Otto von Guericke University Magdeburg

Faculty of Computer Science

Master's Thesis

Monitoring of Life Cycle Data to Determine the Environmental Impact of Information and Communication Technology Products

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September 12, 2016

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Master's Thesis, Otto von Guericke University Magdeburg, 2016.

"The scientific evidence is clear: global climate change caused by human activities is occurring now, and it is a growing threat to society."

(AAAS, 2006, p. 1)

"The increased awareness of the importance of environmental protection, and the possible impacts associated with products […] has increased interest in the development of methods to better understand and address these impacts."

(ISO, 2006a, p. v)

Abstract

The awareness for sustainability has constantly increased in the last decades. Influenced by environmental, social and economic elements, a sustainable development is driven by the sense of meeting the needs of the present without compromising the ability of future generations to meet their own needs. At the center of this thinking is the environmental protection aspect. Increasing numbers of people are interested in the impact of human behavior on the planet's ongoing condition. One major consequence of a progressive pollution of the environment is climate change and its related issues such as an increase in extreme weather events. The majority of scientific and governmental authorities agrees that the planet's current warming is triggered by human-caused greenhouse gases (GHGs) such as carbon dioxide. Especially companies emit a large range of those gases while manufacturing their products. This also applies to goods of the information and communication technology (ICT) industry. Throughout their entire life cycle, from raw materials to production, transportation, customer usage and end-of-life, ICT products and their processes should be designed to have a preferably low environmental impact. Along the product life cycle (PLC), a huge amount of environmentally related data is produced. Accurately analyzing and reporting this data would help companies to decide more reasonably how to influence their footprint. Based on the scientific fields of Environmental Informatics and Green IT, with the core discipline of Life Cycle Assessment (LCA), this paper aims to use Business Intelligence (BI) to monitor the environmental impacts of ICT products. Using the example of product data published by Apple Inc., a model will be created to answer detailed questions regarding the GHG and material impact of Apple's product portfolio. This approach will subsequently be assessed and modified to create a generalized model that can be used by other ICT companies to gather, prepare, analyze, report, communicate, and therefore monitor the environmental impact of their products. Thus, the model will enable ICT companies to decide more reasonable how to influence their footprints and foster the environmental protection aspect of sustainability by supporting the LCA methodology.

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List of Greenhouse Gases

CO_2	Carbon dioxide
CH_4	Methane
N_2O	Nitrous oxide
CHF_3	Hydrofluorocarbon-23
CH_2F_2	Hydrofluorocarbon-32
CH_3F	Hydrofluorocarbon-41
$CF_3CHFCHFCF_2CF_3$	Hydrofluorocarbon-43-10mee
CHF_2CF_3	Hydrofluorocarbon-125
CHF_2CHF_2	Hydrofluorocarbon-134
CH_2FCF_3	Hydrofluorocarbon-134a
CH_2FCHF_2	Hydrofluorocarbon-143
CH_3CF_3	Hydrofluorocarbon-143a
CH_3CHF_2	Hydrofluorocarbon-152a
CF_3CHFCF_3	Hydrofluorocarbon-227ea
CF_3CH2CF_3	Hydrofluorocarbon-236fa
$CH_2FCF_2CHF_2$	Hydrofluorocarbon-245ca
$C_4F_9OCH_3$	Hydrofluoroether-7100
$C_4F_9OC_2H_5$	Hydrofluoroether-7200
CF_4	Perfluorocarbon-14
C_2F_6	Perfluorocarbon-116
C_3F_8	Perfluorocarbon-218
C_4F_{10}	Perfluorocarbon-31-10
c-C_4F_8	Perfluorocarbon-318
n-C_5F_{12}	Perfluorocarbon-41-12
n-C_6F_{14}	Perfluorocarbon-51-14
F_6	Sulfur hexafluoride

Abbreviations

AAAS	American Association for the Advancement of Science
APS	American Physical Society
AR	Assessment Report
BCS	British Computer Society
BI	Business Intelligence
BMJV	Bundesministerium der Justiz und für Verbraucherschutz[1]
CO_2e	Carbon Dioxide Equivalent
CSO	Chief Sustainability Officer
CSV	Comma Separated Values
CUP	Cambridge University Press
DAX	Data Analysis Expression
DSR	Design Science Research
EASO	Environmental Assessment of Sites and Organizations
EBI	Environmental Business Intelligence
EC	European Commission
EI	Environmental Informatics
EIS	Environmental Information System
EPA	Environmental Protection Agency
ERD	Entity Relationship Diagram
ERP	Enterprise Resource Planning
EUR	Euro
FK	Foreign Key
GB	Gigabyte
GeSI	Global e-Sustainability Initiative
GGE	Greenhouse Gas Emission
GHG	Greenhouse Gas
GRI	Global Reporting Initiative

[1] Eng.: Federal Ministry of Justice and Consumer Protection (Translation by author).

GSSB	Global Sustainability Standard Board
GWP	Global Warming Potential
HFC	Hydrofluorocarbon
HFE	Hydrofluoroether
ICT	Information and Communication Technology
iEMSs	International Environmental Modelling & Software Society
Inc.	Incorporated
IPCC	Intergovernmental Panel on Climate Change
IS	Information System
ISESS	International Symposium on Environmental Software Systems
ISO	International Organization for Standardization
IT	Information Technology
IUCN	International Union for Conservation of Nature
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCS	Life Cycle Stage
MIS	Management Information System
MS	Microsoft
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NSIDC	National Snow and Ice Data Center
OECD	Organization for Economic Cooperation and Development
OLAP	Online Analytical Processing
OPAC	Online Public Access Catalog
OS	Operating System
PC	Personal Computer
PDCA	Plan-Do-Check-Act
PDF	Portable Document Format
PFC	Perfluorocarbon
PK	Primary Key
PLC	Product Life Cycle
Q&A	Question & Answer

RoHS	Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment
SCM	Supply Change Management
SEC	Securities and Exchange Commission
SME	Small and Medium Enterprises
SQL	Structured Query Language
TDWI	The Data Warehouse Institute
TR	Technical Report
TS	Technical Specification
UI	User Interface
UN	United Nations
UNEP	United Nations Environmental Programme
U.S.	United States
USA	United States of America
USD	United States Dollar
WTO	World Trade Organization
WWF	World Wide Fund for Nature

1 Introduction

1.1 Data Insights to Support Sustainability in ICT

"Organizations around the world, as well as their stakeholders, are becoming increasingly aware of the need for environmental management, socially responsible behaviour, and sustainable growth and development." (ISO, 2009, p. 3) These claims are summarized under the umbrella of sustainability and comply with its three pillars of environmental, social and economic matters (ISO, 2015a, p. vi). This paper focuses on the environmental aspect of sustainability, since the protection of the environment is the first step in meeting the needs of the present without compromising the ability of future generations to meet their own needs (Hilty and Aebischer, 2015, p. 12; Park, 2007, p. 439). As Page (1996, p. 1) emphasizes: "The protection of our environment is one of the greatest challenges in our industrialized societies. This challenge is addressing politics, economy as well as technology and research." In the course of environmental protection, there is an abundance of areas to consider such as the contamination of water, the pollution of soil, or the handling of wastes (Page and Hilty, 1995, p. 16). However, at the center of today's environmental discussion is climate change and its related issues such as the increase of droughts, the rise of sea levels, and the intensification of extreme weather events (NASA, 2016a). Dahiya and Ahlawat (2013, p. 6.4) confirm: "Climate change is clearly the most important global environmental problem faced by mankind." The majority of climate scientists agrees that the current global warming is mainly caused by human emission of greenhouse gases (GHGs) such as carbon dioxid (CO_2) (NASA, 2016a). Those gases reinforce the expansion of the greenhouse effect, which results when the atmosphere traps heat radiating from Earth towards space (IPCC, 2014, p. 8; NASA, 2016a).

Especially companies emit a large range of those gases while manufacturing their products (EPA, 2016a). This also applies to goods of the information and communication technology (ICT) industry (GeSI, 2012; Greenpeace, 2010). Throughout their entire life cycle, from extraction of raw materials to production, transportation, customer usage, and end-of-life by recycling, reuse or disposal, ICT products and their processes should strive for a preferably low environmental impact. Within the scientific discipline of Environmental Informatics, especially the field of Green IT is entrusted with the question of how ICT products can be managed along their life cycle to achieve a minimal footprint (Murugesan, 2008, p. 1). This is also referred to as sustainability in ICT (Zarnekow and Kolbe, 2013, p. 15). The basis for studies concerning these impacts is given by the international standard of Life Cycle Assessment (LCA) (ISO, 2006a,b). To determine product impacts, LCA inventories the amounts of environmentally related data that are produced along the product life cycle (PLC), and assesses as well as interprets them (ISO, 2006a,b). One company that states to perform such an LCA is Apple Inc. The company declares: "We take the same innovative approach to the environment that we do with our products." (Apple, 2016a) The results of their assessment process are published as reports in the portable document format (PDF) (Apple, 2016b). These reports give an overview of Apple's product impacts by presenting in particular climate change causing greenhouse gas emissions (GGEs), material usage, and energy consumption data (Apple, 2016b). However, Apple's approach has several issues, such as wrong or missing data, limited data views, or inconsistent PLC stage definitions, which complicate the comprehension and lower the credibility of the assessment results. Although Apple does not state to use any kind of LCA software, different IT solutions are available to support the methodology. However, these solutions also show disadvantages such as limited analysis capabilities or an insufficient quality of information presentation. (Lehtinen et al., 2011, p. 13; Solsbach et al., 2011; p. 166; Süpke et al., 2009, pp. 387-398)

These disadvantages and unsatisfied requirements in the available LCA software and especially within the Apple PDF reports show the need of a new approach for Apple in particular and for other ICT companies in general. Therefore, this paper aims to create a model that uses state-of-the-art Business Intelligence (BI) technology (Gartner, 2016a) to gather, prepare, analyze, report, and communicate ecologically related data insights for the monitoring of environmental product impacts. Isenmann et al. (2007, p. 64) confirm the value of the intended solution by stating: "[..] case studies (Marx Gómez and Rautenstrauch, 2001), literature reviews, and benchmarking analyses (Isenmann and Lenz, 2002) made clear that environmental […] reporting will become a dynamic field of research for the next decades, particularly driven by modern ICT (Isenmann and Warkotsch, 1999a,b)." Using the Apple published PDF data, the model will be consecutively implemented by researching the footprint of the entire Apple product portfolio. Afterwards, this approach will be evaluated and modified in order to build a generalized model with a standardized process that can be used by other ICT companies to explore their environmental data. Thus, the model will in particular support the LCA stages of Life Cycle Inventory Analysis (LCI) and Life Cycle Impact Assessment (LCIA) (ISO, 2006a, p. 8). In addition, the LCA stage of interpretation can be reinforced e.g. by enabling data correlation examinations that help to improve the comprehension of the given information (Aspin, 2015, p. 3; ISO, 2006a, p. 8). The intended solution will therewith provide data insights in a substantial and meaningful way, to support enterprise environmental decision-making and to enable a reasonable company environmental policy. Thus, the research can foster the environmental protection aspect of sustainability while providing a new approach for the support of the LCA methodology by the utilization of state-of-the-art BI technology in the framework of the implemented environmental monitoring model.

1.2 State of the Art of Environmental Data Monitoring

"When H.C. von Carlowitz wrote his principles of sustainable forestry in 1713 [(Carlowitz, 1713; cited in Hilty and Aebischer, 2015, p. 5)][2] the world was less complex than today. […] His basic principle was simple: Do not cut more wood than will grow in the same period of time." (Hilty and Aebischer, 2015, p. 5) Today, it is known "that forests have additional functions, such as filtering air and water, holding soil in place and preserving biodiversity, as well as protective and recreational functions. It follows that there is a variety of ideas on how to make sustainable use of a forest." (Hilty and Aebischer, 2015, p. 5) The same is true with ICT products and processes. Several institutions, organizations, conferences, and companies, deal with the topic of sustainability in ICT and the reporting of environmental data. Examples of organizations are the United Nations Environmental Programme (UNEP), the World Wide Fund for Nature (WWF), or the Intergovernmental Panel on Climate Change (IPCC), which are all concerned about how environmental problems can be solved (IPCC, 2014; IUCN *et al.*, 2013). To do so, they develop guidelines and standards, or produce reports, such as the IPCC Assessment Report (IPCC, 2014), which build the foundation for environmental investigation purposes. Other significant contributions come from conferences such as EnviroInfo (2016), ISESS (2016), and iEMSs (2016). Moreover, several companies implement approaches that deliver solutions for certain areas of sustainability and environmental protection (Apple, 2016b; Dell, 2016a). Since all central research fields and approaches will be discussed in the following chapters, this section will be brief, focusing on the most similar methods available in the context of environmental data monitoring.

At the center of today's environmental product impact research is the international standard of Life Cycle Assessment (LCA), which is given by the International Organization for Standardization (ISO) in particular in its standards ISO 14040 (ISO, 2006a) and ISO 14044 (ISO, 2006b). "LCA addresses the environmental aspects and potential environmental impacts[..] [3] […] throughout a product's life cycle from raw material acquisition through production, usage, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)." (ISO, 2006a, p. v) "LCA is different from many other techniques (such as environmental performance evaluation, environmental impact assessment and risk assessment) as it is a relative approach based on a functional unit; LCA may, however, use information gathered by these other techniques." (ISO, 2006a, p. 9) One company that states to base its environmental product impact studies on the LCA methodology is Apple Inc. (Apple, 2016b; Apple, 2016c, p. 4). The outcomes of this process are the Apple Environmental PDF Reports (Apple, 2016b). Those shape the key state of the art for this paper, since they provide

[2] "Carlowitz's book is usually cited as the origin of the word 'nachhaltig', the counterpart of the English word 'sustainable'." (Hilty and Aebischer, 2015, p. 5).

[3] "The 'potential environmental impacts' are relative expressions, as they are related to the functional unit of a product system." ISO (2006a, p. v).

the starting point for the intended inductive environmental data monitoring approach. Below are the first three pages of a sample report (Fig. 1).

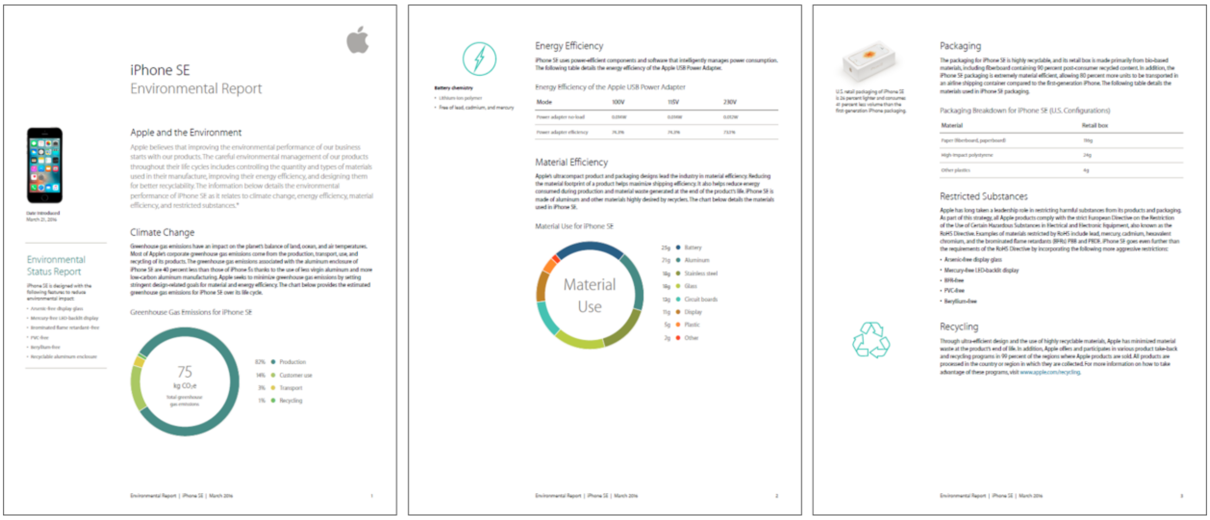

Figure 1: Apple Environmental PDF Report Sample
(Apple, 2016c)

The figure illustrates the basic structure of Apple's PDF reports, which consist of text as well as selected environmental data. Content for all four LCA stages can be found: Goal and scope definition is desciped on the first page, by sentences such as: "The careful environmental management of our products throughout their life cycles includes controlling the quantity and types of materials used in their manufacture, improving their energy efficiency, and designing them for better recyclability." (Apple, 2016c. p. 1) Life Cycle Inventory Analysis (LCI) can be found by listed GGEs and materials (Apple, 2016c. pp. 1-2). Life Cycle Impact Assessment (LCIA) is shown very limited, e.g. by stating which potentially harmful materials have been avoided (Apple, 2016c. p. 3). The interpretation part is kept brief by sentences such as "[…] is made of aluminum and other materials highly desired by recyclers." (Apple, 2016c, p. 2) A proof that LCA is used can be found in each report on page four where Apple states: "[…] accordance with guidelines and requirements as specified by ISO 14040 and ISO 14044." (Apple, 2016c, p. 2)

However, the Apple approach shows several disadvantages, which exacerbate the understanding and credibility of the assessment results. Identified issues are: inconsistencies in product naming conventions, non-standardized product life cycle stage definitions, a misunderstanding in material naming, data errors and missing data, and form inconsistences. Moreover, the reports show only one product in one configuration at a time and are full of marketing statements, which shift the focus from the facts. All of these issues can lead to a restricted view on the product impacts. Therefore, especially the LCA phases of LCIA and interpretation should be improved. In addition, the LCI itself should be collected more accurately in order to prevent data errors as well as missing data (Apple, 2012a).

A similar approach is used by Dell Inc., which also publishes PDF reports (Dell, 2016a). In Fig. 2 are the pages 1, 2, and 4 of a sample Dell Carbon Footprint Report.

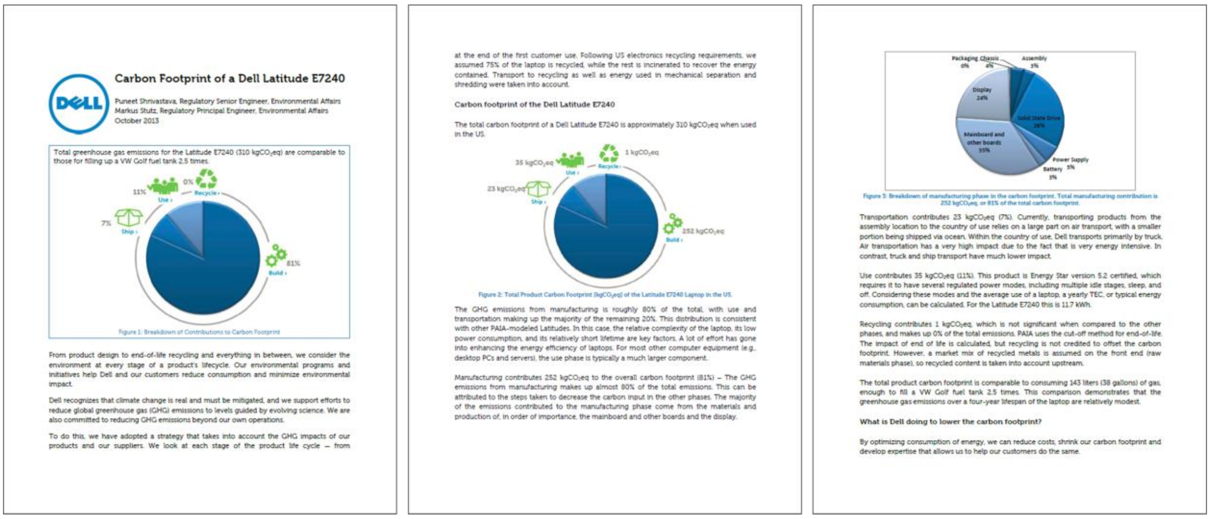

Figure 2: Dell Carbon Footprint PDF Report Sample
(Dell, 2013a)

Similar to Apple's approach, Dell provides environmental data as well as text, e.g. by showing GGE and material amounts (Dell, 2013a, pp. 1,2,4). Dell also uses the same PLC for measuring their product emissions, but with the designations: build, ship, use, and recycle (Dell, 2013a, pp. 1-2). Since the reports do not reveal the use of the ISO 14040 or 14044 (ISO, 2006a,b), it can only be assumed that they rely on the LCA methodology. However, because of the close connection to Apple's approach it seems probable. Goal and scope can be identified by statements such as: "Dell recognizes that climate change is real and must be mitigated, and we support efforts to reduce global greenhouse gas (GHG) emissions to levels guided by evolving science." (Dell, 2013a, p. 1) On the stages of LCI and LCIA, the company provides e.g. data on GGEs and describes their influence. At the interpretation stage, Dell's data show advantages to Apple since, e.g., the GGEs are interpreted in detail and are not just displayed. Furthermore, Dell provides a comparison between their GGEs and the emissions that emerge when filling the tank of a mid-range car (Dell, 2013a, pp. 1,3). That can be helpful in understanding the displayed data. These advantages will be considered later to improve the Apple approach and thereby eventually the generalized model. However, Dell's approach also shows disadvantages, such as an inconsistent definitions of materials or a restricted product view by showing only one configuration at a time, which were also detected at Apple. These issues will also be taken into account in the subsequent chapters in order to improve the intended monitoring models.

Neither Apple nor Dell publish the software they use to produce their outcomes. However, it is possible to support the LCA process by software solutions such as SimaPro (SimaPro, 2016) or GaBi Software (Thinkstep, 2016). Despite each of the available solutions having their utility, they can be insufficient for monitoring the environmental impact of ICT products, particularly in the case of GGE monitoring for climate change prevention (Lehtinen *et al.*, 2011, pp. 14-16). Most of the software has broad approaches, which try to solve all kinds of issues (Lehtinen *et al.*, 2011, pp. 14-16). This encompassing methodologies lead to complex tool landscapes, which have to be integrated in protracting IT projects to fit them into the organization. Thus, several months can go by before even one environmental question can be answered. Because of their complexity, many tools also have difficult user interfaces. As Lehtinen *et al.* (2011, p. 13) confirm: "Most tools are tailored for experts, and only few cater for non-specialists and SMEs [(small and medium enterprises)]." This claim of an easy usability can also be found at Süpke *et al.* (2009, pp. 387-398), who additionally criticize the partially inappropriate presentation of environmental reporting information. They compliment that these issues had been improved through guidelines such as G3 by the Global Reporting Initiative (GRI) (GRI, 2016a), but that there is still space in fulfilling these needs more comprehensively. Supplementary, Solsbach *et al.* (2011, p. 167) add that "[…] most reports are still delivered in terms of a monologue […]" without reliable communication among the stakeholders. Moreover, the current solutions are expensive and thus hardly affordable especially for SMEs (Solsbach *et al.*, 2011, p. 166). As Jamous *et al.* (2012, p. 2) emphasize: "The times in which investments into information systems were mostly investments into an uncertain future are over. Especially looking through the lens of SMEs, information technology must be easy to use, relatively cheap and immediately supporting the core business." Thus, the identified disadvantages and unsatisfied requirements in the available software solutions and in particular, within the research's origin of the Apple PDF reports as well as within Dell's PDFs show the need for a new approach, which offers solutions for the existing issues.

1.3 Objective Target and Structure of Research

Based on the currently available approaches, this paper aims to create a model in combination with state-of-the-art BI technology to research ICT product life cycle (PLC) environmental data. By determining the environmental product and process impact, enterprise environmental decision-making shall be supported. To create such a solution, this research takes an inductive approach deriving from the examination of product data provided by Apple Inc., to subsequently generalize and standardize this model. Therefore, several intermediate goals must be achieved: Apple's product portfolio shall be structured into a hierarchy classification model, to enable a controlled analysis. Afterwards, the environmental data must be collected, cleaned, structured, and stored in a BI data model in order to get an improved data inventory. Based on this the product footprints shall be assessed by analyzing and reporting valuable data insights. Supported by the BI tool, the Apple PDF reports shall be reconstructed with the advantages of the interactive BI approach. Moreover, it is intended to answer comprehensive questions for the entire Apple product portfolio to determine its environmental impact for selected use cases. By this new approach, a variety of the demonstrated issues in Apple's current method shall be solved. Deriving from this, the created Apple model will be evaluated and modified in order to build a generalized model with standardized processing steps. This model shall provide further solutions such as a standardized PLC with consistent definitions to solve the remaining issues. Thus, the method shall be able to be used by other ICT companies to investigate their environmental product footprints. Therefore, the new environmental approach aims to be: flexible, fast to implement, less expensive than current solutions, easy-to-use with significantly presented environmental insights, which are effortlessly shared among all stakeholders and therewith enable an environmental dialog that otherwise would not be possible. Summarizing this entire process, the research question is: How can environmentally related ICT product life cycle data be gathered, prepared, analyzed, reported and appropriately communicated by using state-of-the-art business intelligence technology to monitor the environmental GGE impact of ICT products and processes to support the LCA methodology?

To achieve each of the goals and to answer the research question the paper is based on the scientific methodology of design science research (DSR). This practice gives a framework to create innovative, purposeful, and utilizable IT artifacts to solve real world problems, as also intended by this paper (Hevner and Chatterjee, 2010, p. 9; Hevner *et al.*, 2004, pp. 77, 83). The typical DSR cycle is illustrated below (Fig. 3).

Figure 3: Design Science Research Cycle
Own illustration based to (Hevner and Chatterjee, 2010, p. 9)

The objective is that the research solves a problem (1) in the environment while using the available know-how (2) by creating an artifact (3), which thereby extends (4) the knowledge base. This cycle can be split into a six-step process (Fig. 4).

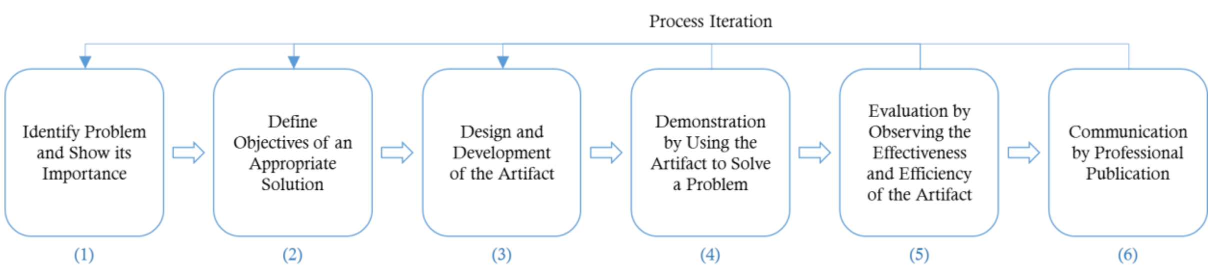

Figure 4: Design Science Research Process
Own illustration based on (Peffers *et al.*, 2006, p. 93)

The process leads in general from the problem and its impacts (1) through the definition of objectives (2) to the proposed solution (3) and its demonstration (4) as useful, to the evaluation (5) of the approach. It is concluded by the communication (6) of the findings e.g. in the form of a scientific paper. From the steps of demonstration, evaluation, and communication, it is possible to iterate back to define new objectives, or to make changes in the artifacts design. The iteration back from demonstration is not part of the DSR process proposed by Peffers *et al.* (2006, p. 93). However, in the understanding of this paper, it is also an important possibility since the real use of the artifact can also influence its design as well as the definition of new objectives. This also applies for the design itself, which influences the objectives. According to these six steps, the paper is structured in following chapters, which reflect the DSR process:

- **Chapter 1** has already introduced the topic by illustrating the problem of accurately reporting environmental data, and showing its importance for humanity in general and companies in particular. Moreover, the state of the art as well as the paper's main objectives have been given. In the following, this chapter will continue to show the paper's structure, describe the literature review, and present the related work.
- **Chapter 2** progresses from the introduction of sustainability and its requirements to environmental protection and its most pressing problem climate change. The chapter is concluded by statistics that show the importance of the topic for consumers as well as companies.
- **Chapter 3** takes up the previously shown explanations and narrows the topic to environmental protection in the ICT industry. Therefore, all necessary fundamentals on Environmental Informatics, Green IT, LCA, BI and the used BI tools will be given.
- **Chapter 4** shows the artifact's design, implementation and demonstration on the example of Apple's environmental product data. Therefore, the entire process of gathering, cleaning, structuring, analyzing, reporting and communicating of the data will be conducted. Thus, the model will be gradually developed while answering several comprehensive questions on the footprint of Apple's portfolio.
- **Chapter 5** evaluates this approach by stating advantages and disadvantages in order to design and implement a generalized model with standardized process steps. Afterwards the application of this model will be demonstrated and therefore evaluated on the example of the Dell Inc. product portfolio, to prove its feasibility and usefulness.
- **Chapter 6** concludes the paper with a summary, showing the main results and giving implications for future research by introducing possible extensions of the model.

1.4 Literature Review and Related Work

The literature used relies on several comprehensive sources. On the internet, the free scientific search engines Google Scholar, Microsoft Academic Research, BioOne[4], and the Directory of Open Access Journals have been used. Also, Google has been used e.g. for searches related to Apple Inc. or research advisory companies such as Gartner Inc. Furthermore, the digital libraries Springer and IEEE provided articles and books. Moreover, publications from the following university libraries have been used: Otto von Guericke University Magdeburg, Humboldt University of Berlin, Technical University of Berlin, Heinrich Heine University Düsseldorf, Ulster University Belfast, and Queens University Belfast. At the mainly used library of the Otto von Guericke University Magdeburg, the following sources have been relevant[5]:

- Bibliothekskatalog OPAC (Eng. Library Catalog OPAC – Online Public Access Catalog)
- Datenbank-Infosystem (Eng. Database Information System) – Areas of expertise: Energie, Umweltschutz, Kerntechnik (Eng.: Energy, Environmental Protection, Nuclear Technology) and Informatik (Eng. Informatics)
- Elektronische Zeitschriftenbibliothek (Eng. Electronic Journals)

Among electronic journals, there have used, e.g.:

- Environmental Impact Assessment Review
- Environmental Modelling and Software
- International Journal of Life Cycle Assessment
- Journal of Industrial Ecology
- Sustainability Accounting, Management and Policy Journal

The most important keywords to find publications as well as relevant content in the identified contributions have been:

- Apple Environmental Policies
- Business Intelligence
- Carbon Dioxide Equivalent
- Climate Change
- Data Monitoring
- Data Provision Process
- Data Visualization
- Environmental Informatics
- Environmental Information System
- Environmental Product Impact
- Environmental Protection
- Global Warming Potential
- Green IT
- Greenhouse Gas Emissions
- Greenhouse Effect
- ICT Environmental Policies
- ICT Product Life Cycle
- Life Cycle Assessment
- Product Classification
- Product Footprint
- Recycling
- Reporting
- Sustainability
- Sustainability Reporting

[4] BioOne is a specialist search engine, where sources about Environmental Science can be found.
[5] Translations by author.

In result of the literature review, important contributions to this paper come in particular from following authors, publications, and institutions: For the fundamentals of sustainability and environmental science, espeicially *Caring for the Earth: A Strategy for Sustainable Living* by IUCN *et al.* (1991) and *Environmental Science: A New Approach* by Dahiya and Ahlawat (2013) have been valuable sources. On climate change, the most important source was the website *Global Climate Change: Vital Signs of the Planet* by the National Aeronautics and Space Administration (NASA) (NASA, 2016b). On behalf of statistical insights, e.g. on the importance of environmental protection, Nielsen (2014) gave insights. For all kinds of environmental definitions, the *Oxford Dictionary of Environment and Conservation* by Park (2007) provided explanations e.g. on environmental sustainability. Besides, online dictionaries such as the *Cambridge University Press Dictionary* have been used (CUP, 2016a). In *ICT Innovations for Sustainability: An Emerging Research Field* by Hilty and Aebischer (Ed.) (2015) several essential definitions of sustainability, Environmental Informatics, Green IT and the entire background of ICT sustainability have been researched. On the scientific field of Environmental Informatics, in particular Page (1996) *Environmental Informatics Towards a New Discipline in Applied Computer Science for Environmental Protection and Research* has been relevant for studying the fundamentals of the topic. For Green IT, *Harnessing Green IT: Principles and Practices* by Murugesan (2008) and *Green IT* by Zarnekow and Kolbe (2013) have been particularly valuable references. Several papers by Arndt have been used to foster the understanding of environmental informatics and sustainability reporting, e.g.: *Sustainability Reporting Using the Extensible Business Reporting Language (XBRL)* (Arndt *et al.*, 2006) and *Umweltinformatik und Design-Eine relevante Fragestellung?*[6] (Arndt, 2013). The book *Environmental Information Systems* by Günther (1998) gave the necessary descriptions on this area. For the central topic of LCA as well as several other environmental affairs, the ISO 14000 standards family (ISO, 2009) with the ISO 14040 (ISO, 2006a) and ISO 14044 (ISO, 2006b), have been used. On this topic, other sources of institutions such as the Intergovernmental Panel on Climate Change (IPCC) have been relevant (IPCC 1996; IPCC, 2014). Those are also widely referenced in NASA (2016b). On the foundations of BI, *Business Intelligence with SQL Server Reporting Services* by Aspin (2015), and *Fundamentals of Business Intelligence* by Grossmann and Rinderle-Ma (2015) have been important references. Regarding the tool MS Power BI, Hart (2016a-c) and Iseminger (2016a-e) gave particularly valuable information. Furthermore, the IT research and advisory company Gartner (2016b) gave insights on different topics such as Green IT (Gartner, 2015a,b) or the state of the art of BI technologies (Gartner, 2016a). For the generalization and standardization of the monitoring model especially the principal guidelines by the Global Reporting Initiative (GRI) in documents such as *Reporting Principles and Standard Disclosure: G4* (2016a,b), as well as *Enterprise Dashboards: Design and Best Practices for IT* by Malik (2005) have been valuable references.

[6] Eng.: Environmental informatics and design – A relevant issue? (Translation by author).

2 Sustainability and its Central Topic of Environmental Protection

2.1 Sustainable Development and Sustainability

Park (2007, p. 439) defines the term *sustainable* as something that is "capable of being sustained or continued over the long term, without adverse effect." In relation to humanity, this means to live in a way that does not affect life's continuity. Therefore, the World Commission on Environment and Development (WCED) describes a *sustainable development* as: "Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs." (WCED, 1987, p. 16)[7] Based on this understanding, Park (2007, p. 439) defines *sustainability* as the overall concept of ensuring a sustainable development. This idea is summarized in nine principals of a *sustainable society*, which are given by the World Conservation Union (IUCN), the United Nations Environment Program (UNEP), and the World Wide Fund for Nature (WWF). These principals are stated below with short descriptions of their contents (IUCN *et al.*, 1991, pp. 9-12)[8]:

- **Respect and care for the community of life**: "[…] reflects the duty of care for other people and other forms of life, now and in the future. […] [Humanity] should aim to share fairly the benefits and costs of resource use and environmental conservation among different communities […]." (IUCN *et al.*, 1991, p. 9)
- **Improve the quality of human life**: "[…] include[s] a long and healthy life, education, access to the resources needed for a decent standard living, political freedom, guaranteed human rights, and freedom from violence. Development is real only if it makes [..] lives better in all these respects." (IUCN *et al.*, 1991, p. 9)
- **Conserve the Earth's vitality and diversity**: "Conservation-based development needs to include deliberate action to protect the structure, function and diversity of the world's natural

[7] This definition by the WCED is usually used as the basis of sustainability descriptions.
[8] The principals have been originally published in the 1991 edition of the work *Caring for the Earth: A Strategy for Sustainable Living* (IUCN et al., 1991, pp. 9-12) and have been reprinted several times, lastly in IUCN *et al.* (2013, pp. 9-12) without changes.

systems […].” (IUCN *et al.*, 1991, p. 9) This includes the conservation of life-supporting systems and biodiversity, as well as the assurance that uses of renewable resources such as soil, forests, or water ecosystems, are sustainable (IUCN *et al.*, 1991, p. 9).

- **Minimize the depletion of non-renewable resources**: “Minerals, oil, gas and coal are effectively non-renewable. Unlike plants, fish or soil, they cannot be used sustainable. However, their ‘life’ can be extended, for example, by recycling, by using less of a resource to make a particular product, or by switching to renewable substitutes where possible.” (IUCN *et al.*, 1991, p. 10)
- **Keep within the Earth’s carrying capacity**: “[…] there are finite limits to the ‘carrying capacity’ of the Earth’s ecosystem – to the impact that they and the biosphere as a whole can withstand without dangerous deterioration. The limits vary from region to region, and the impacts depend on how many people there are […] [and what they consume]. […] Policies that bring human numbers and life-styles into balance with nature’s capacity must be […] [implemented].” (IUCN *et al.*, 1991, p. 10)
- **Change personal attitudes and practices**: “[…] people must re-examine their values and alter their behavior. Society must promote values that support the new ethic and discourage those that are incompatible with a sustainable way of life. Information [on how to implement a sustainable behavior] must be disseminated through […] educational systems so that the policies […] can be explained and understood.” (IUCN *et al.*, 1991, p. 11)
- **Enable communities to care for their own environment**: “Most of the creative and productive activities of individuals or groups take place in communities. Communities […] provide the most readily accessible means for people to take socially valuable action as well as to express their concerns. Properly mandated, empowered and informed, communities can contribute to decisions that affect them and play an indispensable part in creating a securely-based sustainable society.” (IUCN *et al.*, 1991, p. 11)
- **Provide a national framework for integrating development and conservation**: “[..] societies need a foundation of information and knowledge, a framework of law and institutions, and consistent economic and social policies if they are to advance in a rational way. A national programme for achieving sustainability should involve all interests, and seek to identify and prevent problems before they arise. It must be adaptive, continually redirecting its course in response to experience and to new needs.” (IUCN *et al.*, 1991, p. 11)
- **Create a global alliance**: “No nation [..] is self-sufficient. […] to achieve global sustainability a firm alliance must be established among all countries. […]. Global and shared resources, especially the atmosphere, oceans and shared ecosystems, can be managed only on the basis of common purpose and resolve.” (IUCN *et al.*, 1991, pp. 11-12)

These nine principles "reflect values and duties – especially the duty of care for other people, and of respect and care for the nature […]." (IUCN *et al.*, 1991, p. 12) The principles also reveal the complexity of the subject. To illustrate the different facets of sustainability in a more tangible way, a variety of models has been developed (Hilty and Aebischer, 2015, p. 12; Mokosch *et al.*, 2015). One of the fundamental illustrations is the three-pillar model of sustainability (Fig. 5).[9]

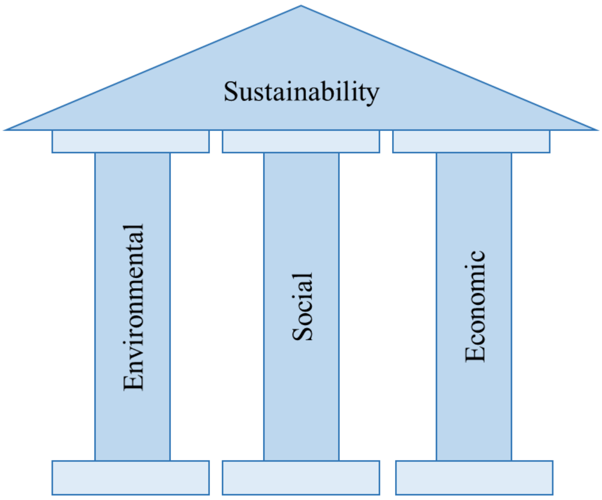

Figure 5: The Three Pillars of Sustainability
Own illustration based on (Hilty and Aebischer, 2015, p. 12; ISO, 2015a, p. vi; Mokosch *et al.*, 2015, p. 416)

The model divides sustainability in an environmental, a social, and an economic component. Most illustrations show the environmental pillar in the middle without stating an intended order. Since this pillar has been identified as the most important, this paper positioned it on the illustration's left side, so it is read at first when viewing the figure (Hilty and Aebischer, 2015, p. 12; Park, 2007, p. 439). The ISO (2015a, p. vi) says: "Sustainable development as a goal is achieved by balancing the three pillars of sustainability." Thus, focusing on driving improvement in one area must always consider the interrelations, which can affect the entire building. Examples of challenges in each pillar, which are also reflected by the nine principles of IUCN *et al.* (1991, pp. 9-12), are:

- **Environmental**: Reduction of greenhouse gas emissions, prevention of water contamination, prevention of soil pollution
- **Social**: Prevention of war, compliance with human rights, fight against poverty
- **Economic**: Ensuring economic growth, obtaining certain levels of prosperity

Several organizations work on different kinds of these problems (AI, 2016; EPA, 2016b; OECD, 2016a; UN, 2016; UNEP, 2016a; WTO, 2016). Since this paper's purpose is to reinforce the pillar of environmental protection, the next section will deepen the understanding of this area.

