and safety. With regard to the environmental impact it was mentioned that electromagnetic radiation could possibly be included, as well as toxicity during the disposal phase.

Another notion that was raised with regard to the completeness, is that the level of completeness, or more specifically, the focus for green IT, may shift per region. As such, the objectives for a green IT policy vary between the global company perspective and the local company perspective. For example, in Nigeria, water management is more of an issue than in Norway. Thus, KPIs that specifically focus on water management are necessary to include in Nigeria, whereas these same KPIs would be superfluous in Norway.

On the question of whether all elements of the IT are covered with all the different modules, it was suggested by one respondent to also include a separate module for people using IT from home. Furthermore, it was mentioned that with the current framework the focus is rather hardware specific. As a result, for example, the environmental impact of the IT department is not accounted for separately. To make a thorough assessment of the environmental impact of IT, it may be wise to also include this element.

Relevance: With regard to the relevance of the KPIs, it was mentioned that there is a redundancy of KPIs. Two experts considered the number of KPIs to be too largeto be communicated to upper management. For the purpose of communication to upper management, it would be more beneficial to reduce the number of KPIs to a set of only a handful. Nonetheless, the long list of KPIs could be used internally to quantify some core KPIs that could be used to communicate externally. Furthermore, it was mentioned that some KPIs, especially on the standards module, could be aggregated.

Usability: With regard to the questions on the usability criterion, all of the experts answered the two questions with the value 'sufficient'. Nevertheless, the experts also mentioned several aspects that were already discussed in the preceding questions. For example, that the KPIs should be fine tuned for different regions as the needs may vary per region. Furthermore it was mentioned that it would be beneficial if the KPIs also give a goal value or goal bandwidth for each quantification of the KPIs. With such a value or bandwidth it would be more clear what the goal of an organisation could be and what effort is required to reach that goal. Furthermore, such a value could also be a first step towards a benchmarking standard, as it gives a clearer indication of which values are required to be considered environmentally friendly.

In the next subparagraph it will be discussed how the insights from the expert reviewing led to alterations to the framework and the KPIs.

5.1.4 Conclusions from the expert reviewing

The insights from the expert reviews led to several alterations of the KPIs. However, none of the results of the expert reviewing necessitated change to the model itself. Below we will discuss per criterion, how the insights from the expert reviewing led to changes of the KPIs. We will also discuss why certain points of critique that derived from the expert reviewing, did not lead to changes to either the model or the KPIs.

Completeness: The point that was mentioned about the choice of the grounds of environmental impact - why exactly these specific grounds of environmental impact were chosen and why not also grounds that focus on health and safety – did not lead to changes. The grounds for environmental impact were chosen by the main stakeholder and served as an early demarcation of the project, as these grounds formed the constraints of the requirements (see paragraph 3.2.2). Here it was purposely chosen to concentrate on environment alone and not also on health and safety. Health and safety are often combined with environment within Shell, as Shell arranges its businesses according to HSE policies (Health, Safety and Environment) (Shell 2008a). However, as said, for this project, the environment pillar of HSE was taken as sole perspective, which led to the focus on the environment alone, for the formulation of the requirements.

The need to include electromagnetic radiation within the grounds of environmental impact was another comment made on the criterion of completeness. Electromagnetic radiation takes the form of self-propagating waves in a vacuum or in matter. Electromagnetic radiation has an electric and magnetic field component, which oscillate in phase perpendicular to each other and to the direction of energy proliferation (wordnet, n.d.). Light is a form of electromagnetic radiation, just as microwaves. Some forms of electromagnetic radiation are considered to be harmful to human health (Lai 1996). However it is scientifically still debatable whether electromagnetic radiation of common (IT) equipment can be considered harmful to the human health (Repacholi 2001; Macklis 1993; Morgan et al. 2000). The latter was also recognized by the expert that uttered the point of critique during the expert review. Since there is no scientific consensus about the harm of electromagnetic radiation and because the problem of electromagnetic radiation concerns the health aspect, rather than the environmental aspect, we chose to not incorporate electromagnetic radiation to the grounds of environmental impact.

A point made by one expert was that toxicity should also be part of the disposal phase of the framework. It was pointed out that this would not be necessary for the procurement phase, as toxicity is already covered at this phase by the incorporation of standards that focus on toxicity of computing equipment. For the disposal phase however, the framework only allows KPIs concerning waste quantities and percentages with regard to the disposal method. It can be said that with the incorporation of KPIs that focus on the WEEE directive and the ROHS directive, it is not necessary to account for toxicity at the disposal phase separately. Both EU directives take the environmental impact of the disposal of computing equipment into account and as such they also focus on the toxicity during the disposal phase. However, as the framework has a modular approach for the purpose of enabling the selective design and quantification of KPIs, it would make sense to design KPIs that pay respect to the toxicity separately, at the disposal phase. For this purpose, environmental disposal standards can be taken as a method of assessment. In Europe, the WEEE and ROHS standard of the EU see on this subject matter and in the US certain legislation with regard to the disposal of IT equipment exists, which is controlled by the EPA (Environmental Protection Agency) (Cui & Forssberg 2003). However, as of yet, there is no global standard with regard to the environmentally friendly disposal of IT equipment. Therefore, taking a standard as a starting point for a KPI on the recycling module proves impossible. It is well imaginable that in the future such a standard will be developed and if this indeed is this case, such a standard could be incorporated in the recycling module. For now, an option to pay respect to the toxicity of computer equipment at the disposal phase is to specify the already existing leading KPI - innovativeness of recycle company– to take the handling of toxic material into special account. How this will be dealt with, could be subject for further research, or could be investigated by the company that effectuates the framework. Once the factor of toxicity is incorporated in the ‘recycling’ module, it is wise to control the KPI through audits. Nonetheless, how these audits should be carried out is subject for further investigation.

Special attention to local situations for the KPIs is another comment that was made at the expert reviewing. However, incorporating this into the framework would entail that separate KPIs should be formulated for every local condition. This is purposely not the objective of this framework and the resulting KPIs. From the formulation of the assignment, which served as the starting point for this study, it is clear that it was required to formulate a set of high level KPIs that should be suitable for Shell worldwide. This was also concluded from the first interviews with the main stakeholder. Therefore in this version of the framework, special attention to local circumstances will not be incorporated. Nonetheless, this could be subject for further research. Here for example, the framework could facilitate tailor made design of KPIs according to local circumstances.

That home workers could be accounted for within a separate module, was also mentioned by one of the experts. As already mentioned before, in theory a module overseeing the environmental impact of all IT employees could be part of the framework. However it was already concluded that this would be too difficult to measure within a reasonable timeframe with a reasonable amount of efforts, as this would require a great number of extra calculations. Factors that should also be taken into account in such a case are among others: traffic distance per employee, working hours, working behaviour, etc. Considering the complexity of gathering all the required data, it is preferred to not incorporate this module in the framework. The same rationale can be followed for a module 'home workers'. Regarding the feasibility of adequately quantifying the KPIs for this module, this module cannot be part of the framework, considering non functional requirements 5 and 6 – 'A KPI should be quantifiable within the organisation within a reasonable amount of time and effort'. Furthermore, it is debateable whether home workers should be accounted for separately, as the IT equipment they use is also accounted for at the procurement phase of the framework. Since the environmental impact of IT equipment whether used at home or at the office is roughly the same, it is not necessary to account for home workers separately.

Relevance: With regard to the relevance of the KPIs, we can conclude from the expert reviews, that there is a redundancy in KPIs, for them to be communicated effectively to upper management and/or to be incorporated in financial reports. The experts suggested to concentrate on merely one or two main KPIs and to utilize the other KPIs to either calculate the main KPIs, and/or to give more insight into the areas where certain efforts can relatively lead to the biggest improvements. As energy consumption is a common KPI on all the modules of the usage phase of the framework, it was suggested to take this KPI as the main KPI and to aggregate this KPI over the separate modules into one KPI. As such, one main KPI would be: total power consumption of the IT.

Secondly, we can conclude from the expert reviews, with regard to the relevance of KPIs, that certain KPIs themselves could be aggregated or left out. One expert mentioned that the KPIs could in particular be aggregated for the standards module. Here, the KPIs that focus on the compliance with the WEEE directive and the ROHS directive, could be aggregated to one. Thus, the two separate KPIs could be merged to one. We formulate the new KPI as follows: Percentage of IT equipment procured in one year complying with the WEEE directive and the ROHS directive. With the formulation of the new KPI, the information transparency decreases, because now it cannot be concluded to which directive the equipment complies and to which it does not. However, the expert expressed that the smaller amount of KPIs is to be preferred, over the more detailed information from KPIs.

With regard to the relevance, a final comment that was made was that for certain KPIs it would be infeasible for now, to measure them within Shell. Examples of these are the KPIs in the recycling module and the waste quantities module. Also the KPIs that normalize the output to the floor area would be infeasible to measure within a reasonable amount of effort and time. Nonetheless, the experts concluded that it is indeed beneficial to include these modules and KPIs in the model, as they can provide valuable insight. Hence, we decided not to alter the model or the KPIs, but rather acknowledge that for now it is infeasible to quantify these KPIs within Shell, but that these KPIs could be quantified nonetheless in the future (more on this in the case study, paragraph 5.2).

Usability: All the experts answered the questions with regard to the usability of the KPIs with 'sufficient'. Yet, one comment was made for the criterion of usability. This is that information from the values of the KPIs themselves alone, would not suffice, as from the numbers alone, no conclusions can be derived with regard to the relative position of the organisation. Consequently, the values of the KPIs provide inadequate information to draw conclusions from. It can be said that the aim of the framework is to enable continual monitoring and that as such, the values of the KPIs will only be utilized once two or more measurements have been conducted. In that case, the values of the KPIs can be compared retrospectively. However, one expert mentioned that it would be beneficial if the values of the KPIs could also be related to business goals. For example, if the aim is to perform top quartile (amongst the best 25%), a goal bandwidth should be specified beforehand and then once the KPIs are quantified, it would be possible to conclude whether the goal has been achieved. Nonetheless, the expert also mentioned that for now it would prove infeasible to determine the bandwidths for Shell, or for any other organisation, as first multiple measurements have to be carried out, to provide yardstick data.

In the table below, per question, the conclusions from the expert reviewing are summarized. In the mid column, the main results from the experts are given and in the far right column, it is specified to which alterations this led for the framework and/or the KPIs, if any.

Table 4: Expert reviewing summary

Question	Main results from experts	Alterations
1. To what extent do the three grounds of environmental impact cover the whole of the environmental impact of IT?	Possibly include toxicity during disposal phase.	Include an element of toxicity in the leading indicator 'innovativeness of recycling company'.
	Possibly include electromagnetic radiation (EMR).	None, as EMR is not proven to be harmful to the environment.
	Possibly include health and safety, next to environment.	None, as the scope for this study is restricted to env.impact.
2. To what extent does the whole of KPIs cover the whole of the environmental impact?	Make a possible prioritization based on local conditions.	None as of yet. Subject for further research.
3. To what extent do the different areas of the IT (modules) cover the total IT within Shell?	Possibly include a separate module; 'home workers'.	None, as the computing equipment of the home workers is already accounted for in the other modules.
4. To what extent is there a redundancy of KPIs?	Too high number of KPIs to be used for communication to upper management.	Inclusion of one main KPI; 'total power consumption of the IT'.
	Certain KPIs can be aggregated.	Combination of the KPIs on the EU directives.
	Certain KPIs are difficult to quantify.	None, as also the KPIs in question are important to include.
5. To what extent can the KPIs be utilized to reduce the overall environmental impact on the long term?	Include goal bandwidth for the KPIs.	None as of yet. Subject for further research.
6. To what extent can the KPIs be utilized for the purpose of the other objectives (reduce costs,	None	None

change mindset of employees, license to operate, reputation management, supplier management)?

Since some KPIs were changed and others were removed because of the expert reviewing, for the sake of completeness, the entire list of KPIs is mentioned below in Table 5.