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[9] For advancements and detailed descriptions, e.g. Mokosch *et al.* (2015) provide valuable information.

2.2 Environmental Protection and Climate Change

"Humans are not immune to the laws of nature after all! Humankind's actions are transforming the Earth's landscapes, oceans, and even the atmosphere, so it is important to ask if our societies can endure as the world changes." (Tomkin, 2016) These changing souroundings are known as the environment, which is generally defined as "all of the external abiotic and biotic factors, conditions and influences that affect the life, development, and survival of an organism or a community." (Park, 2007, p. 149) The abiotic factors are non-biological, such as climate, geology, and the atmosphere (Park, 2007, p. 1). The opposite are the biotic, life containing things, such as humans (Park, 2007, p. 53). In the course of sustainability, there is also the term environmental sustainability, which is defined as "the long-term maintenance of ecosystems and other environmental systems for the benefits of future generations." (Park, 2007, p. 155) If this condition would be entirely achieved, societies would not have to deal with a drastically changing world, which endangers their continued existence. According to this, the environmental pillar of sustainability is based on the idea of protecting the planet from harmful damages. Therefore, Park (2007, p. 154) defines environmental protection as "practices and procedures that are designed to avoid, minimize, eliminate, or reverse damage to the environment and to environmental systems." The protection of the environment shall therefore not only preseve nature, but also reverse the harms already happened to Earth. This includes a broad range of aspects such as the prevention of water contamination, or the mindful handling of rare resources as well as the conscious treatment of hazardous substances.

At the center of today's environmental discussion is the term climate change or global warming and its associated consequences (NASA, 2016a). As Dahiya and Ahlawat (2013, p. 6.4) emphasize: "Climate Change is clearly the most important global environmental problem faced by mankind." Climate is in general defined as: "The long-term average weather conditions of a place, in terms of precipitation, temperature, humidity, sunshine, and wind velocity and phenomena such as fog, frost, and hail storm. These are determined by factors that are fixed through time, such as latitude, position relative to ocean or continents, and altitude." (Park, 2007, pp. 81) "Climate changes from place to place, but much more slowly than weather because climate zones are usually quite large. It also changes through time, [but] again much more slowly than weather." (Park, 2007, pp. 81–82) Climate change is therefore "any natural or induced change in climate, either globally or in a particular area." (Park, 2007, p. 82). One of the most profound sources on climate change is the website *Global Climate Change – Vital signs of the planet* by the U.S. National Aeronautics and Space Administration (NASA) (NASA, 2016a-f). Therein they give an example of climate and its change: "The climate of a region or city is its typical or average weather. For example, the climate of Hawaii is sunny and warm. But the climate of Antarctica is freezing cold. Earth's climate is the average of all the world's regional climates. Climate change, therefore, is a change in the typical or average weather of a region or city. This could be a change in a region's average annual rainfall, for example. Or it could be a change in a city's average temperature for a given month or season. Climate change is also a change in Earth's overall climate. This could be a change in Earth's average temperature, for example. Or it could be a change in Earth's typical precipitation patterns." (NASA, 2016d)

Earth's climate has changed throughout history. There have been seven cycles of glacial advance and retreat in the last 650,000 years, which ended with the last ice age about 7,000 years ago. This marks the beginning of the modern climate era and of human civilization. Most of these changes are attributed to small variations in Earth's orbit that change the amount of solar energy the planet receives. However, most climate scientists agree that the main cause of the current global warming is the expansion of the greenhouse effect, which results when the atmosphere traps heat radiating from Earth toward space. (IPCC, 2014, p. 8; NASA, 2016a) Fig. 6 illustrated this effect.

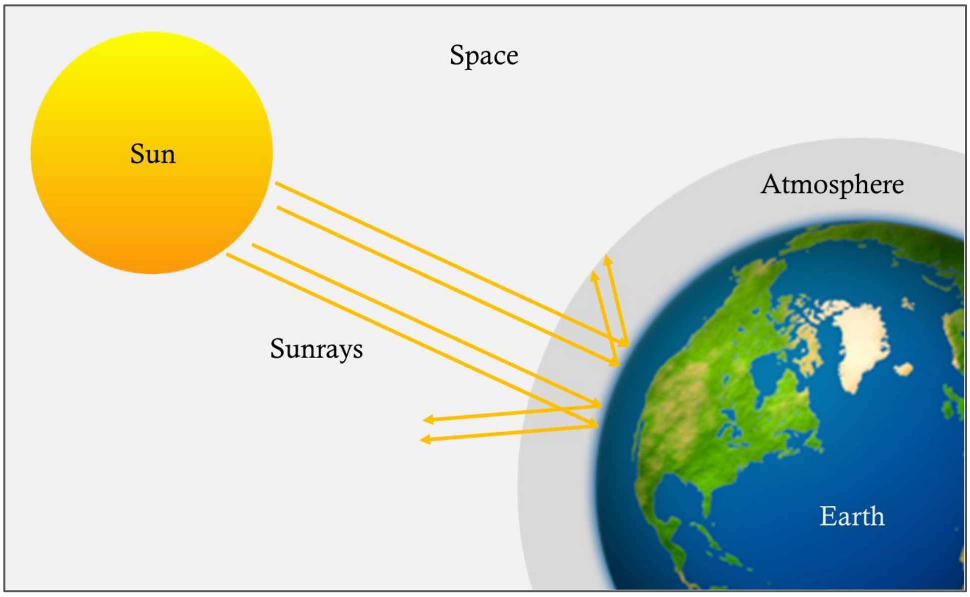

Figure 6: Explanation of the Greenhouse Effect
Own illustration based on (NASA 2016a)

On the left side is the sun sending its rays through space toward Earth on the right. Heat blocking greenhouse gases (GHGs) in the atmosphere prevent a certain amount of heat from escaping. These GHGs are "gaseous constituent of the atmosphere, both natural and anthropogenic, that absorbs and emits radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds" (ISO, 2006c, p. 1) The heat-trapping nature of GHGs was firstly demonstrated in the mid-19th century when "[…] Tyndall recognized the Earth's natural greenhouse effect and suggested that slight changes in the atmospheric composition could bring about climatic variations." (NASA, 2016e) Current research shows again: "There is no question that increased levels of greenhouse gases must cause the Earth to warm […]. Ice cores drawn from Greenland, Antarctica, and tropical mountain glaciers show that the Earth's climate responds to changes in greenhouse gas levels." (NASA, 2016e) This drawn also show that changes happen quickly and do not take several thousand years (NASA, 2016e; NOAA, 2016a; Park, 2007, p. 82; Petit et al., 1999; ProOxygen, 2016). NASA (2016e) supplements: "The current warming trend is of particular significance because most of it is very likely human-induced and proceeding at a rate that is unprecedented in the past 1,300 years." Several scientific, governmental as well as intergovernmental bodies also confirm the growing threat humanity is facing:

- **American Association for the Advancement of Science (AAAS)**: "The scientific evidence is clear: global climate change caused by human activities is occurring now, and it is a growing threat to society." (AAAS, 2006, p. 1)
- **American Physical Society**: "The evidence is incontrovertible: Global warming is occurring. If no mitigating actions are taken, significant disruptions in the Earth's physical and ecological systems, social systems, security and human health are likely to occur. We must reduce emissions of greenhouse gases beginning now." (APS, 2007)
- **Intergovernmental Panel on Climate Change (IPCC)**: "Warming of the climate system is unequivocal […] Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems." (Myles *et al.*, 2014, p. 5)

Consequences of further inadequate human behavior would lead to rapid change of climate conditions and a growing occurrence of developments such as the following:

- **Sea level rise**: "Global sea level rose about 17 centimeters in the last century. The rate in the last decade is nearly double that of the entire last century." (NASA, 2016e, based on data from Church and White, 2006, p. 2)
- **Global temperature rise**: "All three major global surface temperature reconstructions show that Earth has warmed since the year 1880. Most of this has occurred since the 1970s, with the 20 warmest years having occurred since 1981 and with all 10 of the warmest years occurring in the past 12 years." (NASA, 2016e, based on data from Peterson *et al.*, 2009)
- **Warming oceans**: "The oceans have absorbed much of this increased heat, with the top 700 meters […] of ocean showing warming of 0.302 degrees Fahrenheit since 1969." (NASA, 2016e based on data from Levitus *et al.*, 2009)
- **Shrinking ice sheets**: "Data from NASA's Gravity Recovery and Climate Experiment show Greenland lost 150 to 250 cubic kilometers […] of ice per year between 2002 and 2006, while Antarctica lost about 152 cubic kilometers […] between 2002 and 2005." (NASA, 2016e)
- **Extreme events**: "The number of record high temperature events in the U.S has been increasing, while the number of record low temperature events has been decreasing, since 1950.

The U.S. has also witnessed increasing numbers of intense rainfall events." (NASA, 2016e, based on data from NOAA, 2016b)

- **Decreased snow cover**: "The amount of spring snow cover in the Northern Hemisphere has decreased over the past five decades and snow is melting earlier." (NASA, 2016e, based on data from NSIDC, 2016)

Especially companies trigger these developments by the massive emission of GHGs. These greenhouse gas emissions (GGEs) are defined as the "total mass of a GHG released to the atmosphere over a specified period of time" (ISO, 2006c, p. 2). Since different GHGs can have different effects on the earth's warming, the Global Warming Potential (GWP) summarizes the impact of each gas based on their potential contribution to climate change over a given period of time (EPA, 2016c; ISO, 2006c, p. 3). The standard unit for the measurement of the different GWP based GHG impacts to calculate the GGEs is called carbon dioxide equivalent (CO_2e) (ISO, 2006c, p. 3). "For any quantity and type of greenhouse gas, CO_2e signifies the amount of CO_2, which would have the equivalent global warming impact. A quantity of GHG can be expressed as CO_2e by multiplying the amount of the GHG by its GWP. For instance, if 1kg of methane is emitted, this can be expressed as 25kg of CO_2e (1kg CH_4 * 25 = 25kg CO_2e)." (Brander, 2012, p. 2)
Different factors define the relation between each gas and carbon dioxide. The two key influential variables are the ability of the gas to absorb energy (radiative efficiency), and how long the gas stays in the atmosphere (lifetime). The time period that is usually used for the determination of a GHG's GWP is 100 years (EPA, 2016c). Tab. 1 shows the GWPs of gases, stated in the international standard of ISO 14064-1 (ISO, 2006c, p. 20). The referenced values come originally from the second Assessment Report (AR) released by the IPCC in 1996 (IPCC, 1996, p. 22). These report has already been updated so the current GWPs are stated by the AR5 in IPCC (2014, p. 87) and Myhre *et al.* (2013, pp. 731-737). However, the 1996-list is part of ISO 14064-1 (ISO, 2006c, p. 20), which is referenced in ISO 14040 ISO (2006a, p. 20) the standard to which Apple refers in their PDF reports (Apple, 2016b). Therefore, it must be assumed that Apple calculates their GGEs by GWP in CO_2e based on the AR2 values, which is the reason to state these here. In addition, the table shows the AR5 values for comparison purposes.

Gas	**Chemical formula**	**GWP (100-year)**	
		Second Assessment Report (ISO 14064-1)	**Fifth Assessment Report**
Carbon dioxide	CO_2	1	1
Methane	CH_4	21	28
Nitrous oxide	N_2O	310	265
Hydrofluorocarbons (HFCs)			
HFC-23	CHF_3	11.700	12.400
HFC-32	CH_2F_2	650	677

HFC-41	CH_3F	150	116
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1.300	1.650
HFC-125	CHF_2CF_3	2.800	3.170
HFC-134	CHF_2CHF_2	1.000	1.120
HFC-134a	CH_2FCF_3	1.300	1.300
HFC-143	CH_2FCHF_2	300	328
HFC-143a	CH_3CF_3	3.800	4.800
HFC-152a	CH_3CHF_2	140	138
HFC-227ea	CF_3CHFCF_3	2.900	3.350
HFC-236fa	CF_3CH2CF_3	6.300	8.060
HFC 245ca	$CH_2FCF2CHF_2$	560	716
Hydrofluoroethers (HFEs)			
HFE-7100	$C_4F_9OCH_3$	500	421
HFE-7200	$C_4F_9OC_2H_5$	100	57
Perfluorocarbons (PFCs)			
PFC-14	CF_4	6.500	6.630
PFC-116	C_2F_6	9.200	11.100
PFC-218	C_3F_8	7.000	8.900
PFC-31-10	C_4F_{10}	7.000	9.200
PFC-318	$c\text{-}C_4F_8$	8.700	9.540
PFC-41-12	$n\text{-}C_5F_{12}$	7.500	8.550
PFC-51-14	$n\text{-}C_6F_{14}$	7.400	7.910
Sulfur hexafluoride	SF_6	23.900	23.500

Table 1: Global Warming Potential of ISO 14064-1 Greenhouse Gases
(IPCC, 1996, p. 22; IPCC, 2014, p. 87; ISO, 2006c, p. 20; Myhre *et al.*, 2013, pp. 731-737)[10]

The listed GHGs that contribute to the greenhouse effect and their GWP are described in the following:

- **Carbon dioxide (CO_2)**: "Carbon dioxide is released through natural processes such as respiration and volcano eruptions and through human activities such as deforestation, land use changes, and burning fossil fuels." (NASA, 2016a) It "[…] has a GWP of 1 regardless of the time period used, because it is the gas being used as the reference. Carbon dioxide remains in the climate system for a very long time: carbon dioxide emissions cause increases in atmospheric concentrations of carbon dioxide that will last thousands of years." (EPA, 2016c)
- **Methane (CH_4)**: "A hydrocarbon gas produced both through natural sources and human activities, including the decomposition of wastes in landfills, agriculture, and especially rice cultivation, as well as ruminant digestion and manure management associated with domestic livestock." (NASA, 2016a) It "[…] is estimated to have a GWP of [..] [21 in AR2 or 28 in AR5] over 100 years. [...] CH_4 emitted today lasts about a decade on average, which is much

[10] The chemical formulas have been adjusted according to AR5 to fit the latest research. For example, the formula of Hydrofluorocarbons-125 had to be corrected from C_2HF_5 (IPCC, 1996; ISO, 2006c, p. 20) to CHF_2CF_3 (Myhre et al., 2013, p. 732).

less time than CO_2. But CH_4 also absorbs much more energy than CO_2. The net effect of the shorter lifetime and higher energy absorption is reflected in the GWP." (EPA, 2016c)

- **Nitrous Oxide (N_2O)**: "A powerful greenhouse gas produced by soil cultivation practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning." (NASA, 2016a) It "has a GWP […] [of 310 in AR2 or 265 in AR5] for a 100-year timescale. N_2O emitted today remains in the atmosphere for more than 100 years, on average." (EPA, 2016c)
- **Hydrofluorocarbons (HFCs), Hydrofluoroethers (HFEs), and Perfluorocarbons (PFCs)**: "Are sometimes called high-GWP gases because, for a given amount of mass, they trap substantially more heat than CO_2. [..] The GWPs for these gases can be in the thousands or tens of thousands." (EPA, 2016c)

Measuring and controlling the emissions of those gases is crucial to ensure actions for the prevention of climate change and therewith for the protection of the environment as the central aspect of sustainability.

2.3 Growing Importance of Environmental Thinking

The importance of an environmental-friendly life is continuously growing in common thinking. Several profound studies evidence this trend. Relevant research subjects in this context are, for example, the concerns of consumers for environmental affairs, or the actions taken by companies to ensure a low environmental impacting production. Such studies will be shown in this section, starting with the consumer's view on environmentally responsible companies (Fig. 7).

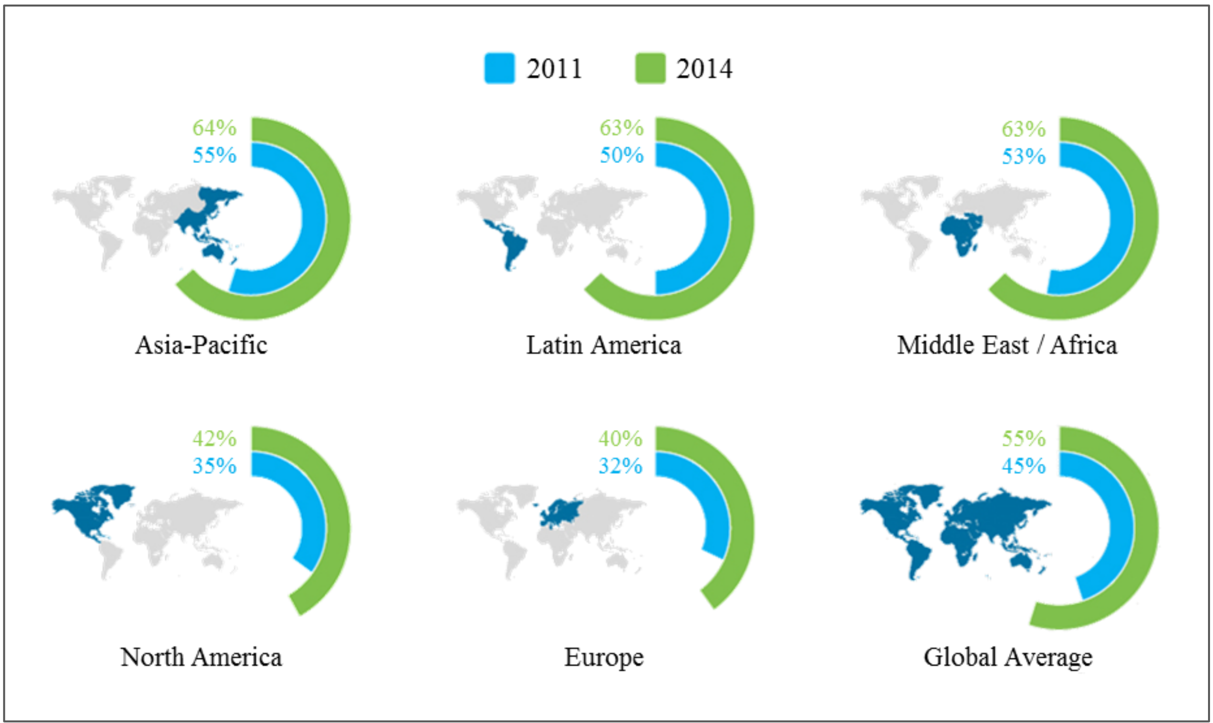

Figure 7: Consumer's Willingness to Pay More for Low Impacting Products (2011 and 2014) (Nielsen, 2014; Statista, 2016a)

Based on a survey of 30,000 online consumers from 60 countries this graphic shows the consumer's willingness to pay more for goods and services from environmentally responsible companies in comparison of the years 2011 and 2014. The graphic is divided into the earth regions: Asia-Pacific, Latin America, Middle East/Africa, North America and Europe. Additionally shown is the global average. As can be seen the willingness increased in total and on each continent. While globally the increase amounts to 10%, the highest growth can be seen in Latin America with an increase of 13%. The lowest rise can be found in North America with 7%. Considering the total values, the highest willingness in 2014 shows the region Asia-Pacific with 64%, which had also the highest value in 2011 with 55%. The lowest value has been surveyed in both years in Europe, whereby the region still shows a growth by 8%. With increases in each region, the study proves that the trend in the thinking of consumers goes to goods and services of companies, which are aware of their environmental responsibility.

Regarding climate change, there are several studies, which determine its recognition. Therefore, the survey in Fig. 8 displays its worldwide perception as a serious problem, and as a current danger for humanity.

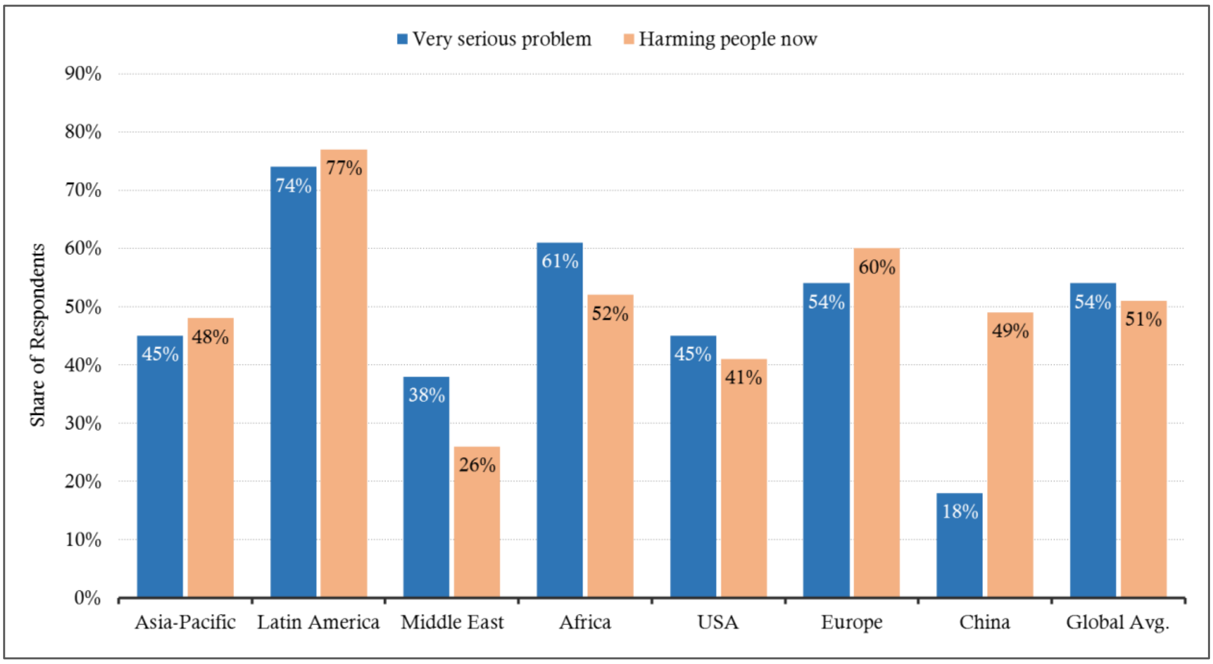

Figure 8: Worldwide Climate Change Concerns by Region
Own illustration based on (Stokes *et al.*, 2015, pp. 4-5)

The study surveyed the regions: Asia-Pacific, Latin America, Middle East, Africa, United States of America (USA), Europe, and China. Also displayed is the global average. The blue bars illustrate the replies to the question: *Is climate change a very serious problem?* Compared with other regions, especially Latin America and Africa show concerns. Latin America has the highest value with 74% thinking climate change is a very serious threat. This corresponds with the survey of Fig. 7 where the region was in a front position in consumers' environmental buying behaviors. The least concerns have been surveyed in China with 18%. The orange bars illustrate the replies to the question: *Is climate change harming people now?* Latin America is again in the lead with 77% followed by Europe with 60%. Although only 18% of people in China take climate change as a serious problem, 49% think that it is harming people right now. As the survey summarizes, people are concerned about climate change and its consequences, despite the values differ in each region. The same study also surveyed climate change as the top worldwide concern, even before threats such as global economic instability, or terrorism (Pew Research Center, 2015, p. 5).

Many consumers see companies in the responsibility to act in a sustainable way (Hill+Knowlton and Carton Council, 2015). "The case for corporate action on climate change has never been stronger and better understood. With the scientific evidence of manmade climate change becoming ever more incontrovertible, leading companies and their investors increasingly recognize the strategic opportunity presented by the transition to a low-carbon global economy." (CDP Worldwide, 2015, p. 6) The statistic in Fig. 9 demonstrates four climate change actions and attitudes of companies worldwide in the comparison between 2010 and 2015.

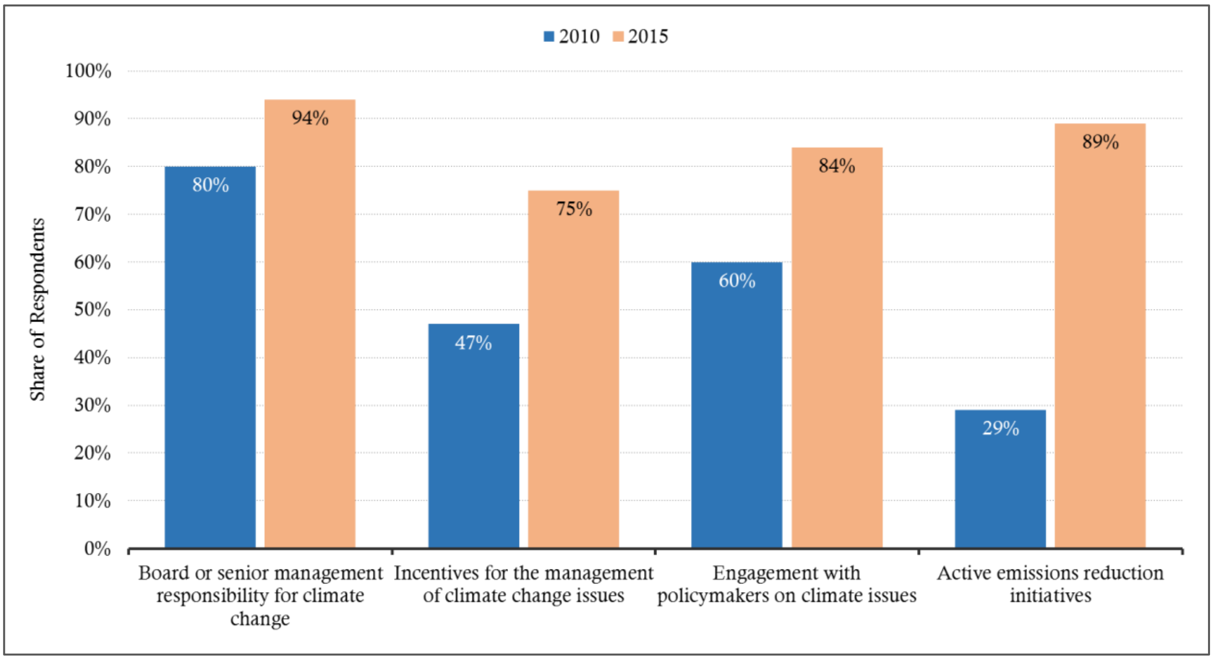

Figure 9: Worldwide Company Actions Against Climate Change
Own illustration based on (CDP Worldwide, 2015, p. 6)

As can be seen, all four engagements have been increased. In 2015 more than 94% of the responding companies declared that they see climate change responsibility on their board or the senior level, which is the highest value among all actions. The highest growth has been in initiatives for the active reduction of emissions, which increased by 60% from 2010 to 2015. In addition, *Incentives for the management of climate change issues* increased by 28% and *Engagement with policymakers on climate issues* increased by 24%. As CDP Worldwide (2015, p. 6) further states: "The United Nations Environment Programme estimates that existing collaborative emissions reduction initiatives involving companies, cities and regions are on course to deliver the equivalent of 3 gigatons of carbon dioxide reductions by 2020. That's more than a third of the 'emissions gap' between existing government targets for that year and greenhouse gas emissions levels consistent with avoiding dangerous climate change."

The presented studies evidence the growing concern and awareness of consumers about the condition of the planet. They further prove that companies take actions to ensure environmental protection, especially in the course of climate change prevention, whether it is because of the growing consumers' interest or a real desire for the preservation of the planet. Further examples such the increasing company investments in clean energy confirm this trend (Bloomberg and UNEP, 2016, p. 15). The next chapter will narrow this understanding to the ICT industry and shows its actions to ensure the sectors environmental responsibility.

3 Background of Environmental Protection in the ICT Industry

3.1 ICT Industry and Environmental Thinking

Information and communication technology (ICT) is defined as "the science and activity of using computers and other electronic equipment to store and send information." (CUP, 2016b) To enable this, the ICT industry offers IT services as well as the necessary hardware and software. The sector shows a continuous growth over the last decades, which can be seen, for example, in rising employment rates (Bitkom, 2016; OECD, 2016b) as well as constantly increasing revenues. As an example, Fig. 10 shows the sector's global revenues from 2009 to 2015 with forecasts for 2016 and 2019 (asterisks).

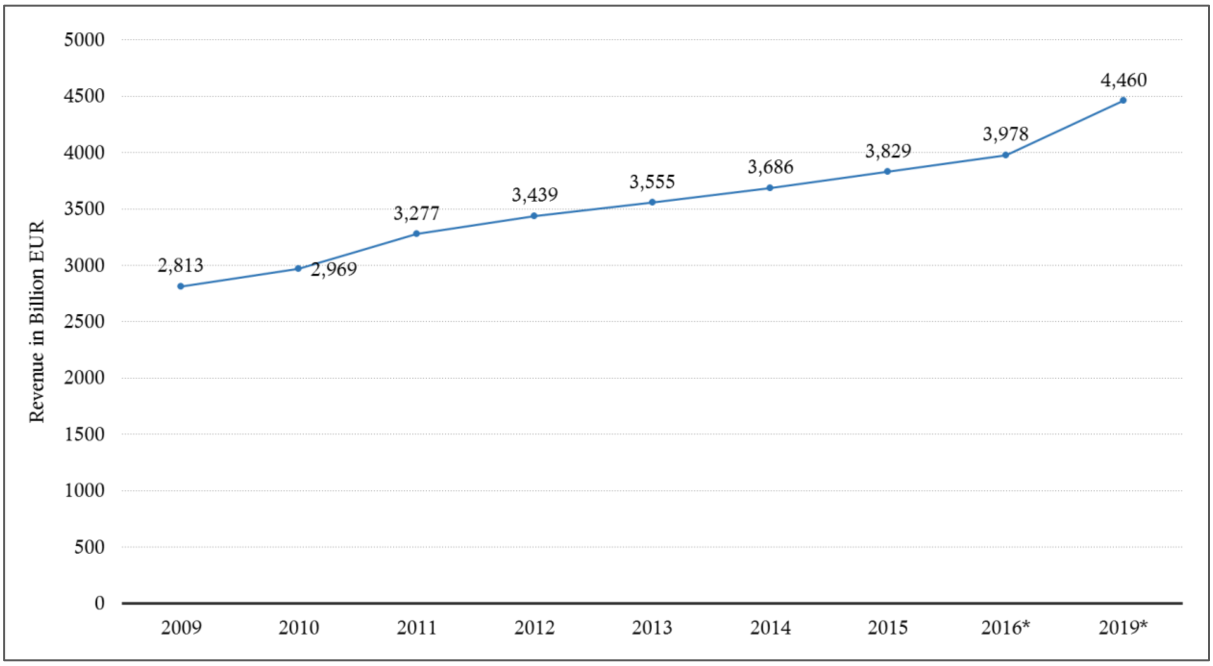

Figure 10: Global Revenue of ICT Sector (2009 to 2015; 2016*, 2019*)
Own illustration based on (IDATE, 2012, p. 40; IDATE, 2013, p. 42; IDATE, 2014, p. 52; IDATE, 2015, p. 36; IDATE, 2016, p. 34)

Summarized are the revenues of the areas: IT services & software, network equipment, telecom services, television and video services, internet services, and devices (IDATE 2016, p. 34). As can be seen, the revenue increased in each year. From 2009 with 2,813 billion EUR to 2015 with 3,829 billion EUR, the growth was more than 36%. Furthermore, the statistic predicts a continuous growth to 4,460 billion EUR revenue in 2019. This corresponds to an increase of nearly 59% compared to 2009. The Global e-Sustainability Initiative (GeSI) confirms: "The ICT industry plays a vital role in the global economy and is a major driver of growth and development." (GeSI, 2012, p. 17)

The increasing consumption of ICT goods and services demonstrates also the sectors growing impact on the planet's condition, since more ICT production and usage indicate a higher demand of resources, a higher amount of waste, and in particular more emission of GHGs. Kim and Lee (2011, p. 423) confirm: "IT sector itself is becoming a major source of GHG." Fig. 11 illustrates the increase from 2002 to 2011 with a forecast for 2020 (asterisk).

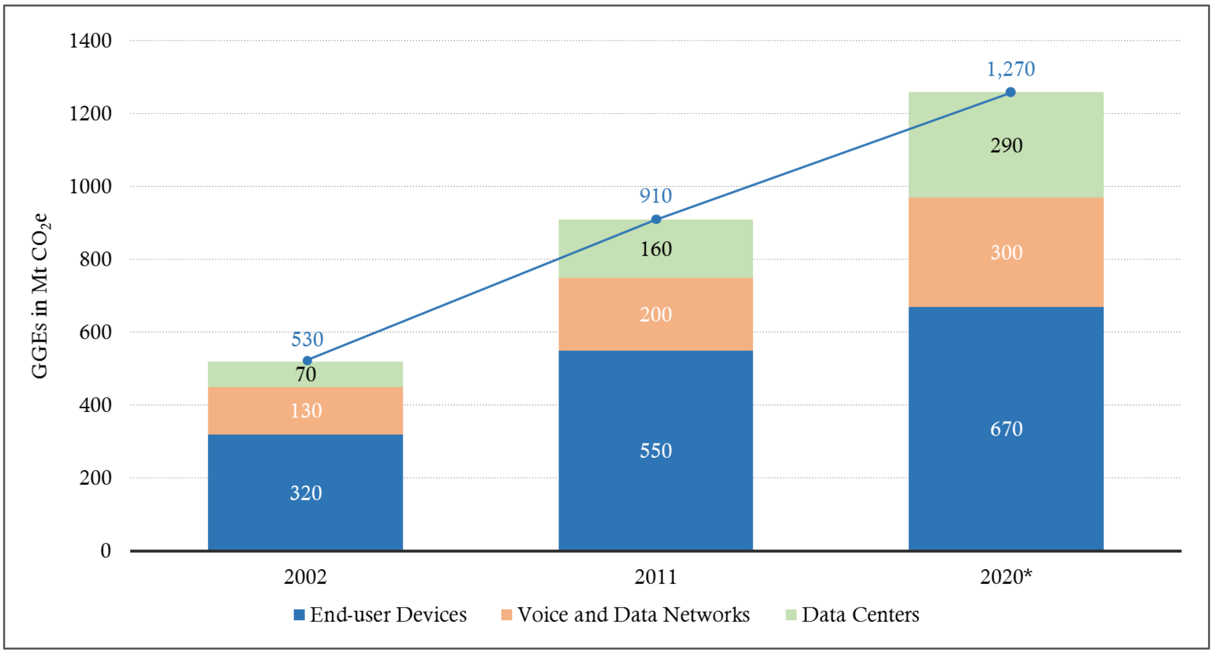

Figure 11: Total ICT Sector GGE Growth in Mt CO_2e (2002 and 2011; 2020*)
Own illustration based on (GeSI, 2012, pp. 21-26)

The statistic shows that the total emissions increased from 530 Mt CO_2e in 2002, to 910 Mt CO_2e in 2011. For 2020, a growth to 1,270 Mt CO_2e is predicted. This corresponds with a reduction in percentage, but still implies an increase by 360 Mt CO_2e compared to 2011. The statistic also shows an ongoing emission increase for the areas of *End-user Devices*, *Voice and Data Network*, and *Data Centers* in which the total is split. On the level of globally economy, the proportion of total GGEs of the sector also increased from 1.3% in 2006 to 1.9% in 2011 and is predicted for 2.3% in 2020 (GeSI, 2012, pp. 22). The GeSI (2012, p. 21) supplements: "[…] the ICT industry's footprint is projected to increase at a faster rate than the total global footprint between 2011 and 2020."

To counteract this trend, the ICT industry must ensure the compliance of their actions and outcomes with environmental regulations. As The Climate Group (2008) says: "To help, rather than hinder, the fight against climate change, the ICT sector must manage its own growing impact and continue to reduce emissions from data centres [sic], telecommunications networks, and the manufacture and use of its products." This includes that an entire company has to define and implement their idea of an environmentally responsible enterprise. Achieving such a mentality is a declared goal of many ICT businesses, which manifest this reasoning in their environmental vision. Examples are:

- **Google**: "Google is creating a better web that's better for the environment. We're greening our company by using resources efficiently and supporting renewable power. That means when you use Google products, you're being better to the environment." (Google, 2016)
- **Microsoft**: "Technology can help create a more sustainable future. Microsoft is pioneering new ways technology can help us make our own operations leaner and more energy efficient. We're also working with customers, governments and others around the world to help them apply our products and services to solving some of the world's toughest environmental challenges." (Microsoft, 2016a)
- **Apple**: "We take the same innovative approach to the environment that we do with our products. We're creating new solar energy projects to reduce our carbon footprint. We're switching to greener materials to create safer products and manufacturing processes. We're protecting working forests and making sure, they are managed sustainably. We're even creating a more mindful way to recycle devices using robots." (Apple, 2016a)
- **Facebook**: "At Facebook, sustainability is an important part of how we do business day-to-day. Not only is the Facebook platform a tool that individuals and organizations can use to apply creativity and ingenuity to environmental challenges, but we as a company are working to address our own environmental impact. A number of Facebook employees are working on sustainability initiatives in different business units throughout the company." (Facebook, 2012)
- **Dell**: "Technology is a powerful tool that helps us manage our precious resources — through smart grids, efficient data centers and electronic health records — to name a few examples. While technology can change the world for the better, we must also ensure we minimize the environmental impact of the products we make while helping our customers further reduce the impact of their IT. At Dell, we are committed to helping customers compute more while consuming less and design next-generation solutions that can make a positive impact on the world we share." (Dell, 2016b)

These environmental mission statements are a few examples from a selection of companies to show the growing environmental consciousness within the ICT industry. However, the implementation of environmental actions to reach these claims must rely on scientific principles and state-of-the-art technologies. The fundamentals of those are introduced in the following sections.

3.2 Environmental Informatics and Green IT

The research field of ICT environmental protection has been manifested under the umbrella of Environmental Informatics (EI). Hilty and Aebischer (2015, p. 15) define: “EI combines methods from the fields of Computer Science and Information Systems such as database systems, geographic information systems, modeling, and simulation, with problem-oriented knowledge from Environmental Science and Management.” The here referenced research field of Environmental Science is defined as “the interdisciplinary study of environmental systems, how they operate, how they interact with people, and how people interact with them.” (Park, 2007, p. 154) Therefore, the field gives the necessary background on which basis EI can find data-driven solutions to environmental problems. Regarding the contribution of EI to sustainability, Hilty *et al.* (2011, p. 16) describe: “Its contribution to sustainable development is that a consensus on environmental strategies and policies may emerge in the long term, based on shared data and understanding.” Therefore, the illustration below shows how human-caused environmental burdens can be counteracted by computerized environmental data (Fig. 12).

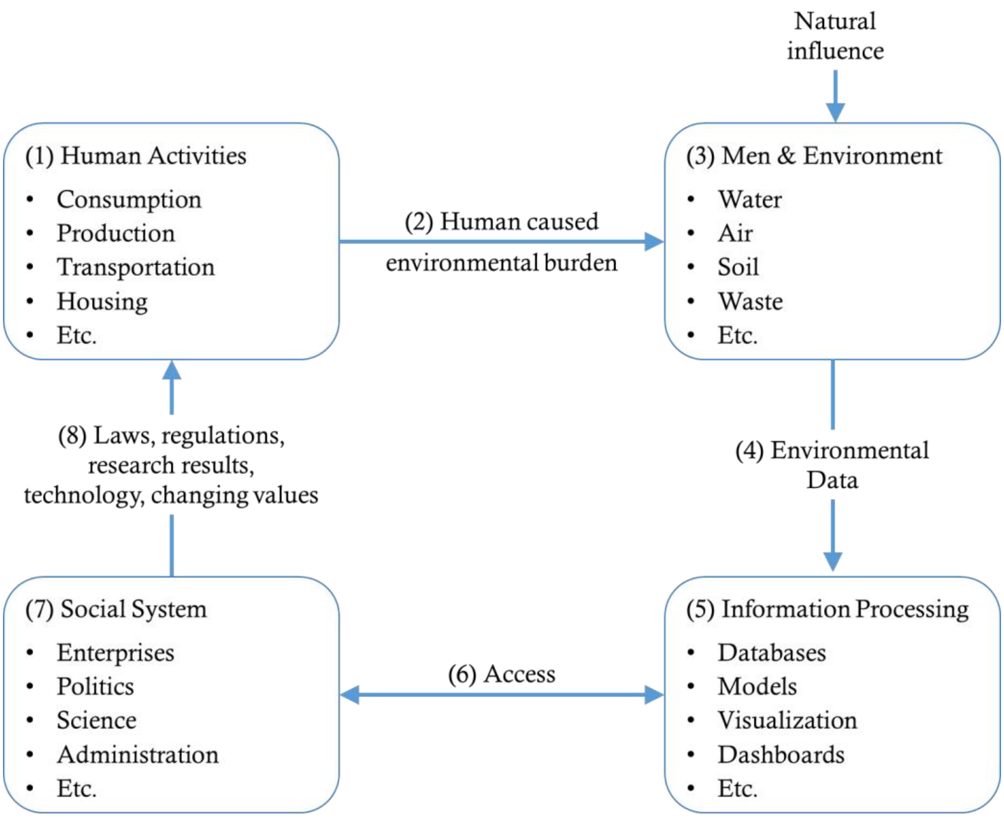

Figure 12: Role of Information Processing in the Field of Environmental Science
Own illustration based on (Hilty and Aebischer, 2015, p. 15; Page, 1996, p. 7; Page and Hilty, 1995, p. 16)

Human activities (1) such as consumption, production, or transportation cause burdens (2) in the environment (3) such as the contamination of water, or the pollution of air and soil. Those are also influenced by nature itself. Data about the environment and these human caused environmental burdens (4) can be gathered into environmental information systems (EIS) to analyze and report them (5). Günther defines: "Environmental Information Systems are concerned with the management of data about the soil, the water, the air, and the species in the world […]. The collection and administration of such data is an essential component of any efficient environmental protection strategy." (Günther, 1998, p. 1) Hilty *et al.* (2011, p. 17) complement: "A broad range of applications is covered by these systems, including monitoring and control, information management, data analysis, as well as planning and decision support." If a system is specialist on the research of GHGs the term Greenhouse Gas Information System is used. Such systems consists of "policies, processes and procedures to establish, manage and maintain GHG information." (ISO, 2006c, p. 2) Deriving from the raw data, these systems (5) generate information and eventually knowledge by the use of technologies and methodology such as databases, models, or visualizations. On the one hand, information processing can access (6) the social system to extend its data and find further correlations. On the other hand, social systems (7) such as enterprises, politics, or science, can access (6) the insights generated by the information systems. The social system (7) itself can influence human activities (8) by laws, regulations, or research results. One example is politics that can adopt laws for environmental protection to influence human activities or in this case, the activities of humans working in an enterprise. Examples for such obligations can be found in the German law[11]: *Bundes-Immissionsschutzgesetz* (BMJV, 2013) (Eng. Federal Emission Restriction Act), *Wasserhaushaltsgesetz* (BMJV, 2016a) (Eng. Water Management Act), and *Kreislaufwirtschaft- und Abfallgesetz* (BMJV, 2016b) (Eng. Waste Management Act). Thus, the collection and reporting of environmental data could also be necessary to evidence the compliance with legal requirements like these (Fischer-Stabel, 2005, p. 2).

In the context of ICT environmental protection, several disciplines of Environmental Informatics are important. Since the purpose of this paper is to foster the understanding of ICT product environmental impacts, the scientific field of Green IT is a central topic. Murugesan (2008, pp. 25-26) defines: "Green IT refers to environmentally sound IT. It's the study and practice of designing, manufacturing, using, and disposing of computers, servers, and associated subsystems – such as monitors, printers, storage devices, and networking and communications systems – efficiently and effectively with minimal or no impact on the environment." In this way, it is important to separate the term from Green IS. Vom Brock and Seidel (2012, p. 1) describe: "While information technology (IT) can help solving environmental problems, it also causes environmental problems through emissions, wastage, and the consumption of renewable and nonrenewable resources throughout its lifecycle." The first part of this sentence means Green IS, which can help other companies of all industries to enable environmental sustainability in a wide range of areas (Zarnekow and Kolbe,

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[11] Translations by author.

2013, p. 15). The second part that points to the fact that IT itself causes environmental burdens, refers to the potential to reduce these by means of Green IT (Zarnekow and Kolbe, 2013, p. 15). Therefore, Green IS must be understood as sustainability by ICT, while Green IT must be understood as sustainability in ICT (Hilty and Aebischer, 2015, p. v; Zarnekow and Kolbe, 2013, p. 15). To capture the complexity of Green IT, Murugesan (2008, p. 26) identifies eleven "focus areas, and activities, including:

- Design for environmental sustainability
- Energy-efficient computing
- Power management
- Data center design, layout, and location
- Server virtualization
- Responsible disposal and recycling
- Regulatory compliance
- Green metrics, assessment tools, and methodology
- Environment-related risk mitigation
- Use of renewable energy sources
- Eco-labeling of IT products"

The listing shows that the topic is still broad since areas such as *energy-efficient computing* also affect fields such as economics. However, in the context of this paper, following focus areas are most important: *design for environmental sustainability*; *responsible disposal and recycling*; *regulatory compliance*; *green metrics*, *assessment tools*, *and methodology*; *and eco-labeling of IT products* (Murugesan, 2008, p. 26). Deriving from this variety of subject areas, Green IT will be further understood as all activities of ICT companies to reduce the negative ecological impact of their provided goods and services (Zarnekow and Kolbe, 2013, p. 16).

Since the ICT industry is becoming a major source of GHG emissions (GeSI, 2012, p. 21-26; Kim and Lee, 2011, p. 423), Green IT should be placed in the core of each company's business strategy (BCS, 2012, p. 1). Such attitude has been shown for a selection of companies in the environmental visions of the previously chapter (Apple, 2016a; Dell, 2016b; Facebook, 2012; Google, 2016; Microsoft, 2016a) and is further emphasized by Gartner (2015a) which states: "Green IT is moving beyond the environmental characteristics of IT equipment, allowing organizations to improve their environmental footprint by using equipment and services that have a low-carbon footprint themselves." To achieve low environmentally impacting ICT goods, Green IT proposes to consider the entire life cycle of a product (Marx Gómez *et al.*, 2016, p. vii). As Hilty *et al.* (2011, p. 17) say: "The most comprehensive methodology to be used here is Life Cycle Assessment (LCA)." This field will be introduced in the following section.

3.3 Life Cycle Assessment Methodology

To support innovation and provide solutions to global challenges, the International Organization for Standardization (ISO) has developed a broad range of standards (ISO, 2016a-c). "A standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose." (ISO, 2016d) "ISO International Standards ensure that products and services are safe, reliable and of good quality. For business, they are strategic tools that reduce costs by minimizing waste and errors, and increasing productivity." (ISO, 2016d) In the area of sustainability a wide range of standard families (ISO, 2016d) have been developed such as *ISO 26000 - Social responsibility* that "provides guidance on how businesses and organizations can operate in a socially responsible way" (ISO, 2010a), or *ISO 50001 - Energy management* that "supports organizations in all sectors to use energy more efficiently." (ISO, 2011a)

In this paper's context the *ISO 14000 - Environmental management* standard family is the most important. These standards "provide practical tools for companies and organizations […] to manage their environmental responsibilities" (ISO, 2016c). To get an overview of the ISO 14000 family the following table classifies the standards by placing them into the ISO PDCA (Plan-Do-Check-Act) cycle (Tab. 2).[12]

Plan	**Do**	**Check**	**Act**
Environmental management system implementation	Conduct life cycle assessment and manage environmental aspects	Conduct audits and evaluate environmental performance	Communicate and use environmental declarations and claims
ISO 14050:2009 Environmental management – Vocabulary	ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework	ISO 14015:2001 Environmental management – Environmental assessment of sites and organizations (EASO)	ISO 14020:2000 Environmental labels and declarations – General principles
ISO 14001:2015 Environmental management systems – Requirements with guidance for use	ISO 14044:2006 Environmental management – Life cycle assessment – Requirements and guidelines	ISO 14031:2013 Environmental management – Environmental performance evaluation – Guidelines	ISO 14021:2016 Environmental labels and declarations – Self-declared environmental claims (Type II environmental labelling)
ISO 14004:2016 Environmental management systems –	ISO/TR 14047:2012 Environmental management – Life cycle	ISO 19011:2011	ISO 14024:1999 Environmental labels

[12] Texts in *italic* show updates, since the original table provided by ISO (2009, pp. 8-10) is not up-to-date with the standard documents, which can be found in: (ISO, 2010b); (ISO, 2011b-e); (ISO, 2012a-d); (ISO, 2013a-d); (ISO, 2015a); (ISO, 2016e,f).

General guidelines on implementation	impact assessment – Illustrative examples on how to apply ISO 14044 to impact assessment situations	Guidelines for auditing management systems	and declarations – Type I environmental labelling – Principles and procedures
ISO 14005:2010 Environmental management systems – Guidelines for the phased implementation of an environmental management system, including the use of environmental performance evaluation	ISO/TS 14048:2002 Environmental management – Life cycle assessment – Data documentation format		ISO 14025:2006 Environmental labels and declarations – Type III environmental declarations – Principles and procedures
			ISO/TS 14033:2012 Environmental management – Quantitative environmental information – Guidelines and examples
Address environmental aspects in products and product standards		Evaluate greenhouse gas performance	
ISO Guide 64:2008 Guide for addressing environmental issues in product standards	ISO/TR 14049:2012 Environmental management – Life cycle assessment – Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis	ISO 14064-3:2006 Greenhouse gases – Part 3: Specification with guidance for the validation and verification of greenhouse gas assertions	ISO 14063:2006 Environmental management – Environmental communication – Guidelines and examples
ISO 14006:2011 Environmental management systems – Guidelines on ecodesign	ISO 14051:2011 Environmental management – Material flow cost accounting – General framework	ISO 14065:2013 Greenhouse gases – Requirements for greenhouse gas validation and verification bodies for use in accreditation or other forms of recognition	
	ISO 14045:2012 Environmental management – Eco-efficiency assessment of product systems – Principles, requirements and guidelines		
	Manage greenhouse gases		

ISO/TR 14062:2002 Environmental management – Integrating environmental aspects into product design and development	ISO 14064-1:2006 Greenhouse gases – Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals	ISO 14066:2011 Greenhouse gases – Competence requirements for greenhouse gas validation and verifiers teams	
	ISO 14064-2:2006 Greenhouse gases – Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements		
	ISO/TS 14067:2013 Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification and communication		
	ISO/TR 14069:2013 Greenhouse gases – Quantification and reporting of greenhouse gas emissions for organizations (Carbon footprint of organization) – Guidance for the application of ISO 14064-1		

Table 2: ISO 14000 Family Plan-Do-Check-Act Cycle with Updated Standards
Own illustration based on (ISO, 2009, pp. 8-10, correctons in italic)

"ISO is helping to meet the challenge of climate change with standards for greenhouse gas accounting, verification and emissions trading, and for measuring the carbon footprint of products." (ISO, 2009, p. 2) In order to research the environmental impact of ICT products, in particular the standards *ISO 14040 Environmental management – Life cycle assessment – Principles and framework* (ISO, 2006a), and *ISO 14044 Environmental management – Life cycle assessment – Requirements and guidelines* (ISO, 2006b) provide the basis with the describtion of the LCA methododology. The further significant standards are all referenced in these both documents and can therefore be gradualy applied to LCA. The ISO (2006a, p. v) define: "LCA addresses the environmental aspects and potential environmental impacts[..] [13] (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, usage, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)." Thus, LCA focuses on the environmental pillar of sustainability. Social as well as economic aspects are outside its scope (ISO, 2006a, p. 8).[14] Therefore, the ISO (2006a, p. v) states that the method can "[…] assist in:

- identifying opportunities to improve the environmental performance of products at various points in their life cycle,
- informing decision-makers in industry, government or non-government organizations (e.g. for the purpose of strategic planning, priority setting, product or process design or redesign),
- [helping with] the selection of relevant indicators of environmental performance, including measurement techniques, and
- marketing (e.g. implementing an ecolabelling scheme, making an environmental claim, or producing an environmental product declaration)."

A product in LCA can be any kind of "services (e.g. transport), software (e.g. computer program, dictionary), hardware (e.g. engine mechanical part), processed materials (e.g. lubricant), an activity performed on a customer-supplied tangible product (e.g. automobile to be repaired) […] [as well as] intangible product (e.g. the income statement needed to prepare a tax return), the delivery of an intangible product (e.g. the delivery of information in the context of knowledge transmission), [or] the creation of ambience for the customer (e.g. in hotels and restaurants)." (ISO, 2006a, pp. 2-3, bullet points changed to commas). A process in LCA is defined as a "set of interrelated or interacting activities that use inputs to deliver an intended result." (ISO, 2015b, p. 15) The inputs of one process can generally be the outputs of other processes and the outputs of one process can generally be the inputs of other processes (ISO, 2015b, p. 15).

[13] "The 'potential environmental impacts' are relative expressions, as they are related to the functional unit of a product system." ISO (2006a, p. v).

[14] To serve these, Social Life Cycle Assessment (S-LCA) for the social pillar, and Life Cycle Costing (LCC) for the economic pillar, offer appropriate solutions (ISO, 2006a, p. 18).

The framework for conducting an LCA study is illustrated below (Fig. 13).

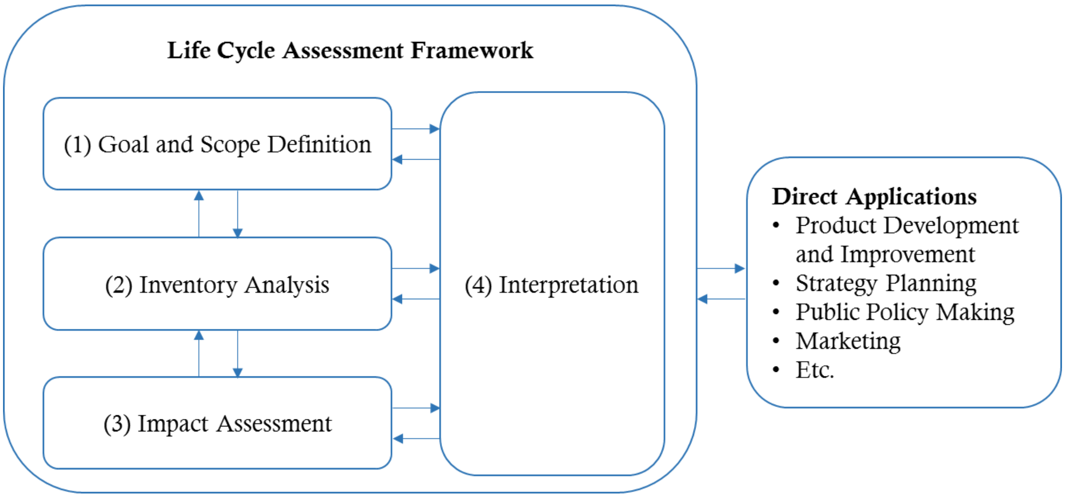


Figure 13: Life Cycle Assessment Framework
Own illustration based on (ISO, 2006a, p. 8)

(1) **Goal and Scope Definition**: "The scope, including the system boundary and level of detail, of an LCA depends on the subject and the intended use of the study. The depth and the breadth of LCA can differ considerably depending on the goal of a particular LCA." (ISO, 2006a, p. v)

(2) **Inventory Analysis**: "The life cycle inventory analysis [(LCI)] phase […] is […] an inventory of input/output data with regard to the system being studied. It involves collection of the data necessary to meet the goals of the defined study." (ISO, 2006a, p. v)

(3) **Impact Assessment**: "The purpose of [..] [the life cycle impact assessment (LCIA) phase] is to provide additional information to help assess a product system's LCI results so as to better understand their environmental significance." (ISO, 2006a, p. v)

(4) **Interpretation**: "Life cycle interpretation is the final phase of the LCA procedure, in which the results of an LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations and decision-making in accordance with the goal and scope definition." (ISO, 2006a, p. vi)

Direct applications are shown outside the framework and include potentials for: product development and improvement, strategy planning, public policy making, or marketing. The framework provides the possibility to perform LCA studies (phases (1)-(4)) and LCI studies (phase (1), (2), and (4)) (ISO, 2006a, p. vi). For the research performed in this paper, the entire process of LCA, consisting of all four stages, is considered significant. As the ISO (2006a, p. 8) further states: "LCA methodology is open to the inclusion of new scientific findings and improvements in the state-of-the-art of the technique." This statement opens up the possibility for the intended support of the methodology by state-of-the-art Business Intelligence technology. The fundamentals of this research area are introduced in the following chapter.

3.4 Business Intelligence Analysis and Reporting

Data is just numbers and disconnected facts, but researching this data and asking the right questions can reveal valuable insights (McCandless, 2010). As Anandarajan *et al.* (2004, p. 19) emphasize: „Making sound business decisions based on accurate and current information takes more than intuition." Providing the right people with the right information at the right time is the central idea of Business Intelligence (BI). As Grossmann and Rinderle-Ma (2015, p. v) confirm: "Intelligent businesses need Business Intelligence […]." Because of the field's complexity, there is a variety of definitions available, which approach the subject in different ways. Larson (2009, p. 11) defines BI as "the delivery of accurate, useful information to the appropriate decision makers within the necessary timeframe to support effective decision making." In a similar way describes Schrödl (2008, p. 9) BI as the decision supporting gathering, preparation, and presentation of information relevant to business. This view explicitly shows the process of information provision, which is also a central topic in this paper. Such a process-oriented view can also be found by Kemper et al. (2010, p. 8). To enable further perspectives, Gluchowski (2001, p. 7) provides a framework, which describes BI from a narrow understanding (e.g. Online Analytical Processing (OLAP), or Management Information Systems (MIS)), to an analytical perspective (e.g. Ad-hoc Reporting, or Key Performance Indicators (KPIs)), to a wide understanding (e.g. Data Warehousing, or Standard Reporting). One important part of BI in several publications is data analytics, which describes "the process of examining information, […], to find something out, or to help with making decisions." (CUP, 2016c) However, Grossmann and Rinderle-Ma (2015, p. v) emphazise: "[…] data analytics, is only one part […]. Before […] one actually needs to collect the data and present them in a unified form, a process that is often referred to as data provisioning. This, in turn, requires extracting the data from the relevant business processes […], cleaning, transforming, and integrating them, and loading them into a […] database." This description complies with the process oriented views also supported by Schrödl (2008, p. 9) and Kemper *et al.* (2010, p. 8).

Deriving from these BI persepectives, this paper also supports the process oriented understanding and emphazises that, when approaching BI the entire progression of getting data insights from raw data extraction to the eventual presentation of the insights must be considered. This also illustrates the interrelationship of BI and Environmental Informatics (EI). While EI is considering the entire field of environmental concerns in ICT (Hilty and Aebischer, 2015, p. 15), BI concentrates on the information provision process for all kind of research fields and can therefore be applied also to environmental affairs. In the context of this paper, BI is therefore narrowed to Environmental Business Intelligence (EBI) that defines the process of collecting, preparing, analyzing, reporting, and communicating ecologically related data insights for environmental monitoring purposes. Ecologically related data is each data, which has a connection to environmentally concerning fields, e.g.

GHG emissions, resource use, or fuel consumption for transportation. This understanding complies with Park (2007, p. 153) who defines environmental monitoring as "Technologies, procedures, and protocols for collecting, analysing [sic], interpreting, and reporting environmental information […]."

As Page (1996, p. 1) emphasizes: "It is clear that the various problems in environmental protection, environmental planning, research and engineering can be only solved on the ground of a comprehensive and reliable information basis." Founded on a structured environmental dataset, Aspin (2015, pp. 1-3) and Few (2006, pp. 4-6) claim that the analysis with the eventually discovered insights shall be presented by a clear and meaningful, up-to date communication. Therefore, Aspin (2015, pp. xxvii, 1-3) pledges for the use of reports and dashboards since they provide such possibility. This paper also relies on these communication media, which are defined in the following:

- **Report**: A report is "a document containing information organized in a narrative, graphic, or tabular form, prepared on ad hoc, periodic, recurring, regular, or as required basis. Reports may refer to specific periods, events, occurrences, or subjects […]" (WebFinance, 2016a) In this paper's context, the term is used for different environmental purposes such as presenting GGE and material amounts, or investigating developments such as the total GGEs over years. A reporting concentrating on environmental issue related data is called Environmental Reporting (Isenmann and Marx Gómez, 2008, p. 13; Park, 2007, p. 154). If the reporting is even specified on GHGs, it is called Greenhouse Gas Reporting (ISO, 2006c, p. 3).
- **Dashboard**: A dashboard is considered as "a visual overview of essential corporate data. It can display many possible data snapshots of multiple aspects of business, or show a highly specific set of metrics relating to a business area or department." (Aspin, 2015, p. 3) They have a "rich computer interface with charts, reports, visual indicators, and alert mechanisms that are consolidated into a dynamic and relevant information platform." (Melike, 2005, p. ix). In this paper, dashboards will be used to show possibilities for the sharing and therefore communicating environmental insights by aggregating report delivered information as well as for extended data examination purposes.

Both media are made up of multiple elements, called widgets, to provide the information in a significant and reliable way. Most important for this paper are key performance indicators (KPIs), charts, tables, maps, treemaps, and gauges (Aspin, 2015, p. 3; Melike, 2005, p. ix), which are defined in the following:

- **Key Performance Indicator (KPI)**: "Are a way of measuring progress towards a defined organizational objective." (Aspin, 2015, p. 19) This involves the core elements goal and value. The goal is a target one is measuring an outcome against. This is crucial for a KPI and has to be specified and displayed with it. The value is the actual data that is compared to the target. These two elements can be extended with the status of the value compared to the goal that indicates how well something is doing, or with the trend of how well something is doing over time. (Aspin, 2015, p. 19) In focus here are environmental KPIs, in particular GHG related measures, such as life cycle emission goals.

- **Charts**: Are illustrations that show "information in a simple way, often using lines and curves to show amounts." (CUP, 2016d) Common types are: bar charts, line charts, pie charts, donut charts, stacked area charts, or any combination form (Hart, 2016c).
- **Tables**: Sort data into columns and rows. Tables "work well with quantitative comparisons among items where there are many categories." (Hart, 2016c) A special form are matrix tables. "A matrix can be collapsed and expanded by rows and/or columns. If it contains a hierarchy, [..] one can drill down/drill up. It can display totals and subtotals by columns and/or rows. […] a matrix can display data without repeating values." (Microsoft, 2016b)
- **Maps**: Basic maps "are used to associate both categorical and quantitative information with spatial locations." (Hart, 2016c) Filled maps show data by intensifying the color for higher values (Hart, 2016c).
- **Treemaps:** "Are charts of colored rectangles, with size representing value. They can be hierarchical, with rectangles nested within the main rectangles." (Hart, 2016c)
- **Gauges**: Display "[…] a single value that measures progress toward a goal/KPI. The goal, or target value, is represented by the line (needle). Progress toward that goal is represented by the shading. […] All possible values are spread evenly along the arc, from the minimum (left-most value) to the maximum (right-most value)." (Hart, 2016b)

"These core elements can be combined to produce multiple variations on a theme." (Aspin, 2015, p. 3). They, as well as their overall hosts of reports and dashboards are the basic structures of the BI technologies used for this paper. These tools are introduced in the following chapter.

3.5 Data Monitoring Software Tools

It is important to select and combine the right tools to monitor environmental data since not all of them are equally suitable for this purpose (Günther, 1998, p. 2). This paper uses a combination of Microsoft Excel 2013 version 15.0.4841.100 64-Bit (Microsoft, 2013) and Microsoft Power BI with its desktop tool in version 2.37.4464.461 64-bit (Microsoft, 2016c) and its service tool in version 13.0.1500.516 (Microsoft, 2016d). These enable a structured proceed to analyze the Apple data and allow a subsequent adjustment of the approach for other ICT companies.

Microsoft Excel 2013

MS Excel is a "software […] that allows users to organize, format, and calculate data with formulas using a spreadsheet system broken up by rows and columns."[15] (WebFinance, 2016b) Excel is also an analysis tool since it e.g. enables to calculate KPIs and visualize data. However, the most significant components that turn the tool into a BI platform are not part of the software itself. These are separate add-ons such as Power Query, Power Pivot, Power Map, and Power View. All of these standalone applications have their own interface and logic. This complexities and inconsistences led to the creation of the Microsoft Power BI Suite, which combines all the mentioned tools and shows on top advantages such as the sharing of data among all kinds of devices. (Branscombe, 2015) However, MS Excel is still useful in the data inventory collecting section of this paper, where it will serve as a central place to get an overview of the given data by Apple. Moreover, it will be used for a table analysis model in a sample investigation of the Apple case.

Microsoft Power BI Suite

"Power BI is a suite of business analytics tools to analyze data and share insights." (Microsoft, 2016f) Microsoft promotes the tool with: "Stay in the know, spot trends as they happen, and push your business further." (Microsoft, 2016f) The suit consists of an installation called *Power BI Desktop*, and a web service called *Power BI Service*, which is part of the Office 365[16] suite. In addition, applications for devices such as smartphones, or tablets exist, which are used to view the service tool information. To get data insights, the tool's three major building blocks are datasets, reports and dashboards (Hart, 2016a). These are reflected in a three-step process, which leads from the raw data to the insights and their communication (Fig. 14).

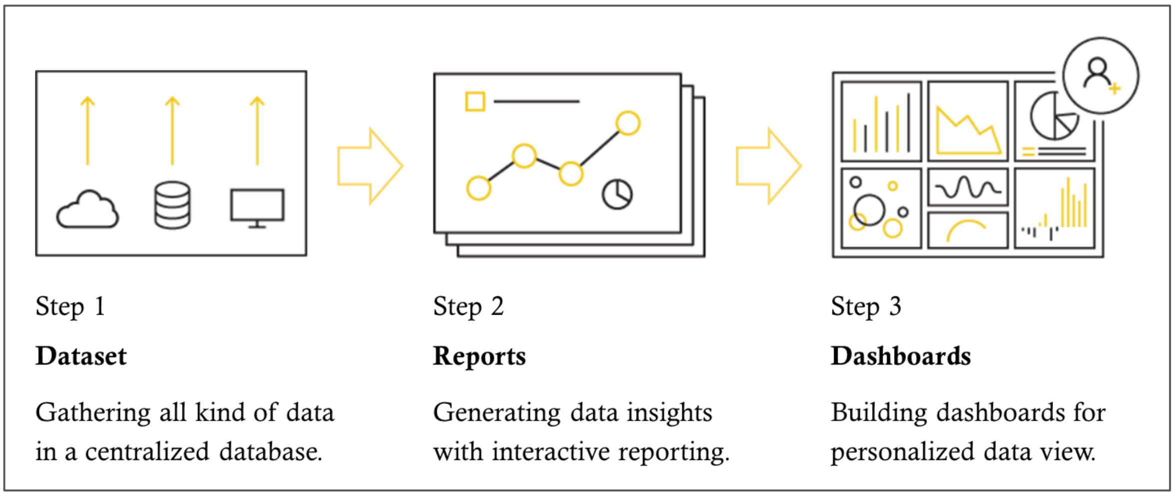


Figure 14: Microsoft Power BI Process
Own illustration based on (Microsoft, 2016f)

[15] For detailed information on the basic usage of MS Excel, Microsoft (2016e) provides descriptions.
[16] For more information on Office 365, Microsoft (2016g) provides information.

The first step is the gathering of all kind of data in a centralized database by importing or connecting different sources to Power BI in order to create a dataset (Hart, 2016a). Examples for sources are MS Excel spreadsheets, Google Analytics data, or MS SQL Server databases. The sources can be external cloud provided or on premise company data. In the context of LCA, the dataset corresponds with the inventory phase of the methodology (ISO, 2006a, p. 8). The second step is the reporting of the data. Power BI reports consist of one or more pages with visualizations and metrics (Hart, 2016a). All visualizations in a report come from a single dataset. In the third step, the reports are published to create dashboards. A Power BI dashboard is a single canvas that contains zero or more widgets. Each widget displays a single visualization that was created from a dataset in a report and then pinned to the dashboard. (Hart, 2016a) Therefore, reports and dashboards correspond to the assessment and the interpretation phases of the LCA methodology (ISO, 2006a, p. 8). The first two steps of the process are performed in the desktop tool and the last step is performed in the service tool while the shared dashboards can also be viewed in different device applications. (Goupil, 2016)

To understand the later performed analysis, it is further important to get to know the user interfaces (UIs) of the Power BI tool landscape. Fig. 15 starts by showing the UI of the desktop application.

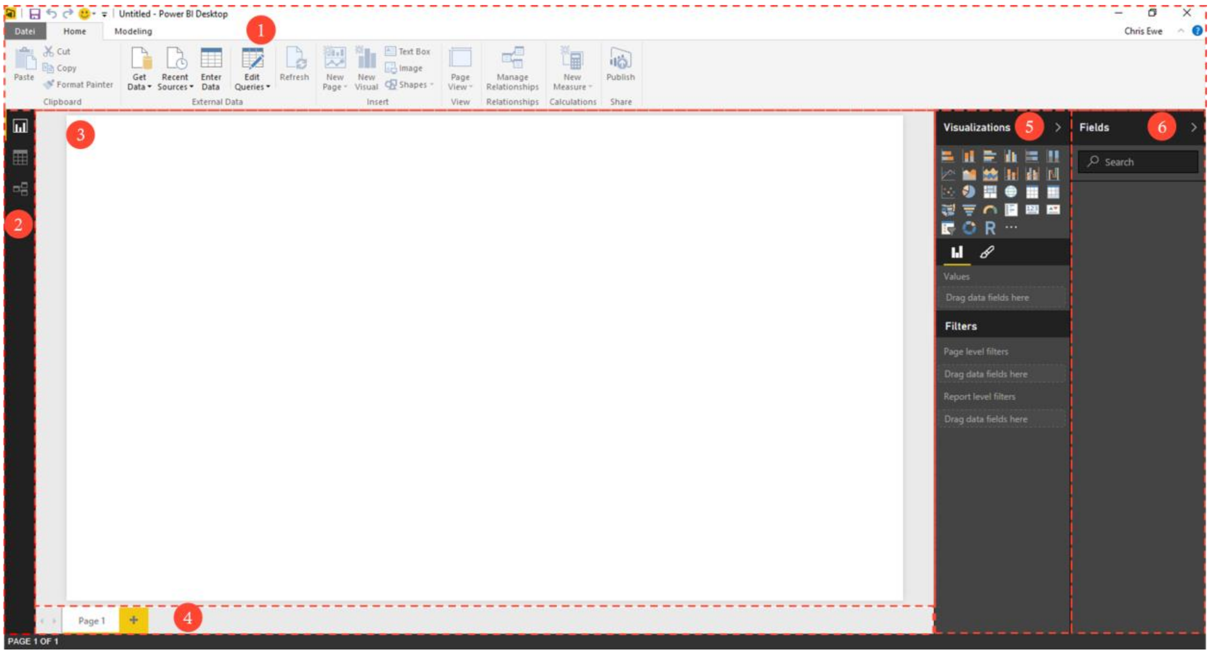


Figure 15: Microsoft Power BI Desktop User Interface
(Hart, 2016a; Iseminger, 2016a) with red marks by author

The ribbon (1) offers the possibility to switch between different tabs. In each of them, there are functions that enable e.g. the connection to different data sources or the modeling of data. The left sidebar (2) contains three views: report view, data view, and relationship view. The working space (3) shows the current report page. The bar in (4) serves as a switch between different pages. For the later analysis, it is important to keep in mind that one insights page will also be referred as a report since a report can also consist of only one page. The *Visualizations* bar (5) contains the widgets such as KPIs, tables, and different chart types. There, it is also possible to import new visualization types, which are provided by Microsoft (2016h). In the *Fields* bar (6) the dataset is presented in the form of tables with its columns. (Iseminger, 2016a)

Fig. 16 continues the description, by showing the UI of the Power BI Service with a data sample provided by the tool.

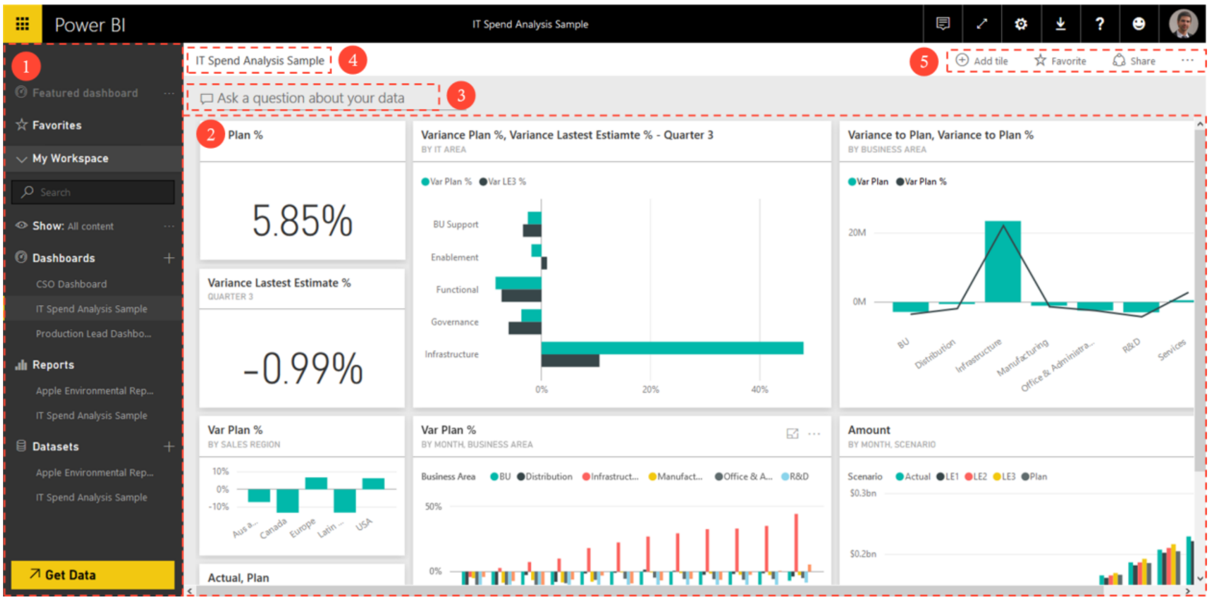


Figure 16: Microsoft Power BI Service User Interface with Sample Data (Microsoft, 2016d) with red marks by author

The navigation bar (1) serves to operate between different datasets, reports, and dashboards. The middle area (2) contains the current workspace, e.g. the current selected dashboard with its widgets. Here, it is filled out on the tools predefined *IT Spend Analysis Sample*. With the Q&A field (3) it is possible to ask real-life questions on the dataset. The title (4) shows e.g. the name of the currently selected dashboard. Additional actions (5) are e.g. for sharing options.

To demonstrate Power BI's UI on other devices, Fig 17 shows three screenshots of the Apple iPhone application version 8.6 filled out again with the tool provided data sample.

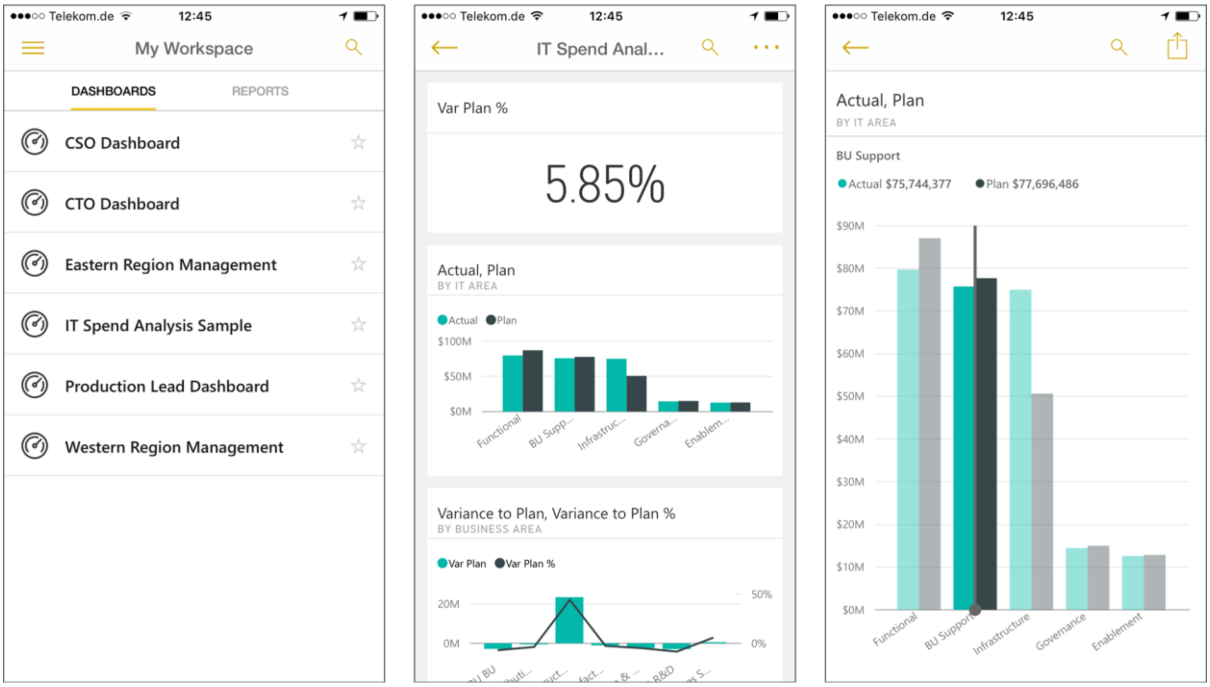


Figure 17: Microsoft Power BI iOS User Interface with Sample Data
Own illustration in (Microsoft, 2016i)

The illustration demonstrates the three levels of the smartphone application. The first screenshot shows an overview of the available dashboards and reports. The second screenshot shows the sample dashboard with its widgets. The third screenshot shows a single chart of the sample. Here the user can examine the provided insight in detail by selecting specific areas of the widget.