Table 5: Final list of KPIs

Standards module:
1. Percentage of IT equipment procured in one year, complying with the WEEE and ROHS directive
2. Percentage of IT equipment procured in one year, complying with the Energy Star standard
3. Percentage of desktops and notebooks procured in one year, complying with EPEAT Gold
4. Percentage of outstanding orders complying with the Energy Star standard (leading)
5. Importance of environmental criteria in the procurement process (leading)
Data centre computing
1. Total power consumption
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area in
5. Is there a policy in place aimed at reducing the energy consumption of the data centre? (leading)
6. Virtualization of the data centre (leading)
End user computing
1. Total power consumption
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area
5. Is there a policy in place aimed at switching of the equipment at night? (leading)
6. Awareness of the employees with green IT (leading)
Telephony
1. Total power consumption
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area
5. Use of fixed line telephony opposed to e-mail and/or mobile telephony (leading)
Networking
1. Total power consumption
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area
5. Power consumption per Gbps
6. Power consumption per port
7. Usage of wireless rather than a wired network (leading)
Document imaging
1. Total power consumption of document imaging equipment
2. Total CO2e

3.	Power consumption per employee
4.	Power consumption per m^2 of floor area
5.	Number of employees per printer
6.	Number of pages printed per year per employee
7.	Awareness of employee on the amount of prints (dashboard) (leading)
8.	Ease of changing printing settings (leading)
Waste quantities	
1.	Total amount of IT equipment disposed
2.	Is there an internal company wide policy in place for green disposal? (leading)
Recycling	
1.	Percentage of disposed equipment that gets recycled or reused
2.	Percentage of contracts with recycle companies (leading)
3.	Innovativeness of recycle companies (leading)
Main KPI	
1.	Total power consumption of the IT

5.2 Case Study

As expert reviewing only takes the opinion of the expert in question into account, it should not be used exclusively to validate the model (Tory & Moller 2005). For an adequate test of the usability of a design, it is important to also include a summative evaluation of some sort, which entails that the design is tested by the user and put into practice(Verschuren & Hartog 2005; Tory & Moller 2005). For this purpose, we have chosen to conduct a second test of the framework and the KPIs. Namely, by a case study. Case research can have multiple forms and objectives and allows for a great deal of flexibility and individual variation (Cavaye 1996). Two research methods that are closely related to case research are field studies and action research. With a field study, a phenomenon is researched in its natural environment. Here, the researcher is an observer and has no intent to control or manipulate variables (Stone, 1978). In action research, the researcher not only observes and records, as with a field study, but also actively takes part in the attempt to solve the problem at site (Mansell, 1991). Eisenhardt (2002;1991), acknowledges that case research can be used to either generate new theories, or to test and validate theories. This is later also acknowledged by Cavaye (1996). Whether case research will be used to generate new theories, or to validate theories, is narrowly related to the application of case research in the interpretivist tradition and case research in the positivist tradition. In the interpretivist tradition, the aim is to understand phenomena from the point of view of participants directly involved with the phenomenon under study. In the positivist tradition, empirical observations are used to rather test theory (Cavaye 1996).

In this study, we have carried out the case study mainly to evaluate the framework and its KPIs. Thus, the main goal of the case study is to validate the theory, as opposed to formulating new theories. For this case study, the KPIs are quantified within Shell, for the purpose of a test case. In subparagraph 5.2.1 the case study methodology will be described and in subparagraph 5.2.1, the case study conclusions will be discussed.

5.2.1 Case study method

Before we discuss how we designed the case study and how it was carried out, it is wise to denote that next to the distinction of case studies between the interpretivist approach and the positivist approach, another important distinction between case studies can be made. This is the distinction between single case studies and multiple case studies. Multiple case study research has the added value of analyzing data across cases and as such enables the researcher to verify the data transversely (Miles & Huberman 1994). However, for the purpose of this study, we have carried out a single case study. Considering the fact that the time for this research is limited and that the study was carried out as part of an internship within one company, it was infeasible to utilize multiple cases. The case of Shell is therefore the solitary case that serves as the input for the case study.

The KPIs that derive from the expert reviewing are taken as the starting point for the case study. These KPIs are to be verified by means of a case study by structurally quantifying each individual KPI. From this, the design of the KPIs can be verified. Second, in the process of quantifying the KPIs, the measurement processes can be tested. Moreover, the overall process of quantification and possible selection of KPIs is tested. As said, in this phase of the study the case research serves mainly the purpose of a test of the design, as the tests are part of the validation phase of this study. Therefore, for the purpose of this study, the insights that derive from the case study that could lead to major changes in the design, will not be used to make fundamental alterations to the model. Rather, where the case study gives starting points for drastic alterations to the model, this could be used as input for further research. In the following subparagraph we describe what the main conclusions of the case study are.

5.2.2 Conclusions from the case study

A first conclusion from the case study is that there is no overall process method for the quantification and selection of the KPIs. As mentioned before, the framework is constructed with a modular approach to enable the selection of separate modules. However, for the organisation that effectuates the framework, the framework does not provide a methodological approach on how to select the modules. Moreover, once certain modules are selected for quantification by the organisation that effectuates the framework, it is unclear which KPIs should be included for each module. It would be beneficial if along with the framework, a process design were provided. A process design is key for reaching the end result of consistent and accurate KPIs. Given that without a process design, there would be no standardised method for quantifying the KPIs, thus reducing the benchmarking abilities of the KPIs. Furthermore, a thoroughly structured process design aids in the process of quantifying the KPIs, since it describes which steps should be followed in which order and how. Only with a proper process design in conjunction with the remainder of the framework, can the KPIs be quantified properly. However, as of yet, the process design is not a part of the framework. This is therefore, subject for further research.

The method which is used in this case study to quantify the KPIs, is to take the feasibility constraint as a starting point. For each KPI, we concluded whether it was feasible to properly quantify the specific KPI considering the information at hand within Shell. By taking this approach, a small subset of KPIs remained that were to be quantified for the purpose of this case study. These

KPIs were also suggested to select for quantification by one of the experts of the expert reviewing. These are the following KPIs:

Table 6: List of KPIs for the case study within Shell

Data centre computing
1. Total power consumption
2. Total CO2e
3. Power consumption per employee
End user computing
1. Total power consumption
2. Total CO2e
3. Power consumption per employee
Telephony
1. Total power consumption
2. Total CO2e
3. Power consumption per employee
Networking
1. Total power consumption
2. Total CO2e
3. Power consumption per employee
Document imaging
1. Total power consumption of document imaging equipment
2. Total CO2e
3. Power consumption per employee
Main KPI
1. Total power consumption of the IT

In Appendix E it is described how these KPIs are quantified. During the process of quantification of the KPIs, another important shortcoming in the framework surfaced. Namely, the framework does not specify strict rules on measurement processes and accounting rules. This is closely related to the fact that there is no process design for the framework. We have already pointed out in chapter three, that it would be too much to specify the accounting procedures and measurement process requirements for the KPIs within this study and that therefore the rules of the GHG protocol should be followed. However , the rules of the GHG protocol leave options open and do not impose strict accounting rules (The Green House Gas Protocol 2004). If the aim is to use the KPIs for cross business benchmarking, it is important that there indeed are strict rules on the measurement processes and accounting rules. Therefore, this should be incorporated within the framework or better yet, within the process design that would complement the framework. As we have said before however, this would be subject for further research, considering the effort it would require to adequately construct this process design.

Another conclusion we can draw from the case study is that in order to quantify one KPI on one specific module, multiple information sources had to be conducted. For example on the end user computing module, to calculate the total power consumption, information had to be gathered from the organisation's asset centre, but also from other sources, as the asset centre did not provide all the information required. Shell's asset centre for example, does not provide data on the amount of docking stations or monitors. Therefore, these numbers had to be estimated. This shows the importance of business intelligence with regard to the process of quantifying the KPIs. Only if the right information is available at the right places, the KPIs can be quantified successfully. In case the information cannot be consulted within the organisation properly, the process of quantifying the necessary KPIs will prove futile.

One final conclusion that derives from the case study is also closely related to the fact that there is no process design that goes with the framework. Namely, when the KPIs are quantified it is not clear how they should be validated. For the purpose of the case study, the values of the KPIs are not validated and as such it is questionable whether the values of the KPIs are representative for the real life situation. Once a process design to complement the framework has been devised, a phase that focuses on the verification and validation of KPIs should be included. Again however, this should be subject for further research.

5.3 Requirements check

One final method of validation we will carry out is the requirements check. Here, the final KPIs that derived from the expert reviewing will be compared to the requirements that were formulated at the beginning of this study. These requirements are given below.

Table 7: functional and non-functional requirements on the total of KPIs

	Functional requirements
1	As a whole, the KPIs should reflect the environmental impact of IT
2	As a whole, the KPIs should reflect the objectives of the organisation effectuating a green IT policy (e.g. in Shell’s case; reduce environmental impact, reduce costs, change the mindset of employees, ensuring the license to operate, reputation management and supplier management)
3	The measurement of a KPI should be repeatable
4	A KPI should be consistently measurable
5	A KPI has to measure only those things that the organisation can influence
6	A KPI should only focus on those areas of the IT where a potential difference will lead to measurable changes
	Non-functional requirements
1	A KPI should be able to measure aspects of the functional areas of the IT individually (e.g. data centre computing, end user computing, printing, etc.)
2	There should be a KPI that takes changes to the organisation into account
3	There should be a KPI that takes changes to the organisation’s environment into account
4	A KPI should preferably provide benchmarking opportunities
5	A KPI should be quantifiable within the organisation within a reasonable timeframe
6	A KPI should be quantifiable within the organisation within a reasonable amount of effort
7	There should preferably be a combination of leading and lagging KPIs

As discussed before in subparagraph 3.2.3, the functional requirements articulate the things the framework has to do and the non-functional requirements articulate the qualities that the framework should have. Since the non-functional requirements only focus on the intrinsic worth of the KPIs, it would be superfluous to check on these requirements too, as the requirements were also used as the main input for the design of the KPIs. Therefore, for the functional requirements only, we will investigate per requirement, if the KPIs as a whole meet the requirement in question and how.

As a whole, the KPIs should reflect the environmental impact of IT : Within the expert review, we firstly asked the experts whether our interpretation of environmental impact of IT undeniably covers the total environmental impact. Secondly, we asked the experts whether as a whole the KPIs cover the environmental impact of IT as we specified it. Both questions were answered positively by the experts. Therefore we can conclude that as a whole the KPIs indeed reflect the environmental impact of IT.

As a whole, the KPIs should reflect the objectives of the organisation effectuating a green IT policy (e.g. in Shell's case; reduce environmental impact, reduce costs, change the mindset of employees, ensuring the license to operate, reputation management and supplier management): Also this requirement recurred in the expert review as a separate question. Again, here the experts answered positively to this question. Therefore, we can conclude that as a whole, the KPIs suffice to this requirement.

The measurement of a KPI should be repeatable: From the case study we can derive that in essence the quantification for all the KPIs are reproducible. However, we can only conclude this with certainty for the KPIs that were part of the case study. As denoted, only a subset of the total of KPIs was taken for the case study. To adequately conclude whether the measurements of all the KPIs are repeatable, we suggest further research, whereby the total of KPIs will be tested. However, we also concluded from the case study, that since the framework does not provide a standardized process design, the measurement process itself is also not standardized. Hence, this too, is subject for further research.

A KPI should be consistently measurable: Again from the case study we can conclude that in order for the KPIs to be consistently measureable, a standardized process design should be in place. As of yet, this process design is not incorporated into the framework. Therefore it is questionable whether the KPIs can be measured consistently. We can conclude that as long as the KPIs are used internally for one company and the measurement process is carried out in the same manner, the KPIs are indeed consistently measurable. However, considering the lack of a standardized process design along with the framework, we can also conclude that for cross business benchmarking purposes the KPIs are not adequately consistently measurable. Therefore, as a whole, the KPIs fail on this requirement with regard to cross business consistent measurability. This again stresses the importance of a proper standardized process design.

A KPI has to measure only those things that the organisation can influence: In the expert review, questions were included on the completeness and usability of the KPIs. Here, none of the experts commented on the infeasibility for Shell to utilize the KPI. Since the experts agreed on the subject that every KPI that was specified, can be utilized by Shell in a certain manner and the experts are also aware of the end goals of the KPIs, we can conclude that the KPIs suffice to this requirement.

A KPI should only focus on those areas of the IT where a potential difference will lead to measurable changes: Again, in the expert review this requirement was incorporated implicitly, by balancing the completeness criterion to the relevance criterion. None of the experts commented in the line of this requirement and therefore we can conclude that the KPIs meet this requirement.

We can conclude from the requirements check, that as a whole the KPIs meet the specified requirements to a large extent. However, we also concluded that on the requirement of consistent measurability, as a whole, the KPIs fail. In order for the framework and its KPIs to pass on this requirement, an adequate standardized process design should be in place. However within this study it is infeasible to provide this process design along with the framework. Hence, we can conclude that at present, the framework and its KPIs fail on the requirement of consistent measurability and that in order to pass this requirement, further research needs to be conducted into a standardized process design that should complement the framework.

6. Conclusions, limitation, reflection and further research

In this chapter the conclusions of the study will be first presented in paragraph 6.1. Here, a summary of the study will be given and the design objective will be revisited. This is the final step of the design and is demonstrated below in Figure 9. Next, in paragraph 6.2, the theoretical contribution and the societal relevance of the project will be discussed. Hereafter, we will present the limitations of the research in paragraph 6.3. Here, we will discuss the elements that may hamper the generalization of the outcomes. Further, in paragraph 6.4 we will reflect on the project as a whole. Finally, in paragraph 6.5, we will sum up and discuss the recommendations for further research.