Selection of Monitoring Tools

MS Power BI has been selected as the central analysis tool because of its: easy handling, cloud delivery possibilities, wide range of data analysis capabilities, accessibility from all kinds of platforms, real-time live dashboard capabilities, natural language query functionalities, and fast innovation cycle with new major features every month or less (Evelson *et al.*, 2015, pp. 9-10; Gartner, 2016a; Microsoft, 2016c,d,f,i). These qualities are confirmed by different institutions such as Forrester Research Inc., which sees MS Power BI in a leading role for agile BI platforms. The term agile signifies that the BI tool offers a high "[…] flexibility by accelerating the time it takes to deliver value with BI projects." (TDWI, 2016) Forrester evaluated several BI vendors to identify the most significant software providers in the category and researched, analyzed and scored them. Their study details findings of how well each vendor fulfills the review criteria and where they stand in relation to each other. This intends to help selecting the right platform for agile BI requirements. (Evelson *et al.*, 2015, p. 1) The study's result for Q3/2015 is shown below (Fig. 18).

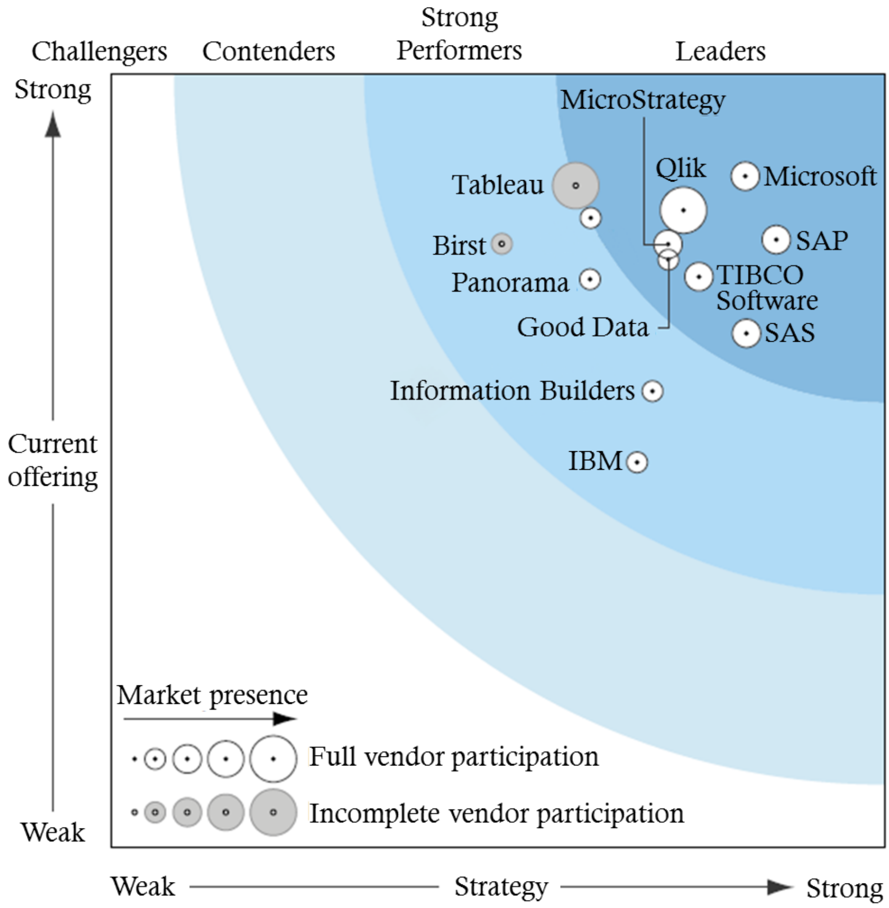


Figure 18: Forrester Wave: Agile Business Intelligence Platforms, Q3/2015 (Evelson *et al.*, 2015, p. 9)

Forrester describes: "Microsoft Power BI leads the Agile BI pack. Throughout the history of the BI market, Microsoft has dominated and will continue to dominate the market with Excel, the de facto and most commonly used BI platform around the globe. Indeed, with every new release of its BI platform, Microsoft makes it more difficult for large enterprises that have already deployed Microsoft Office, Office365, SharePoint, and SQL Server not to consider Power BI as its enterprise BI platform. Familiar Excel UI, agile in-memory PowerPivot architecture, hybrid (on-premises SQL Server-based data, cloud-based Power BI platform) deployment, completeness of BI functionality (from data sourcing to visual storytelling), and low acquisition cost differentiate Power BI from its competition." (Evelson *et al.*, 2015, p.10) Beside the listing of Power BI's market leading capabilities, this description also includes a confirmation of usefulness for MS Excel, which is described as the de facto standard of BI platforms with Power BI as its successor.

Another study that confirms the capabilities of Power BI, is the Gartner Magic Quadrant for Business Intelligence and Analytics Platforms, which is illustrated in Fig. 19.

Figure 19: Gartner Magic Quadrant: Business Intelligence and Analytics Platforms, 02/2016 (Gartner, 2016a)

Gartner (2016a) writes: "Microsoft offers a broad range of BI and analytics capabilities, both on-premises and in the Microsoft Azure cloud. Microsoft Power BI is the focus for this Magic Quadrant and is on its second major release, offering cloud-based BI with a new desktop interface – Power BI Desktop. […] Power BI offers data preparation, data discovery and interactive dashboards via a single design tool. […] Microsoft is positioned in the Leaders quadrant, with strong uptake of the latest release, major product improvements, an increase in sales and marketing awareness efforts, new leadership and a clearer, more visionary product roadmap. Microsoft's vision to provide natural-language query and generation via its Cortana personal digital assistant, together with its strong partner network and its strategy to provide prebuilt solutions, positions it furthest to the right on the Completeness of Vision axis." As both studies confirm: With Power BI, Microsoft has developed a flexible and powerful BI tool that in combination with Excel 2013 provides the ideal basis for the analysis purposes of this paper.

4 Apple Environmental Product Life Cycle Data Monitoring

4.1 Apple Environmental Policies

Apple Inc. "[…] designs, manufactures and markets mobile communication and media devices, personal computers and portable digital music players, and sells a variety of related software, services, accessories, networking solutions and third-party digital content and applications." (U.S. SEC, 2015) With their offered products and services, Apple became one of the largest (Sharf, 2016) and most successful businesses of all time, so wrote the Telegraph in 2015: "Apple reports biggest annual profit in history with net income of $53.4bn." (Titcomb, 2015) This success is also due to the company's product design. As Arndt (2013, p. 935) confirms: Apple shows like almost no other company how an intelligent and trendsetting combination of hardware and software can be developed and marketed on the basis of a design-driven philosophy.[17] In addition to basic design-driven goals such as the production of easy to use goods with a pleasant haptic, Apple also identifies the achievement of a minimal environmental impact as one of the key factors in their PLC implementation (Apple, 2016a). At the center of these environmental efforts is the prevention of climate change, which was also identified by this paper as the most threatening environmental issue of today (Dahiya and Ahlawat, 2013, p. 6.4). Apple (2016a) states: "We do not want to debate climate change. We want to stop it." To substantiate such statements, the company provides data in the form of PDF reports, which demonstrate the environmental impact of their products and processes (Apple, 2016b). Creating these, Apple states to rely their examinations on the guidance provided by the ISO 14040 (ISO, 2006a) and the ISO 14044 (ISO, 2006b), which indicates their implementation of the LCA methodology (Apple, 2016b; Apple, 2016c, p. 4). Information on how the exact assessment is performed, is not available, therefore, only the PDFs as the assessment's outcomes can be obtained. Since the PDF report data provide an appropriate basis for the intended creation of an environmental PLC data model in combination with state-of-the-art BI technology to support the LCA methodology, the company was chosen as the starting point of the research. Besides, the

[17] Translation by author. Original in German: „Die Firma Apple […] zeigt wie kaum ein anderes Unternehmen, wie auf Grundlage einer Designphilosophie eine intelligente und richtungsweisende Kombination von Hardware und Software entwickelt und vermarktet werden kann." (Arndt, 2013, p. 935)

reports are freely accessible, easy to understand, and contain all necessary data for an emission analysis with additional data to determine possible causes of the GGE developments. Moreover, Apple has a wide range of different products to analyze, which serve as an illustrative example of a modern ICT company's product portfolio.

4.2 Conception of Apple Monitoring Model

Models as an abstract description of real-life phenomenon have long been an important analysis tool in a variety of disciplines such as environmental science (Günther, 1998, p. 133; Hilty and Aebischer 2015, p. 15; Page, 1996, p. 7; Page and Hilty, 1995, p. 16). The model implemented here will enable different stakeholders to monitor and investigate the environmental impact of a single product, a product category or an entire product portfolio. The overall process, which will be taken to explore Apple's environmental data, is illustrated below (Fig. 20).

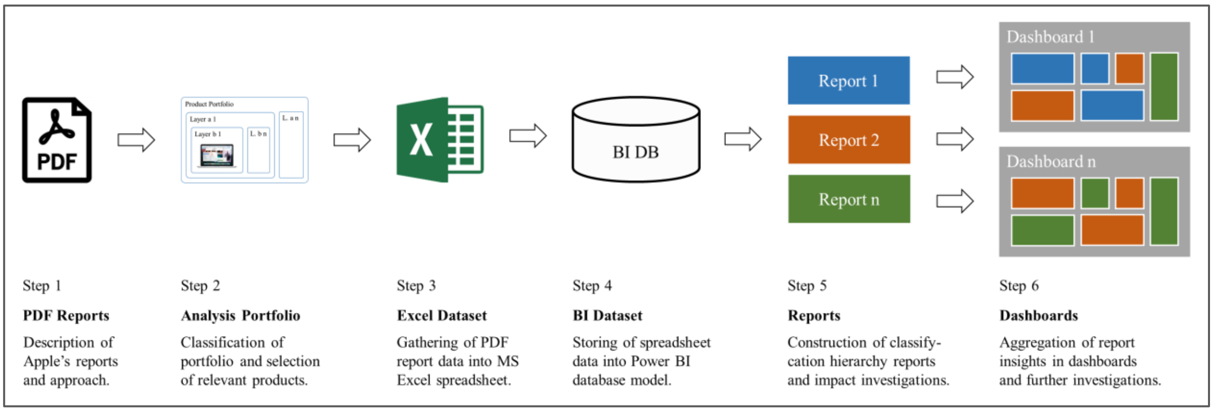


Figure 20: Apple Environmental Product Life Cycle Data Monitoring Model
Own illustration based on (ISO, 2006a, p. 8; Microsoft, 2016f; Russo, 2015)

The model is based on a combination of the ISO 14040 LCA framework of inventory analysis (LCI), impact assessment (LCIA), and interpretation (ISO, 2006a, p. 8)[18], with the MS Power BI process of datasets, reports, and dashboards (Microsoft, 2016f)[19]. The single process steps are described as following:

(1) **PDF Reports**: In the first step, all relevant aspects of the Apple PDF reports are examined and categorized in the framework of the research. In this way, the necessary definitions of Apple's internal approach are given. These include in particular the description of the PLC and the listed inventory data.

(2) **Analysis Portfolio**: This step structures the Apple product naming convention in a classification hierarchy, which enables the analysis on different levels such as portfolio, category,

[18] See Chapter 3.3 – Fig. 13.
[19] See Chapter 3.5 – Fig. 14.

products, or different product properties. Afterwards, the relevant products for the analysis are selected and listed into an MS Excel file. This marks the transition to the next step.

(3) **Excel Dataset**: The PDF reports contain data as the outcomes of the Apple conducted LCI (ISO, 2006a, p. 2). The most important are: total GGEs, life cycle GGEs, and amounts of materials. These must be extracted into the MS Excel spreadsheet. Afterwards, it is possible to clear the data, e.g. by finding anomalies and correcting them in order to get a conflict-free and validated spreadsheet inventor.

(4) **BI Dataset**: By understanding Apple's data structure, it is possible to create a data model that is necessary for storing the inventory. The model must then be displayed in Power BI Desktop. Afterwards all data can be uploaded into the model in order to get a well-structured analyzable BI dataset that therewith forms the final BI life cycle inventory.

(5) **Reports**: In this step, the BI tool is used to analyze the created dataset. The analysis is conducted by visualizing the data in different comprehensive ways. Therefore, the developments are also given with relation to other data in order to find possible correlations and thereby potential explanations. Thus, this step complies with the LCA stages of LCIA and interpretation (ISO, 2006a, p. 2).

(6) **Dashboards**: In this last step, the report findings are aggregated by creating dashboards in Power BI Service. The dashboards are used for a simplified communication of the insights as well as further analysis and interpretation purposes. Therefore, this step is also associated with the LCA stages of LCIA and interpretation.

The following sections will gradually reflect this process. Therefore, the chapters are subdivided into two overall parts. The first part shows the dataset creation (step 1-4). The second part concentrates on the analysis and insights communication (step 5-6). Lastly, a summary of the main results as well as the achieved business values will be given.

4.3 Creation of Analyzable LCI Dataset

4.3.1 Description of Apple PDF Reports and Approach

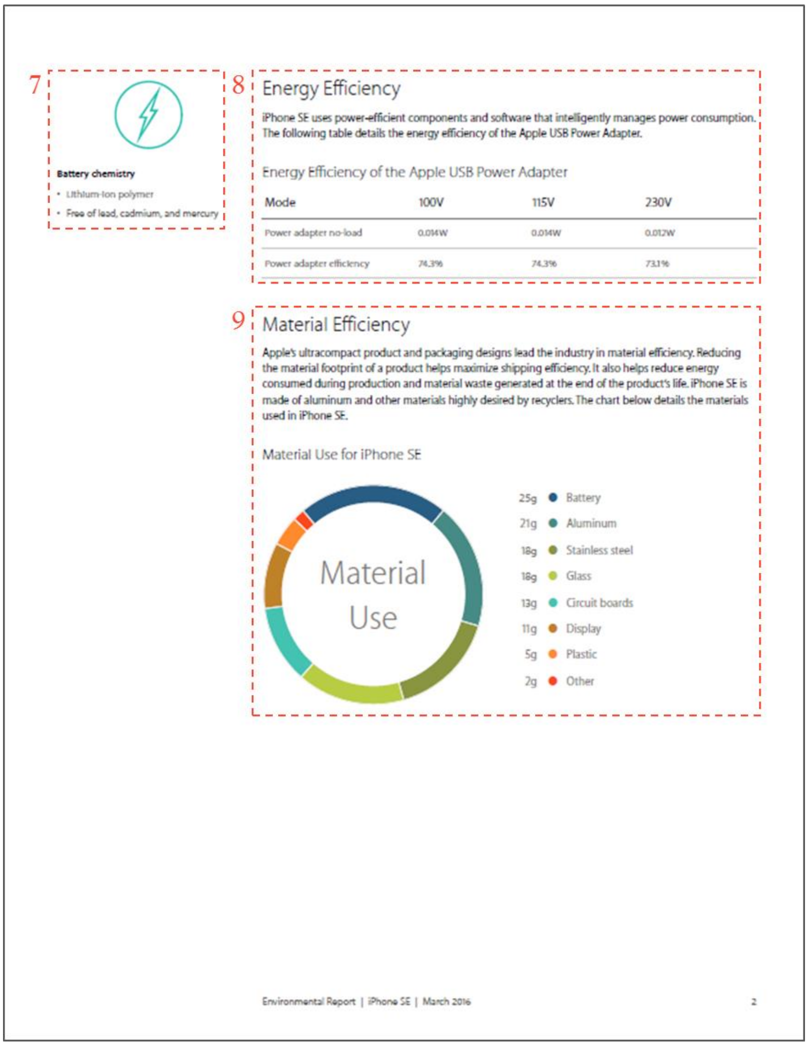
The PDF reports are available for almost each product in Apple's portfolio (Apple, 2016b)[20]. Single reports are provided for a model of a category with specific properties, such as its display size. The reports are similar for each product, but not identical. Throughout the product generations, e.g. visualization types and formulations have been changed. As an example, the PDF report of the

[20] Available are only hardware products. Among these, for example, iPhone 2G has no report.

iPhone SE (Apple, 2016c) will be described in Fig. 21 to Fig. 24. Each report page is illustrated extended by red marks and numbers, which are used to define the different parts:

Figure 21: Apple Environmental PDF Report Example – iPhone SE – Page 1 (Apple, 2016c, p. 1) with red marks by author

Page one shows the category *iPhone* and the model *SE* (1). For other products the display size, and if the product has a retina display, would additionally be shown at this position. Below is the text *Environmental Report* (2) that is equal in each report. On the upper left side (3) are a picture of the product and the product's release date, in this case *March 21, 2016.* As will be shown later, the combination of the category and model with the properties release data, size, and retina, always identify a single product. The upper left area (3) can also display different model numbers, if a product model has one or more. Since each of these numbers share the same report, this level will not be considered in the analysis. The *Environmental Status Report* section (4) shows improvements for the regarding product, e.g. the use of *Arsenic-free display glass*, or a *Mercury-free LED-backlit display*. In the section *Apple and the Environment* (5) the company shows its vision of environmental protection. This area states in the selected report: “Apple believes that improving the environmental performance of our business starts with our products. The careful environmental management of our products throughout their life cycles includes controlling the quantity and types of materials used in their manufacture, improving their energy efficiency, and designing them for better recyclability. […]” (Apple, 2016c, p. 1) The most important report part for this paper is *Climate Change* (6). Apple states: “Greenhouse gas emissions have an impact on the planet’s balance of land, ocean, and air temperatures. […]. Apple seeks to minimize greenhouse gas emissions by setting stringent design-related goals for material and energy efficiency.” (Apple, 2016c, p. 1) The chart below this statement shows the GGEs in total and as percent for the single PLC stages. As can be seen, the iPhone SE emits in total *75 kg CO_2e*. These are allocated by *82% production*, *14% customer use*, *3% transport*, and *1% recycling*. Following, the description continuous with the second page (Fig. 22).



7

Battery chemistry

- Lithium-ion polymer
- Free of lead, cadmium, and mercury

8 Energy Efficiency

iPhone SE uses power-efficient components and software that intelligently manages power consumption. The following table details the energy efficiency of the Apple USB Power Adapter.

Energy Efficiency of the Apple USB Power Adapter

Mode	100V	115V	230V
Power adapter no-load	0.014W	0.014W	0.012W
Power adapter efficiency	74.3%	74.3%	73.1%

9 Material Efficiency

Apple's ultracompact product and packaging designs lead the industry in material efficiency. Reducing the material footprint of a product helps maximize shipping efficiency. It also helps reduce energy consumed during production and material waste generated at the end of the product's life. iPhone SE is made of aluminum and other materials highly desired by recyclers. The chart below details the materials used in iPhone SE.

Material Use for iPhone SE

Material Use

25g Battery
21g Aluminum
18g Stainless steel
18g Glass
13g Circuit boards
11g Display
5g Plastic
2g Other

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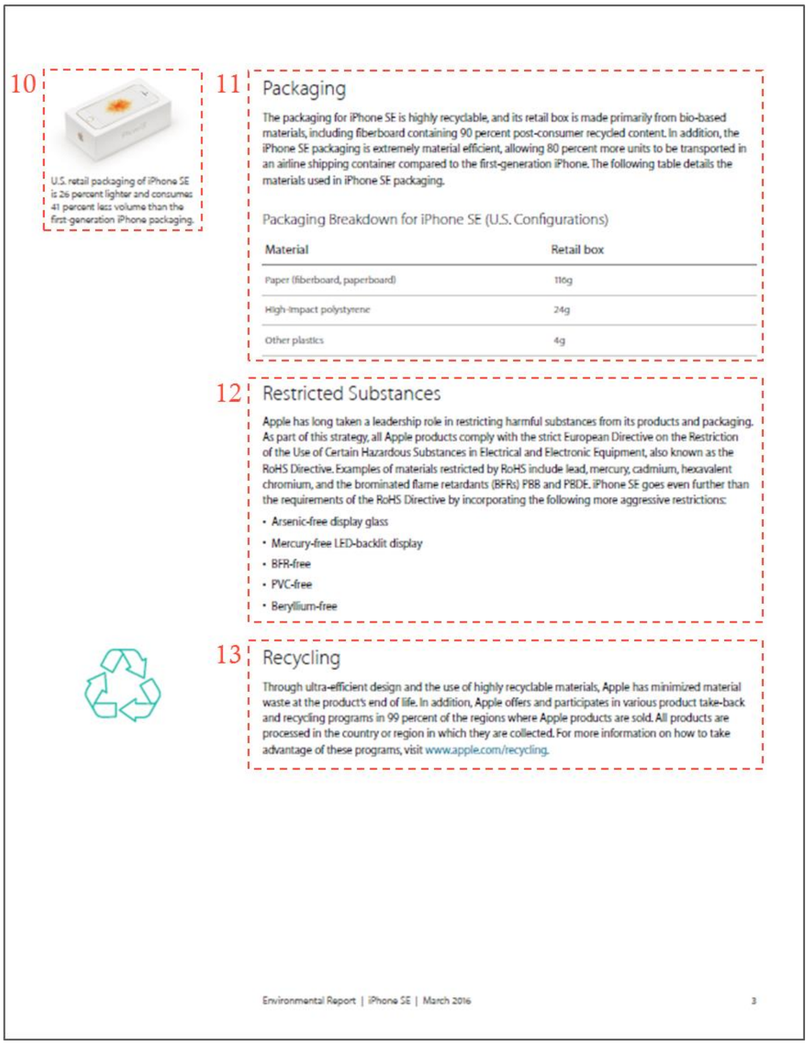
Figure 22: Apple Environmental PDF Report Example – iPhone SE – Page 2
(Apple, 2016c, p. 2) with red marks by author

The page shows on the left side (7) details about the battery used and other energy concerning facts, e.g. that the battery’s chemistry is “free of lead, cadmium, and mercury” (Apple, 2016c, p. 2). The

Energy Efficiency section (8) shows the energy consumption of the products power adapter. Subsequently the *Material Efficiency* (9) is illustrated. In the example, this section states: "Apple's ultra-compact product and packaging designs lead the industry in material efficiency. Reducing the material footprint of a product helps maximize shipping efficiency. It also helps reduce energy consumed during production and material waste generated at the end of the product's life. […]." (Apple, 2016c, p. 2) Afterwards, the materials are displayed with their amounts in grams. By adding the grams, the total weight of the product can be calculated. This data is crucial since it can be analyzed itself as well as serve as a possible explanation for the development of the GGEs. Following the description continuous with the third page (Fig. 23).


10

U.S. retail packaging of iPhone SE is 26 percent lighter and consumes 41 percent less volume than the first-generation iPhone packaging.

11

Packaging

The packaging for iPhone SE is highly recyclable, and its retail box is made primarily from bio-based materials, including fiberboard containing 90 percent post-consumer recycled content. In addition, the iPhone SE packaging is extremely material efficient, allowing 80 percent more units to be transported in an airline shipping container compared to the first-generation iPhone. The following table details the materials used in iPhone SE packaging.

Packaging Breakdown for iPhone SE (U.S. Configurations)

Material	Retail box
Paper (fiberboard, paperboard)	116g
High-impact polystyrene	24g
Other plastics	4g

12

Restricted Substances

Apple has long taken a leadership role in restricting harmful substances from its products and packaging. As part of this strategy, all Apple products comply with the strict European Directive on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment, also known as the RoHS Directive. Examples of materials restricted by RoHS include lead, mercury, cadmium, hexavalent chromium, and the brominated flame retardants (BFRs) PBB and PBDE. iPhone SE goes even further than the requirements of the RoHS Directive by incorporating the following more aggressive restrictions:

- Arsenic-free display glass
- Mercury-free LED-backlit display
- BFR-free
- PVC-free
- Beryllium-free

13

Recycling

Through ultra-efficient design and the use of highly recyclable materials, Apple has minimized material waste at the product's end of life. In addition, Apple offers and participates in various product take-back and recycling programs in 99 percent of the regions where Apple products are sold. All products are processed in the country or region in which they are collected. For more information on how to take advantage of these programs, visit www.apple.com/recycling.

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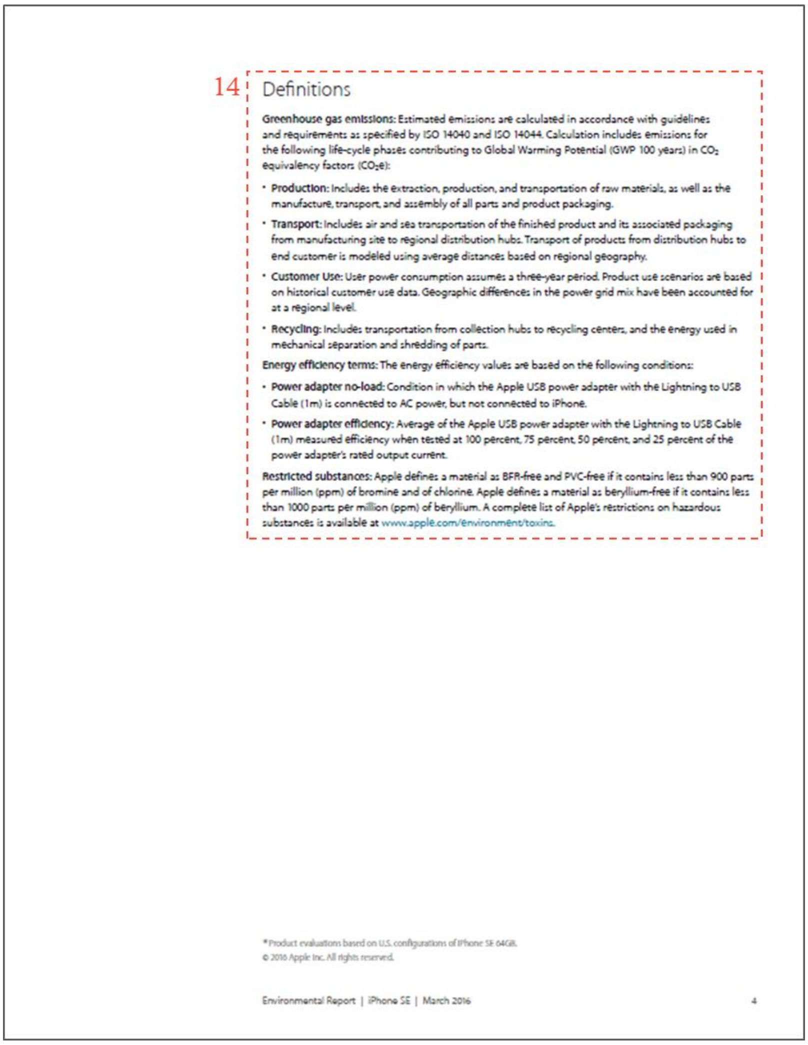
Figure 23: Apple Environmental PDF Report Example – iPhone SE – Page 3
(Apple, 2016c, p. 3) with red marks by author

The page shows on the left side the progress in the field of packaging (10) by indicating weight or volume improvements. The progress is shown by comparing with the predecessor or, like in the example, with the first model of the corresponding category. Next to it, Apple describes the *Packaging* (11) itself. In the example this area states: "The packaging for iPhone SE is highly recyclable, and its retail box is made primarily from bio-based materials, including fiberboard containing 90 percent post-consumer recycled content. In addition, the iPhone SE packaging is extremely material efficient, allowing 80 percent more units to be transported in an airline shipping container compared to the first-generation iPhone. […].” (Apple, 2016c) Afterwards, the report shows the packaging material usage. The area of *Restricted Substances* (12) lists in the same manner as the *Environmental Status Report* section (4) on page one, that e.g. *Arsenic-free display glass* has been used. This section also references to the compliance of products and packaging with the *European Directive on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment* (RoHS Directive) (EC, 2016). The last section demonstrates the product's *Recycling* (11), with statements on Apple's waste management approach. Following, the description of the report will be completed with the last page (Fig. 24).


14

Definitions

Greenhouse gas emissions: Estimated emissions are calculated in accordance with guidelines and requirements as specified by ISO 14040 and ISO 14044. Calculation includes emissions for the following life-cycle phases contributing to Global Warming Potential (GWP 100 years) in CO_2 equivalency factors (CO_2e):

- **Production:** Includes the extraction, production, and transportation of raw materials, as well as the manufacture, transport, and assembly of all parts and product packaging.
- **Transport:** Includes air and sea transportation of the finished product and its associated packaging from manufacturing site to regional distribution hubs. Transport of products from distribution hubs to end customer is modeled using average distances based on regional geography.
- **Customer Use:** User power consumption assumes a three-year period. Product use scenarios are based on historical customer use data. Geographic differences in the power grid mix have been accounted for at a regional level.
- **Recycling:** Includes transportation from collection hubs to recycling centers, and the energy used in mechanical separation and shredding of parts.

Energy efficiency terms: The energy efficiency values are based on the following conditions:

- **Power adapter no-load:** Condition in which the Apple USB power adapter with the Lightning to USB Cable (1m) is connected to AC power, but not connected to iPhone.
- **Power adapter efficiency:** Average of the Apple USB power adapter with the Lightning to USB Cable (1m) measured efficiency when tested at 100 percent, 75 percent, 50 percent, and 25 percent of the power adapter's rated output current.

Restricted substances: Apple defines a material as BFR-free and PVC-free if it contains less than 900 parts per million (ppm) of bromine and of chlorine. Apple defines a material as beryllium-free if it contains less than 1000 parts per million (ppm) of beryllium. A complete list of Apple's restrictions on hazardous substances is available at www.apple.com/environment/toxins.

*Product evaluations based on U.S. configurations of iPhone SE 64GB.

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Figure 24: Apple Environmental PDF Report Example – iPhone SE – Page 4
(Apple, 2016c, p. 4) with red marks by author

The page shows *Definitions* (14), which are important for the intended analysis, since they continue to describe Apple's internal environmental approach in more detail. Moreover, the page includes the statement: "[…] in accordance with guidelines and requirements as specified by ISO 14040 and ISO 14044." This declaration induces the assumption that Apple's approach is based on the LCA methodology (ISO, 2006a,b). Furthermore, the Apple PLC is defined (Fig. 25):

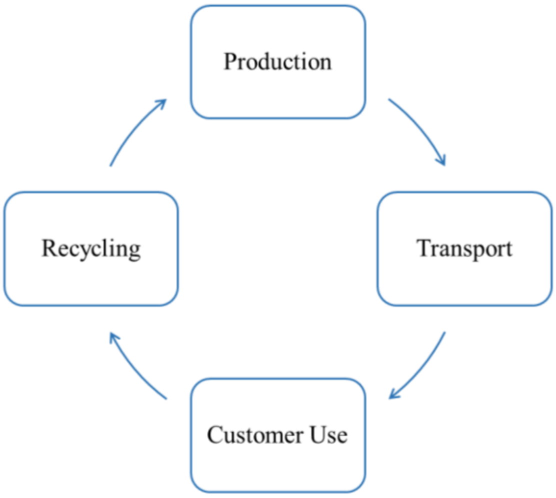


Figure 25: Apple Product Life Cycle
Own illustration based on (Apple, 2016b; Apple, 2016c, pp. 1,4)

Although the PLC is equal in each PDF report, the definitions of the four stages can be slightly different. To recognize possible alterations, following the definitions for the sample report of the iPhone SE (Apple, 2016c, p. 4) are compared to the definitions of the iPhone 3G (Apple, 2008, p.4). The content-related differences are highlighted in *italic*:

- **Production**:
  SE "Includes the extraction, production, and transportation of raw materials, as well as the manufacture, transport, and assembly of all parts and product packaging." (Apple, 2016c, p. 4)
  3G Equivalent definition (Apple, 2008, p.4).
- **Transport**:
  SE "Includes air and sea transportation of the finished product and its associated packaging from manufacturing site to *regional* distribution hubs. *Transport of products from distribution hubs to end customer is modeled using average distances based on regional geography*." (Apple, 2016c, p. 4, emphases in *italic*)
  3G "Includes air and sea transportation of the finished product and its associated packaging from the manufacturing site to the *continental* distribution hub. *Transport of products from distribution centers to the end customer is not included*." (Apple, 2008, p.4, emphases in *italic*)

- **Customer Use**:

  SE “User power consumption assumes a three-year period. *Product use scenarios are based on historical customer use data*. Geographic differences in the power grid mix have been accounted for at a *regional* level.” (Apple, 2016c, p. 4, emphases in *italic*)

  3G “End-user power consumption assumes a three-year period. *Product use scenarios are modeled on data that reflects intensive daily use of the product*. Geographic differences in the power grid mix have been accounted for at a *continental* level.” (Apple, 2008, p.4, emphases in *italic*)

- **Recycling**:

  SE “Includes transportation from collection hubs to recycling centers, and the energy used in mechanical separation and shredding of parts.” (Apple, 2016c, p. 4)

  3G Equivalent definition (Apple, 2008, p.4).

Differences can be found in the transport and in the customer use stage. While the model SE considers the transportation to regional hubs, the model 3G considers these on a continental level. It is not clear, if only the wording has changed, since Apple does not define what to understand by *regional* or *continental*. Assuming that a region is typically smaller than a continent it is indicated that the iPhone SE shows data in more detail. Furthermore, the SE includes the transport to the customer, while the 3G does not measure this distance. This also contributes to a higher level of detail for the SE data, since the product considers further relevant transportation ways. At the customer use stage, the SE report states that product use scenarios rely on historical data, while the 3G measures are based on intensive daily usage. Since the 3G was the second iPhone, there was no sufficient historical data to estimate usage scenarios. It can therefore be assumed that the calculations of the SE are more accurate. In addition, the differentiation issue between *regional* and *continental* consideration occurs at the accounting of geographic differences in the power grid mix. Assuming again that a region is smaller than a continent, iPhone SE would also on this stage show data in more detail. These differences are issues in Apple’s internal approach that have to be corrected by a generalized model, so all PLC data can be gathered under the same conventions. Knowing about these possible deviations is crucial for the comprehension of the later performed analysis, since it is important to take into account that some data could be based on slightly different assumptions.

4.3.2 Portfolio Classification and Product Selection

ICT companies like Apple can have a wide range of different products, which are registered in a product portfolio. Before starting the analysis, the relevant products must be structurally listed.

Afterwards, the environmental data can be assigned to the single items. Fig. 26 shows a selection of products in Apple's portfolio.

Figure 26: Apple Portfolio Product Examples
Own illustration based on (Apple, 2016b) with images by (Apple, 2016d)

Illustrated are the products: *MacBook Pro 2015 15-inch*, *iPhone 6S*, *iMac 2015 27-inch*, *Apple TV 3. Gen.*, and *iPad Air2*. Despite all of the depicted products could be extended by further properties, these designations are the shortest possibilities that identify the single good within Apple's portfolio. As can be seen, the conventions are different for each product. For example, the illustrated MacBook needs four terms to be identified whereas the iPhone only needs two. This conditioning depends on the variety of products within a category. In order to identify the exact product at any time and to enable a structured analysis among different levels of product designations, a standardized product classification with a dimensional hierarchy is required. Fig. 27 shows the proposed system in form of a box diagram, which is read in a way that the bigger box encloses all the boxes in it.

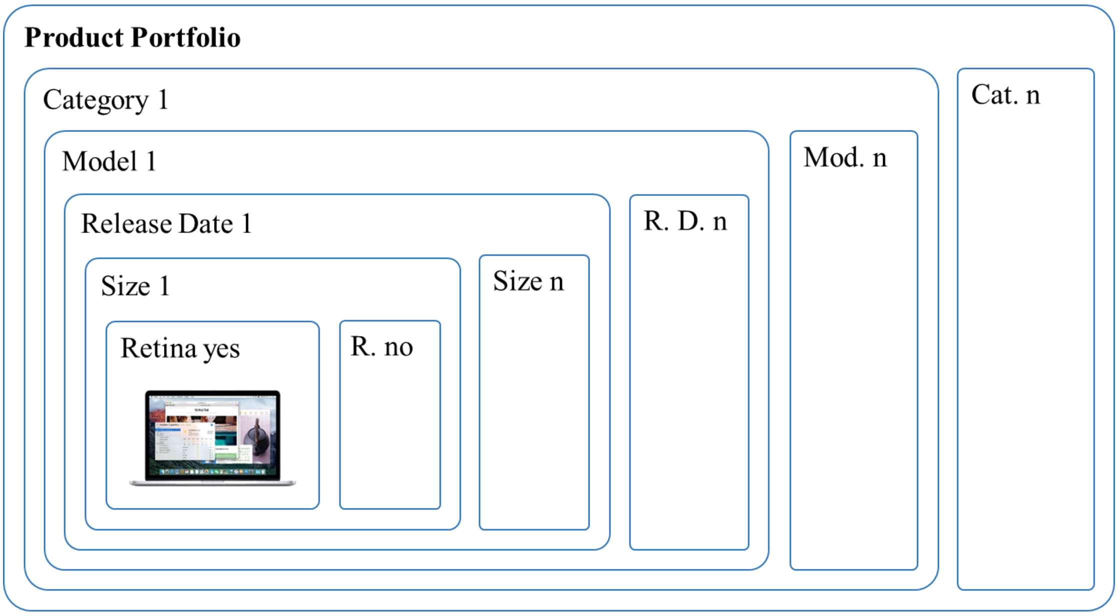


Figure 27: Apple Portfolio Hierarchy Classification Model
Own illustration based on data from (Apple, 2016b) with an image from (Apple, 2016d)

The product portfolio consists of several categories such as MacBook, or iPhone. Each of these categories can have different models such as Pro, or Air in the case of the MacBook. If this differentiation is not sufficient, properties of the product have to be considered to identify the exact good.

These are the release date (Month Day, Year), the display size, and if the product has a retina display. Only the distinctive combination of the levels leads to the defined product. To demonstrate the hierarchy model more illustratively, Fig. 28 shows three sample products with their unique classification.

Figure 28: Apple Portfolio Hierarchy Classification Model – Examples
Own illustration based on data from (Apple, 2016b) with images by (Apple, 2016d)

On the left is the category iPhone in model 6S. Within this category, there is no second model with the same name. Therefore, these levels are sufficient for differentiation. The example in the middle shows the category iPad and the model Pro. Since there are two iPad Pros in the portfolio, the release date has to be considered, too. Taking the size or the retina property would have brought in this case the same result. However, staying in the proposed structure is important, as will become apparent in the following sections. For the product on the right, each hierarchy level has to be considered, since there are two products in the portfolio that have: category MacBook, model Pro, release date Jun. 11, 2012, and size 15-inch; but only one of them has a retina display.

After demonstrating how to identify each product structurally, all products that will be part of the analysis must be listed in an MS Excel spreadsheet. This reflects the different hierarchy levels as column headlines (Tab. 3).

Category	**Model**	**Release Date**	**Size**	**Retina**
AirPort	Express	June 11, 2012	-	-
AirPort	Extreme	June 10, 2013	-	-
AirPort	Time Capsule	June 10, 2013	-	-
Apple TV	1.Gen.	September 1, 2010	-	-
Apple TV	2.Gen.	March 7, 2012	-	-
Apple TV	3.Gen.	September 9, 2015	-	-
Apple Watch	42SSCwLLB	April 24, 2015	-	-
Display	LED-Cinema	October 14, 2008	24-inch	-
Display	LED-Cinema	July 27, 2010	27-inch	-

Display	Thunderbolt	July 20, 2011	27-inch	-
iMac	-	July 27, 2010	21.5-inch	No
iMac	-	July 27, 2010	27-inch	No
iMac	-	May 3, 2011	21.5-inch	No
iMac	-	May 3, 2011	27-inch	No
iMac	-	October 23, 2012	21.5-inch	No
iMac	-	October 23, 2012	27-inch	No
iMac	-	September 24, 2013	21.5-inch	No
iMac	-	September 24, 2013	27-inch	No
iMac	-	February 22, 2014	27-inch	No
iMac	-	June 18, 2014	21.5-inch	No
iMac	-	October 13, 2015	21.5-inch	No
iMac	-	October 13, 2015	21.5-inch	Yes
iMac	-	October 13, 2015	27-inch	Yes
iPad	2	March 2, 2011	9.7-inch	No
iPad	2	March 7, 2012	9.7-inch	No
iPad	3.Gen.	March 7, 2012	9.7-inch	No
iPad	4.Gen.	October 23, 2012	9.7-inch	No
iPad	Air	October 22, 2013	9.7-inch	Yes
iPad	Air2	October 16, 2014	9.7-inch	Yes
iPad	mini	October 23, 2012	7.9-inch	No
iPad	mini	October 22, 2013	7.9-inch	No
iPad	mini2	October 22, 2013	7.9-inch	Yes
iPad	mini3	October 16, 2014	7.9-inch	Yes
iPad	mini4	September 9, 2015	7.9-inch	Yes
iPad	Pro	September 9, 2015	12.9-inch	No
iPad	Pro	March 21, 2016	9.7-inch	Yes
iPhone	3G	July 11, 2008	-	-
iPhone	3GS	June 8, 2009	-	-
iPhone	4	June 24, 2010	-	-
iPhone	4S	October 5, 2011	-	-
iPhone	5	September 12, 2012	-	-
iPhone	5c	September 10, 2013	-	-
iPhone	5s	September 10, 2013	-	-
iPhone	6	September 9, 2014	-	-
iPhone	6+	September 9, 2014	-	-
iPhone	6S	September 9, 2015	-	-
iPhone	6S+	September 9, 2015	-	-
iPhone	SE	March 21, 2016	-	-
iPod	classic	September 9, 2009	-	-
iPod	nano	September 9, 2009	-	-
iPod	nano	September 1, 2010	-	-
iPod	nano	September 12, 2012	-	-
iPod	nano	July 14, 2015	-	-
iPod	shuffle	March 11, 2009	-	-
iPod	shuffle	September 1, 2010	-	-
iPod	shuffle	September 12, 2012	-	-
iPod	shuffle	July 14, 2015	-	-
iPod	touch	September 9, 2009	-	-
iPod	touch	June 10, 2013	-	-

iPod	touch	June 26, 2014	-	-
iPod	touch	July 14, 2015	-	-
Mac Pro	-	March 3, 2009	-	-
Mac Pro	-	October 22, 2013	-	-
Mac mini	-	June 15, 2010	-	-
Mac mini	Snow Leopard S.	June 15, 2010	-	-
Mac mini	-	July 20, 2011	-	-
Mac mini	Lion Server	July 20, 2011	-	-
Mac mini	-	October 23, 2012	-	-
Mac mini	OS X Server	October 23, 2012	-	-
Mac mini	-	October 23, 2014	-	-
Mac mini	OS X Server	October 23, 2014	-	-
MacBook	-	October 20, 2009	13-inch	No
MacBook	-	March 9, 2015	12-inch	No
MacBook	Air	October 20, 2010	11-inch	No
MacBook	Air	October 20, 2010	13-inch	No
MacBook	Air	July 20, 2011	11-inch	No
MacBook	Air	July 20, 2011	13-inch	No
MacBook	Air	June 11, 2012	11-inch	No
MacBook	Air	June 11, 2012	13-inch	No
MacBook	Air	June 10, 2013	11-inch	No
MacBook	Air	June 10, 2013	13-inch	No
MacBook	Air	April 29, 2014	11-inch	No
MacBook	Air	April 29, 2014	13-inch	No
MacBook	Air	March 9, 2015	11-inch	No
MacBook	Air	March 9, 2015	13-inch	No
MacBook	Pro	February 24, 2011	13-inch	No
MacBook	Pro	February 24, 2011	15-inch	No
MacBook	Pro	February 24, 2011	17-inch	No
MacBook	Pro	October 24, 2011	13-inch	No
MacBook	Pro	October 24, 2011	15-inch	No
MacBook	Pro	October 24, 2011	17-inch	No
MacBook	Pro	June 11, 2012	13-inch	No
MacBook	Pro	June 11, 2012	15-inch	Yes
MacBook	Pro	June 11, 2012	15-inch	No
MacBook	Pro	October 23, 2012	13-inch	Yes
MacBook	Pro	February 13, 2013	13-inch	Yes
MacBook	Pro	February 13, 2013	15-inch	Yes
MacBook	Pro	July 29, 2014	13-inch	Yes
MacBook	Pro	March 9, 2015	13-inch	Yes
MacBook	Pro	May 19, 2015	15-inch	Yes

Table 3: Selected Apple Analysis Product Portfolio
Own illustration based on data from (Apple, 2016b) in (Micrsoft, 2013)

The portfolio contains all products for which Apple provides analyzable data in form of a PDF report. These are in total 100 items.

4.3.3 GGE and Material Data Extraction

The product classification data can then be extended by collecting, cleaning and structuring the necessary environmental data from the Apple PDF reports into the spreadsheet. The headings of the Excel file are listed under *Heading in MS Excel Dataset*, extended by an example product to show possible values. Therefore, Tab. 4 starts by restating the classification columns.

Heading in MS Excel Dataset	**Example**
Category	MacBook
Model	Pro
Release Date	Jun. 11, 2012
Size	15-inch
Retina	Yes

Table 4: MS Excel Dataset – Portfolio Hierarchy Classification Columns with Example
Own illustration based on data from (Apple, 2015) in (Micrsoft, 2013)

The listed headings reflect the headlines of Chapter 4.3.2 – Tab. 3 and the example reflects the regarding table row. The product classification listing can then be extended by the environmental data columns. Tab. 5 is therefore showing the GGE data.

Heading in MS Excel Dataset	**Example**
Total GGEs in kg CO_2e	710
Production GGEs in %	0.73
Customer Use GGEs in %	0.21
Transport GGEs in %	0.05
Recycling GGEs in %	0.01
Production GGEs in kg CO_2e	518.30
Customer Use GGEs in kg CO_2e	149.10
Transport GGEs in kg CO_2e	35.50
Recycling GGEs in kg CO_2e	7.10

Table 5: MS Excel Dataset – Greenhouse Gas Emission Columns with Example
Own illustration based on data from (Apple, 2015) in (Micrsoft, 2013)

The total GGEs are provided in kg CO_2e while the life cycle GGEs are available in percent from the total. Since it is more useful to have both in kg CO_2e these values are also displayed. The BI tool can convert them back to percent, so only the kg CO_2e will be included in the subsequently implemented BI dataset. Tab. 6 shows the last extension by the amount of materials.

Heading in MS Excel Dataset	**Example**
Aluminum in g	735.0
Aluminum and Magnesium in g	0.0
Aluminum and Steel in g	0.0
Battery in g	455.0
Ceramic in g	0.0
Circuit Boards in g	200.0
Copper in g	0.0
Cords and Cables in g	0.0
Display in g	125.0
Display Panel in g	0.0
Glass in g	165.0
Hard Drive in g	0.0
Hard Drive and Optical Drive in g	221.0
Leather in g	0.0
Magnets in g	0.0
Main Board in g	0.0
Other in g	0.0
Other Metals in g	135.0
Other Plastics in g	0.0
Plastic in g	55.0
Polycarbonate in g	0.0
Power Supply in g	0.0
Sapphire in g	0.0
Solid State Drive in g	13.0
Speakers in g	0.0
Steel in g	0.0
Stainless Steel in g	0.0
Trackpad and Keyboard in g	140.0

Table 6: MS Excel Dataset – Material Columns with Example
Own illustration based on data from (Apple, 2015) in (Micrsoft, 2013)

The amounts are given in grams (g). The percentages can be calculated by the BI tool, so only the gram-values will be included in the dataset. To list the materials all reports were reviewed to find each material that has ever been used in a product, which is part of the analysis portfolio. If a product does not have a material that is indicated by a zero. The materials are listed with the same name as stated in the reports. This is important to mention since Apple does not use standardized material definitions. For that reason, equally named materials do not have to mean the exact same resource. These and further issues of Apple's material handling are going to be discussed in the Apple Model evaluation in more detail. In the following, if two reports write a name such as aluminum, it is considered the same material.

With the identified column headings, the structure of the spreadsheet is complete. In the next step, the file can be filled by the values of the entire product portfolio. Afterwards, it is important to verify all data in order to find possible anomalies. One source of error is the release date. The iPhone 3G, for example, states Jun. 8, 2009 (Apple, 2008, p. 1), which seems to be a copy and paste error from the report of the iPhone 3GS that was actually introduced on this date (Apple, 2009). Furthermore, missing data must be found to enrich the dataset. One example is the 2009 released MacBook, which has no size value. These data can be enhanced by researching the appropriate pages on the technical support website of Apple (Apple, 2016e). The result of the MS Excel inventory collection is shown in the following file (Tab. 7).[21]

Table 7: MS Excel Dataset – MS Excel Dataset.xlsx
Own illustration based on data from (Apple, 2016b) in (Micrsoft, 2013)

The columns and their order comply with the specification by Tab. 4 to Tab. 6. The rows are alphabetically sorted by the category. Unused materials with the value zero are marked in red. In this form, the file represents the cleaned and enhanced Apple life cycle inventory. Based on the spreadsheet it is possible to understand the data structure with each single interrelation. That is the prerequisite to build the data model in the next step.

4.3.4 Implementation of Data Model and Table Structure

To get a flexible, well-structured and analyzable dataset the extracted inventory must be inserted into a data model. This is first implemented in an entity relationship diagram (ERD) with attributes in a field below the entity. Fig 29 shows how the notation works.

Figure 29: Entity Relationship Diagram Notation
Own illustration

On the left is the general structure of an entity with the *Entity Name* in the top and the *attributes* with their *data types*[22] and if there are *null* values allowed in the body. On the right is an example of the entity *Category* that has two attributes. The attribute *Category_Id* uniquely identifies an entry with

[21] Please open the MS Excel spreadsheet via double click.
[22] For more information on data types, e.g. Harrington (2016) can be consulted.

the data type *uniqueidentifier*. The attribute *Category* equals the name with the data type *nvarchar (100)*, which gives the possibility to enter a text of up to 100 signs. It is allowed to have *null* values for this attribute, what signifies that the data field can be empty. In the notation, two entities are set in connection with a rhombus symbol that shows the relationship. This symbol can also have attributes with data types and null allowance. In addition, cardinalities are shown, which further specify the relationship of two entities by numerical values. Possible are: one-to-one (1:1), one-to-many (1:n), or many-to-one (n:1). The entire data model is constructed by following this notation (Fig. 30).

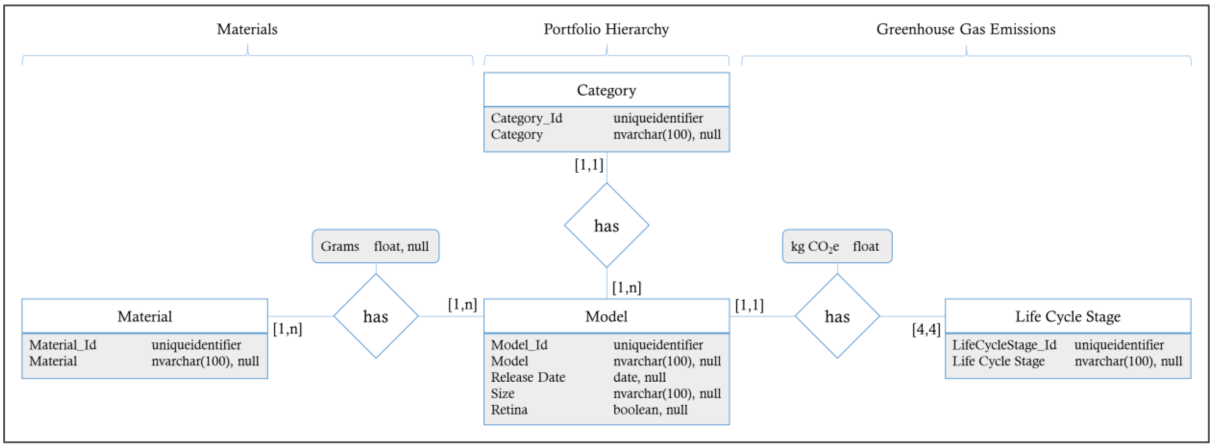


Figure 30: Apple Environmental Entity Relationship Diagram
Own illustration

The ERD is divided into three areas, which reflect the overall research objects:

- **Portfolio Hierarchy**: The portfolio hierarchy represents the in Chapter 4.3.2 – Fig. 27 as a box diagram introduced Apple Portfolio Hierarchy Classification Model. This classification descibs that a certain product is a model of a category, which in some cases has to be additionally defined by its release date, size, or if it has a retina display. The structure shows the entities *Category* and *Model*. Both have an *Id* with the data type *uniqueidentifier*. Furthermore, each entity has a name, which is *Category* for the *Category* entity and *Model* for the *Model* entity. The model entity has additionally all identified properties for the Apple naming convention as attributes: *Release Date* as *date*, *Size* as *nvarchar(100)*, and *Retina* as *boolean*. All of them allow the value *null*, since e.g. some categories do not have the retina display property. Each model belongs exactly to one category, and one category can have a number of n models.
- **Materials**: On the left side is the *Material* entity with its attributes *Material_Id* and *Material* for the name. One model can have several materials and one material can be assigned to several models. The amount in *grams* is an attribute of the relationship with the data type *float*. It allows *null* values, since not all models use all materials.

- **Greenhouse Gas Emissions**: On the right side is the *Life Cycle Stage* entity. It consists of the attributes *LifeCycleStage_Id* and *Life Cycle Stage* for the name. One model has exactly four life cycle stages: production, customer use, transport, and recycling. The GGE amount in *kg* CO_2e is an attribute of the relationship with the data type *float*. It does not allow *null* values, since each product causes emissions on each stage.

Based on this ERD, a relational database can be created, which converts the ERD given entities and connections into tables with attributes as columns.[23] Tab. 8 lists the database tables with *table name*, *key*[24], *column name*, *data type* and *null* allowance.

Table Name	Key	Column Name	Data Type	Null
Categories	PK	Category_Id Category	uniqueidentifier nvarchar(100)	 null
CategoriesModels	FK FK	Category_Id Model_Id	uniqueidentifier uniqueidentifier	
Models	PK	Model_Id Model Release Date Size Retina	uniqueidentifier nvarchar(100) date nvarchar(100) boolean	 null null null null
Material Amounts	FK FK	Model_Id Material_Id Material in Grams	uniqueidentifier uniqueidentifier float	 null
Materials	PK	Material_Id Material	uniqueidentifier nvarchar(100)	 null
GGE Amounts	FK FK	Model_Id LifeCycleStage_Id GGEs in kg CO_2e	uniqueidentifier uniqueidentifier float	 null
Life Cycle Stages	PK	LifeCycleStage_Id Life Cycle Stage	uniqueidentifier nvarchar(100)	 null

Table 8: Tables of Apple Environmental PLC Data Monitoring Model
Own illustration

There are seven tables listed. *Categories*, *Models*, *Materials*, and *Life Cycle Stages* comply with the four entities of the ERD. The tables *CategoriesModels*, *Material Amounts*, and *GGE Amount*s comply with the connections of the entities. *CategoriesModels* connects *Categories* with *Models* via their Ids. *Material Amounts* connects *Models* with *Materials* via their Ids and contains additionally the *Material in Grams*. *GGE Amounts* connects *Models* with *Life Cycle Stages* via their Ids and contains additionally

[23] For more information on relational databases, e.g. Harrington (2016) can be consulted.
[24] PK = primary key; FK = foreign key.

the caused *GGEs in kg CO_2e*. This structure must now be implemented in Power BI Desktop in order to store the data in the tools database and to create the final analyzable BI inventory dataset.

4.3.5 Implementation of Data Model in MS Power BI Desktop

For the implementation of the data model in Power BI Desktop, the tables must be created with their particular relationships. Afterwards, the Apple data can be inserted. To do so, the third option of the sidebar menu leads to the data modeling section of the tool. There, *Enter Data* in the ribbon menu must be selected to navigate to the *Create Table* view (Fig. 31).[25]

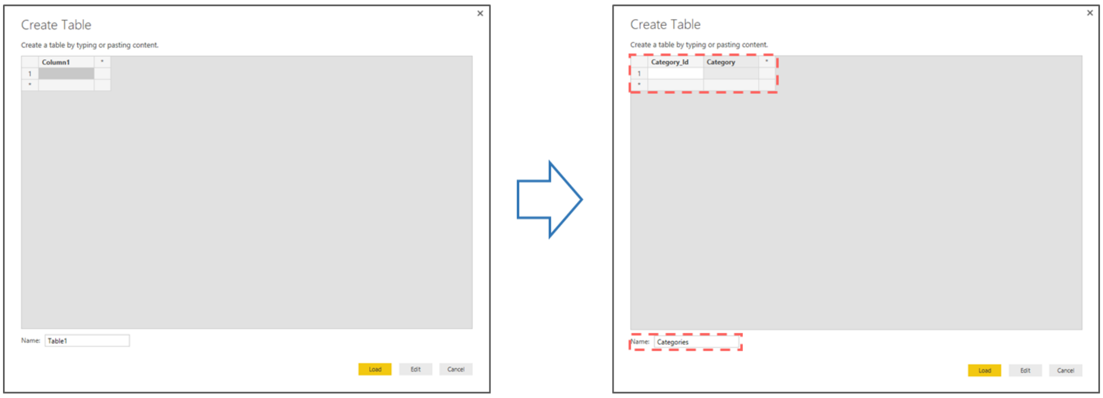


Figure 31: Apple Table Creation in MS Power BI Desktop Data Modeler
Own illustration in (Microsoft, 2016c)

The left screenshot shows the starting screen. By entering attributes as headers and the table name, here as an example for the table *Categories*, the right screen results. This has to be accomplished for all introduced database tables (Chapter 4.3.3 – Tab.8). Afterwards, the table's relationships can be defined. By selecting *Manage Relationships* in the ribbon menu, the *Create Relationship* view is reached (Fig. 32).

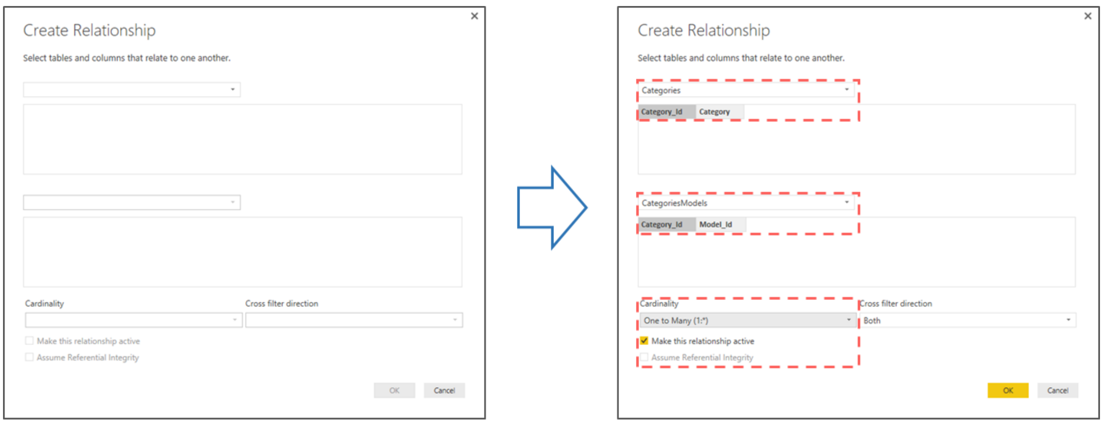


Figure 32: Apple Table Relationship Creation in MS Power BI Desktop Data Modeler
Own illustration in (Microsoft, 2016c)

[25] For the Power BI Desktop UI description, see Chapter 3.5 – Fig. 15.

The left screenshot shows the starting view. By setting a relationship, here as a sample between the *Category* table and the *CategoriesModels* table, which are connected via the *Category_Id* column, the right screenshot results. Since one category can include several models, the relationship is determined as *One to Many (1:*)*.[26] After implementing all tables, the data model in Power BI Desktop results (Fig. 33).

Figure 33: Apple Data Model in MS Power BI Desktop
Own illustration in (Microsoft, 2016c)

This model equals the ERD of Chapter 4.3.4 – Fig. 30 and therewith the database tables of Chapter 4.3.4 – Tab.8, which were created in the previous chapter.[27] By inserting all inventory data of the MS Excel dataset, the final Apple LCI BI dataset results.

[26] This relationship can also be expressed as one-to-many (1:n), as implemented in the data model of Chapter 4.3.4 – Fig. 30.

[27] For the Power BI data type conventions, Iseminger (2016b) provides information.

All tables of the data model are displayed in the MS Power BI report view, which is reached by selecting the first option in the sidebar. The tables and columns appear in the fields menu on the right side of the tool's interface (Fig. 34).

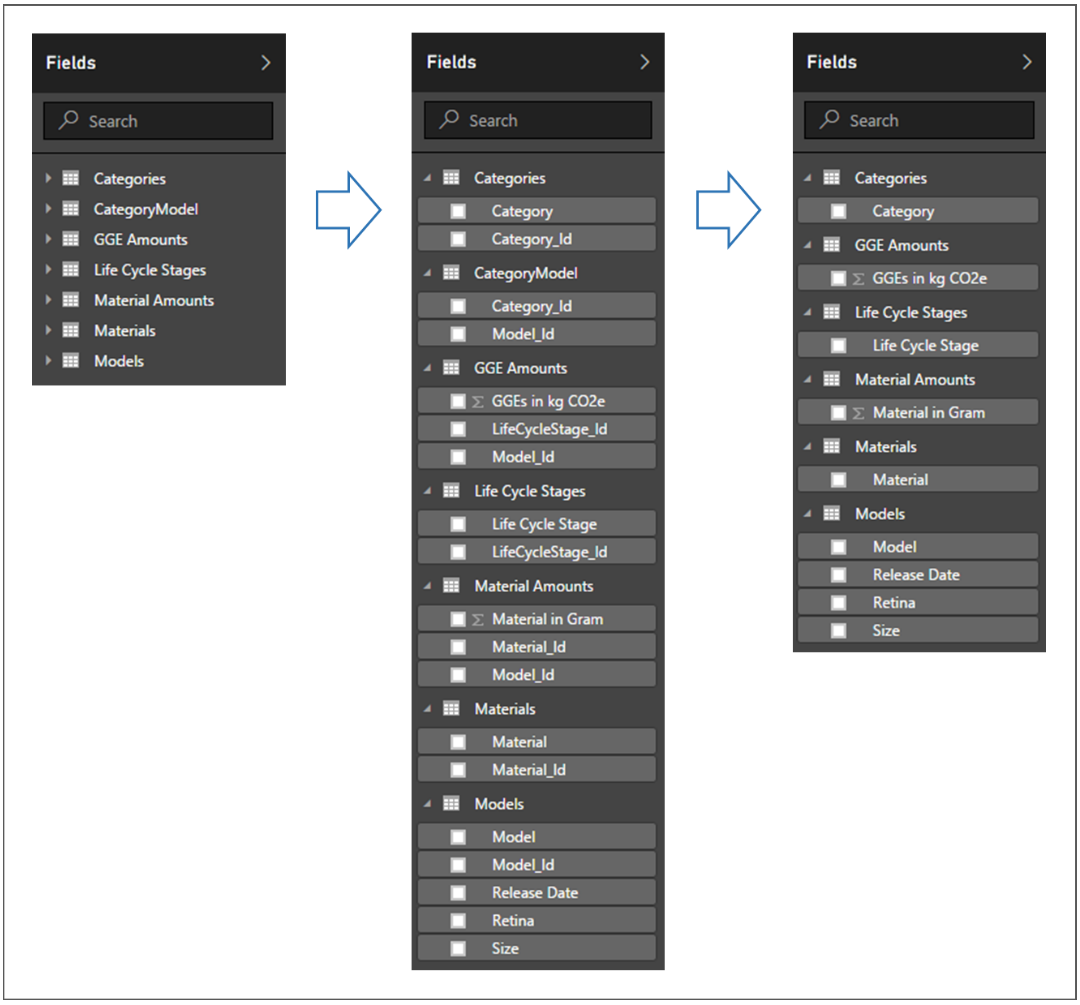


Figure 34: Apple Dataset in MS Power BI Desktop Fields Menu – Structuring Step 1
Own illustration in (Microsoft, 2016c)

The left screenshot shows all tables. By expanding them, the middle screenshot results. Since Power BI displays all columns of the data model, the unnecessary ones can be hidden to get a better handling for the analysis. For example, the entire connection table *CategoriesModels* is hidden, since it consists only of two Id-columns. Afterwards, the cleared column display of screenshot three results. Furthermore, it is necessary to create additional columns and measures[28] based on the already existing ones. To do so, Power BI's Data Analysis Expression Language (DAX) is used. "DAX is a collection of functions, operators, and constants that can be used in a formula, or expression, to calculate and return one or more values." (Iseminger, 2016c)

[28] Both function forms provide in the presented cases the same results. For more information on possible differences in other settings, Iseminger (2016d,e) provides information.

Firstly, a product column is needed (Equ. 1).

```
Product = CONCATENATE(RELATED('Categories' [Category]) & " " & 'Models'[Model] & " " & 'Models'[Release Date] & " " & 'Models'[Size] & " "; 'Models'[Retina])
```

Equation 1: Product Concatination DAX Function
Own Calculation in (Microsoft, 2016c)

The designation *Product* results as a concatenation of category, model, release date, size, and retina. The term *related* implies that also columns of other tables then the one in which the new column is placed are used. For example, *'Category' [Category]* signifies that the category name column from the category table is used.

Another necessary calculated column is the extraction of the year out of the release date, to simplify the handling of reports on a yearly level.

```
Year = YEAR('Models'[Release Date])
```

Equation 2: Year Extraction DAX Function
Own Calculation in (Microsoft, 2016c)

Here, the *YEAR* function is used to filter the year out of the *Release Date* column, which is located in the *Models* table.

Two more measures that are necessary are the previously announced percentages for the GGEs and the material amounts. Equ. 3 starts with the *GGEs in Percent*.

```
GGEs in Percent = DIVIDE(SUM('GGE Amounts'[GGEs in kg CO2e]); CALCULATE(SUM('GGE Amounts'[GGEs in kg CO2e]); ALL('Life Cycle Stages'[Life Cycle Stage])); 0)
```

Equation 3: GGE Amounts in Percent DAX Function
Own Calculation in (Microsoft, 2016c)

By dividing the total GGEs by the GGEs in the regarding life cycle stage the values for each single stage result.

Equ. 4 shows the same structure for the *Material in Percent* function.

```
Material in Percent = DIVIDE(SUM('Material Amounts'[Material in Grams]); CALCULATE(SUM('Material Amounts'[Material in Grams]); ALL('Materials'[Material])); 0)
```

Equation 4: Material Amounts in Percent DAX Function
Own Calculation in (Microsoft, 2016c)

By dividing the total weight of a material by the overall total weight, the percent values for each material result.

By adding these four columns and measures[29] to the data model, Fig. 35 results, which completes the field menu process of Fig. 34. The added columns are marked in red.

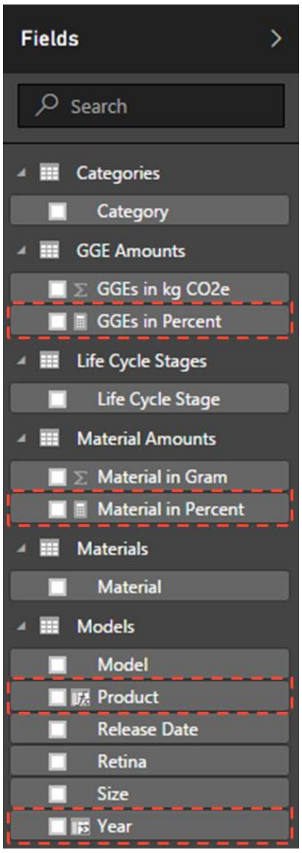


Figure 35: Apple Dataset in MS Power BI Desktop Fields Menu – Structuring Step 2
Own illustration in (Microsoft, 2016c)

The fields menu eventually contains all relevant tables and columns. As can be seen, *Product* and *Year* are part of the *Model* table. The *GGEs in Percent* belong to the *GGE Amounts* table and *Material in Percent* belong to the *Material Amounts* table. The new elements extend by implication the database with its table structure and thus the ERD model. Therewith the BI dataset is finalized. Based on that, the analysis for the product footprint of the Apple portfolio can be performed. This consist of the reports and the dashboards step of the Apple Environmental PLC Data Monitoring Model, which are both part of the following investigation section.

[29] Columns are indicated by a table symbol. Measures are indicated by a calculator symbol.

4.4 Environmental BI Analysis and Reporting

4.4.1 Basic Reporting Possibilities

Before researching the dataset concerning environmental affairs, the data can also answer general questions such as: which products are part of the analysis portfolio?, which products have been released within a specific time period?, or: how many products are part of the analysis portfolio in total or within a specific time period? The *Product Release Report* below can answer these kinds of questions (Fig. 36).

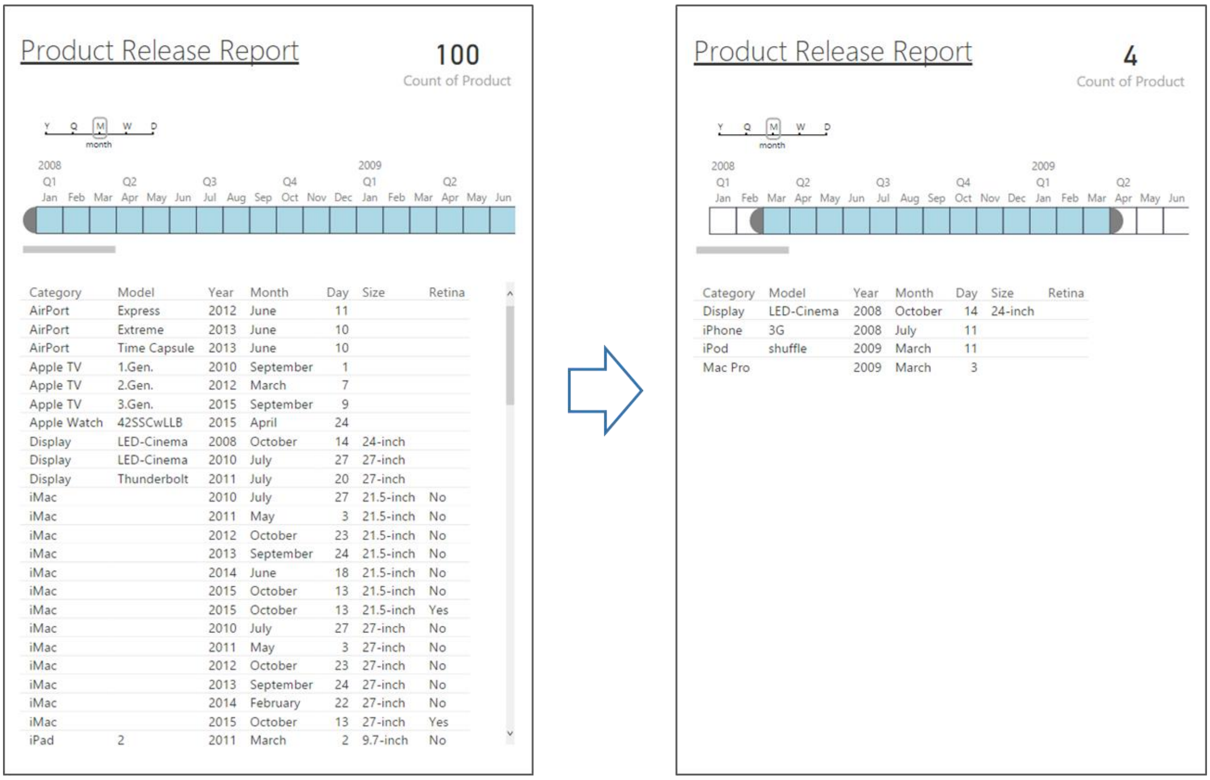
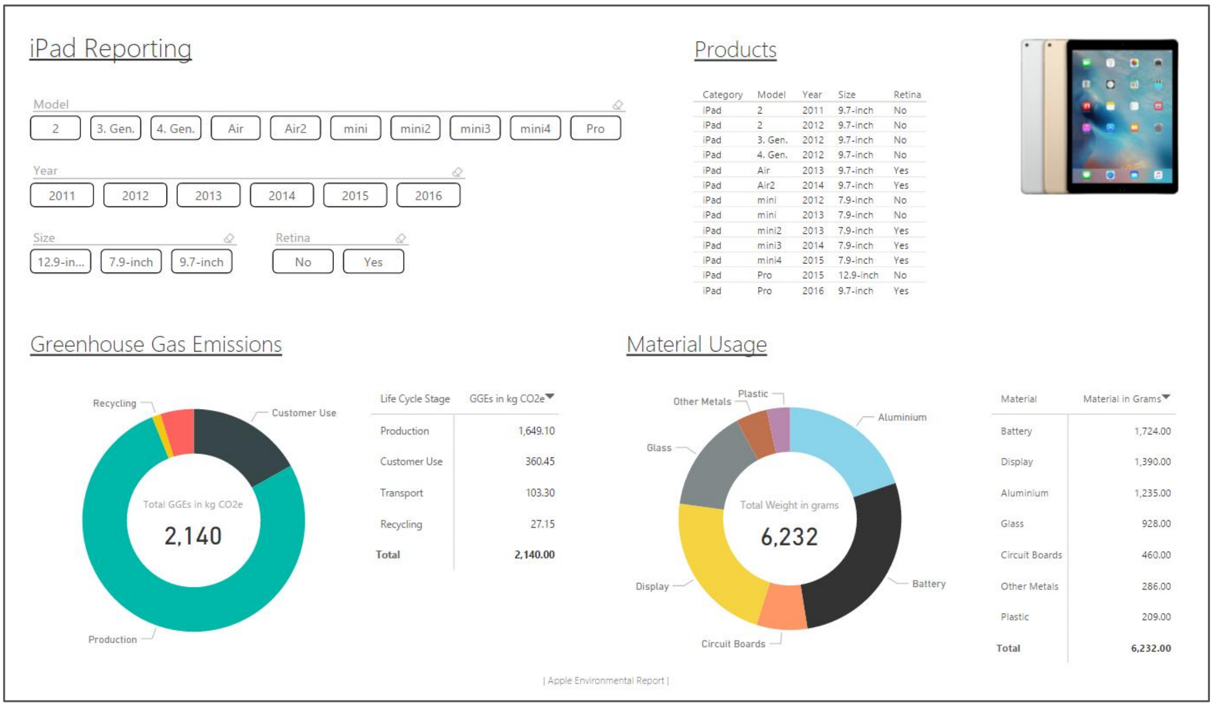


Figure 36: Product Release Report
Own Calculation based on data from (Apple, 2016b) in (Microsoft, 2016c)

By using a timeline and a list consisting of *category*, *model*, release data (separated into *year*, *month*, and *day*), *size*, and *retina*, the products that have been released in between a specific time period can be determined. By adjusting the timeline's granularity between year, quarter, month, week, or day, it is possible to specify the release times. The amount of products, which have been introduced within a time period or all products if no time period is selected, are counted in the upper right corner. In the left report there is no timespan selected. Therefore, the list consists of all products that are in the analysis portfolio. This complies with the Apple analysis product portfolio selected in Chapter 4.3.2 – Tab. 3, consisting of 100 products. In the report on the right, the timeline is adjusted from March 2008 to March 2009. Therein, four products have been released: *Display LED-Cinema 2008-October-14 24-inch*, *iPhone 3G 2008-July-11*, *iPod shuffle 2009-March-11*, and *Mac Pro 2009-March-03*. Such list can in particular be helpful in preparation of an environmental analysis. Thus, the model provided information show first benefits by answering a simple set of questions.

4.4.2 Reconstruction of Apple PDF Reports

To give an overview of the advantages of the BI solution compared to the current internal Apple approach, this section will reconstruct the Apple PDF reports in the framework of interactive BI reporting based on the portfolio hierachy classification, to examine the environmental impacts for the different levels. At this point, the indicators and visualizations are not going to be comprehensively assessed and interpreted. This kind of footprint analysis will be performed in the next section. The reconstruction is shown on the example of the category iPad. The reporting is carried out on one report page with selection fields that allow to navigate through the hierarchy structure. Fig. 37 starts by illustrating the data for the entire category since no model or property is selected, yet. Because the other reports show the same structure, this first will be described in detail and for the others, only the differences will be highlighted.



Category	Model	Year	Size	Retina
iPad	2	2011	9.7-inch	No
iPad	2	2012	9.7-inch	No
iPad	3. Gen.	2012	9.7-inch	No
iPad	4. Gen.	2012	9.7-inch	No
iPad	Air	2013	9.7-inch	Yes
iPad	Air2	2014	9.7-inch	Yes
iPad	mini	2012	7.9-inch	No
iPad	mini	2013	7.9-inch	No
iPad	mini2	2013	7.9-inch	Yes
iPad	mini3	2014	7.9-inch	Yes
iPad	mini4	2015	7.9-inch	Yes
iPad	Pro	2015	12.9-inch	No
iPad	Pro	2016	9.7-inch	Yes

Figure 37: Category Report: iPad
Own illustration based on data from (Apple, 2016b) in (Microsoft, 2016c)

The report contains all utilized data from the Apple PDFs for the category iPad. In the upper left corner is the header *iPad Reporting* that is kept general for this interactive report. Below are selection fields that are used to navigate to the other hierarchy levels. In the upper right corner is an image of an iPad to support the reader visually. The table to the left of this image lists all iPads. As the other widgets, this table adjusts while drilling down/up the hierarchy. The bottom half contains the GGEs and the amounts of materials used. On the left are the GGEs in the form of a donut chart, which is also used in newer versions of the PDF reports. By hovering over the chart, the GGEs in kg CO_2e with their corresponding percentage appear. In the chart's center are the *Total GGE in kg CO_2e*. Right beside is a list of the single life cycle emissions in kg CO_2e, sorted from most emitting to least. As e.g. can be seen, the iPad category emits in total 2,140 kg CO_2e. Thereby production shows the most emissions with 1,649.10 kg CO_2e. The right bottom corner displays the material usage, again in the form of a donut chart. By hovering over the chart, the grams of the material with their percentage appear. In the chart's center is the *Total Weight in grams*. To the right of that is a list with the materials used, sorted from most used to least. It can e.g. be seen that *Battery* is with 1,724 g the most used material of the category. The report is concluded by a footer that states *Apple Environmental Report*. By selecting *mini* from the model selection fields, Fig. 38 results.