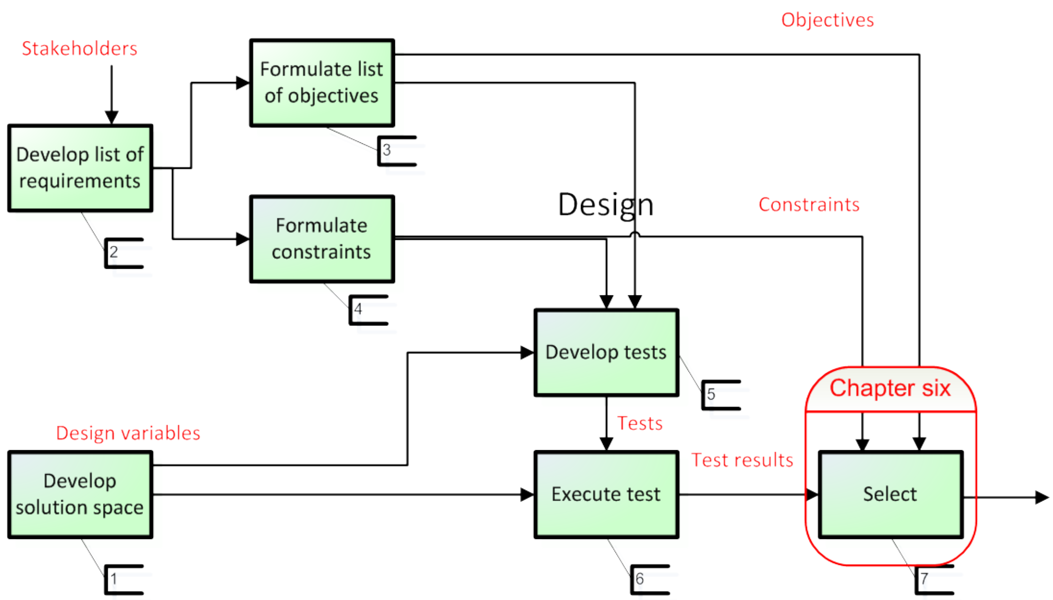

Figure 11: metamodel chapter 6

6.1 Main conclusions

Having presented the design and validation of this research, we will now go back to the main design objective that initiated this study. This design objective was formulated as follows: ***The design of KPIs for assessing the environmental impact of the IT itself for Shell.***

We have chosen to approach this design study by the methodology of the metamodel. For this purpose, a first step was to define the solution space. Here, we concluded that we would limit the problem situation to the environmental impact of the IT itself only. This entails that only the direct negative effects on the environment of the production, usage and disposal of IT equipment was to be investigated. The second step was to formulate the objectives and constraints. The objectives were formulated on the basis of interviews that were conducted with the main stakeholders within Shell. The same approach was used for the formulation of the constraints. From the formulation of the objectives and the constraints, we have derived the total list of requirements. These requirements are shown above in Table 7 in paragraph 5.3.

By taking the requirements as a starting point, we initiated the actual design. As it was quickly realized that the design of KPIs alone would not suffice, we started with the design of an encompassing framework. The key purpose of the framework is to provide a method to analyze the IT of a large-scale multi-national organisation for its environmental impact and to eventually deduce a number of KPIs. This framework is visualized in Figure 12.

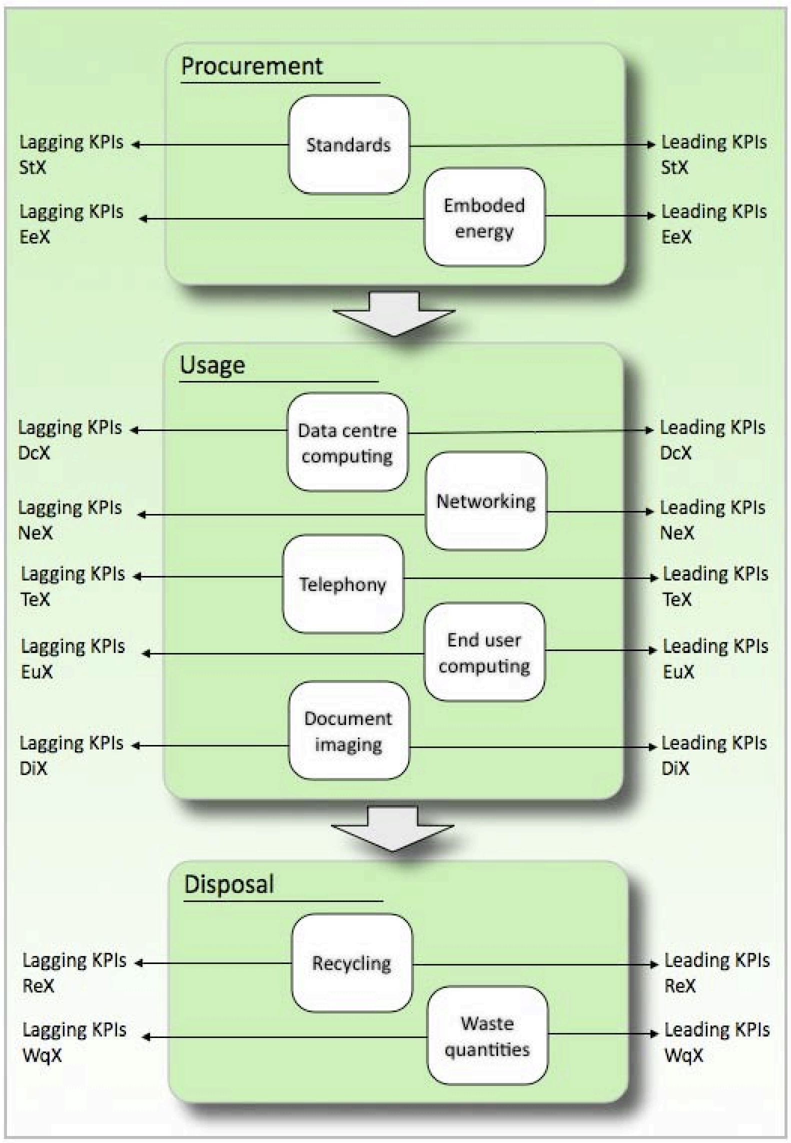

Figure 12: Core of the framework

The three large green boxes represent the building blocks. The nine smaller white boxes represent the modules. The design of the framework purposely makes use of a modular approach. Due to the modular design of the framework, certain aspects of the organisation's IT can be neglected at one time (for example because of lack of data), but can be measured for the organisation at another point in time (for example when more information becomes available). The arrows that come out of the modules signify the KPIs. For each module, one output arrow stands for the leading indicators and the other output arrow represents the lagging indicators. This entails that for each module separate leading as well as lagging indicators should be designed and quantified. Lagging indicators are result indicators and are focused on measuring certain parts at certain moments of time from which a change in any direction of the KPI can be concluded. Hence, lagging indicators can only be validated retrospectively. Leading indicators on the other hand measure internal practices or efforts, for example company policies, which are expected to improve performance. The purpose of leading indicators is less to measure results, but aimed more on encouraging certain actions (Leahy 2007)

From the framework, the initial list of KPIs to assess the environmental impact is derived. These KPIs are summarized in paragraph 5.1.4. in Table 5. The initial list of KPIs was in turn validated through an expert reviewing for the purpose of summative evaluation and acquiring a different perspective on the KPIs. Secondly the validation took place by means of a case study, for the purpose of testing the framework and the quantification of the KPIs in practice. The expert reviewing led to some alterations in the set of KPIs. The main alteration being the inclusion of one overall KPI that should be used for the communication to upper management. Another alteration is the aggregation of two KPIs on the standards module. The final list of the KPIs is given below in Table 8.

Table 8: Final list of KPIs

Standards module:
1. Percentage of IT equipment procured in one year, complying with the WEEE and ROHS directive
2. Percentage of IT equipment procured in one year, complying with the Energy Star standard
3. Percentage of desktops and notebooks procured in one year, complying with EPEAT Gold
4. Percentage of outstanding orders complying with the Energy Star standard (leading)
5. Importance of environmental criteria in the procurement process (leading)
Data centre computing
1. Total power consumption
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area in
5. Is there a policy in place aimed at reducing the energy consumption of the data centre? (leading)
6. Virtualization of the data centre (leading)
End user computing
1. Total power consumption
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area
5. Is there a policy in place aimed at switching of the equipment at night? (leading)
6. Awareness of the employees with green IT (leading)

Telephony	
1.	Total power consumption
2.	Total CO2e
3.	Power consumption per employee
4.	Power consumption per m^2 of floor area
5.	Use of fixed line telephony opposed to e-mail and/or mobile telephony (leading)
Networking	
1.	Total power consumption
2.	Total CO2e
3.	Power consumption per employee
4.	Power consumption per m^2 of floor area
5.	Power consumption per Gbps
6.	Power consumption per port
7.	Usage of wireless rather than a wired network (leading)
Document imaging	
1.	Total power consumption of document imaging equipment
2.	Total CO2e
3.	Power consumption per employee
4.	Power consumption per m^2 of floor area
5.	Number of employees per printer
6.	Number of pages printed per year per employee
7.	Awareness of employee on the amount of prints (dashboard) (leading)
8.	Ease of changing printing settings (leading)
Waste quantities	
1.	Total amount of IT equipment disposed
2.	Is there an internal company wide policy in place for green disposal? (leading)
Recycling	
1.	Percentage of disposed equipment that gets recycled or reused
2.	Percentage of contracts with recycle companies (leading)
3.	Innovativeness of recycle companies (leading)
Main KPI	
1.	Total power consumption of the IT

6.2 Scientific and practical contributions

The study that has been carried out, contributes in a number of ways to the practice of green IT and to the scientific theory concerning green IT. We will first discuss how the study contributes to the practice. Firstly, the research that has been carried out for this study raises awareness for the environment in general and for green IT in particular. In the introduction to this report, we mentioned how the attention for the environment has grown among the masses and how this was triggered. Furthermore we mentioned why IT specifically is interesting to look into with regard to sustainable development and we also discussed what can be done to decrease the environmental impact of IT. Raising awareness for green IT has broad implications for society. It is expected that the use of IT will grow substantially in the near future and therefore it is important that proper initiatives are undertaken at present to be prepared for the future (The Climate Group 2008).

However, raising awareness for green IT is not the only manner in which this study has social relevance. The outcome of this study is also a framework from which KPIs can be deduced to assess the environmental impact of a non-IT organisation, including the KPIs that derive from the framework. This framework has the added value of providing a structured approach to deduce a number of KPIs that can be used to assess the environmental impact of an organisation's IT. Since this study was carried out as part of an internship that was pursued within Shell, the framework is tailored to the objectives and requirements of Shell. However, as we will see in paragraph 6.3, the framework itself and to a large extent the KPIs too, could also be used in other (multi-national) organisations. This increases the practical contribution even further. From the initial literature study carried out at the beginning of this research, we concluded that as of yet, there is no standardized uniform method to assess the environmental impact of an organisation's IT. The framework that has been developed within this research could fill this knowledge gap and thus provide the means to structurally assess the environmental impact of an organisation's IT.

In addition to the practical contributions of this study, there are also theoretical contributions. Firstly, this study contributes to the theory of framework design, as it utilizes the metamodel, initially designed by Herder et al. (2004), to design a framework from the ground up, with a requirements input based approach. The metamodel was structurally used for each step of the design cycle to lead to the final product. It is argued by some that the metamodel is not intended to be used as a design approach. However, others argue that the metamodel indeed can be used as a design approach (Koppenjan & Groenewegen 2005; Apotheker). This study shows that although the metamodel itself was not developed to be used as a design approach, it can nonetheless be used in this fashion, as it structurally provides the steps a designer follows for the design of a framework.

The second theoretical contribution is of course the framework itself and its KPIs. As already discussed, we concluded at the beginning of this study that there was no standardized uniform method to assess the environmental impact of an organisation's IT. Until now, the amount of scientific debate on this subject has been relatively limited. Nonetheless, within the scientific literature available, it is acknowledged that the environmental impact of IT may grow to be a problem in the near future. Indeed research has been done on what measures can be taken to reduce the environmental impact of IT, particularly concentrating on the data centres. Yet, relatively little research has been done on the aspect of measuring the current environmental impact of the IT. The method that is designed in this research provides the opportunity to fill this knowledge gap not only from a practical perspective, but also from a scientific perspective. This model could catalyze the scientific debate on measurement standards and processes for assessing the environmental impact of the IT. Better yet, the model could be used and optimized by scientists, in order to provide one standardized uniform approach for the assessment of the environmental impact of an organisation's IT.