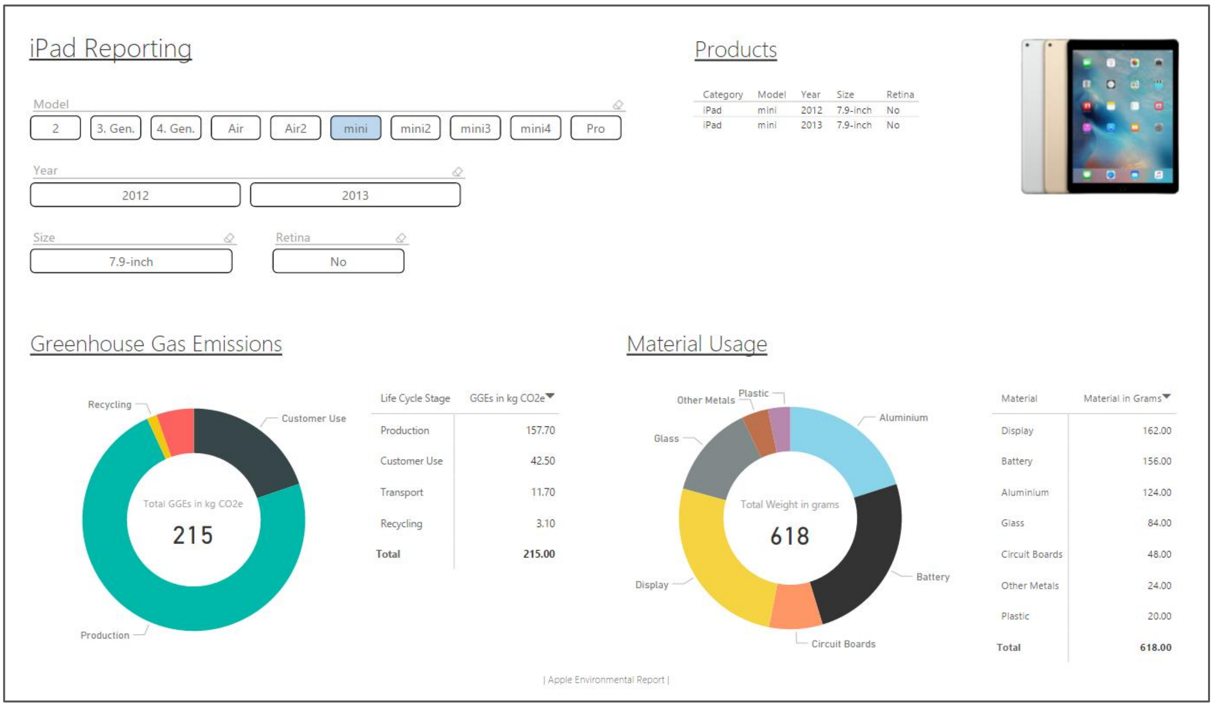


Figure 38: Model Report: iPad mini
Own illustration based on data from (Apple, 2016b) in (Microsoft, 2016c)

All widgets adjust according to the selected model. The table of products shows that there are two iPad minis available. The years adjust to 2012 and 2013 since these are the release years of both products. Also, size and retina show the remaining options. The data in the bottom half also adjust and show the GGEs and the amounts of materials used for both iPad minis. Thereby it can e.g. be seen that 215 kg CO_2e are caused by both products, or that their common weight amounts to 618 grams. By additionally selecting the year 2013, the product iPad mini 2013 is defined (Fig. 39).

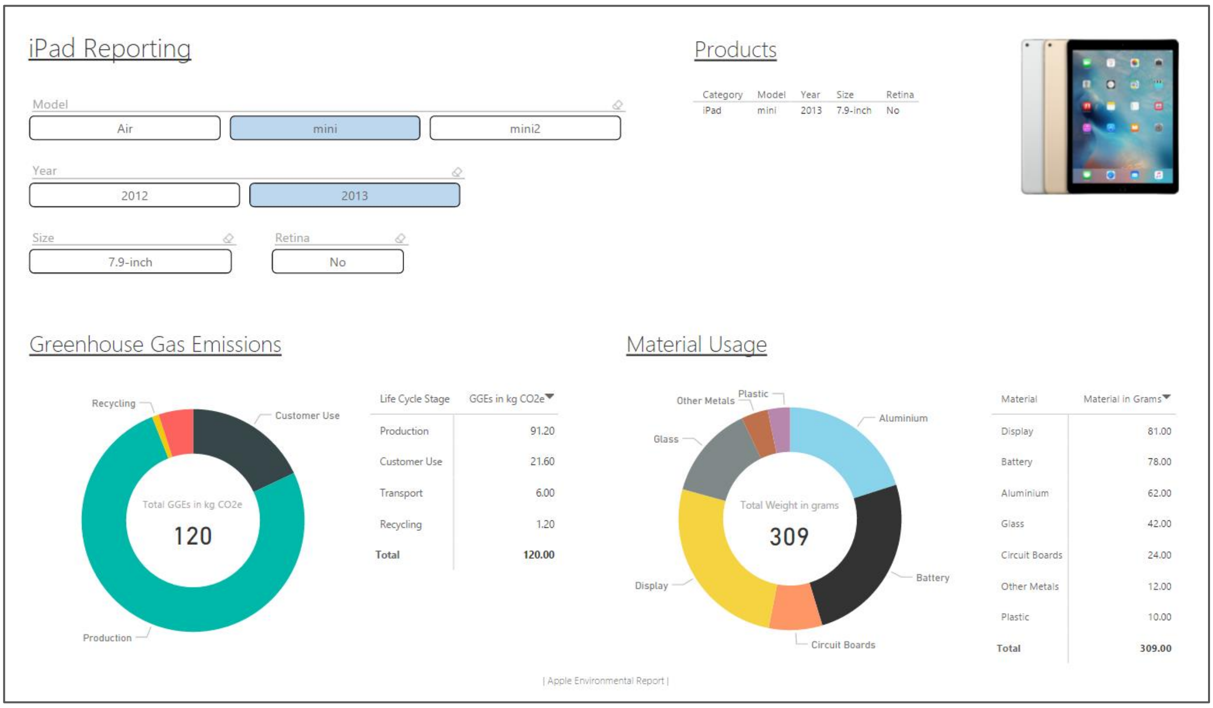


Figure 39: Product Report: iPad mini 2013

Own illustration based on data from (Apple, 2016b; Apple, 2013b) in (Microsoft, 2016c)

This report shows the same data as the Apple PDF for the iPad mini from 2013 with a 7.9-inch non-retina display (Apple, 2013b). On the contrary to the PDF, total and percent values are displayed for the GGE and material amounts. As can be seen, the iPad mini 2013 causes 120 kg CO_2e, while production is the most emission causing LCS with 91.20 kg CO_2e, which effects its listing in the first position of the LCS emission table. On the material usage side, the total weight is shown as 309 grams. This is a calculation by the BI tool based on the material weights that was not shown in the PDF reports. The report further enables an automated value control to avoid data errors, since it e.g. calculates the single emissions and shows the total. This was one point of error in the Apple PDFs, where e.g. for the iPod shuffle from 2012 a life cycle of 101% has been displayed (Apple, 2012a). This report could further be contrasted with reports of other products in order to get answers on questions such as: which product has the higher GGEs?, how is the rank order of the single LCS emissions?, or: do both products use the same amount of a specific material? Moreover, comparison data could be presented as presented in the carbon footprint report of Dell (Dell, 2013a).

In addition to the shown category, model, or product reports, it is possible to display all combinations of products. As an example, Fig. 40 shows the combined report for the iPad Air2 and the iPad Pro 2016.

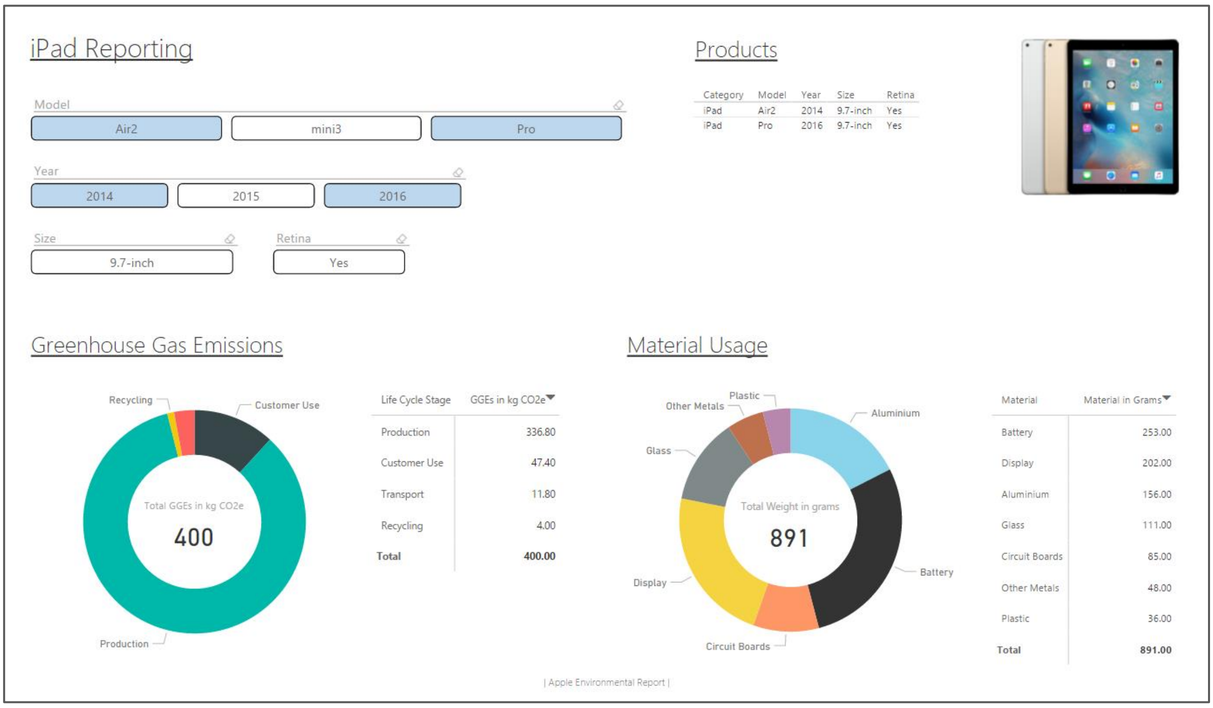


Figure 40: Product Combination Report: iPad Air2 and iPad Pro 2016
Own illustration based on data from (Apple, 2016b) in (Microsoft, 2016c)

As in the last examples, all widgets adjust according the selection. There are several business cases, where this report would be helpful. One example is the question how much GHGs a product combination emits in a specific LCS such as customer use. In the example the answer is 47.70 kg CO_2e, which complies with 11.85% overall. Another question would be to ask for the most used material of two products. As the list reveals *Battery* is used the most with 253 grams, which complies with 28.4% overall. The *Battery* has also been revealed as the most used material of the entire category (Fig. 38). Based on that knowledge further examinations regarding this material could be made. The values could also be compared to other product combinations, e.g. the predecessor models, to get answers regarding a product line impact or similar. That kind of product combination reporting could also be performed for different categories, if the report would be extended by this hierarchy level.

The use case mentioned lastly is the possibility to directly select properties, e.g. to get a report for all iPads that have a retina display (Fig. 41).

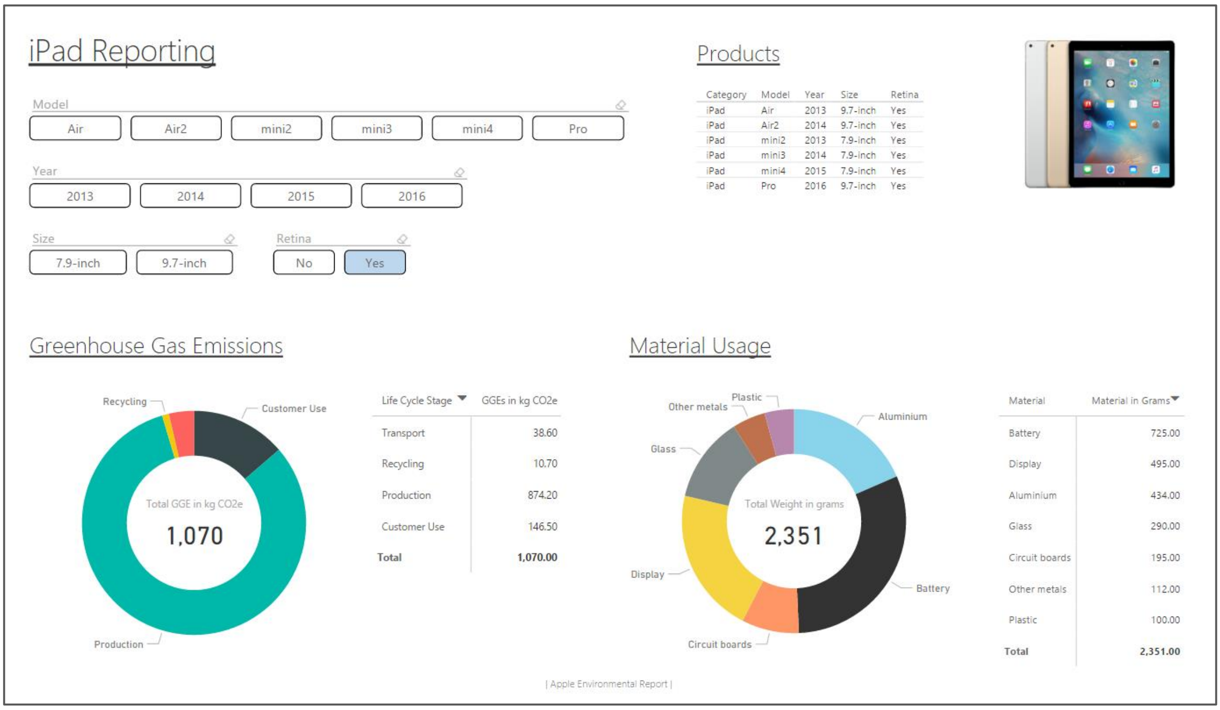


Figure 41: Property Report: iPads with Retina Display
Own illustration based on data from (Apple, 2016b) in (Microsoft, 2016c)

The report shows that there are six products of the category iPad with a retina display. The GGEs, for example, could now be compared to the no retina products to detect if a retina display might influence the total GGEs in the category iPad. This kind of research is in the focus of the next section.

With these examples, the shown reports fundamentally illustrate the capabilities of BI reporting in the framework of the developed Apple Model on each level of the product hierarchy. This gives a first proof for the usefulness of the solution, especially when comparing to the current Apple approach of the PDF reports.

4.4.3 Portfolio Impact Analysis for Selected Cases

4.4.3.1 Course of Analysis and Scientific Issues

This section will use the revised Apple environmental LCI in form of the BI dataset to perform an Apple Environmental PLC Data Monitoring Model supported LCIA and interpretation. Doing so, questions regarding the environmental impact along the Apple Portfolio Classification Hierarchy will be answered. Therefore, the analysis starts on the portfolio level and consecutively drills down until a single property. Since there are various analysis possibilities, the investigations have to be understood as samples. For instance, the total GGEs for each product of the category iPhone will be shown. While this could also be conducted for any other category, the iPhone research stands as an example to demonstrate the system. Furthermore, the stated developments will be questioned by finding possible correlations to other data. Statista (2016b) defines: "A correlation measures the strength of a statistical link between two variables. Given a positive correlation, the following statement applies: 'the more of variable A….the more of variable B', or vice versa. Given a negative correlation, that statement would be 'the more of variable A…. the less of variable B' or vice versa." In this paper's context, the relationship analysis will examine if two graphs always run in the same direction, regardless whether they increase or decrease. If so, a significant impact will be assumed as indicated.[30] To comprehend the results of the relationship analyses, it is further essential to keep in mind that all correlations are indicators for causalities between different information, but they do not definitely prove them (Statista, 2016b). Moreover, it is important to take into account that all investigations are interconnected with one another. For that reason, e.g. an impact of a single category stands in relation with the total impact of the entire portfolio. Each of these investigations will use different visualizations such as KPIs, charts, or tables. These can all be displayed as single widgets on the report pages. However, in order to get an easy to read overview of the data insights, tables that would stand on a single page will be copied into the text file to support the readability. This is the case, if tables are too large to be displayed with their associated graph as well as if there is no illustration for the table values. All analysis examples are selected by means of their usefulness for Apple, so each of them can provide value for Apple's environmental efforts and decision-making. Therefore, this chapter will give the idea of an analysis in the context of BI supported environmental investigations and can in consequence be used as a template for researching further cases.

4.4.3.2 Product Portfolio GGE Impact

The first use case aims to get an overview of the total GGE development for Apple's entire portfolio. Furthermore, a possible correlation for the shown development shall be questioned through the comparison with the amount of released products. Getting such overview is important to obtain an initial indication on the company's current environmental status.

Total GGEs 2008 – 2016

The table below starts the examination by showing the years 2008 to 2016 with their single emissions in kg CO_2e as well as the overall total (Tab. 9).

[30] For further information regarding the calculation of correlation indicators, e.g. Sedgwick (2012) can be consulted.

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	**Total**
kg CO_2e	1,035	2,618	6,127	8,360	6,960	5,710	5,565	6,040	285	**42,700**

Table 9: Total GGEs of Portfolio by Year (2008 – 2016)
Own Calcualation based on data from (Apple, 2016b) in (Microsoft, 2016c)

In total 42,700 kg CO_2e have been emitted by the entire product portfolio. Furthermore, the table shows that e.g. 2008 caused GGEs of 1,035 kg CO_2e. Since 2016 is the current year, the value is an interim result. Therefore, exclusively the already concluded years are considered in the following.

Total GGEs 2008 – 2015

The single GGEs for the concluded years are illustrated in form of a line chart extended by the corresponding data table, which consists of year, GGEs in kg CO_2e, and the emission changes to the previous year in percent (Fig. 42).

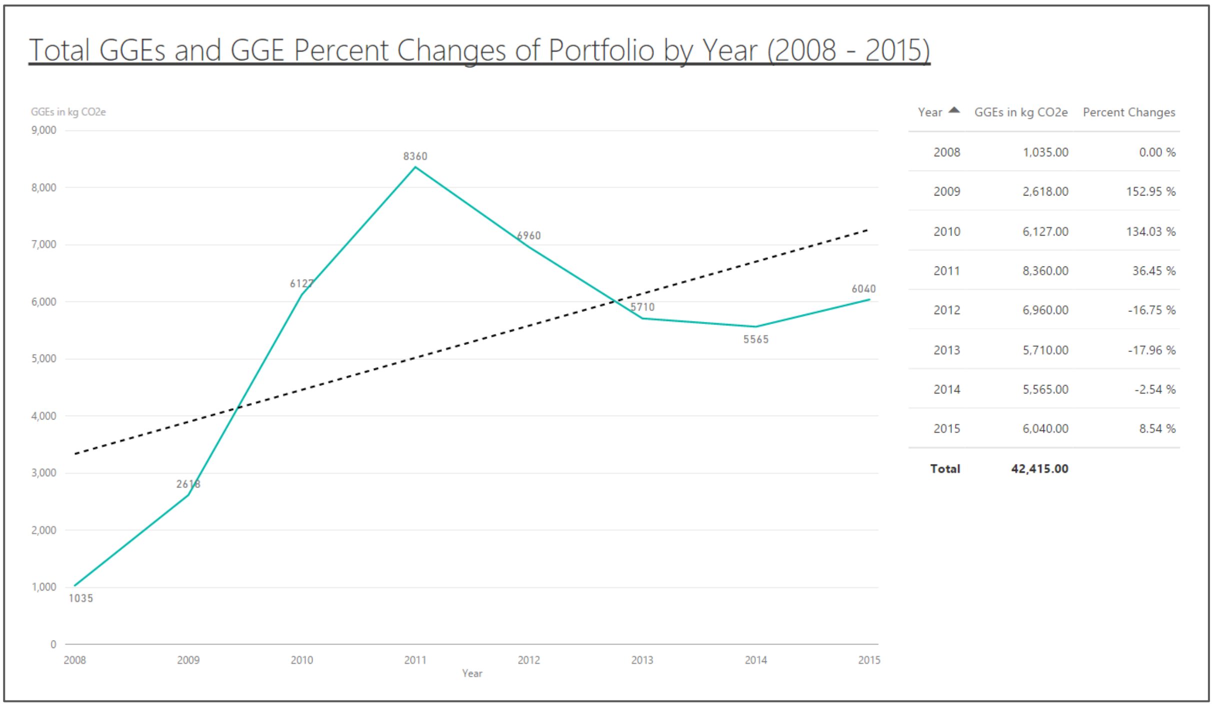


Figure 42: Total GGEs and GGE Percent Changes of Portfolio by Year (2008 – 2015)
Own Calcualation based on data from (Apple, 2016b) in (Microsoft, 2016c)

The X-axis shows the considered years in which products have been released. The Y-axis shows the GGEs in kg CO_2e. Starting with 1,035 kg CO_2e in 2008 the GGEs constantly increased up to 8,360 kg CO_2e in 2011. From there the amount decreased over the next four years down to 5,565 kg CO_2e in 2014. This value only slightly increased again to 6,040 kg CO_2e in 2015. The dashed trend line shows an overall increase. The strongest growth between two consecutive years can be seen from 2008 to 2009 where the emissions increased by nearly 153%. The strongest decrease between two consecutive years can be seen from 2012 to 2013 where the emissions dropped by nearly 18%.

To set this development in a larger context, the data can be compared to other surveyed emissions. Such possibility has been shown in the state of the art of Chapter 1.2 for the environmental reporting of Dell (2013a, p. 1). Inspired by this, e.g. the in Chapter 3.1 – Fig. 11 displayed emission growths of the ICT sector could be utilized (GeSI, 2012, pp. 21-26). Therein, it is shown, that the total emissions increased from 2002 to 2011 by more than 71%. Further, each displayed area caused more emissions. For example, end-user devices increase from 2002 to 2011 by nearly 72%. In the case of Apple, the emissions increased from 2008 to 2015 by over 483%. Considering only the years 2008 to 2011, the growth was nearly 708%. This increase is by far higher than the stated examples, even considering that the settings are very different.[31] To examine possible reasons for this development, connections to other data have to be researched.

Released Products 2008 – 2015

An example for a possible correlation, which is also in focus of the LCA methodology (ISO, 2006a, p. v), is the amount of released products per year. In total 100 products are part of the analysis portfolio. Within the concluded years 2008 to 2015, 98 products have been released. Therefore, Fig 43 shows the amount development within these years extended by the amounts table.

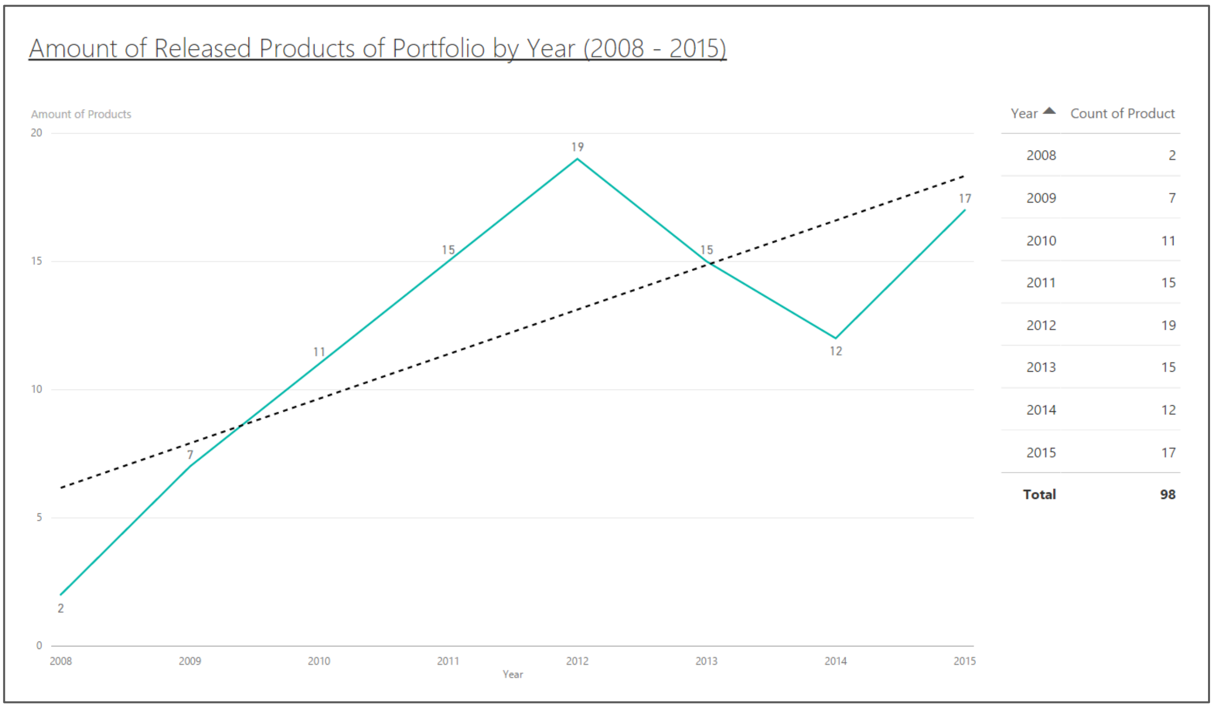


Figure 43: Amount of Released Products of Portfolio by Year (2008 – 2015)
Own Calcualation based on data from (Apple, 2016b) in (Microsoft, 2016c)

[31] Further comparison values can e.g. be found in Metz (2007) or in UNEP (2016b).

Starting with two products in 2008 the amount constantly increased by 4.75 releases per year, up to 19 in 2012. Afterwards, the graph falls until 2014 with 12 products. In 2015, the second largest amount with 17 products has been released. The dashed trend line shows an overall increase.

Total GGEs and Released Products by Visualization

After showing the graphs separately, both can be compared. The question is if a higher or lower amount of released products, always results in an emission increase respectively decrease. This would indicate a significant correlation. Therefore, both graphs are illustrated below (Fig. 44).

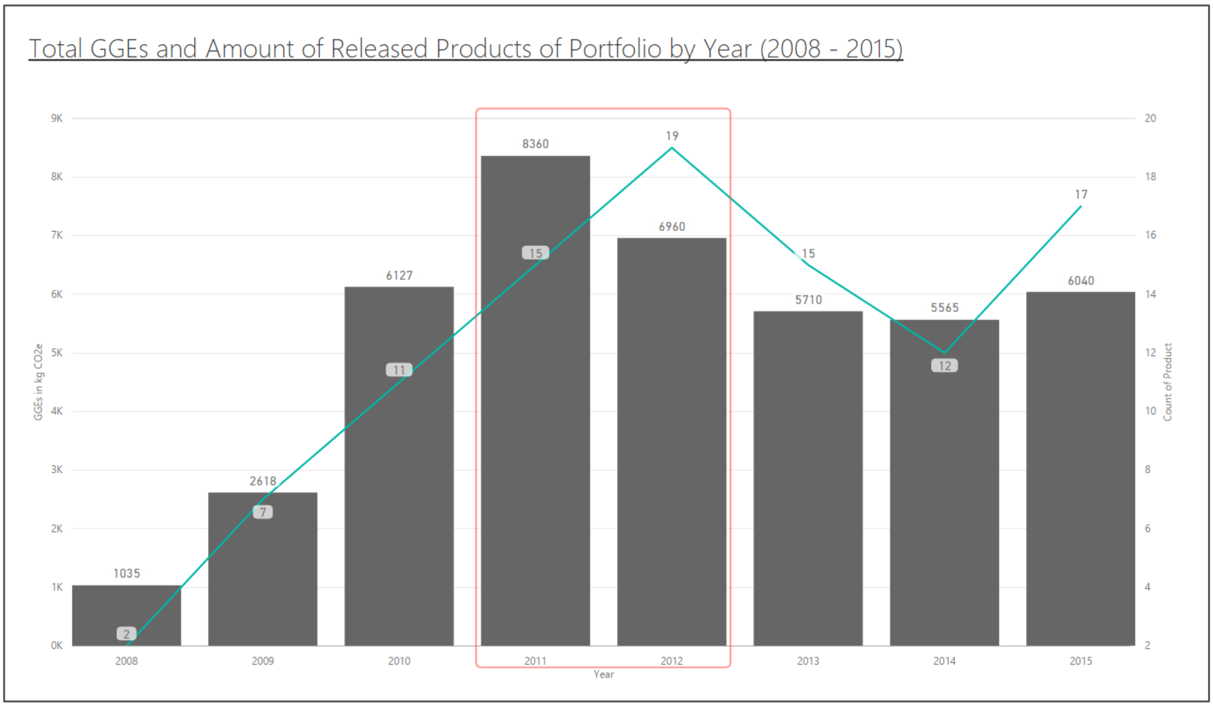


Figure 44: Total GGEs and Amount of Released Products of Portfolio by Year (2008 – 2015) Own Calcualation based on data from (Apple, 2016b) in (Microsoft, 2016c)

The GGE graph is visualized in the form of a stacked column chart and the amount of released products is shown as a line chart. The X-axis displays the considered years. The left Y-axis is for the emission graph and shows the GGEs in kg CO_2e. The right Y-axis is for the released products chart and shows their amount. This gives an overview and a prompt answer to the question if the graphs always run in the same direction. As can be seen until 2011 the graphs show a related trend. However, while the amount of released products in 2012 increased again, the total GGEs dropped (marked with a red square). Afterwards, both run similar again. Thus, the question, if a significant impact can be detected, has to be denied. Moreover, the years of 2011 and 2013 with 15 products each, show a discrepancy of 2,650 kg CO_2e. In addition, 2011 shows an emission increase from its predecessor year, while 2013 shows a decrease in this regard. That further proofs that there is no explicit relationship. Such differences over several years or generations of products are in focus of the following analysis approach.

Total GGEs and Released Products by Value Distance Model

To dig even deeper into the data, it is possible to consider the single changes of the emissions as well as the amount of released products not only between consecutive, but also between non-consecutive years. This kind of research is enabled by using the Value Distance Model that shall first be introduced by an example in the table below (Tab.10).

Year	2008	2009	2010
2008	-	1	2
2009	-1	-	1
2010	-2	-1	-

Table 10: Value Distance Model – Example
Own illustration

Despite the values, the first row, and the first column mirror each other. In this case, they show the years. Following sample values are used: 2008 = 1, 2009 = 2, and 2010 = 3. Read from left to right shows the chronological order. The diagonal displays dashes because it would compare the same years with one another. From 2008 to 2009, for example, there is a difference of one; while from 2008 to 2010, there is a difference of two. Below the diagonal, the values change their signs since the view goes in the opposite direction. For example, from 2009 to 2008 the difference is minus one. Negative values are written in red to give a visual support. These tables are created in MS Excel (Microsoft, 2013) since the current version of MS Power BI Desktop (Microsoft, 2016c) provides no possibility for a two-dimensionally usage of one database field, in this case the year. As can be seen in Microsoft (2016j) this functionality is part of the Power BI development plan and shall be available in one of the next releases.

The table below uses the method by showing the single emission changes of the product portfolio by year (Tab. 11).

Year	2008	2009	2010	2011	2012	2013	2014	2015
2008	-	1,583	5,092	7,325	5,925	4,675	4,530	5,005
2009	-1,583	-	3,509	5,742	4,342	3,092	2,947	3,422
2010	-5,092	-3,509	-	2,233	833	-417	-562	-87
2011	-7,325	-5,742	-2,233	-	-1,400	-2,650	-2,795	-2,320
2012	-5,925	-4,342	-833	1,400	-	-1,250	-1,395	-920
2013	-4,675	-3,092	417	2,650	1,250	-	-145	330
2014	-4,530	-2,947	562	2,795	1,395	145	-	475
2015	-5,005	-3,422	87	2,320	920	-330	-475	-

Table 11: Changes of Total GGEs of Portfolio by Year (2008 – 2015)
Own Calcualation based on data from (Apple, 2016b) in Microsoft (2013)

As can be seen, e.g. from 2008 to 2009 the GGEs increased by 1,583 kg CO_2e. The marked fields are part of the following comparison.

To set this in relationship to the amount of released products the single changes are written in the same structure (Tab. 12).

Year	2008	2009	2010	2011	2012	2013	2014	2015
2008	-	5	9	13	17	13	10	15
2009	-5	-	4	8	12	8	5	10
2010	-9	-4	-	4	8	4	1	6
2011	-13	-8	-4	-	4	0	-3	2
2012	-17	-12	-8	-4	-	-4	-7	-2
2013	-13	-8	-4	0	4	-	-3	2
2014	-10	-5	-1	3	7	3	-	5
2015	-15	-10	-6	-2	2	-2	-5	-

Table 12: Changes of Amount of Released Product of Portfolio by Year (2008 – 2015)
Own Calcualation based on data from (Apple, 2016b) in Microsoft (2013)

As mentioned, the denial of the question if the amount of releases significantly influences the total GGEs requires one example that proves the opposite. As has been shown this applies to the consecutive years 2011 and 2012 where the emissions decreased by 1,400 kg CO_2e, while four more products had been released (market blue in both tables). The Value Distance Model enables to see such propositions more easily also for non-consecutive years. For example, between 2010 and 2013 the amount of products increased by four, while the GGEs decreased by 417 kg CO_2e (marked green in both tables). The model indicates again that despite there is a correlation between both developments, the amount of released products does not have a significant influence on the total emissions, neither in consecutive nor in non-consecutive years. The implementation of this Value Distance Model in Power BI with an automated detection of these cases could be a valuable further step, when the possibility of a two-dimensional usage of one database field is enabled. This could then show all possibilities in standardized colors to reveal where differences happen or that both information always show the same course.

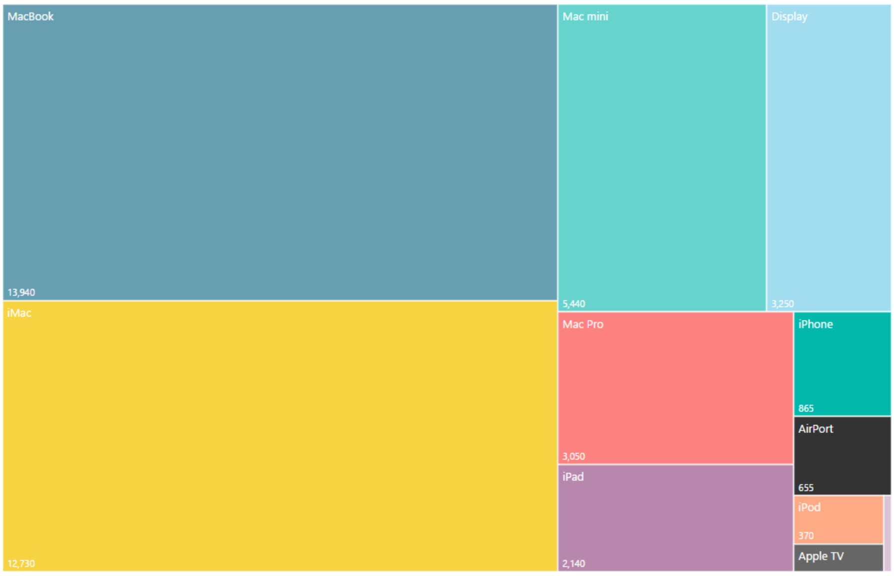
4.4.3.3 Category GGE Impact

In this section, the different impacts on the level of categories shall be examined by answering questions on the total and life cycle emissions. Therefore, e.g. a rank order from most to least emitting category will be displayed. For this research, also the year 2016 is considered.

Total GGEs by Categories

At first, the total portfolio GGEs are allocated by the single categories to show the impact shares. Therefore, a treemap[32] is used supplemented by its corresponding table (Fig. 45).

Allocation of Total GGEs by Categories



Category	GGEs in kg CO2e
MacBook	13,940.00
iMac	12,730.00
Mac mini	5,440.00
Display	3,250.00
Mac Pro	3,050.00
iPad	2,140.00
iPhone	865.00
AirPort	655.00
iPod	370.00
Apple TV	210.00
Apple Watch	50.00
Total	**42,700.00**

Figure 45: Allocation of Total GGEs by Categories
Own Calcualation based on data from (Apple, 2016b) in (Microsoft, 2016c)

All categories have a different square size that expresses their share on the total GGEs. As can be seen the category with the most emissions is MacBook with 13,940 kg CO_2e, followed by iMac with 12,730 kg CO_2e, and Mac mini with 5,440 kg CO_2e. These three emit more than 75% of the total portfolio GGEs. Following are Display with 3,250 kg CO_2e, Mac Pro with 3,050 kg CO_2e, and iPad with 2,140 kg CO_2e. All categories after these show minor impacts compared to the others with three-/two-digit emissions.

LCS GGEs by Categories

To comprehend how the total emissions for the categories are allocated by each PLC stage, the table below states all necessary values (Tab. 13).

Category	Production in kg CO2e	Customer Use in kg CO2e	Transport in kg CO2e	Recycling in kg CO2e
MacBook	10,016.50	2,967.20	781.70	174.60
iMac	5,599.20	6,320.00	615.20	195.60
Mac mini	1,865.60	3,448.90	71.10	54.40
Display	1,200.40	1,944.80	72.30	32.50

[32] For a description of treemaps, see Chapter 3.4 – Treemaps.

Mac Pro	1,391.70	1,555.10	72.70	30.50
iPad	1,649.10	360.45	103,30	25,15
iPhone	639,30	176,25	38,90	10,55
AirPort	161.95	464.00	20.60	8.45
iPod	266.01	77.79	21.25	4.95
Apple TV	125.10	73.50	7.20	4.20
Apple Watch	34.50	5.00	8.00	2.50
Total	**22,949.36**	**17,392.99**	**1,812.25**	**545.40**

Table 13: Total and LCS GGEs by Categories
Own Calcualation based on data from (Apple, 2016b) in (Microsoft, 2016c)

The table is sorted from the in Fig. 45 calculated most emitting category to least. On the single stages, e.g. the MacBook emits 10,016.50 kg CO_2e in production. The last row shows the total for the regarding LCS. Production records with 22,949.36 kg CO_2e the most emissions, followed by customer use with 17,392.99 kg CO_2e, transport with 1,812.25 kg CO_2e, and recycling with 545.40 kg CO_2e.

Fig. 46 illustrates the single table values along with the amount of released products for each category to give a better insight on how to interpret the values as well as a possible correlation.