6.3 Limitations

An initial limitation of this research, is that it has been carried out from the perspective of only one organisation, namely Shell. It was already acknowledged at the beginning of this study that the requirements were to be formulated through interaction with Shell and that therefore the design as a whole would be largely influenced by the context of the Shell organisation. If the research had been carried out amongst multiple organisations, the requirements could have been formulated on a more business independent basis. If the case were that the requirements were formulated on the basis of multiple organisations, the initiatives with regard to cross business benchmarking could also be realized more effectively. However, reflecting on the model and its resulting KPIs teaches us that at present there is not an abundance of Shell specific elements. Although the framework was developed within Shell and on the basis of the requirements that were specified within Shell, general cross business applicability was continuously kept in mind during the design of the framework. Therefore, the framework itself could be used properly within other organisations that aim to assess the environmental impact of their IT, as the framework does not have any clear Shell specific elements. The same can be said for most of the KPIs that result from the framework. Those elements within the model that are relatively more Shell specific are the leading indicators. However, we also discussed that the leading indicators are still in a conceptual phase and that in order for them to be used properly, further research should be conducted.

One limitation that may hamper the generalization of the outcome is closely related to the fact that the study has been carried out solely within Shell. Namely, that for the validation of the model, no experts outside Shell were involved . Moreover, in general the relatively small number of experts that were interviewed for the validation of the model, may in essence hamper the generalization of the outcome. In theory it could have provided fruitful insight, to consult a higher number of experts, who also operated outside of Shell. In such a way a more critical reflection on the model could have been provided. However, we have chosen to limit the number of experts to three persons that work within Shell, since this study is carried out internally for Shell for the purpose of an internship. Nonetheless, the model and its KPIs has been reflected on in general, by a member of the graduation committee from Delft University of Technology. From this general reflection we have concluded that the KPIs are suited for application in other organisations.

6.4 Reflection

Next to the limitations of the study, we will reflect on the process of the study and the applicability of the outcome of the study. First of all, we can conclude that with this report, the measurement problem with regard to the environmental impact of IT for Shell is not entirely solved. Rather, this report provides a potential method to provide support in the process of quantification of the environmental impact of the IT. Hence, before the actual measurements can take place, it would be wise to initiate a pilot project with regard to the effectuation of the framework. In essence, such a pilot project has been carried out on a much smaller scale for the purpose of the case study within this study. Within the case study we concluded that it would not be feasible to quantify the total of KPIs and therefore a subset of KPIs was chosen. Hence, the feasibility of the measurement process was confined by business intelligence deficiencies. Therefore, concepts with regard to business intelligence should also have a role in the framework, since elements that are not at hand within the organisation also cannot be measured properly. The aforementioned can be related to the design from an institutional perspective and its interrelation with the design from a technical perspective and a process perspective. The framework and its KPIs can clearly be contributed to the technical perspective. It was already concluded that the process design should be part of the framework and is therefore subject for further research. The same can be concluded for the institutional perspective, where the concept of business intelligence should have an important role as well. More on this in paragraph 6.5; recommendations for future research.

With regard to the process of this study, we can conclude that it potentially would have been beneficial, to include actors outside of Shell in the study. The process that was followed for the design of the framework, was from the specific case of Shell. After, the theory was tested for its general applicability by means of an interview. A favourable approach would have been to include multiple cross business stakeholders in the overall design process and as such also create support for the applicability of the framework.

6.5 Recommendations for further research

Within this study we concluded a number of times that to a certain extent further research was required. In this paragraph we will structurally give an overview of the points where further research would be beneficial.

Further research with regard to the framework

From the case study we concluded that there is no overall process method for the quantification and selection of the KPIs. As mentioned before, the framework is constructed with a modular approach, to enable the selection of separate modules. However, for the organisation that effectuates the framework, the framework does not provide a clear structural approach on how to select the modules. Moreover, once specific modules are selected for quantification by the organisation that effectuates the framework, it is unclear which KPIs should be included per module. It would be beneficial if along with the framework, a process design would be provided. A process design is key for reaching the end result of consistent and accurate KPIs, given that without a process design there would be no standardised method for quantifying the KPIs, thus reducing the benchmarking abilities of the KPIs. Furthermore, a thoroughly structured process design aids in the process of quantifying the KPIs, since it describes which steps should be followed, in which order and how. Only with a proper process design in conjunction with the remainder of the framework, the KPIs can be quantified properly. However, as of yet, the process design is not a part of the framework. This is therefore, subject for further research. We can conclude from the requirements check, that as a whole, the KPIs meet the specified requirements to a large extent. However, we also concluded that on the requirement of consistent measurability, as a whole, the KPIs fail. In order for the framework and its KPIs to pass on this requirement, an adequate standardized process design should be in place. Therefore, further research that focuses on the design of a standardized process design that would complement the framework, needs to be conducted.

Special attention to local situations for the design of KPIs, was mentioned at the expert reviewing as a potential alteration to the model (see paragraph 5.1.4). However, incorporating this into the framework would entail that separate KPIs should be formulated for every local condition. Hence, the framework should be tailored to the specific requirements of every local entity of an organisation that would effectuate the framework. This is purposely not the objective of this framework, nor of the resulting KPIs. From the formulation of the assignment, which served as the starting point for this study, it is clear that it was required to formulate a set of high level KPIs that should be suited for Shell worldwide. This was also concluded from the first interviews with the main stakeholder. Therefore in this version of the framework, special attention to local circumstances will not be incorporated. Nonetheless, this could be subject for further research. Within this research it could be investigated how the framework might be altered to enable the formulation of environmental KPIs on a local level.

Another aspect where further research can be conducted concerns the institutional design that could complement the framework. The institutional design comprises of the whole of rules and regulations that is in place (Klijn & Koppenjan 2000). Thus, in the case of this study, the institutional design would see on the processes that should be in place within the organisation to acquire the relevant information from the different business units. From the case study we can conclude that it proved infeasible to gather the required data to quantify the KPIs on all the modules. We already pointed out that a standardized process design would aid in the process of quantifying the KPIs, as it gives a clear process description for the quantification. However, the process design does not give clear directions on the institutional issues for the gathering of information within the organisation. For this purpose an institutional design would aid. A thoroughly worked out institutional design would cover aspects of business intelligence, in order to facilitate the process of quantifying the KPIs. Therefore an institutional design for the process design and the framework is also a subject for further research. A potential first step of the combination of the process design and the institutional design, is raising the awareness of green IT within the company. Undertaking this, could prove fertile from a business intelligence point of view, as it could stimulate the co-operability within the organisation.

Further research with regard to the KPIs

The suggested leading KPIs for the end user computing module are: 'Is there a policy in place aimed at switching off the equipment at night?' and 'Awareness of the employees with green IT'. The first KPI could be quantified by simply specifying whether the policy is in place or not. The underlying rationale for this KPI is that if there is a policy in place, there will be compliance with the policy and as such the power consumption of end user computing equipment will be lower. However, it cannot be guaranteed that if there is a policy in place, there will actually be compliance with the policy. Therefore, this could be subject of further research, wherein the correlation between policy and energy consumption could be investigated. The second leading KPI – 'Awareness of the employees with green IT' - deserves a similar side note with regard to the further research that should be conducted. For this KPI, it is assumed that if the employee is more aware of green IT, he or she will also act more environmentally friendly. However, again, this assumption should be tested and as such is a subject for further research.

Similar to the leading KPIs on the end user computing module, the leading KPIs on the document imaging module also require further research. The first leading KPI for the document imaging module is 'Awareness of employee on the amount of prints.' This KPI should measure how aware a given employee is with the number of prints he or she makes. By confronting the employee with the amount of prints, he or she could acquire more insight into the environmental impact of his or her behaviour. A method to make the employee more aware of the number of prints is to build a printing dashboard, where an employee can acquire insight dynamically into the number of prints.

An underlying assumption for this KPI is that when the employees are more aware of the number of prints, they will print less. However, as Kollmuss & Agyeman (2002) show, environmental awareness does not necessarily lead to environmentally friendly behaviour. Therefore, this assumption should be tested. This is subject for further research, where the relationship between awareness of green IT and behaviour will be the focus. The second leading KPI for this module is 'Ease of changing printing settings'. From the workshop it was concluded that in a large number of cases, the printing settings were suboptimal (see appendix C). This entails that multiple printing requests were necessary at times. This problem could be taken care of easily, by prompting the printing settings to the user every time he or she does a printing request. Hence, the ease of changing the printing settings could lead to a lower number of prints in total. Again, this assumption has to be tested, which is subject for further research.

The leading KPIs on the waste quantities modules also provide input for further research. The first KPI of this module is the total amount of IT equipment disposed per year. In other words, the waste quantity itself. As already mentioned, it is important to make some clear definitions around this KPI, as it is debatable what could be considered waste and whether all types of waste should be subject for analysis, or only the type of waste that is harmful to the environment. A second KPI for this module, is a leading KPI that derives from the workshop (see appendix C). This KPI is: 'Is there an internal company wide policy in place for green disposal?' With this KPI, an immediate conclusion can be drawn on the effort of an organisation with regard to the disposal of IT equipment. However, as with all the other suggested leading indicators, is it important that there will be consensus on the interpretation of the KPI. Elements within this KPI that are open for debate are whether the initiative can be considered a policy, whether it can be considered company-wide and whether it can be considered green disposal. These questions are all subject for further research and can only be answered once more information from more organisations besides Shell is available. The further research should therefore concentrate on a multiple case study, from which information can be compared transversely.

Considering the KPIs of the recycling module. It was suggested that we should pay note to the toxicity of computer equipment at the disposal phase by specifying the already existing leading KPI - innovativeness of recycle company – in such a manner to take the handling of toxic material into special account. How this will be dealt with, is subject for further research. Once the factor of toxicity is incorporated into the 'recycling' module, it is wise to control the KPI through audits. Nonetheless, how these audits should be carried out is another subject for further investigation.

A framework for assessing the environmental impact of an organisation's IT

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Abstract

As of yet no encompassing assessment method for an organisation's IT exists and therefore we developed such a method in the form of a framework. The framework acquired its shape based on a Life Cycle Analysis approach and by taking the grounds for the environmental impact of IT as the basis. The framework we will present in this paper does not serve as the assessment metric itself. Rather, it provides an approach that has as measurable output, a number of environmental KPIs. However, within this paper we will not present, nor suggest the KPIs that should be used in accordance with the framework. The intention of this paper is purely to give a first understanding of how the assessment of an organisation's IT could take place by taking a structured approach. Hence, the aim of this paper is to stimulate the scientific debate with regard to this subject.

Keywords: Green IT, framework, assessment, environmental impact

1. Introduction

The climate on earth is changing. Scientific consensus has been reached that this is due to the increasing amount of CO2 emissions. Therefore, multiple initiatives arose worldwide, which aim at reducing the amount of CO2 emissions. The IT does not get neglected and is also investigated for possible room for improvement with regard to the amount of CO2 emissions. However, before measures are put into effect that aim to reduce the environmental impact, it is wise to know the current environmental impact of the IT, for which potential progress in this regard can be monitored structurally and consistently. As such, an assessment tool should be in place that can give insight into the current environmental impact of the IT within an organisation. In addition, it is preferable to have the means to compare the results regarding the environmental impact over multiple organisations to get a better understanding of the relative position of one organisation. From a literature study we have concluded that currently there is no encompassing assessment method for an organisation's IT (Leahy 2007; Mingray 2007). Therefore, we have developed an assessment method for the environmental impact of an organisations IT on the basis of existing assessment tools. This paper gives an

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overview of this overall assessment method, which is presented in the form of a framework.

First of all, we will discuss who will benefit from the framework and for which purposes the framework is not suited. Thus, the scope of the framework will be discussed at first in section two. Second of all we will provide an overview of the foundation of the framework. As such, we will discuss how the framework acquired its appearance. This will be presented in section three. Hereafter, the framework itself will be presented in section four. Finally, in section five, we will present the conclusions where we reflect on the framework.

2. Scope of the framework

To begin with, it is important to denote that there are multiple perspectives to look at IT with regard to sustainable development and thus there are multiple perspectives to characterize green IT. First of all, IT can be investigated on its own for room for improvement in its environmental impact, the so-called first order effects. Since as of yet no uniform method exists to properly quantify the first order effects, the focus of the framework that will be presented in this paper is on these first order effects of IT. Next, IT can also be seen as the enabler of working towards sustainable development, the so-called second order effects (Berkhout & Hertin 2001; The Climate Group 2008). Implications of the second order effects perspective of looking at IT could consist for example of; intensifying the usage of video conferencing and utilizing IT to optimize certain processes, with a view to reducing the negative environmental impact. The second order effects perspective of looking at IT is unquestionably interesting to look at for any organisation for the purpose of reducing the company's negative impact on the environment. Nevertheless, considering the company wide implications it would require to properly investigate the possibilities for the enabling effect of IT with regard to the environmental impact, it would not be viable to incorporate elements of the second order effects of IT within the framework.

The framework we will present in this paper provides an approach for the assessment of the environmental impact of an organisation's IT. That approach should subsequently have as output a number of variables that can be easily interpretable to serve as clear measurements of the environmental impact of an organisation's IT. In other words, the variables should properly assess possible changes to the IT with regard to the environmental impact. These variables can be typified as environmental key performance indicators (KPIs). However, within this paper we will not present nor suggest the KPIs that should be used in accordance with the framework. The intention of this paper is merely to give a first understanding of how the assessment of an organisation's IT could take place by taking a structured approach. Hence, the aim of this paper is to stimulate the scientific debate with regard to this subject. Hereon after, the focus could shift on the actual design of uniformly applicable KPIs that would coincide with the framework.