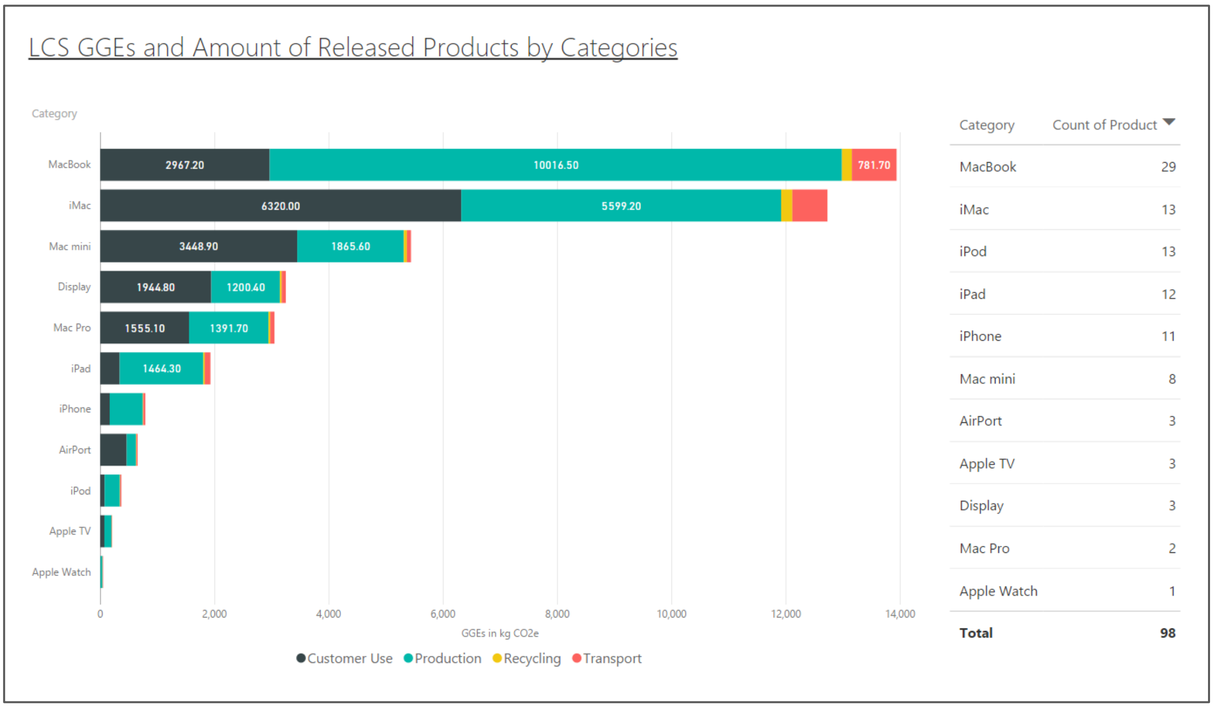


Figure 46: LCS GGEs and Amount of Released Products by Categories
Own Calcualation based on data from (Apple, 2016b) in (Microsoft, 2016c)

The categories are again sorted from most emitting to least. Here the single LCS compositions can be identified. For MacBook, the production stage is the most emitting, while for the iMac it is the customer use stage. In both, transport and recycling, show low impacts. Although Mac mini is only the third most emitting category, it causes in the customer use stage more emissions than MacBook. Next to the bars are the amount of released products, also sorted from most to least. The table shows that 29 MacBooks are part of the portfolio, followed by 13 iMacs. Until there, the list correlates with the emissions chart. However, the third most releases has the iPad, which is only the sixth most impacting category. This shows again that the amount of products does not significantly influence the total emissions also on the level of categories. Furthermore, it can be seen, that although, there are only 13 products in the category iMac, those emit almost as much GGEs as the MacBooks. The iMac category emits per product 979.23 kg CO_2e. This is twice as many as the average in the MacBook category with 480.68 kg CO_2e. Also on each PLC stage, the iMac emits on average more than the MacBook. For example, in production, iMac emits 430.70 kg CO_2e per product and MacBook emits 345.40 kg CO_2e. While MacBook is in overall the category with the most emissions, the iMac shows the most emissions per product in total and on each PLC stage. These kind of insights can be helpful e.g. in the case of a design decision for the MacBook. Since the usage shows significant lower total emissions than the production, an ecologically decision at Apple could be to extend the lifespan of the products in the MacBook category in order to produce less that last longer. However, many factors are part of such a decision. It could be possible that the lifespan extension would not be achievable without a huge amount of resources and therefore a strongly increasing amount of GGEs in designing new batteries or similar. To reveal the usefulness of such an idea a calculation should include considerations that lead to an answer if such an adjustment would amortize in an acceptable period of time, so higher emissions today could reward in long-term improvements.

4.4.3.4 Model/Product GGE Impact – iPhone

It is also possible to research all distinct models or products of a category. As an example, the iPhone is chosen since it is Apple's most important product category with revenue shares of over 50% in each of the last quarters (Apple, 2016e). The category iPhone defines a product directly by the hierarchy level of models. Therefore, an iPhone model equals a distinctive product. Thus, both can be used as synonyms. To investigate the footprints, different questions on total and LCS emissions, as well as on possible correlations will be consecutively examined in the following.

Total GGEs by Model/Product

The first graph shows the total emissions by iPhone models organized by their release date from first to last. Additionally, a matrix table[33] shows the release years, the models in these years, and their emissions (Fig. 47).

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[33] For a description of matrix tables, see Chapter 3.5 – Tables.

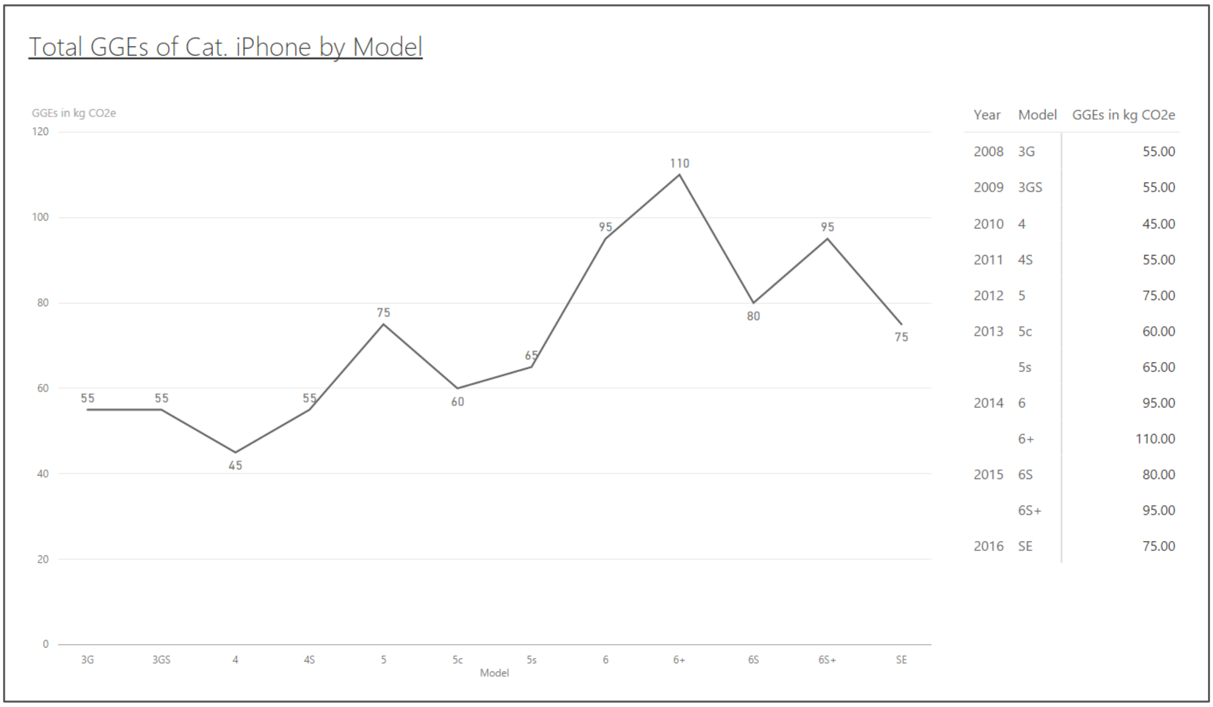


Figure 47: Total GGEs of Cat. iPhone by Model
Own Calcualation based on data from (Apple, 2016b) in (Microsoft, 2016c)

Starting with 55 kg CO_2e of the iPhone 3G in 2008 the emissions vary only by 10 kg CO_2e until iPhone 4S in 2011. From there, increasing emissions can be seen with several variations and the highest emissions for the 2014 models 6 with 95 kg CO_2e and 6+ with 110 kg CO_2e. Thus, 2014 has the highest impact with 205 kg CO_2e. It can be seen that model 6+ causes twice as many emissions as the first considered iPhone, model 3G. When looking at the direct succeeding models for 6 and 6+ in the subsequent year, the emissions had been decreased in each case by 15 kg CO_2e to model 6S as well as 6S+. The latest model SE from 2016 causes 75 kg CO_2e and is therewith slightly above the average of 72.08 kg CO_2e. In total, the category emits 865 kg CO_2e, which conforms to the seventh most emissions among all categories as shown in Chapter 4.4.3.3. – Fig. 45.

LCS GGEs by Model/Product

The course of the single models can then be be divided into its life cycle emissions. Below all necessary data is illustrated (Tab. 14).

Model	Production in kg CO_2e	Customer Use in kg CO_2e	Transport in kg CO_2e	Recycling in kg CO_2e
3G	24.75	26.95	2.75	0.55
3GS	24.75	26.95	2.75	0.55
4	25.65	15.30	3.60	0.45
4S	33.00	17.05	3.85	1.10
5	57.00	13.50	3.00	1.50
5c	36.50	10.50	2.00	1.00

5s	52.00	9.10	3.25	0.65
6	80.75	10.45	2.85	0.95
6+	89.10	15.40	4.40	1.10
6S	67.20	8.00	4.00	0.80
6S+	79.80	10.45	3.80	0.95
SE	61.50	10.50	2.25	0.75
Total	**639.30**	**176.25**	**38.90**	**10.55**

Table 14: LCS GGEs of Cat. iPhone by Model
Own Calcualation based on data from (Apple, 2016b) in (Microsoft, 2016c)

As can be seen, e.g. model 3G causes in the LCS of production 24.75 kg CO_2e. The last row calculates the total GGEs for each PLC stage. According to that, most emitting is production with 639.30 kg CO_2e, followed by customer use with 176.25 kg CO_2e, transport with 38.90 kg CO_2e, and recycling with 10.55 kg CO_2e. The same rank order had also been revealed for the entire portfolio respectively for all categories in Chapter 4.4.3.3 – Tab. 13. The single LCS developments are illustrated in the line chart below (Fig. 48)

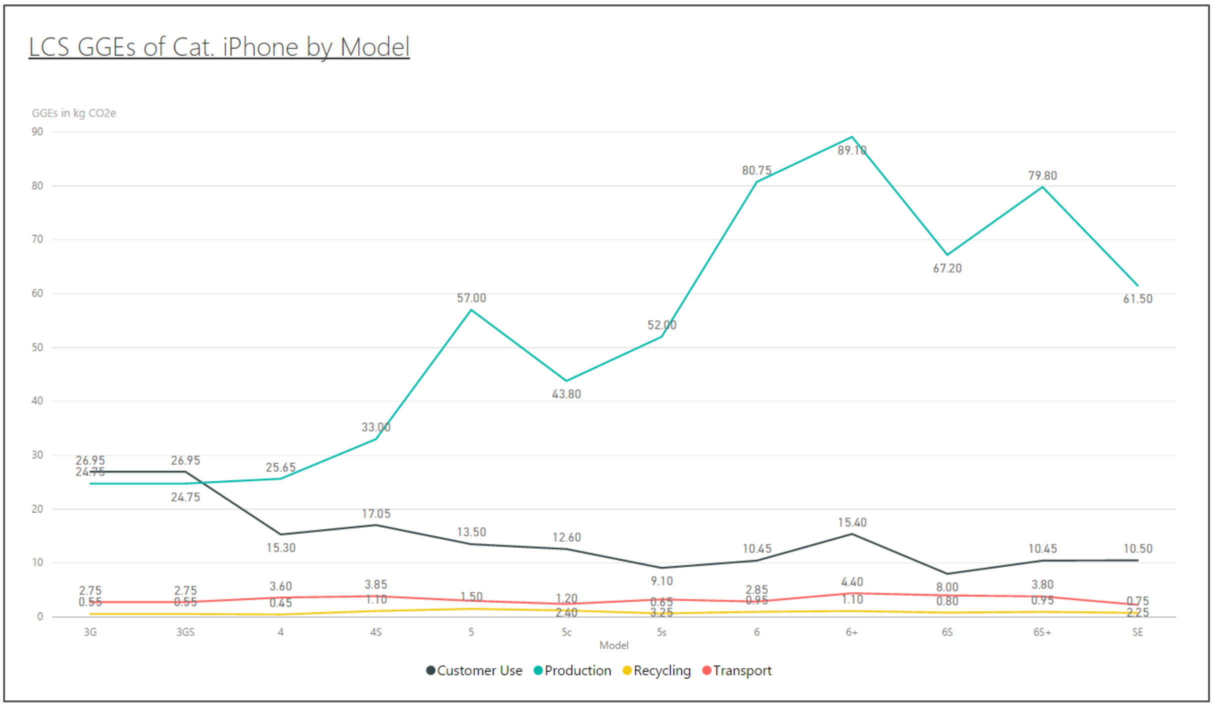


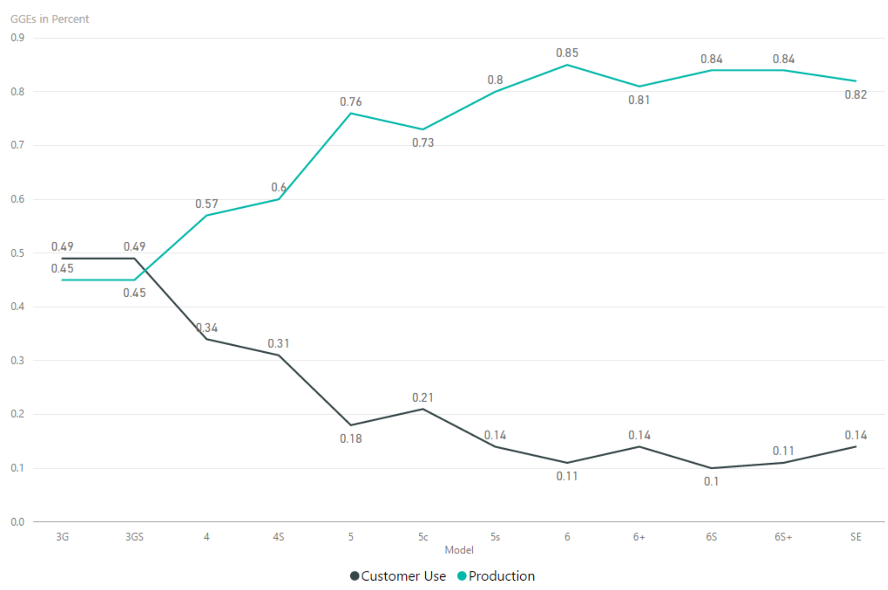
Figure 48: LCS GGEs of Cat. iPhone by Model
Own Calcualation based on data from (Apple, 2016b) in (Microsoft, 2016c)

The graphs illustrate each emission progression in detail. As shown in the table before, production is in total the most emitting LCS followed by customer use. However, at the first two models (3G and 3GS) customer use was the most emission causing stage. The graph demonstrates that the usage emissions has been reduced in total over time with only slightly peaks in between. On the contrary, the production GGEs show an increase over time. This identifies the production phase as the most critical LCS to perform improvements that would be conducive to a progressive environmental policy at Apple. Transport and recycling display a continuously low influence and can therefore be considered as the areas with the lowest saving potentials. Since there is no possibility to access production data in more detail, which could e.g. help to assess why the production of model 6+ emits with 89.10 kg CO_2e almost three times as much as the production of model 3G with 24.75 kg CO_2e, future studies should attempt to get more data for a deeper investigation on the reasons.

Production and Customer Use GGEs in Percent by Model/Product

One further investigation possibility by using the currently available dataset is to analyze the LCSs developments in percent. This is useful to evaluate the shares of each stage on the total emissions, to examine their overall performance. Since production and customer use were identified as the most emitting LCSs, the percent investigation will consider these two stages. Below both graphs with the corresponding table are illustrated (Fig. 49).

Production and Customer Use GGEs in Percent of Cat. iPhone by Model



Model	Customer Use	Production
3G	0.49	0.45
3GS	0.49	0.45
4	0.34	0.57
4S	0.31	0.60
5	0.18	0.76
5c	0.21	0.73
5s	0.14	0.80
6	0.11	0.85
6+	0.14	0.81
6S	0.10	0.84
6S+	0.11	0.84
SE	0.14	0.82
Total	**0.20**	**0.74**

Figure 49: Customer Use and Production GGEs in Percent of Cat. iPhone by Model
Own Calcualation based on data from (Apple, 2016b) in (Microsoft, 2016c)

The line chart reveals a remarkable development since both stages only run parallel in the first two models. Afterwards, they seem to influence each other in the form that when one goes up the other goes down, which results in the illustrated pattern. The only exception apart from the first two models can be found from model 6S to 6S+ where the customer use emissions increase while the production emissions stay the same. This could be because of a slight increase of customer use emissions by only 0.01%. The pattern seems reasonable since the LCSs of transport and recycling do not have a significant impact on the total GGEs. If one of the two most emitting stages loses or gains emissions the other is likely to do the opposite.

Possible Explanations of Selected Developments

After assessing and interpreting the total as well as the life cycle GGEs, selected cases for both shall be questioned. Since all products do have diverse properties on top of the introduced release date, size, and retina, these can also serve as possible explanations of the examined developments. To illustrate possible model differences, Fig. 50 shows a visual comparison of the products iPhone 3G and iPhone 6 in scale 1:2.

Figure 50: Visual Differences of iPhone 3G compared to iPhone 6 (scale 1:2)
Images by (Apple, 2016f)

These two products have several distinguishing characteristics such as their height, width, and depth, their weight, or materials, which all apply to their footprints. In material usage, for example, the iPhone 6 uses aluminum (Apple, 2014b) while the iPhone 3G does not include this material (Apple, 2008). In the following, the examples of the product weights as well as the effects of different materials for all iPhone models will be used to investigate possible correlations with the emissions.

1) Product Weights and Total GGEs

This case aims to examine if the weights of the single products show a possible connection to the total GGEs. Therefore, both developments are combined in the report below (Fig. 51).

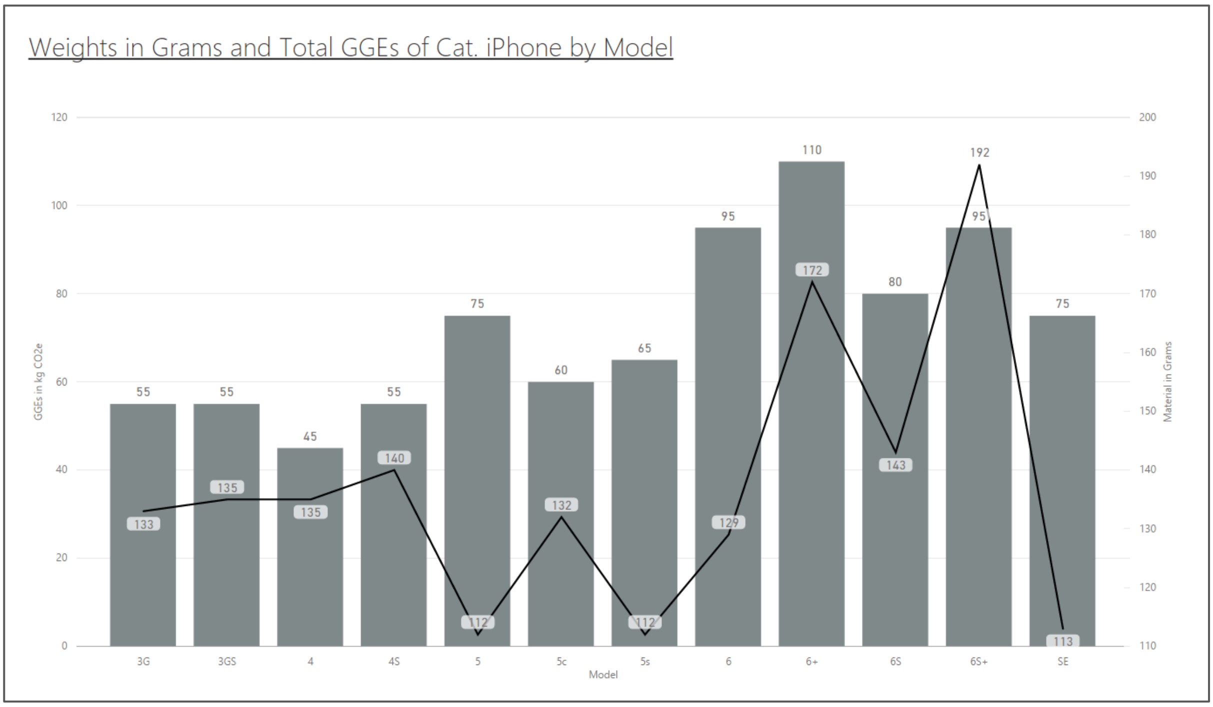


Figure 51: Weights in Grams and Total GGEs of Cat. iPhone by Model
Own Calcualation based on data from (Apple, 2016b) in (Microsoft, 2016c)

The report shows the emissions per model (Fig. 47) as a stacked column chart and the model weight as a line chart. The X-axis shows the iPhone models. The left Y-axis states the GGEs in kg CO_2e. The right Y-axis shows the weight of the according product in grams by summarizing all material weights. The report enables to research if there are obvious deviations between both graphs. For example, the two models 5 and 5s have the same weight with 112 grams, but model 5 emits with 75 kg CO_2e, 10 kg CO_2e more than model 5s with 65 kg CO_2e. Another possibility is to determine single models and their predecessors. From model 4S to 5, for example, the emissions increase by 20 kg CO_2e, but the weight decreases by 28 grams. A further example is the examination, if the most emitting product is at the same time the heaviest. Most emitting is the iPhone 6+, but it has only the second highest weight. The heaviest iPhone is the 6S+ that causes 95 kg CO_2e. The same emissions can be detected for the model 6 that is with 129 grams, 63 grams lighter than model 6S+. As the examination reveals, there is no explicit correlation between weight and GGEs. This result clarifies that the consideration of individual factors can be insufficient for such a complex problem. On the one hand, a higher weight would also explain a higher material consumption and hence e.g. a higher demand for fossil fuels. On the other hand, the change of materials also requires considering their emissions or potentially adopted production processes that could have lower environmental impacts. A heavier product with improved processes could thus cause fewer emissions.

To deeper investigate this relationship, a further possibility would be to use the Value Distance Model that was introduced in Chapter 4.4.3.2 – Tab. 10 for an easier recognition of deviations also between non-consecutive models.

2) Material Impact on Total GGEs

Another possible correlation could exist between the total GGEs and specific materials. The illustration below shows first the material composition for all iPhone models (Fig. 52).

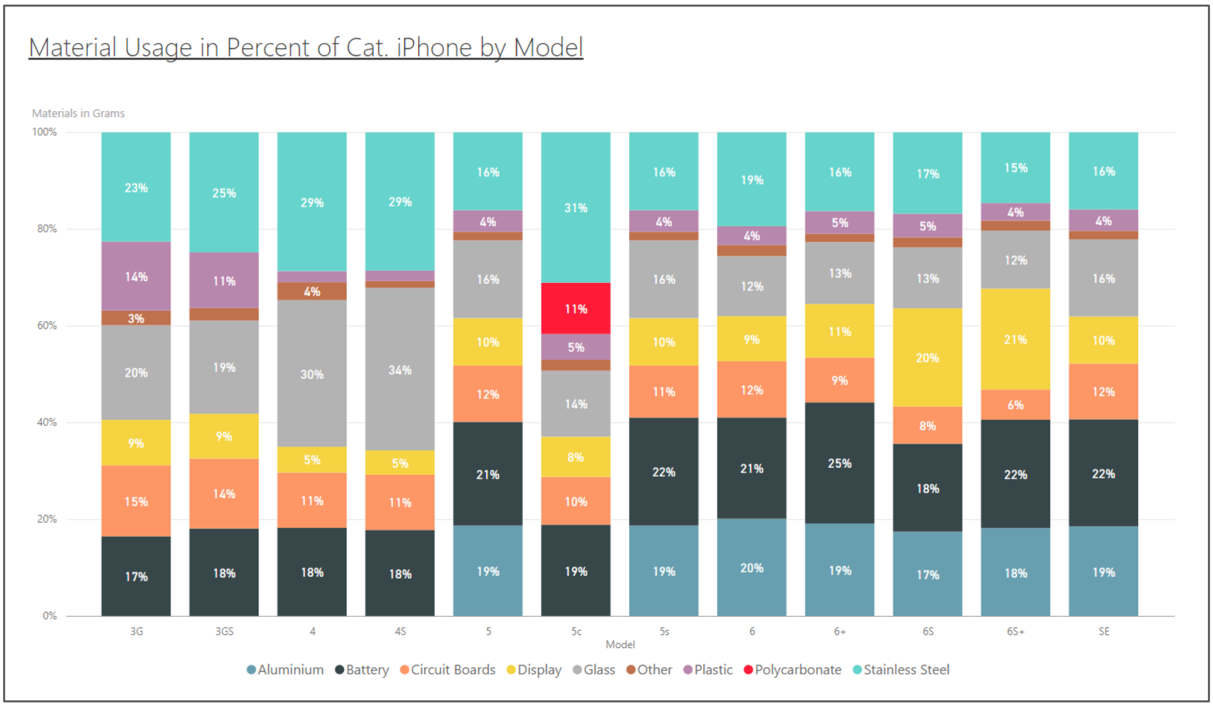


Figure 52: Material Usage in Percent of Cat. iPhone by Model
Own Calcualation based on data from (Apple, 2016b) in (Microsoft, 2016c)

The legend at the bottom center lists all materials, which are used by the category iPhone in alphabetical order: *aluminum*, *battery*, *circuit board*, *display*, *glass*, *other*, *plastic*, *polycarbonate*, and *stainless steel*. The illustration e.g. shows that the models 5, 5c, 6, 6+, 6S, 6S+, and SE use *aluminum*, or that all models need a *battery* for their composition. It is also possible to see that only one model has a red part that stands for *polycarbonate*, which is a harmful material that should be avoided (Guerra, 2006, p. 54; Wired, 2013). Further studies could question the impact of that material by conducting the model 5c and its emissions in more detail.
Based on this illustration the question occurs, if there is a material that shows a significant impact on the total GGE development. To examine this possibility, the total emission graph must be compared to each material development. Doing so, the aluminum graph matches the expectations. The illustration below shows the combination of both graphs (Fig. 53).

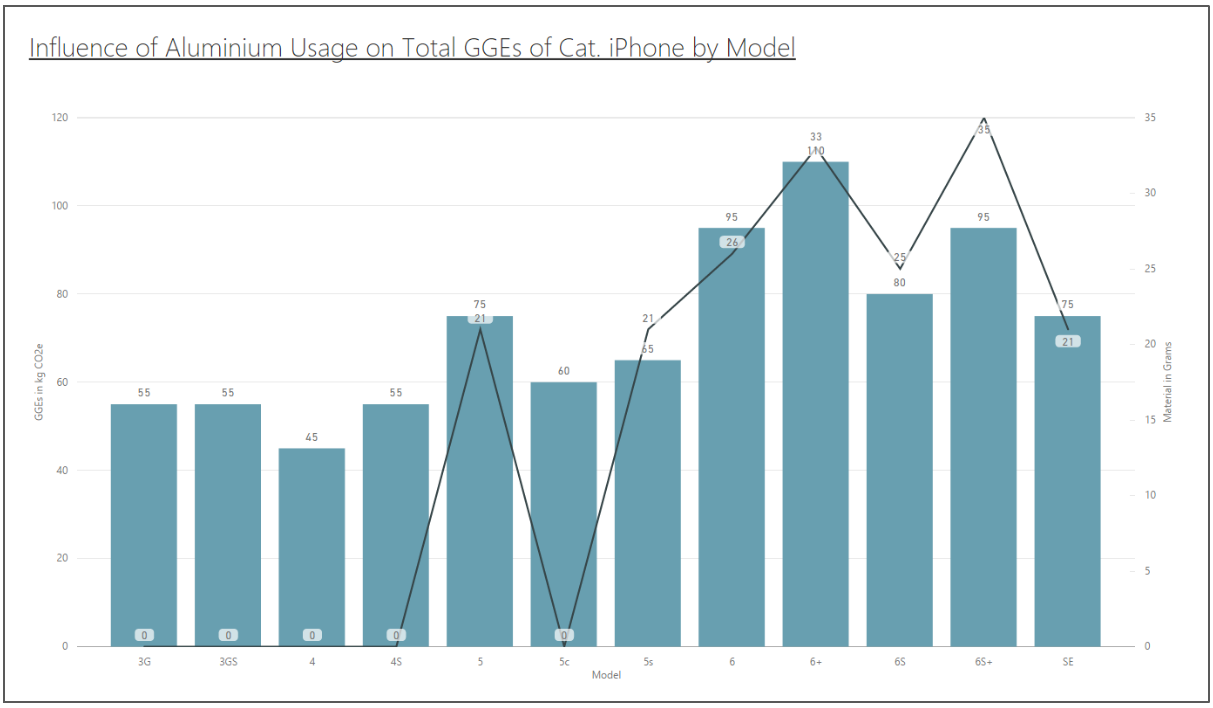
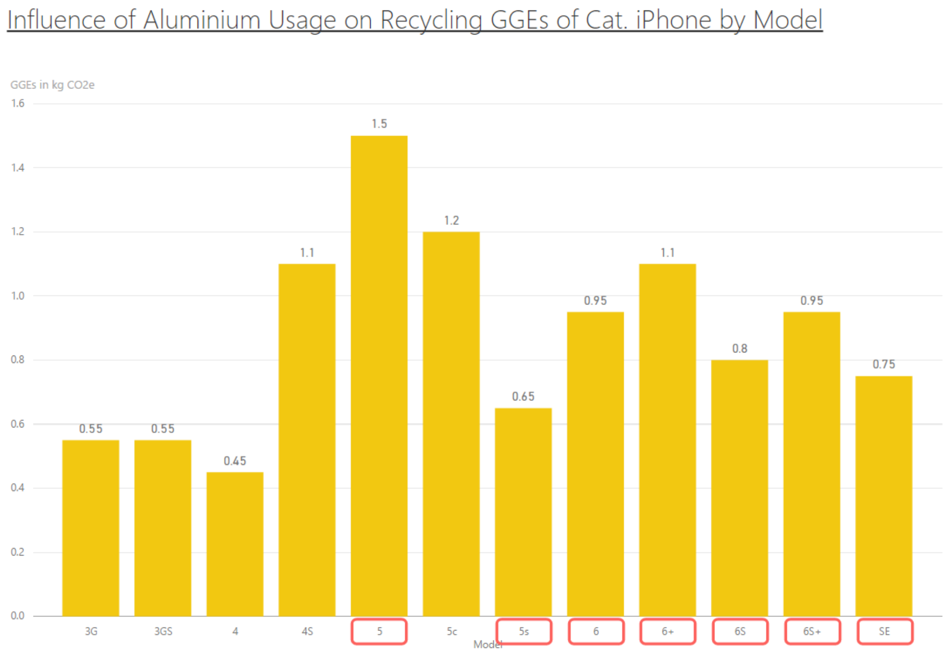


Figure 53: Influence of Aluminum Usage on Total GGEs of Cat. iPhone by Model
Own Calcualation based on data from (Apple, 2016b) in (Microsoft, 2016c)

The report shows the emissions per model (Fig. 47) as a stacked column chart and the aluminum usage as a line chart. The X-axis shows the iPhone models. The left Y-axis states the GGEs in kg CO_2e. The right Y-axis shows the grams of used aluminum. Since aluminum was not part of the first four models, the examination starts by considering the change from 4S to 5. It can be seen that whenever the use of alumnium increases or decreases the GGE graph is going in the same direction. It can also be seen that all models without aluminum (3G, 3GS, 4, 4S, 5) show emissions between 45 kg CO_2e and 60 kg CO_2e. The aluminum models show emissions from 65 kg CO_2e to 110 kg CO_2e. By these observations, it is indicated that aluminum has a profound impact on the total emissions in the category iPhone. However, aluminum is a good example to demonstrate again the complexity of the problem, since for the models 5 and 5s the same amount of aluminum has been used, but neither the emissions show the same value nor the emission changes from the predeceasing models are equal. Therefore, deeper investigations e.g. on single LCS emissions would be necessary to further research the indicated correlation. Therefore, the last investigation example researches the aluminum impact on the LCS of recycling in more detail.

3) Influence of Aluminum on the LCS of Recycling

According to Apple, aluminum is used because it is almost indefinitely recyclable (Apple, 2016h). Deriving from this statement the question occurs, how the recycling of aluminum influences the LCS of recycling itself. Fig. 54 shows the recycling GGEs in kg CO_2e and states the models that are using aluminum in red cycles supplemented by a table with the amount of aluminum usage by each model.



Model	Material in Grams
5	21.00
5s	21.00
6	26.00
6+	33.00
6S	25.00
6S+	35.00
SE	21.00
Total	**182.00**

Figure 54: Influence of Aluminum Usage on Recycling GGEs of Cat. iPhone by Model
Own Calcualation based on data from (Apple, 2016b) in (Microsoft, 2016c)

At the first impression one can see that the three lowest recycling emissions are at models that do not use aluminum (3G, 3GS, 4). The other two non-aluminum models (4S, 5c) have with 1.1 kg CO_2e and 1.2 kg CO_2e significant higher emissions. The highest GGEs has model 5 that uses aluminum. In general it could be assumed, that when more recycable materials are used the recycling efforts and therewith the emissions of this stage increase. However, by looking at the table on the right and the emissions it is revealed, that there is no clear interconnection of aluminum and the recycling GGEs. On the one hand, Model 5 has the highest recycling emissions and uses aluminum. On the other hand, Model 5s uses with 21 grams the same amount of aluminum but does only have 0.65 kg CO_2e. That is less than half of the emissions caused by model 5. This relationship has already been demonstrated for aluminum and the total GGEs and applies also to aluminum and the recycling emissions. It must therefore be assumed, that the emission causing factors in the LCS of recycling are based on other materials or indicators such as machine usage or similar. However, while using aluminum because of its recyclability is a good intention, Apple should also consider possible side effects that could influence e.g. the PLC stage of recycling in a negative way.

4.4.3.5 Property GGE Impact – Retina Display

Researching the question if the use or not use of a retina display has a possible impact on the total or the life cycle GGEs shall be the last sample environmental impact analysis for the Apple dataset.

Total GGE Impact of Categories with Retina Display

Firstly, the chart below lists all products that have a retina display and their total GGEs. In addition, two tables beside the chart show the amount of retina products for each category and the emissions by category. Both are sorted from most to least (Fig. 55).

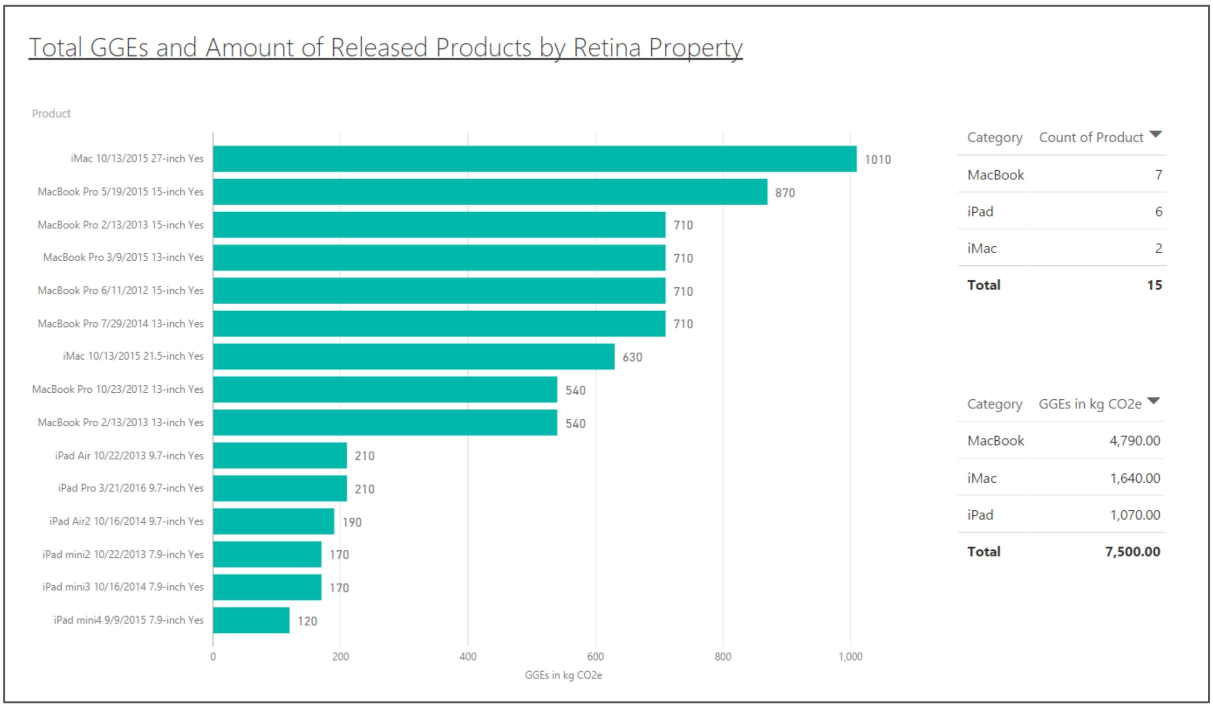


Figure 55: Total GGEs and Amount of Released Products by Retina Property
Own Calcualation based on data from (Apple, 2016b) in (Microsoft, 2016c)

It can be seen that the property retina display only occurs in the categories iMac, MacBook, and iPad. As the chart lists, the highest footprint is detected by the *iMac 2015 27-inch* with 1,010 kg CO_2e, followed by several MacBooks. The lowest emissions are shown by products of the category iPad. The first table displays that MacBook has with an amount of seven the most retina products, followed by iPad with six, and iMac with two. In total, 15 of the 100 products in the analysis portfolio have a retina display. The second table shows that the highest impact of a category has MacBook with 4,790 kg CO_2e, followed by iMac with 1,640 kg CO_2e. However, on average the iMac causes with 820 kg CO_2e the most emissions, followed by MacBook with 684.28 kg CO_2e. Therefore, the data reveals that the number of products and the GHG emissions do not show a correlation also among products with retina displays. As further shown, in total 7,500 kg CO_2e are emitted by retina products, which complies with 17.55% of the portfolio emissions.

Retina Impact on Total and Life Cycle GGEs

Taking this overall picture in a smaller context shall reveal, if there is a significant retina impact. Therefore, the portfolio contains two products that have, except their retina display, no differences: iMac 2015 21-inch, and MacBook Pro 2012 15-inch. Fig. 56 illustrates their total and life cycle emissions as tables and stacked column charts.