3. Foundation of the framework

Before we will present the framework, we will first discuss how the framework acquired its appearance. One main foundation of the framework is the objective of contributing to the goal of reducing the environmental impact of the IT of the organisation in question. We can conclude from Berkhout and Hertin (2001), that the current impact of IT on the environment is relatively large and is continuing to grow even larger. Where exactly this impact on the environment occurs and how the impact occurs, can however be hard to grasp at first sight, as the effects of the environmental impact of IT are not nearly as visible as par example the environmental impact of the automobile industry or the aviation industry. Therefore, below a summarization is given on the areas of environmental impact of the IT.

- Direct pollution of air water and land from the manufacturing, transport, use and disposal of IT equipment.
- GHG emissions resulting from manufacturing, use (power) and disposal of IT equipment and GHG emissions from transport and travel of IT equipment
- Use of hazardous, non-degradable and finite materials at the manufacturing- and disposal phase of IT equipment.

From the summary above we can conclude that a distinction on the general environmental impact of IT can be made on three grounds. The first ground is the direct pollution. This entails the immediately visible impact on the environment. In the case of the manufacturing of the IT equipment, this can be the air pollution from factories, producing IT equipment, but also earlier in the product life cycle, the ground pollution and potential sound pollution from the mining of raw materials. The direct pollution from the use of IT equipment is as already mentioned less apparent. Nonetheless, direct pollution due to the usage of IT equipment can manifest for example when printing from a laser printer, as this emits ultra fine particles (Morawska et al. 2008; Schripp et al. 2008)

The second ground for the general impact of IT on the environment, is the GHG emissions resulting from the manufacturing, use and disposal of IT equipment and the transport and travel. Before the IT equipment will be put to use, in for example an office building, it first has to be produced from raw material and then transported to its destination. In the production phase a relatively large part of energy is needed to make the equipment. According to some, more energy is consumed at the production phase of IT equipment than at the usage phase of the same equipment (Costanza 1980; Brown & Herendreen 1996). The energy that is required for the production of the IT equipment is in most cases derived from fossil fuels and therefore accountable for the emission of GHGs. Next to the GHG resulting from the production of IT equipment, GHG emissions result from the transport of IT equipment, for example from the production facility to the retailer or from the retailer to the end user. Whether this transport is by boat, plain, train or truck, GHGs are highly likely to be emitted. GHG emissions resulting from the usage of IT equipment are due to the energy requirements of the IT equipment and as long as the energy that powers the devices does not solely result from renewable sources, GHGs are emitted. Finally, at the disposal phase GHGs are likely to be emitted whenever the equipment is disassembled with use of energy consuming machinery for recycling or refurbishment.

The third ground for the general environmental impact of IT, is the use of hazardous, non-degradable and finite materials at the manufacturing- and disposal phase of IT equipment. For specific IT equipment, hazardous material is used, such as lead, cadmium, mercury and chromium (Hazardous waste directory 2008). These materials can have a harmful impact on the environment at the disposal phase of the IT equipment, if they are not to be taken care of properly. Furthermore, considering scarce resources, with an average worker printing about 1000 pages per month, water and wood required for the paper is consumed in large amounts too.

Considering the three grounds discussed, it should be concluded that whenever an organisation wants to improve its environmental impact of the IT, it should focus on more than for example the power consumption of the equipment alone. The three grounds where the environmental impact of the IT can occur, should be kept in mind whenever thorough measures are to be taken with regard to the environmental impact of an organisation's IT. This also goes for the organisation that is looking into green IT largely from a reputational point of view, as a focus on decreasing energy use alone for example, could easily be characterized by others as a cost reduction initiative, rather than a serious green IT initiative. The grounds for the environmental impact make up an important constraint for the design of the metrics.

4. The framework to assess the environmental impact of an organisation's IT

The grounds that are presented above, relate clearly that the environmental impact of IT occurs at every stage of the life cycle (e.g. manufacturing, transport, use and disposal). Furthermore, the grounds show that a distinction can be made on the type of environmental impact of the IT (e.g. direct pollution of air water and land, GHG emissions and use of hazardous, non-degradable and finite materials). Therefore the environmental life cycle of the IT industry is interesting to look into. A life cycle analysis (LCA) based focus also derives from the ISO 14042 standard, where an environmental LCA is recommended for the assessment of the environmental impact of a product (Hertwich & Pease 1998). A visualization of the environmental life cycle of IT is given below.

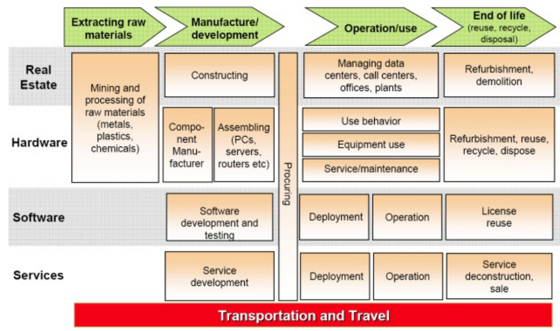

Figure 1: Environmental life cycle of the IT industry (visualization adopted from Gartner)

If this environmental life cycle of IT is studied in more detail, it can also be concluded that the level of the environmental impact of IT equipment varies along that life cycle. However, actions aimed at reducing the environmental impact of IT, are not for every organisation at every level of the environmental life cycle achievable to put into effect. For example, a company that produces IT equipment can indeed make a difference in the first part of the environmental life cycle for the IT equipment, whereas a company that only uses IT equipment, will not have that ability. Since the framework is not intended solely for IT producing companies, but rather for non-IT producing organisations, the product centric environmental life cycle for IT equipment shall not provide favourable results for the foundation of the framework. The environmental life cycle is therefore adjusted, so it is confined to the organisational boundaries of a non-IT producing organisation. The 'cradle to grave approach' that is reminiscent of the environmental life cycle is therefore replaced by 'an organisation's entry to organisation's exit approach'. As a result, the following building blocks are to be omitted: "mining and processing of raw materials" and "component manufacturing". Both are areas where a non-IT producing organisation will not be actively involved. Another variation to the environmental life cycle that should be made, entails that the hardware element is taken as chief perspective. This choice is made, considering the fact that most results with regard to reducing the environmental impact can be made the fastest on the hardware level, as the effort to quantify the environmental impact of software and services would be much more laborious. Thus, to keep the focus on those areas of the IT where a potential difference will lead to measurable changes and to keep the assessment feasible within a reasonable timeframe and a reasonable amount of effort, the framework will have a hardware centric focus. This is demonstrated in the visualization below.

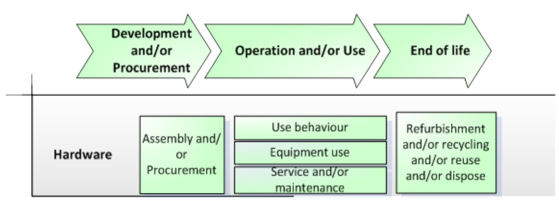

Figure 2: Environmental life cycle of IT for a non-IT producing organisation (adopted from: Gartner)

Given the hardware centric focus of the framework, it could be assumed that the framework deals solely with the IT equipment itself. However, within an organisation, the manner in which the employees are using the IT can have huge effects on the environmental footprint of an organisation's IT as well. Therefore usage patterns are also taken into consideration within the framework. Furthermore, from the visualization it can be concluded that a factor such as transport is not explicitly taken into account within the framework. Still, it can also be subject to assessment through the embodied energy module. We will discuss both these aspects below.

The three areas of environmental impact of IT which are mentioned in section three are taken as the foundation for the design of the framework. In turn, those three areas are transformed to the environmental life cycle of IT for a non-IT producing organisation. The core of the framework, which is deduced from the aforementioned, is visualized below in Figure 3.

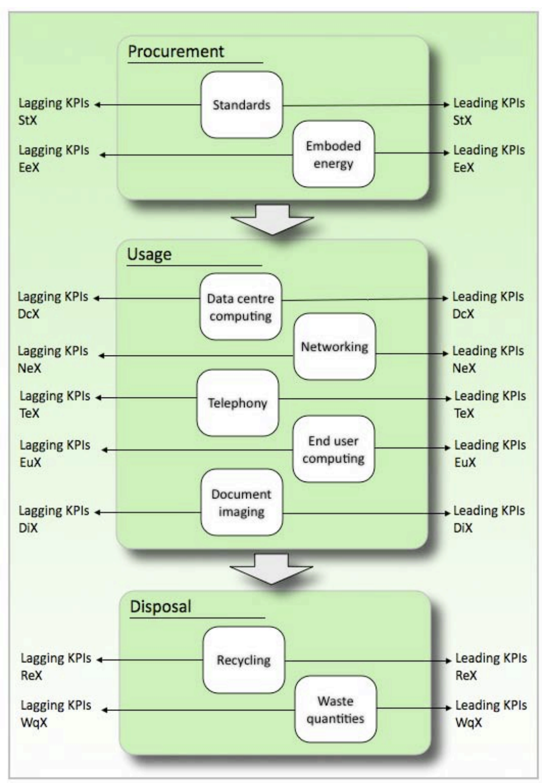

Figure 3: Core of the framework

The three large green boxes represent the building blocks. The nine smaller white boxes represent the modules. We will shortly discuss each individual module in the remainder of this section. As said before, within this paper we will not discuss the KPIs that could and/or should correspond with each module, as this is still subject for further scientific research.

Standards

This module is part of the procurement phase. The procurement phase is an important phase to look into for a non-IT producing organisation if it aims to reduce its environmental impact, since a non-IT producing organisation cannot make a difference in the first phases of the life cycle (e.g. extracting raw materials, manufacturing, developing, etc.). A non-IT producing organisation can however make a judgement on the type of equipment they procure and whom they procure from, with regard to the environmental impact of that equipment. Within Europe there are multiple standards available for the producers of IT equipment to assess the environmental impact of its products. The International Organisation for Standardization (ISO) has categorized the different voluntary standards into three broad types of labels. Type I (ISO 14024) consists of a voluntary, multiple criteria-based, third party program that awards a license that authorises the use of environmental labels on products, based on life cycle considerations. Type II (ISO 14021) consists of informative environmental self-declaration claims. The third type consists of environmental product declarations, but is not widely in use as of yet (November 2008) (Jonbrink & Amen 2007). Although the different types of voluntary agreements have different origins, their meaning and use can be the same for the consumer, which is to acquire immediate insight into the environmental friendliness of the product. For this purpose, it is essential that the label for environmental friendliness is awarded on sufficient grounds and in a just manner. Examples of standards that satisfy these criteria are: Energy Star, TCO, the Flower, the Swan, the Blue Angel and EPEAT.

Embodied energy

Embodied energy is the energy required directly and indirectly to manufacture products (Treloar 1998). This can be seen as an accounting methodology with the goal of quantifying the total amount of energy that was necessary to acquire the end result of the product in question. In order to quantify this number, different steps of the product life cycle should be investigated, including the raw material extraction-, refining-, transport-, manufacturing-, assembly- and installation phase. In addition, the final phases of the product life cycle should also be accounted for, including disassembly, deconstruction and/or decomposition. There are different methodologies to quantify the embodied energy. One of these methodologies is that of 'process analyses', for this methodology the energy embodied in a product is traced upstream by examining the inputs to each preceding process towards raw materials. Unsurprisingly, this methodology can lead to serious feasibility problems, as it is extremely difficult to quantify the amount of energy as input for every step of the product life cycle. Another major embodied energy analysis methodology, is the 'input-output analysis', this comprises the use of national statistics combined with product specific conversions, in order to quantify the total amount of embodied energy of a certain product (Treloar 1998). This method makes use of many assumptions and generalizations and therefore this method produces unreliable results if inadequate effort is spent on the computation processes (Lenzen 2002).

Data centre computing

The data centre computing module belongs to the usage phase of the framework. So for this module, only the environmental impact resulting from the usage of a data centre will be quantified by means of KPIs. However, this is a more encompassing task than it might seem at first sight, since a data centre houses more than only the data servers themselves. For example, the cooling for the data servers is a crucial element of data centre computing. Data centres are characterized by very high energy utilization intensities and the internal heat load of the servers creates a nearly constant demand for air conditioning to maintain equipment within a narrow range of temperature and humidity, which is necessary for proper operation (U. S. Environmental Protection Agency Combined Heat and Power Partnership 2007). Accordingly, data centres have much higher energy utilization intensities, approximately 20 to 100 watts per square foot, compared to typical commercial buildings, which average at 2 Watts per square foot (Energy Information Administration 2007).

The equipment contained in a data centre can be divided into two main categories: infrastructure equipment and Information Technology (IT) equipment. The first category includes the equipment for conditioning and distributing electrical power (e.g. transformers, switch gear, uninterruptible power supplies, power distribution units, circuit breakers, and distribution wiring), as well as equipment used to remove waste heat from the data centre (e.g. Computer Room Air Conditioners [CRA Cs], Computer Room Air Handlers, Direct Expansion (DX) coolers, chillers and pumps for circulating chilled water, and cooling towers). IT equipment includes the servers that run the operating system and application software that produce the primary work product of the data centre along with support hardware such as storage devices and networking equipment (The Green Grid 2008).

Since there are multiple ways to look at data centre computing, it is wise to give a clear definition of data centre computing as it is used for this module. For example, data centre computing can be approached by looking solely at the servers at a data centre. On the other hand, data centre computing can be approached by taking the whole data centre as a starting point, thereby including all infrastructure equipment from the data centre, the IT equipment from the data centre and the network elements necessary to connect the data centres to the office environment. The definition of data centre computing for this module fits in the midst of the two types of definitions given above. Data centre computing for this module involves all equipment that is situated at a data centre, thus including all infrastructure equipment and IT equipment. However, the network necessary to connect the data warehouse to the office environment is not included. We made this choice, since it is wise to only include KPIs that measure aspects that the organisation can adjust. The network itself which is used to connect the data warehouse to the office environment is in most cases not owned or managed by the same organisation that uses the data centre. Hence, there is little to no influence on the type of network to be used and as such it is not worthwhile measuring these data. The same underlying rationale, justifies the decision to incorporate the cooling and network equipment in the definition. The cooling and network equipment is in a large number of cases either property of the same organisation that uses and manages the data centre and otherwise, the organisation that only uses the data centre can have influence on the type of equipment that should be used for this purpose.

Telephony

Telephony is by some seen as an important part of IT and others characterize telephony as a separate communication medium that should not be categorized to IT. Accordingly, whether telephony will be subject for assessment, is a choice that should be made by the organisation that aims on designing the environmental KPIs by using the framework. While an average piece of end user computing equipment uses somewhere between 50 and 300 W of power when in use, an average telephone uses somewhere between 1 and 8 W, whether in use or in standby (Clevers & Verweij 2007; Rosen, Meier & Zandelin 2007). Therefore the total power consumption could be low if the number of telephones within the organisation is also low. Yet, if the number of telephones is relatively high, the overall environmental impact of telephony can also be high considering the fact that the equipment consumes energy continually. Therefore, if an organisation's IT department does have control over the telephony within the organisation, it may be beneficial to also design KPIs on telephony. In the end, the choice of incorporating the telephony module, is one that should be made by the organisation that effectuates the framework. This framework does provide the guideline for assessing telephony within the company and therefore it is important to look into the difference between traditional telephony and IP telephony.

An increasing number of organisations is making the switch from traditional telephony to IP telephony (Jiang et al. 2001) This switchover is often initiated considering the benefits of IP telephony over traditional telephony, as lower costs and easier expandability (Jiang et al. 2001). IP telephony has these advantages since it can use the company's intranet and/or the Internet instead of a separate network which traditional telephony requires (Jiang et al. 2001). In view of that, a crucial choice for this module, is whether IP telephony should be part of the telephony module, or that it should belong to the networking module. Incorporating IP telephony into the networking module has its benefits and disadvantages. One benefit of including IP telephony into the networking module is that the same measurement process can be used for both, which is IP scanning. IP telephony largely uses the same network and networking equipment as the IT equipment of the networking module. As a result, if IP scanning will be used as measurement method for the networking module, the danger of double counting is high if the elements of IP telephony are to be measured and reported separately for another module. However, a disadvantage of incorporating IP telephony into the networking module is that whenever the division between traditional telephony and IP telephony changes, a movement between modules occurs. For example, if an organisation decides on switching a large part of their traditional telephony to IP telephony, the numbers on the KPIs of the telephony module will diminish, whereas the numbers on the KPIs of the networking module will increase. This is unfavourable for proper periodical comparisons of the KPIs. Another disadvantage of incorporating IP telephony into the networking module, is that the KPIs for the telephony module will not represent the actual situation within the organisation, since a portion of telephony, namely the IP telephony part, is accounted for at the networking module. Thus, in such a situation the numbers of the KPIs of the telephony module do not represent all telephony equipment, but only the traditional telephony equipment. This is adverse for the communicative value of the KPIs.

Although the measurement process will be more troublesome and labour intensive if IP telephony will be part of the telephony module instead of the networking module, this is nevertheless preferred considering the fact that the KPIs should be repeatable and consistently measurable to be of use. As already discussed, will this be very difficult if IP telephony is part of the networking module and the division of traditional telephony opposed to IP telephony changes. Therefore, incorporating IP telephony into the telephony module is clearly preferred.

Next to the telephones themselves, all supporting equipment for telephony should be part of this module. In the case of traditional telephony, these are the Private Automatic Branche eXchange (PABX) devices and the wires themselves. In the case of IP telephony, the situation is largely analogous, with the difference that special VOIP PABXs are necessary (Jiang et al. 2001). By stating that all supporting equipment should be used, it is not intended to also measure the elements of the telephony- and or IP network that are not owned or controlled by the organisation. The elements outside the organisation (e.g. glass fibre, copper wires, satellites and switches) are property of the network company and should not be subject for analysis, as these elements cannot be adjusted by the company in question.

Mobile telephony has not been discussed yet. Whether mobile telephony should be part of the assessment, is another choice to make. Even more so than fixed line telephony, which was discussed above, the environmental impact of mobile telephony within an organisation is relatively small (Clevers & Verweij 2007; Rosen, Meier & Zandelin 2007). Again, the largest environmental impact is made at the infrastructure level, which is beyond the scope of measurement for most organisations, since the network operators control this infrastructure. One area where mobile telephony differs from fixed line telephony is that the energy consumption is battery based and that the charging of the battery often takes place outside the office environment. In view of the aforesaid, the question might arise whether numbers on the energy consumption of mobile telephony should be specified. If an organisation decides to design KPIs for the telephony module. Another aspect that should be kept in mind is that the energy consumption per mobile device can vary to a great extent and this may trouble the measurement process for the total energy consumption of mobile telephony greatly. Considering the feasibility of the measurement process, it may justify to not incorporate mobile telephony in the measuring process, for the company in question.

Networking

In almost every large scale multinational organisation there are one or more networks within the company, to facilitate, among other things, communication between the employees (Varshney et al. 2002). Although the exact topology of the network differs largely per organisation, the basic lay out of a network consists mostly of routers and switches and of course the network cables. It is important to clearly specify at first what is included in the networking module, since the interpretation of the scope may vary. For the purpose of the module, networking consists not of data centres etc., as these are already covered with another module. The elements that are indeed covered by this module are the pieces of networking equipment itself, such as routers, switches, transceiver modules, etc.

End user computing

Whereas data centre computing concentrates on the computers that form the backbone of most modern organisation's computer networks, end user computing constitutes the forefront of the computer network for most of the organisation's employees. Thus, end user computing comprises the computing equipment the employees within the organisation use for their daily work. Desktop computers, monitors, thin clients and notebooks therefore belong to this module. This module can be considered as the most important module of the framework, since the visibility of the equipment that belongs to this module is very high and at the same time, the overall environmental impact of the equipment that belongs to this module is also relatively high (Mingray 2007). However, the effort to properly design and quantify adequate KPIs to assess the elements of this module can also be considered the biggest. Unlike the situation of data centre computing, the equipment is in most situations not confined to one location that allows for measuring the power usage from the meter. In reality, the equipment is scattered throughout the offices and thus the power usage of the total equipment cannot be concluded from the power meter.

Since end user computing equipment is part of the office environment, elements such as illumination and cooling of the building, should not be accounted for the quantification of KPIs for this module. In the case of illumination of the building this is obvious, as illumination would also be necessary in more or less the same quantity in the situation that an office building has a large amount of end user computing equipment or in the case that the office building has no end user computing equipment. However, exactly the same cannot be said about the cooling of the building. In certain buildings, the air-conditioning in a building has to work harder to cool the waste heat from the end user computing equipment within the building. Therefore, extra energy is needed for the cooling of the building, due to end user computing. However, this is only the case if the office is in a location where the outside temperature is higher than the required office temperature and consequently air-conditioning within the building is required. In the case of an office building where the outside temperature is lower than the required inside temperature, the end user computing equipment aids in the process of heating the office building. In such a case, less energy is required from the central heating of the building. For that reason, it seems unproductive to quantify the exact amounts of waste heat and accordingly the extra energy requirements for the cooling of the building. The latter would only be valuable if it concerns an organisation with office buildings solely in a warm climate, where the air conditioning is required year round.

Document imaging

This module focuses on printing devices, scanners, copiers, faxing machines and multifunctionals. In short, everywhere within the organisation where there is an interaction between digital documents and paper. This module is of great importance for an organisation that aims to reduce its environmental impact, as the visibility of printing is high and therefore the associations of printing and environmental impact among employees is also high. The latter can be explained by the fact that unlike with the modules discussed above, there is a direct noticeable effect, with regard to the environmental impact, of the printing request, which is paper and ink that is consumed for the prints. Consequently, for this module not only the power consumption of the equipment should be analysed but also the use of paper, ink and toner.

Waste quantities

While the preceding five modules were part of the usage phase of the framework. The next two modules that will be dealt with are part of the disposal segment of the framework. As said before, the general impact on the environment of the IT, implies more than the effects of the power requirements of the IT equipment alone. Therefore, it is also important to look into the disposal segment of the framework, as this aims to address the direct pollution of air, water and land from the disposal of IT equipment and the GHG emissions resulting from the disposal of IT equipment.

Firstly, the waste quantities module will be discussed. At first, it is important to specify what exactly is meant with waste. Secondly, it is important to scope the types of waste. With regard to the former, it has to be decided at which moment in time a product is considered 'waste'. For some organisations, this is whenever the product gets disposed of through a contract with the disposal company. Other companies however, have a policy where equipment is considered waste after the equipment type has reached a certain life time (Kelly 1993). The definition of waste is therefore not strict and has to be made by the company that aims to quantify this module. Another problem they then have to deal with, is as already mentioned, the scoping of the types of equipment. One suggestion is to include the same equipment as the modules that are chosen to include in the usage phase of the framework. Thus, if for example only the end user computing module and the telephony module are included, then also the equipment of only these two modules could be included for the waste quantities module. However, this may hamper the consistent comparison of the KPIs of the waste quantities module. For example, if in a given year an organisation incorporates only two modules and the next year it incorporates four, the scope of the waste quantities module would be bigger and as such incomparable to preceding measurement. Therefore, it is not recommended to base the scoping for this module on other modules. An alternative to scope this module, is by clearly investigating at first which waste could be measured and then to stay with this group of waste for a number of years (e.g. 5 years) and potentially evaluate the group after this period for incorporating other types of waste. By doing this, the KPIs of this module would be consistently comparable for fixed periods.

Recycling

With the waste quantities module, the amount of waste is the key metric. The underlying rationale there is, the less waste an organisation produces, the more environmentally friendly that organisation operates. Nevertheless, the manner in which an organisation deals with its waste, also determines the environmental friendliness of the company. Disposal of IT equipment can be categorized into several categories. The first category is that of landfill. Landfill is the oldest form of waste treatment and entails the dumping of the equipment on specially designated sites (Grenchus, Keene & Nobs 1997). A second category is that of recycling. Recycling involves processing used materials into new products in order to prevent among others the waste of potentially useful materials and reduces water pollution by reducing the need for "conventional" waste disposal as landfill (Kopacek & Kopacek 1999). A third category is that of reuse. With reuse, the IT equipment gets only a slight update or alteration and then will be reused by another customer. In the case of computers or laptops, frequently the hard drive will be wiped for its data too (Grenchus, Keene & Nobs 1997).

When the different methods of disposal are put in order, according to the level of environmental impact, landfill would be first, as this is the least environmental friendly option, followed by recycling at second and reuse as last (Grenchus, Keene & Nobs 1997; Kopacek & Kopacek 1999; Jung & Bartel 1999). Thus, the higher the percentage of recycling and reuse of disposal as opposed to landfill, the more environmentally friendly an organisation operates.

5. Conclusions

In this paper we have presented an approach for assessing the environmental impact of an organisation’s IT. This approach is presented in the form of a generic framework. The strength of the framework lies in the fact that it provides a structured approach for an organisation aiming to assess its IT on the environmental impact. The eventual goal is to decipher the assessment into a number of KPIs. For this purpose, each module of the framework should be used as input for one or more of these KPIs. Within this paper, intentionally no KPIs are suggested. Rather, the aim of this paper is to stimulate the debate on possible KPIs for each module. Hereby the end goal is to design a number of KPIs that are widely applicable and are supported by a number of different actors to promote cross business assessment and/or benchmarking. We believe this framework serves as the catalyst for the debate on a uniform assessment tool for the environmental impact of an organisations IT and therefore we expect that in the future this framework could be used in its entirety as a tool for the purpose of an environmental assessment.

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Appendix B: Comparison of measurement methods

In this appendix we will discuss what different methods are already at hand, for assessing the environmental impact.

Multiple benchmarking methods exist for IT equipment. However, most of these methods are aimed at the assessment of the computing power of the IT equipment. Most methods currently in use to assess the environmental impact of computing equipment is based on a Life Cycle Analysis (LCA) approach. When using life cycle assessment, the calculations should ideally yield environmental impact relative to a unit of performance. However, since personal computers are used to fulfil a large amount of different needs, it is practically impossible to find one technical performance measure that could represent all these needs in a proper manner (Jonbrink & Amen 2007).

Considering LCA based approaches, the International Organisation for Standardization (ISO) provides a toolkit in the form of ISO 14000. The ISO 14000 standards, aims to provide guidance for developing a comprehensive approach to environmental management and for standardizing some key environmental tools of analysis, such as labelling and life cycle assessment (Cascio, Woodside & Mitchell 1996, p. 4). However, several authors argue that LCA based approaches are less suitable to be conducted within non IT producing organisations (Goedkoop 1999; Goedkoop 2001; Cascio, Woodside & Mitchell 1996, p. 37; ISO 14000 n.d.). Considering the fact that this study is conducted for a non-IT producing organisation, we therefore decided to focus on standards for assessing the environmental impact of the IT within the organisation.

Under the ISO 14000 standards, three broad types of voluntary labels can be categorized (Jonbrink & Amen 2007).

- Type I (ISO 14024) a voluntary, multiple criteria-based, third party program that awards a license that authorises the use of environmental labels on products indicating overall environmental preferability of a product within a particular product category based on life cycle considerations
- Type II (ISO 14021) informative environmental self-declaration claims
- Type III (ISO/TR 14025) environmental product declaration, EPD, voluntary programs that provide "quantified environmental data for a product with pre-set categories of parameters based on the ISO 14040 series of standards, but not excluding additional environmental information".

The different relevant standards are discussed extensively in the main text. Here we concluded that the ISO 14024 standard is the most developed one. The initiatives with regard to the other standards are slowly starting to emerge. Below we present an overview of the different standards of ISO 14024, by means of a table.

Table 8: Comparison of ISO 14024 standards for desktops (Jonbrink & Amen 2007)

Criteria for desktops	TCO'05	The Swan	Blue Angel	EU Flower	Energy Star
Visual Ergonomics	X				
Workload ergonomics	X				
Electromagnetic Emissions	X	X	X	X	
Acoustic Noise	X	X	X	X	
Energy	X	X	X	X	X
Ecology	X	X	X	X	

Appendix C: Leading indicator workshop

In this appendix we will discuss the process and outcome of the leading indicator workshop.

Workshop goals

- To come up with leading Key Performance Indicators (KPIs) to be used in the assessment of the environmental impact of Shell's IT.
- Create awareness for Green IT amongst Shell employees.

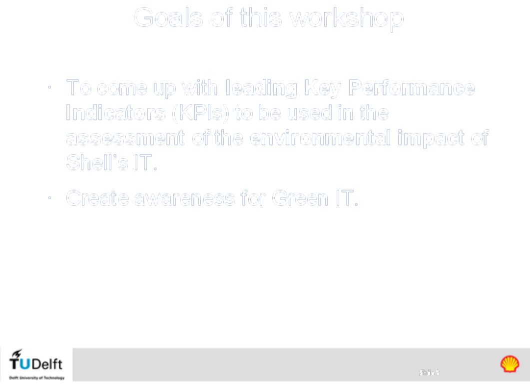
Workshop methodology

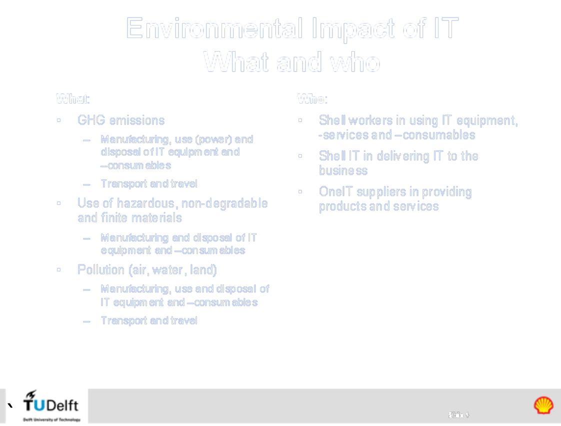
Considering the workshop goals, which are mentioned above, we have designed the workshop in such a way to achieve as much interactivity as possible. The main exercise of the workshop was hereby to have brainstorm sessions in several small groups. However, before the brainstorm sessions could take place. It was important that every participant was aware of the need to focus on green IT, which area to focus upon and more concrete which type of KPIs to brainstorm on. Therefore, before the brainstorm could commence, an introduction to the concept of green IT was given at first, the programme manager of green IT within Shell. This introduction took about an hour including questions. The programme of the workshop is shown below.

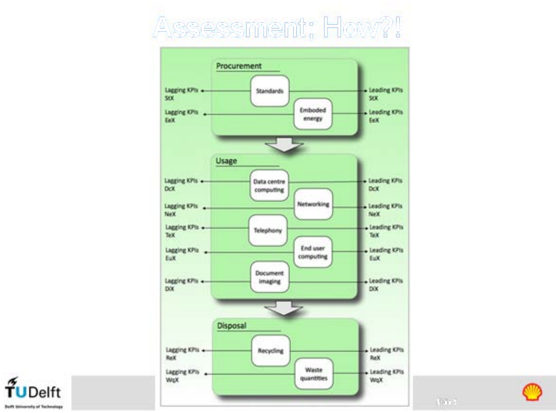
Table 9: Workshop programme

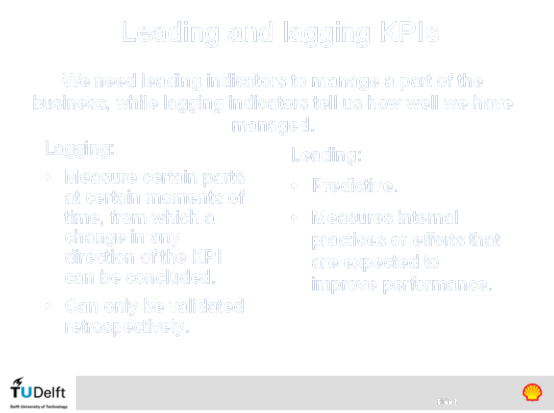
Start	End	What	Who	How
14:00	14:30	Talk about Green IT and the Energy Challenge @ Work	Ben	Presentation
14:30	14:45	Question round	All	
14:45	15:00	Introduction to leading Key Performance Indicators (KPIs) and the environmental impact of IT	Jeffrey	Presentation
15:00	15:15	Brainstorm on leading KPIs in duos	All	Brainstorm session
15:15	15:30	Read out of brainstorm results, plus discussion on brainstorm results	All	Plenary on flip over
15:30	15:40	Look for fit of the KPIs to the assessment model	All	Plenary on flip over + PowerPoint
15:40	15:45	Wrap up & thanks	All	

The PowerPoint sheets we used for the workshop are shown below.









Lagging KPIs examples

Standards module:

- Percentage of IT equipment procured in one year, complying with EPEAT Gold.
- Percentage of IT equipment procured in one year, complying with the WEEE directive.

Data centre computing module:

- Total power consumption of the preceding year

End user computing module:

- Power consumption per employee of the preceding year

TUDelft Slide 7

Leading KPIs examples

- Sales pipeline (the sales under progress)
- The sales staff on board over last three months
- Customer satisfaction

TUDelft Slide 8

Brainstorm (1/2)

- 15 minutes
- Duos
- With reason/possible positive correlation
- Without reason/possible positive correlation
- Put it in Shell context
- Minimum of 2 per building block
- Think out of the box!!!!!!

TUDelft Slide 9

Brainstorm (2/2)

TUDelft Slide 10

Thanks

TUDelft Slide 11

Questions

TUDelft Slide 12

Workshop attendants

At the workshop 9 persons from within Shell attended. For privacy reasons we will not publish their names. Their positions however, are summed up below.

Workshop findings

At the read out phase of the workshop, all KPIs that were specified by the groups were written down. This process was ordered according the different phases of the framework; procurement, usage and disposal. The results are summarized below in Table 10.

Table 10: workshop findings (raw data)

Procurement	
1	Number of outstanding orders complying to EPEAT gold (depending on product group)
2	Number of competitors offering green IT products.
3	Is there knowledge about the energy consumption of products procured?
4	Amount of nagging (use of buying power).
Usage	
1	Awareness of employees.
2	Is there a policy in place to switch of IT equipment for cleaning personnel?
3	Distance from desk to printer.
4	Dashboard on amount of prints.
5	Use of communicator and/or telephone, opposed to e-mailing.
6	Number of paper closets.
7	Monitor screen size with regard to printing.
8	Use of smart power of switches.
9	Number of unused IT equipment
10	Printing standard (quality and double sided)
11	Ease of changing the printing settings
Disposal	
1	Number or percentage of contracts with recycle companies per asset type.
2	Is there a internal policy in place for green disposal.
3	Innovativeness of recycling company.

From the workshop findings we can conclude immediately that a number of KPIs that are mentioned by the workshop participants cannot be qualified as leading indicators, but rather as lagging indicators. Which indicators are selected for further analysis and how they are incorporated into the model is discussed In the main text.

Appendix D: Expert reviewing

In this appendix we describe what process we followed for the expert reviewing and the outcome of the expert reviewing.

For the purpose of the expert reviewing, the experts were presented a pre-read with, among other things, a description of the model. The pre-read is presented below.

Start of pre-read

Purpose of this document

This document contains a very brief description of the environmental impact of IT and the green IT assessment model I have developed for the purpose of my graduation thesis – Quantifying the environmental impact of the IT of a multi-national organisation.

For validation purposes of the model, I would like to ask you a couple of questions about the model. In particular concerning its completeness, relevance and usability. With regard to the completeness I would like to investigate whether the KPIs that derive from the model indeed cover the whole of the environmental impact of IT. With regard to the relevance, I would like to research whether certain KPIs can be left out. With regard to the usability I would like to investigate whether the KPIs can be utilized to decrease the environmental impact of the IT on the long term.

A. Introduction on environmental impact

The ongoing rapid development of the IT in developing countries triggers the overall growth of IT quickly. Therefore the overall impact on the environment of IT continues to increase. According to a study carried out by Gartner, the IT industry is estimated to currently be responsible for almost 2% of global CO2 emissions, most resulting from the power consumption of PCs, servers and cooling systems. Where exactly the impact on the environment occurs of IT and how the impact occurs, can however be hard to grasp at first sight, since the effects of the environmental impact of IT are not nearly as visible as par example the environmental impact of the automobile industry or the aviation industry. Therefore below a summarization is given on the areas of environmental impact of the IT.

- Direct pollution of air water and land from the manufacturing, transport, use and disposal of IT equipment.
- GHG emissions resulting from manufacturing, use (power) and disposal of IT equipment and GHG emissions from transport and travel of IT equipment
- Use of hazardous, non-degradable and finite materials at the manufacturing- and disposal phase of IT equipment.

From the summary above it can be concluded that a distinction on the general environmental impact of IT can be made on three grounds. The first ground is the direct pollution. This entails the immediately visible impact on the environment. In the case of the manufacturing of the IT equipment, this can be the air pollution from factories, producing IT equipment, but also earlier in the product life cycle, the ground pollution and potential sound pollution from the mining of raw materials. The direct pollution from the use of IT equipment is as already mentioned less apparent. Nonetheless, direct pollution due to the usage of IT equipment can manifest for example when printing from a laser printer, as this emits ultra fine particles.

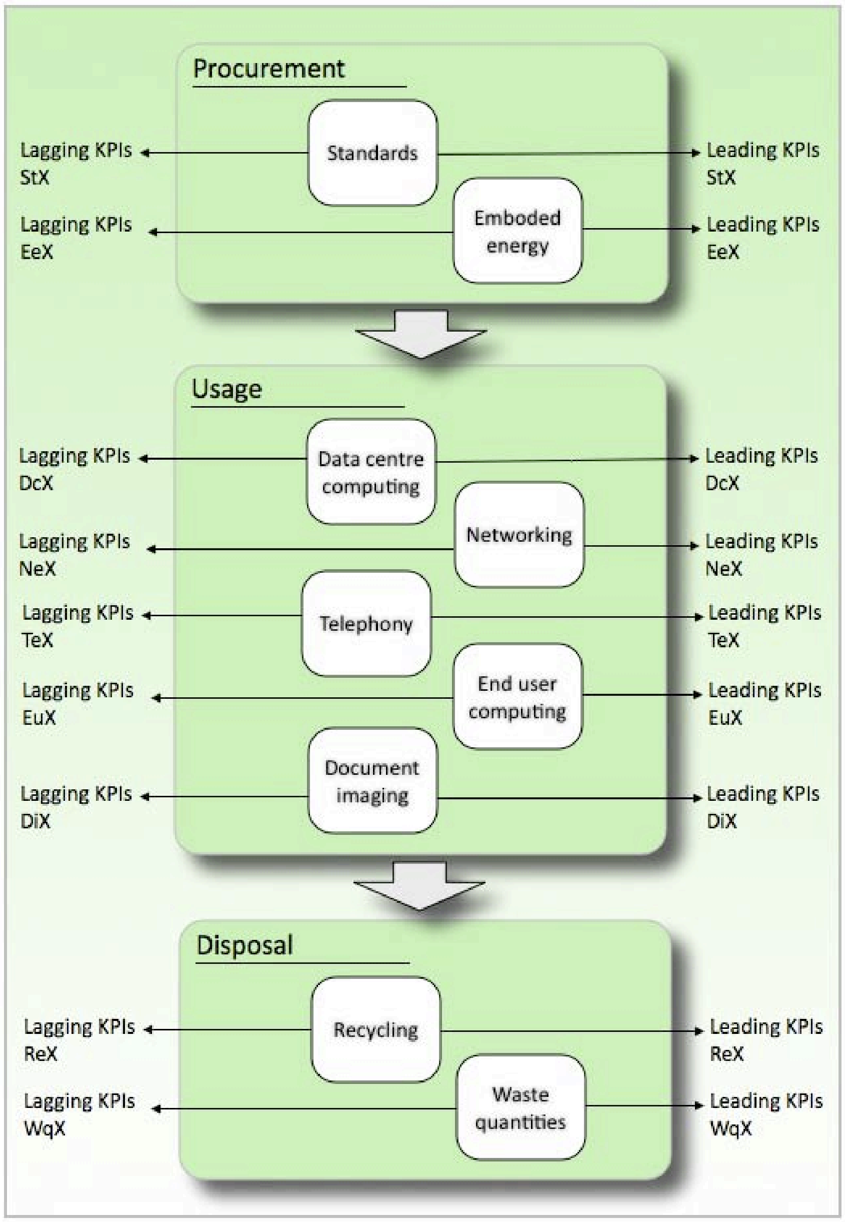
The second ground for the general impact of IT on the environment, is the GHG emissions resulting from the manufacturing, use and disposal of IT equipment and the transport and travel. Before the IT equipment will be put to use, in for example an office building, it first has to be produced from raw material and then transported to its destination. In the production phase a relatively large part of energy is needed to make the equipment. According to some, more energy is consumed at the production phase of IT equipment than at the usage phase of the same equipment. The energy that is required for the production of the IT equipment is in most cases derived from fossil fuels and therefore accountable for the emission of GHGs. Next to the GHG resulting from the production of IT equipment, GHG emissions result from the transport of IT equipment, for example from the production facility to the retailer or from the retailer to the end user. Whether this transport is by boat, plain, train or truck, GHGs are highly likely to be emitted. GHG emissions resulting from the usage of IT equipment are due to the energy requirements of the IT equipment and as long as the energy that powers the devices does not solely result from renewable sources, GHGs are emitted. Finally, at the disposal phase GHGs are likely to be emitted whenever the equipment is disassembled with use of energy consuming machinery for recycling or refurbishment.

The third ground for the general environmental impact of IT, is the use of hazardous, non-degradable and finite materials at the manufacturing- and disposal phase of IT equipment. For specific IT equipment, hazardous material is used, such as lead, cadmium, mercury and chromium. These materials can have a harmful impact on the environment at the disposal phase of the IT equipment, if they are not to be taken care of properly. Furthermore, considering scarce resources, with an average worker printing about 1000 pages per month, water and wood required for the paper is consumed in large amounts too.

Considering the three grounds discussed, it should be concluded that whenever an organisation wants to improve its environmental impact of the IT, it should focus on more than for example the power consumption of the equipment alone. The three grounds where the environmental impact of the IT can occur, should be kept in mind whenever thorough measures are to be taken with regard to the environmental impact of an organisation's IT. This also goes for the organisation that is looking into green IT largely from a reputational point of view, as a focus on decreasing energy use alone for example, could easily be characterized by others as a cost reduction initiative, rather than a serious green IT initiative.

B. The green IT assessment model

The three areas of environmental impact of IT are taken as foundation for the design of the framework from which KPIs can be derived. At its turn, those three areas are transformed to the environmental life cycle of IT for a non-IT producing organisation. The core of the framework, which is deduced from the aforementioned, is visualized below.



Core of the framework

The three large green boxes with round edges represent the building blocks. The nine smaller white boxes represent the modules.

The KPIs that are to be designed and quantified serve two main purposes. Firstly, long term repeatable and consistent monitoring of the environmental impact of a large-scale multi-national organisation's IT. Secondly, benchmarking the environmental impact of the organisation's IT relative to other organisations. However, these two purposes can conflict with each other, since for the purpose of benchmarking it is important that there are clear rules on the accounting and reporting procedures to create a level ground, whereas the latter is not required for the purpose of internal monitoring. By indeed incorporating strict rules within the framework on the accounting and reporting procedures, the adoptability and general applicability of the framework would suffer. In addition, since the primary goal of the framework is consistent and internal monitoring and the secondary goal benchmarking, the choice is therefore made not to impose strict accounting and reporting requirements within the framework. As a result the framework will offer the choice between multiple measurement and reporting methods and does not specify a definitive list of KPIs, nor a definitive list of measurement methods. Hereby it is acknowledged that this is disadvantageous for the benchmarking opportunities of the framework. However, the benefit of benchmarking does not outweigh the strict requirements that otherwise would have to be imposed on the accounting and reporting procedures. Furthermore, benchmarking across businesses will still be able if enough details are reported with regard to the measurement processes.

The KPIs that can be used in Shell's case are as follows:

Standards module:

1. Percentage of IT equipment procured in one year, complying with the WEEE directive
2. Percentage of IT equipment procured in one year, complying with the ROHS directive
3. Percentage of IT equipment procured in one year, complying with the Energy Star standard
4. Percentage of desktops and notebooks procured in one year, complying with EPEAT Gold
5. Percentage of outstanding orders complying with the Energy Star standard (leading)
6. Importance of environmental criteria in the procurement process (leading)

Embodied energy:

0. None

Data centre computing

1. Total power consumption
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area in
5. Is there a policy in place aimed at reducing the energy consumption of the data centre? (leading)
6. Virtualization of the data centre (leading)

End user computing

1. Total power consumption
2. Total CO2e

3. Power consumption per employee
4. Power consumption per m^2 of floor area
5. Is there a policy in place aimed at switching of the equipment at night? (leading)
6. Awareness of the employees with green IT (leading)

Telephony

1. Total power consumption
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area
5. Use of fixed line telephony opposed to e-mail and/or mobile telephony (leading)

Networking

1. Total power consumption
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area

Document imaging

1. Total power consumption of document imaging equipment
2. Total CO2e
3. Power consumption per employee
4. Power consumption per m^2 of floor area
5. Number of employees per printer
6. Number of pages printed per year per employee
7. Awareness of employee on the amount of prints (dashboard) (leading)
8. Ease of changing printing settings (leading)

Recycling

1. Percentage of equipment that is disposed that gets recycled
2. Percentage of contracts with recycle companies (leading)
3. Innovativeness of recycle companies (leading)

Waste quantities

1. Total amount of IT equipment disposed
2. Is there an internal company wide policy in place for green disposal? (leading)

C. Questions

Please prepare to answer the question below on the flowing scale: Sufficient, partially sufficient and insufficient.

Completeness:

1. To what extent do the three grounds of environmental impact cover the whole of the environmental impact of IT?
2. To what extent do the KPIs as a whole cover the whole of the environmental impact?
3. To what extent do the different areas of the IT (modules) cover the total IT within Shell?

Relevance:

4. To what extent is there a redundancy of KPIs?

Usability:

5. To what extent can the KPIs be utilized to reduce the overall environmental impact on the long term?
6. To what extent can the KPIs be utilized for the purpose of the other objectives (reduce costs, change mindset of employees, license to operate, reputation management, supplier management)

End of pre-read

In the e-mail that was sent along with the pre-read, it was mentioned that the questions were only given to indicate what the respondent could expect, but that it was not necessary for the respondent to answer the questions in depth. Furthermore, it was mentioned that the respondents are supposed to answer each question on a three point ordinal scale which ranges from 'sufficient' to 'insufficient', with 'partly sufficient' as the mid-value. Before the interview commenced, we explained the respondents the process of the interview. Furthermore, we deliberately pointed out that the respondent is not supposed to confine his or her answer to the three point scale, but to give a motivation for the choice and to, where possible, give suggestions for improvement. The duration of each interview was approximately one hour. The results of the expert review are presented below as raw data, the conclusions are discussed in the main text in paragraph 5.1.4.

The results from the expert working as 'Senior Advisor Technology Investigation' within Shell, are presented at first below:

Table 11: results from expert review 1

Question	Value	Motivation
1	Ps	Toxicity within disposal and possible audit for disposal.
2	Ps	Inclusion of value description (legenda).
3	S	
4	Ps	Aggregate certain standards, specifically those that see on WEEE and ROHS. Benchmarking cross business would only prove helpful within the same industry. Normalization to employees of the data centre module is debatable.
5	S	Know what the targets are. What is needed to reach top quartile performance?
6	S	Possibly measurements on individual employee level. However, probably not feasible.

The results from the expert working as 'Senior Sustainable Development Advisor' within Shell, are presented below:

Table 12: results from expert review 2

Question	Value	Motivation
1	S	Possibly include electromagnetic radiation.
2	S	Global perspective versus company perspective. Priorities change between companies in different regions.
3	Ps	Depends on how you define IT. How IT is used can also have positive effects for the total environmental impact.
4	Ps	Global level not, perhaps for company perspective. Prioritizing for several countries possible.
5	S	Fine tune for countries. Also consider outsourcing.
6	S	Take into account that priorities of companies might vary.

The results from the expert working as 'Group HSE Performance and Reporting Manager' within Shell, are presented below:

Table 13: results from expert review 3

Question	Value	Motivation
1	S	Include ISO 14000 pint of view
2	Ps	Should not attempt to cover the whole.
3	Ps	Possibly home workers as separate module.
4	Ps	Indeed redundancy for effective communication to upper management.
5	S	
6	S	Reputation and supplier management are indeed important but difficult to include.

Appendix E: Case study

In this appendix we describe which KPIs are quantified for Shell and how they are quantified.

The method which is used in this case study to quantify the KPIs, is to take the feasibility constraint as a starting point. For each KPI, we concluded whether it was feasible to properly quantify the specific KPI considering the information at hand within Shell. By taking this approach, a small subset of KPIs remained that were to be quantified for the purpose of this case study. These KPIs were also suggested to select for quantification by one of the experts of the expert reviewing. The list of KPIs is given in Table 14 on the next page. Below we will discuss per module how the KPIs were quantified.

Data centre computing: In order to quantify the selected KPIs for this module, the data from Shell's asset centre was taken as a starting point, for an estimation on the amount of equipment. Next, an estimate was taken for the power consumption of data centre equipment. Finally, the Data Centre Efficiency rate (DCE), which is described in paragraph 4.2.3, was taken to also include other equipment from the data centres, as cooling and lighting in the calculation. The total amount of CO2 was calculated by taking the world average for the energy mix from the GHG protocol.

End user computing: The KPIs for this module are calculated by taking the numbers of energy usage from the manufacturer and multiplying these numbers by usage patterns and amount of equipment. In order to gather the number on energy usage and amount of equipment, multiple data sources within Shell had to be consulted. Again, to calculate the numbers on CO2e the world average for the energy mix was taken, which is specified by the GHG protocol.

Telephony: The KPIs for this module are calculated for mobile telephony and fixed line telephony. The values are calculated by simply specifying the number of telephone lines and multiplying this number with the power consumption of the telephone.

Networking: The KPIs for this module are estimated by looking at the number of network ports, wired as well as wireless, and multiplying the amount of ports with the average power consumption per port. This average is estimated to be 4 W per port for wired ports and 6 W for wireless ports.

Document imaging: The KPIs for this module are calculated on the basis of estimations on the amount of employees per printer.

Table 14: List of KPIs for the case study within Shell

Data centre computing
1. Total power consumption
2. Total CO2e
3. Power consumption per employee
End user computing
1. Total power consumption
2. Total CO2e
3. Power consumption per employee
Telephony
1. Total power consumption
2. Total CO2e
3. Power consumption per employee
Networking
1. Total power consumption
2. Total CO2e
3. Power consumption per employee
Document imaging
1. Total power consumption of document imaging equipment
2. Total CO2e
3. Power consumption per employee
Main KPI
1. Total power consumption of the IT

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