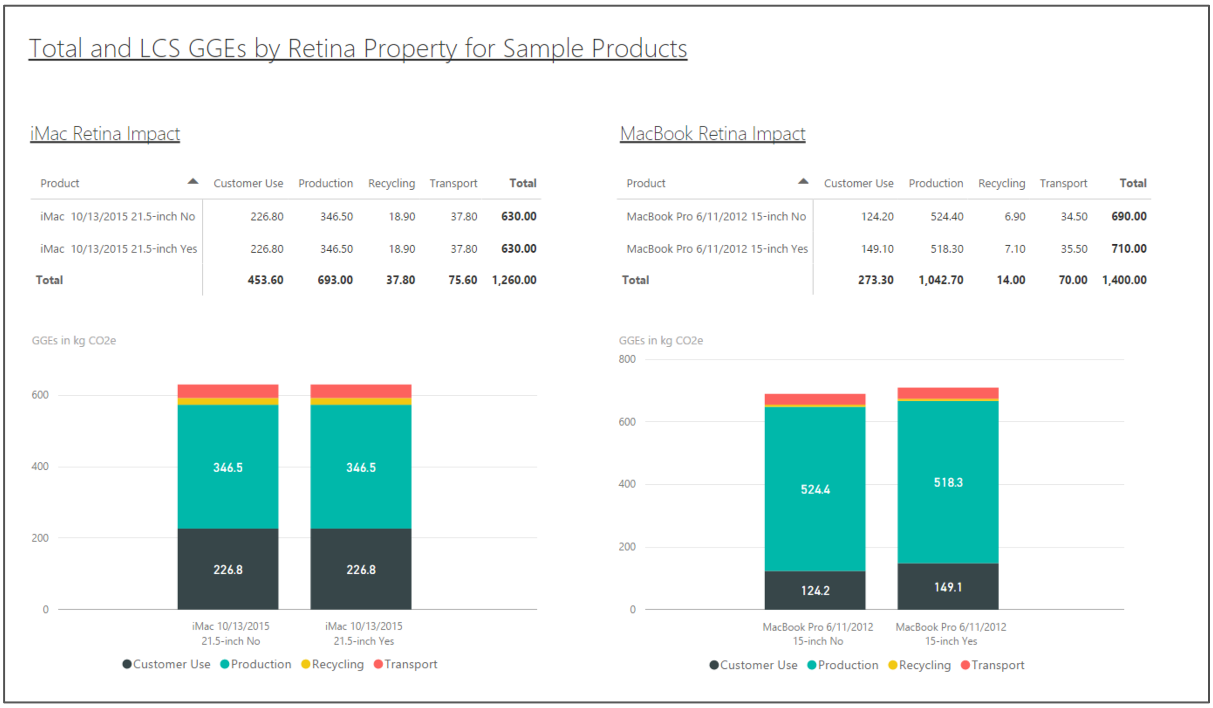


Figure 56: Total and LCS GGEs by Retina Property for Sample Products
Own Calcualation based on data from (Apple, 2016b) in (Microsoft, 2016c)

As the left side shows, both iMacs have the same total and life cycle emissions. Therefore, retina seems to have no impact. On the contrary, the right side shows that the MacBook with retina display emits more GHGs than the non-retina model in total and in each LCS. Thus, no explicit correlation between retina and total or life cycle GGEs can be revealed.

4.4.4 Dashboard Insights Communication and Discovery

Since this paper is about analyzing and communicating valuable environmental insights, building dashboards based on the created reports is the last important step of the Apple Environmental PLC Data Monitoring Model. The usefulness of dashboards for this purpose is confirmed by several publications, which describes them as a unique and powerful medium that enables information sharing and live monitoring so the right people at the right time can make well-informed decisions (Aspin, 2015, p. 3; Few, 2006, p. 2; Melike, 2005, p. ix). To create dashboards in the framework of the implemented model, Power BI Desktop must be connected to Power BI Service, since the service focuses on the information sharing on different device applications via dashboards. Fig. 57 shows the process of connecting both with one another.

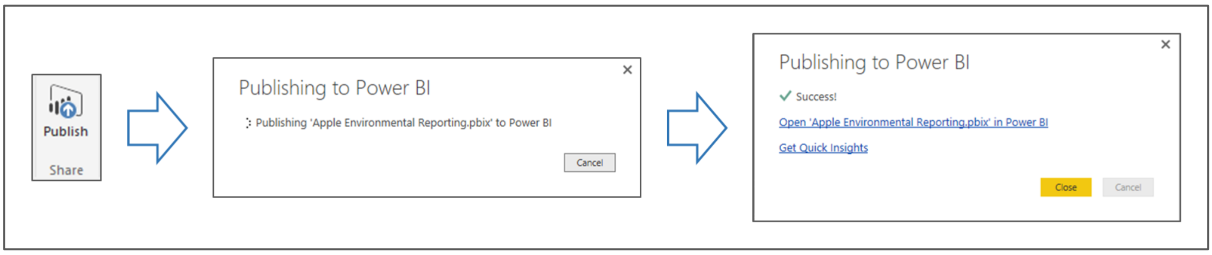


Figure 57: Report Publishing Process in MS Power BI Desktop
Own illustration in (Microsoft, 2016c)

Via *Publish* in the ribbon menu of the desktop tool the upload starts. With a succeeded publishing process, screenshot three results and the data appears in the navigation bar of the services tool (Fig. 58).[34]

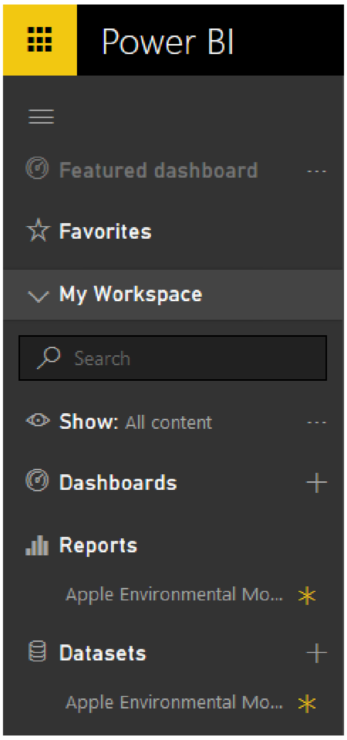


Figure 58: Apple Dataset in MS Power BI Service
Own illustration in (Microsoft, 2016d)

The data is structured by datasets, reports, and dashboards. This complies with the Power BI process (Chapter 3.5 – Fig. 14) and therefore, with the last three steps of the Apple Model (Chapter 4.2 – Fig. 20). By selecting the created report, the single insights can be viewed as in the desktop tool. Above are the dashboards, which have various possibilities in creating them. Examples could

[34] For a description of the Power BI Service UI, see Chapter 3.5 – Fig. 16.

be production dashboards for positions such as plant managers, regional dashboards for managers of the eastern or western region, or specific category dashboards e.g. for the iPad team. Considering the last case, the entire iPad category report from Chapter 4.4.2 – Fig. 37 could be transferred to a dashboard and shared with each iPad team member. To illustrate a further possible use case, Fig. 59 shows a sample dashboard for the Chief Sustainability Officer (CSO). The screenshot is extended by numbers for the subsequent description.

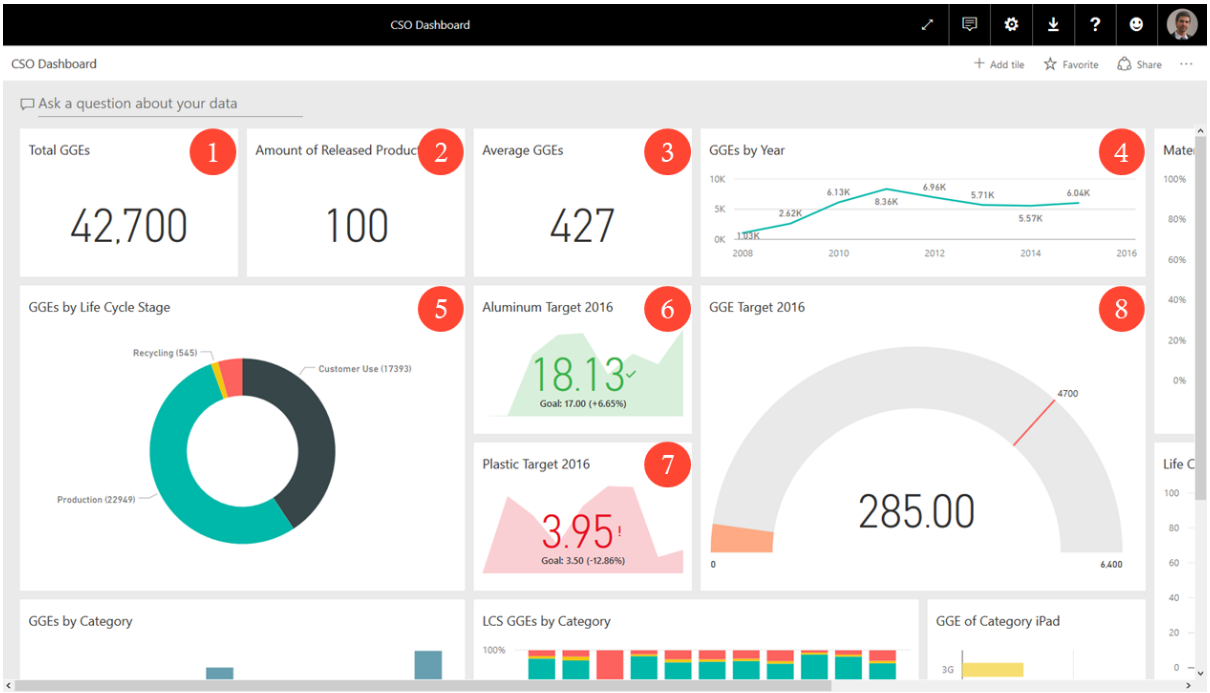


Figure 59: Chief Sustainability Officer Dashboard – Browser View
Own Calculation based on (Apple, 2016b) in (Microsoft, 2016d)

For the *CSO Dashboard* it is assumed that the CSO needs an overview of the most significant environmental developments among the entire portfolio. Therefore, the dashboard shows the total GGEs with 42,700 kg CO_2e (1). These are produced by 100 products (2). The average is therefore 427 kg CO_2e (3). In addition, the development of the total portfolio GGEs by year (4) and the life cycle emission assembly (5) for the entire product portfolio are presented. Furthermore, two KPIs are displayed, which warn the user when they are out of acceptable boundaries. One example case (6) is that the CSO has given the goal that the percentage of aluminum usage in 2016 always has to be above 17% because the recyclability of the material is appreciated. The *Aluminum Target 2016* KPI measures this by showing the goal of 17.00% and the current amount of 18.31%. Therefore, the target is surpassed by 6.65% currently, which effects a green coloring of the widget. Additionally, an overall trend based on a yearly consideration is given in the background. A second example (7) shows the case that not more than 3.5% of plastic should be used in 2016, because the material has been identified as harmful to the nature. Currently, this goal is not reached since 3.95% of plastic are used in the two released products of 2016. That complies with an exceedance of 12.86%, which effects a red coloring of the KPI. The *Plastic Target 2016* KPI is therefore out of acceptable boundaries, which can affect an alert of the CSO. In this case, a notification via email and in the respective applications for all connected devices prompt to communicate that an action might be needed. A last important indicator (8) are the GGEs in 2016. The gauges[35] widget displays the case that the CSO has announced the goal that in 2016 not more than 6,400 kg CO_2e (emissions of 2015) are acceptable, but the target is to emit not more than 4,700 kg CO_2e. Until today there are 285 kg CO_2e emitted within 2016. The goal is therefore still achievable.

This dashboard can be accessed in real-time via mobile devices such as tablet PCs or smartphones. As Malik (2005, p. ix) says: "The term dashboard has acquired a vibrant new meaning in the field of information management as leading organizations worldwide embrace the idea of empowerment through improved real-time information systems." Therefore, Fig. 60 shows three screenshots of the *CSO Dashboard* in the Power BI iOS application.

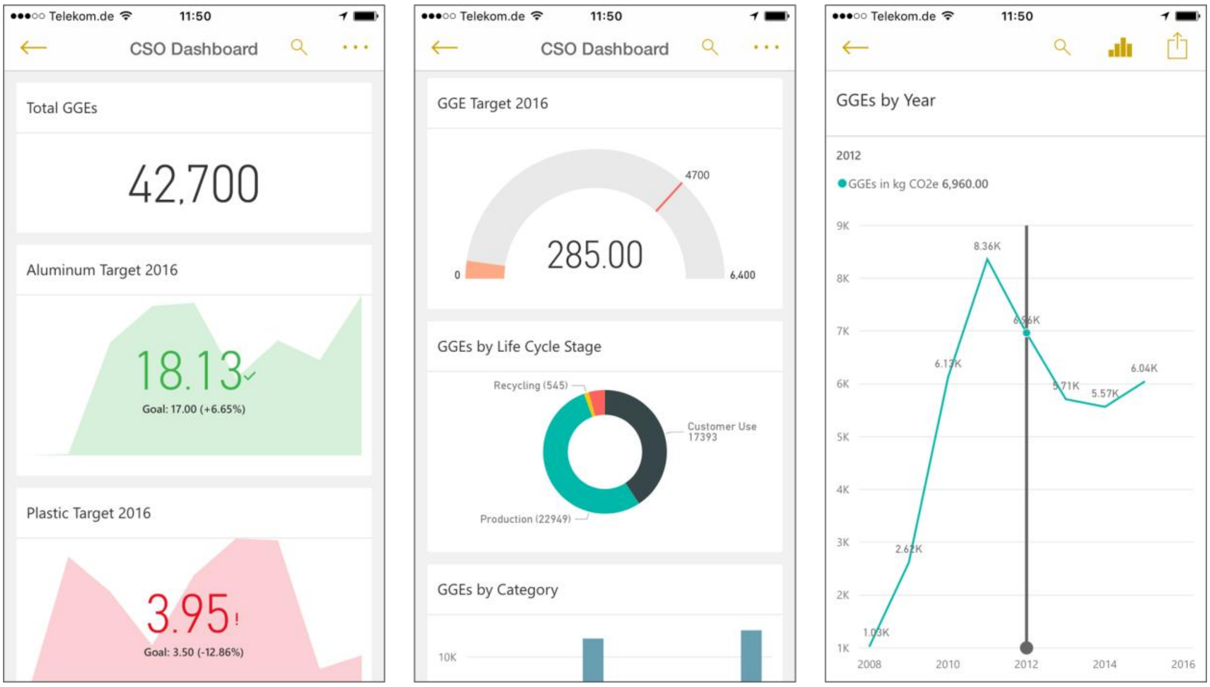


Figure 60: Chief Sustainability Officer Dashboard – Mobile View (iOS)
Own Calculation based on (Apple, 2016b) in (Microsoft, 2016i)

Herein, the CSO can see all relevant data via its smartphone. For example, the left screenshots shows the aluminum and the plastic target KPIs. By selecting a widget the single insight can be viewed, such as in screenshot three, which shows the total GGE development by year. This widget can be interactively examined, e.g. by selecting a specific year. Furthermore, the CSO can make notes directly on the widget and send it via email or messengers to other employees to ask questions. Moreover, in the case of a KPI outrage alert, the application can prompt a notification.

[35] For a description of gauges, see Chapter 3.4 – Gauges.

The service has further capabilities that can be useful to obtain additional environmental insights. One possibility is to get similar insight suggestions based on already created widgets. This shall be shown on the example of the total GGEs over year graph, which was created in Chapter 4.4.3.2 – Fig. 42. By using the functionality, the below illustrated graph is recommend as a possible related insight (Fig. 61).

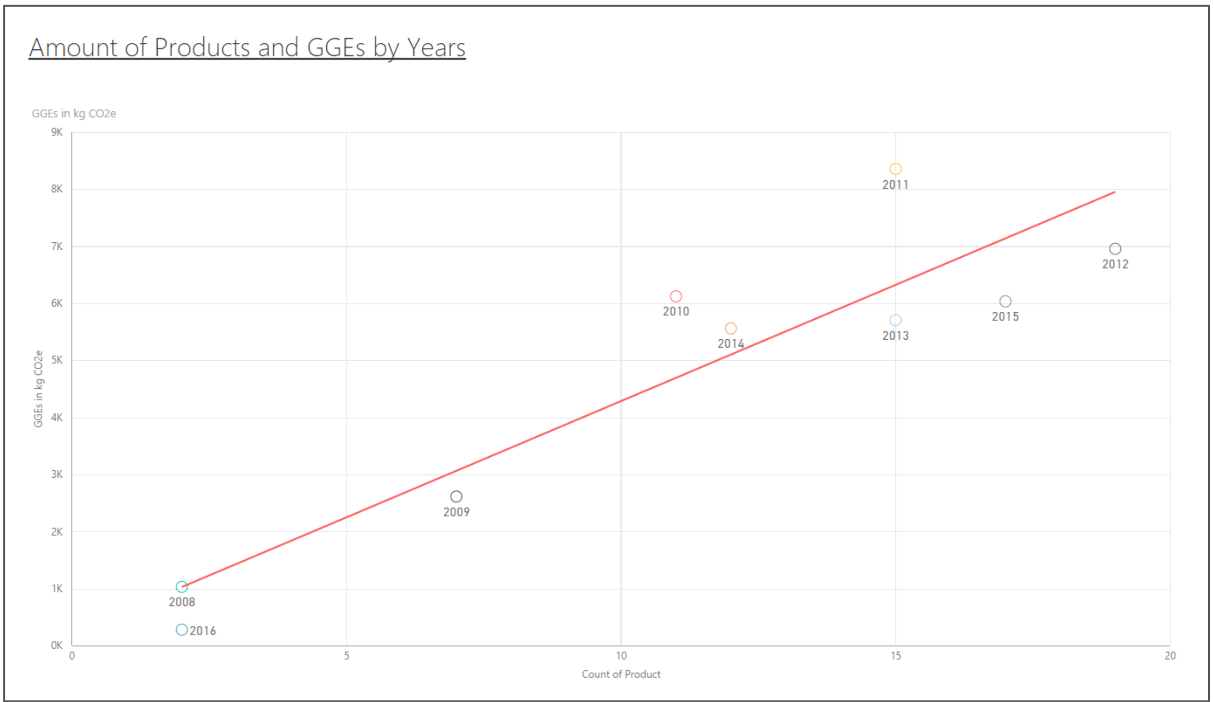


Figure 61: Power BI Service Automated Insights – Amount of Products and GGEs by Year
Own Calculation based on (Apple, 2016b) in (Microsoft, 2016d)

The service indicates that the number of released products correlates with the total GGEs by year for the entire product portfolio. Therefore, the graph presents on the X-axis the count of products and on the Y-axis the GGEs in kg CO_2e. The data points show the placement of the year in this graph. The line displays the trend of the total GGEs. A similar examination was already performed in Chapter 4.4.3.2 – Fig. 44 in form of a stacked column and line chart. Although the relationship is not explicit in each case, a correlation can be recognized. Thus, this suggestion gives a useful data insight that is automatically discovered by the tool.

Another valuable capability provided by the service tool is the question and answer (Q&A) functionality that can respond on real-life questions with insights from the dataset. It can be found on each dashboard in the upper left by the text *Ask a question about your data*. Therein, the user also gets advice on what to ask for. To demonstrate the functionality one sample question is: how much GGEs in kg CO_2e does the iPhone model 6 emit as card? (Fig. 62).

Figure 62: Power BI Service Q&A Functionality – Total GGE of iPhone 6
Own Calculation based on (Apple, 2016b) in (Microsoft, 2016d)

As the service correctly displays the iPhone 6 emits 95 kg CO_2e in total (Apple, 2014b). This capability could be combined with the MS language engine Cortana (Microsoft, 2016k) so a user could ask verbal questions to the dataset (Gartner, 2016a). That is another unique capability offered by the selected BI tool. All these examples demonstrated the utility of the service-oriented provision of environmental reporting insights. Based on the shown examples, further investigation can be performed in a similar way.

4.5 Main Results and Business Values

After implementing the entire process of the Apple Environmental PLC Data Monitoring Model, this section will summarize the key results and show the models business values. In preparation for the impact assessment, the first four steps of the model had the goal to revise the Apple PDF report data by creating a conflict-free data inventory in form of the analyzable BI dataset. Therefore, several steps were taken, from the spreadsheet based data collection, through the data model creation, to the final dataset provision in Power BI Desktop. Based on the created reliable database the last two steps of the Apple Model were conducted by building environmental investigation reports as well as communicating the obtained insights by the use of Power BI Service dashboards. First, the report building enabled several impact determination potentials of the model. Beside the shown general reporting possibilities, it has been proven that the BI approach is able to reconstruct the Apple PDF reports, extended by the interactively rewards of the BI solution. Resulting advantages have been, for example, the navigation trough different levels of the portfolio hierarchy, or the simultaneously display of two or more products in one report. Afterwards, the single environmental impacts of Apple's products regarding GGEs and associated data such as material usages were researched. This revealed that the entire product portfolio records a GGE increase by over 483% among the concluded years 2008 to 2015. Questioning this development by the hypothesis that the number of released products always determines the GGE course, revealed a correlation, but no significant impact. Afterwards, the hierarchy level of product categories was researched by showing a rank order from most emission-causing category to least. Thereby, MacBook was revealed as the most emitting category followed by iMac, while iMac has the most emissions per product with MacBook in second place. Subsequently, the impact on the model and in this case simultaneously product level was studied on the example of the iPhone category. This section discovered that the 2014 models 6 and 6+ are the most GHG causing products of the category. Further considering the single LCS emissions revealed that production and customer use show the most GGEs. Considering the percentage developments of these both stages discovered that the graphs influence each other in the form that when one goes up the other goes down or stays. Afterwards, sample correlation investigations were performed to find possible explanations for the GGE developments of the iPhone category. Here it was shown that the product weight has no profound effect on the total GGEs. Furthermore, the influence of materials on the emissions has revealed that aluminum significantly correlates with the total GGEs, what therefore indicates that this material could have a profound impact on the total emissions. However, the analysis also discovered that an identical amount of used aluminum does not necessary result in identical emissions or an identical emission increase from predecessor to successor. In addition, it was shown, that aluminum has no significant correlation with the emissions in the PLC stage of recycling. The last investigation section researched the influence of the property retina display on total and life cycle GGEs. As discovered, no significant correlation exists. Lastly, all of these report insights were published to the Power BI Service tool to create a sample dashboard for the CSO. This added several more capabilities such as a real-time communication of data insights among different devices, the ability to get ad hoc data insights, or a real-life Q&A functionality. Therewith, the service provided further comprehensively visualized environmental insights that can be utilized by any stakeholder. With all of these capabilities, the model provides a progress and a significant business value for Apple's environmental data monitoring and thus impact reduction efforts.

5 Assessment of Apple Approach and Model Generalization

5.1 Course of Assessment and Generalization

This chapter aims to evaluate the previously implemented Apple Environmental PLC Data Monitoring Model by stating advantages and disadvantages in order to build a generalized model. To do so, it will especially be emphasized which limitations and problems the research revealed in the Apple PDF reports, since these simultaneously limit the analysis possibilities of the Apple Model. Therefore, already solved issues as well as still existing ones are going to be highlighted. By solving the remaining issues, the Generalized Environmental PLC Data Monitoring Model will comprise all advantages of the Apple Model, but without its restrictions. For example, Apple's internal PLC specifications will be questioned to create a more valuable life cycle by using different scientific and practical approaches. Another improvement is the creation of a unified GHG measurement and GGE calculation approach based on current scientific guidance. In addition, components that were created by this paper such as the implemented data model in form of the ERD with its connected table structure have to be generalized to enable their applicability for other organizations. Moreover, reports and dashboards must be handled in a reliable way with clear rules of effective and efficient information provision in order to ensure the usefulness of the communicated insights. Resulting from these assessments and adaptations, the generalized model will offer the necessary standardized process for the monitoring of environmental data that can be applied by other ICT businesses. As Kim and Lee (2011, p. 423) confirm: "Standardization is essential in putting green IT solutions into practical use […]." However, in this context it is important to consider that "depending on the goal and scope of the study, different structuring approaches can be useful." (ISO, 2006b, p. 36) Therefore, the solution provides the overall framework, but constituted by elements that are still flexible, so they can be adjusted to fit different requirements that might exist in the variety of use cases. Deriving from these considerations, the initially stated research question will be eventually answered: How can environmentally related ICT product life cycle data be gathered, prepared, analyzed, reported and appropriately communicated by using state-of-the-art business intelligence technology to monitor the environmental GGE impact of ICT products and processes to support the LCA methodology?

5.2 Generalized Environmental Product Life Cycle Data Monitoring

5.2.1 Conception of Generalized Monitoring Model

The generalized model consists of all necessary steps of the Apple approach corrected and supplemented by elements that are required to generalize and standardize the methodology as well as to enhance its monitoring capabilities. The entire process is illustrated below (Fig. 63).

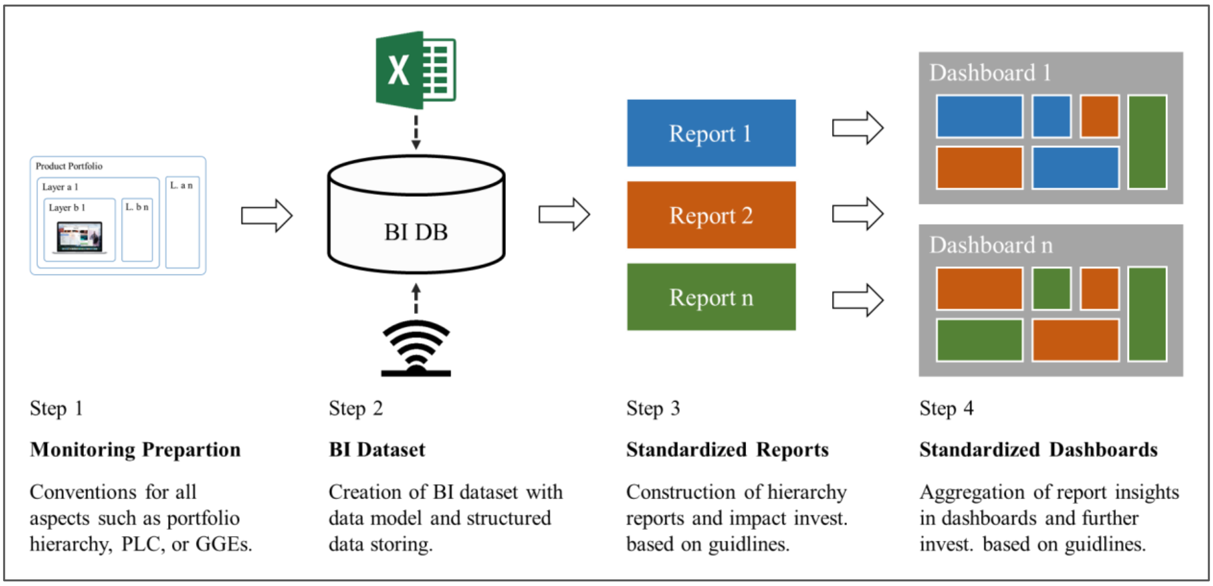


Figure 63: Generalized Environmental Product Life Cycle Data Monitoring Model
Own illustration based on (ISO, 2006a, p. 8; Microsoft, 2016f; Russo, 2015)

Since the model is based on the Apple approach, it is simultaneously oriented on the ISO 14040 LCA framework[36] (ISO, 2006a, p. 8), and the MS Power BI process[37] (Microsoft, 2016f). The single model steps are described in the following:

(1) **Monitoring Preparation**: In the first step, all preconditions for a structured approach must be created. These include the classification of the product portfolio with the choice of the analysis objects, the use of a standardized PLC with consistent stage definitions, a standardized GHG measurement and GGE calculation, and the creation of a company-wide reliable understanding of materials.

(2) **BI Dataset**: All necessary environmental data must be gathered in the proposed data model respectively connected to it, in order to get a well-structured LCI in form of the analyzable BI dataset. Several different data sources can be used such as spreadsheets, sensors, or other

[36] See Chapter 3.3 – Fig. 13.
[37] See Chapter 3.5 – Fig. 14.

databases as well, which should follow defined data quality demands. The required transition steps are included in this stage.

(3) **Standardized Reports**: Based on the created dataset, reports can be implemented for the assessment and interpretation of the inventory. Thus, a wide range of comprehensive environmental questions can be answered. All provided insights should thereby follow guidelines for an effective environmental reporting, to ensure their usefulness.

(4) **Standardized Dashboards**: By allocating the report insights, dashboards can be created. These are used especially for data sharing purposes and further analysis capabilities. Like their underlying reports, they should also follow guidelines for effective insights presentations.

The following sections will gradually reflect this process. The first step is therefore split into four sub units that describe the prerequisites of the environmental monitoring approach.

5.2.2 Preparation of BI Monitoring

5.2.2.1 Generalized Portfolio Classification and Product Selection

A consistent product identification based on a portfolio hierarchy classification is the starting point for a structured environmental impact investigation and monitoring. In the case of Apple, the product names were not standardized, so each product could have different naming conventions. For example: among the category iPhone, all models are uniquely named. Thus, the analysis would only need the model hierarchy level to identify a single product. However, there have been more complicated arrays of names for instance by product categories such as MacBook, where in addition to the model, the properties, release date, size, and retina could have been important for the identification of the exact good. Another issue was discovered in the category iMac that has no model names, but distinguishes by release date and size. All these considerations led to the construction of the Apple Portfolio Hierarchy Classification Model (Chapter 4.3.2 – Fig. 27). Its basic system can be adjusted for any other company by generalizing its levels. As with the Apple classification, the new structure is presented in the form of a box diagram, which is read in a way that the bigger box encloses all the boxes in it (Fig. 64).

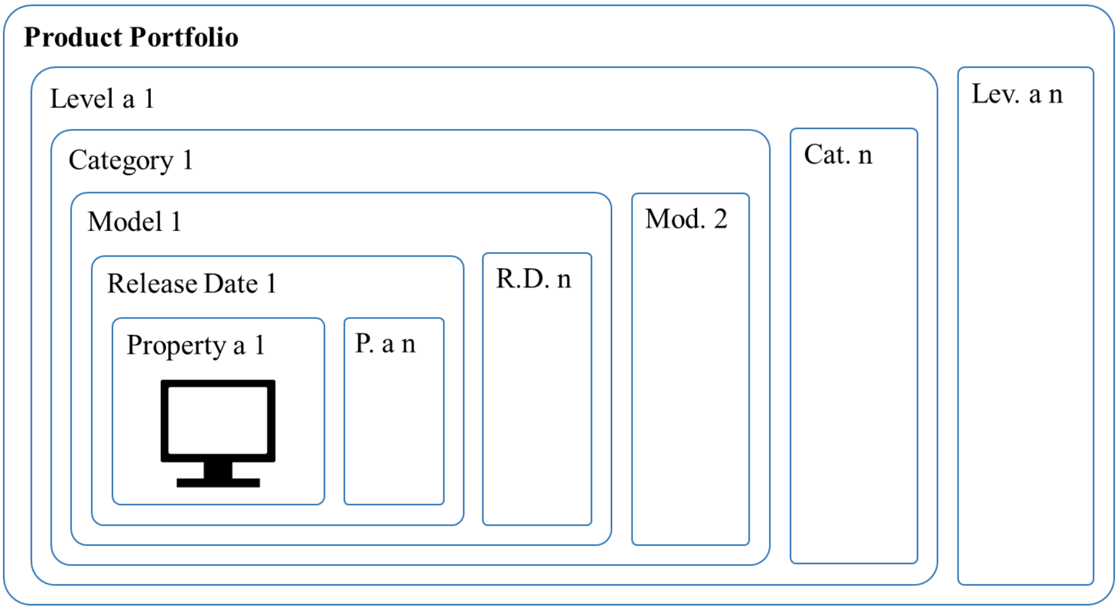


Figure 64: Generalized Portfolio Hierarchy Classification Model
Own illustration based on data from (Apple, 2016b,d)

At Apple there have been categories that included models with their properties. Here, the first level, named *Level a* as a placeholder, is a possible extension that could be used by other companies to have an additional hierarchy level above category. One example of usage for this might be product segments, so one segment would contain all categories that possess a particular combination of attributes. For Apple, this level could group the categories iMac, Mac Pro, and Mac mini to the segment *Desktop PCs*. For a company with several different smartphones a segment could group them to *Smartphones*. Moving on, the *Category*, as well as the *Model* level stay the same. After *Model*, it would also be possible to add another level (not included in the graphic). At Apple, this could be the model number, which has been taken out of scope since Apple does not provide different reports for different model numbers. At the property levels, it is proposed to stay with the *Release Date* since it is proven as a strongly distinguishing characteristic as well as a valuable component for the report investigation step. The following property levels should be adjusted to meet the requirements of the researched portfolio. At Apple, these properties have been size and retina, since both were part of the company's naming convention. Other organizations must consider properties that best describe their own products, or properties they want to analyze despite if they are conductive to the identification or not. This entire hierarchical scheme implementation was necessary for the Apple portfolio in order to enable the analysis. However, as will be shown later, an even better solution would be to give each product or even each product configuration a single identification Id. In this case, levels such as *category*, or *segment* as well as different properties would still be used to provide further analysis capabilities and to enable an analysis for different properties, but a single good could be identified more easily since no level concatenation would be needed anymore.

To get a preferably complete picture of the product portfolio environmental impacts, it is further important to consider as many products, or more specifically product configurations, as possible within the analysis. In the case of Apple, there are several restrictions within the Apple PDF reports, so one report addresses only one or a few product configurations. For example, the Apple Watch PDF report states: "Product evaluation based on US configurations of 42mm Stainless Steel Case with Leather Loop band. Values will vary by configuration." (Apple, 2016g, p. 4). Here, the report only considers the U.S. configuration of the product. Since Apple does not state what this means, it can only be assumed that configurations for other countries cause different emissions. Moreover, it is stated that the report addresses only the Apple Watch with Leather Loop band. One report for each band would be needed or rather each band should be included in the BI solution so that it is possible to display a specific Apple Watch configuration in combination with a band to summarize the emissions and materials. A similar problem can be detected in the Mac mini 2014 report that states: "Product mass will vary by configuration and region." (Apple, 2014a, p. 4) This also relates to regional differences that are not specified so it is unclear what the alternations might effect. The problem that shall be mentioned lastly can be detected in the iPhone reports. While the iPhone 4S inventory was gathered for the 16GB version (Apple, 2011), e.g. the iPhone 5 report considered the 64GB version (Apple, 2012b). For some reports, the version is not even listed, e.g. for the model 3GS (Apple, 2009). All these issues are examples of product determination and consideration limitations that result from the Apple PDFs. They shall serve as a warning for possible problems that should be avoided by other ICT companies in the framework of the generalized model. Therefore, it is recommended to include as much products with their configuration as possible in the analysis.

5.2.2.2 Standardized PLC with Consistent Definitions

The Apple PLC comprises the four stages: production, transport, customer use, and recycling (Apple, 2016b). However, these stages can be insufficient to capture all facets of a product's life from raw material extraction to its end-of-life treatment. Moreover, the single stages are not defined consistently. This was shown on the comparison between the PLC definitions of the iPhone SE (Apple, 2016c, p. 4) and the iPhone 3G (Apple, 2008, p.4) in Chapter 4.3.1. Differences have been identified in particular in the transport and the customer use stage. For example, in transport, the SE includes the shipping to the customer while the 3G does not consider this distance. For that reason, the life cycle emissions in the transport stage as well as the total emissions cannot be compared one-to-one. Beside these inconsistences between different products, some definitions show disadvantages by themselves. An example can again be detected for transportation that can possibly be included in other PLC stages. As, for example, the iPhone SE report states: "[Recycling] includes transportation from collection hubs to recycling centers […]." (Apple, 2016c, p. 4) That leads to an incomplete view on the transport stage since this distance is missing as well as to a false view on the recycling emissions since in the view of this paper here only recycling activities such as the shredering of parts should be considered. These inconsistences and unsatisfying PLC specifications of the Apple internal approach and therewith of the Apple Model show the need for a standardized and enhanced life cycle with clearly defined stages that apply to each product in the same manner. Starting point of this new PLC implementation are the four Apple stages, but without considering the mentioned disadvantages of their definitions. Also considered is the Dell PLC, since the company also uses these four stages (Dell, 2016a). The scientific base for the PLC creation is formed by the LCA methodology. The life cycle should therefore be oriented on the ISO 14040 guidelines (ISO, 2006a) that define the PLC as: "[…] from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)." (ISO, 2006a, p. v) Deriving from the Apple and Dell stages, the ISO definition adds specifically raw materials as a stage and defines more clearly the end-of-life by adding disposal as an option next to recycling. However, the phase of transport is missing. Since this paper appreciates the separate consideration of the transport emissions, this stage will still be part of the new PLC and should include all transportation activities whereby simultaneously no other stage considers transportations. A further valuable perspective derives from Stark (2015, p. 7), who describes: "A natural resource […] is extracted from the earth, the resource is processed, the processed resource is used in the manufacturing of a product, the product is used, and when the product is no longer needed, the resource/waste is managed. It may be reused, recycled or disposed of." This perspective adds specifically the option of reuse to the end-of-life stage. Thus, this stage consists of recycling, reuse, and disposal. It is not clear if Apple means all of these possibilities by its recycling stage, since most company websites exclusively mention the term recycling (Apple, 2016a,b). However, the name is misleading and will therefore be replaced by the designation end-of-life. The approach mentioned lastly comes from Haes and van Rooijen (2005, p. 14), who propose the six stages of product design, raw material extraction and processing, manufacturing of the product, packaging and distribution to the consumer, product use and maintenance, and end-of-life management by reuse, recycling, and disposal. The main adaptations from this perspective are the addition of a product design stage and the recognition of the product's maintenance as part of the customer use stage. Furthermore, this perspective combines transportation to the customer with the product's packaging. However, these two components should not be mixed together, since the general transport stage should also encompass the delivery to the customer, while the packaging should stay as part of the regarding stages. Haes and van Rooijen (2005, p. 14) additionally emphasize that in every stage inputs and outputs interact with other systems. This is depicted with an Earth in the middle of the PLC with arrows showing the interaction of the stages with the peripheral systems.

Resulting from all these life cycle composition perspectives and their definitions, this paper proposes the following standardized PLC as the basis for environmental data monitoring purposes in the framework of the generalized environmental monitoring model (Fig. 65).

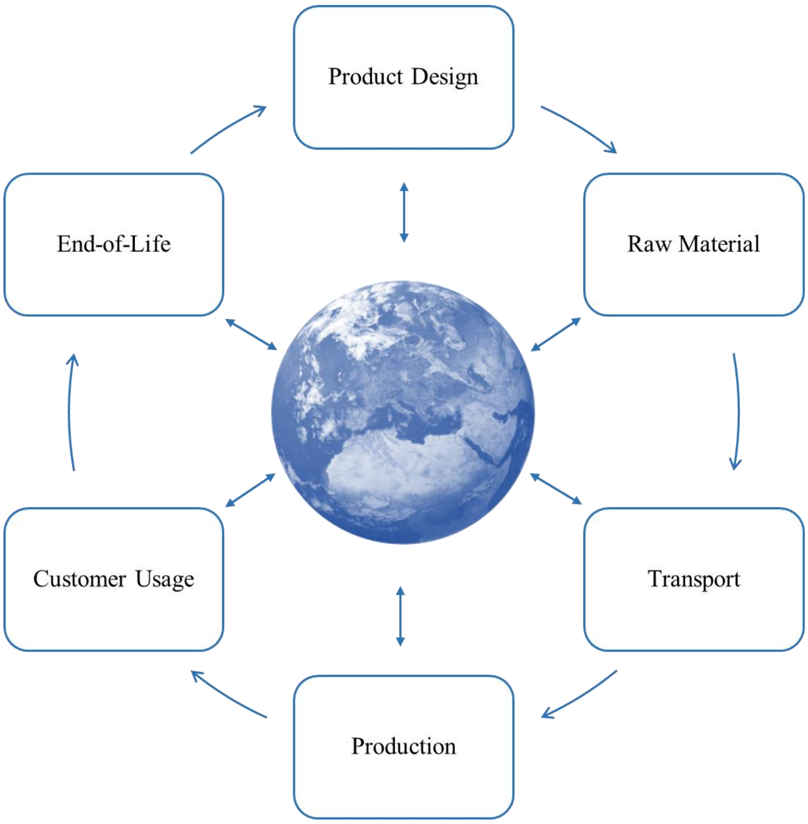


Figure 65: Standardized ICT Product Life Cycle
Own illustration based on (Apple, 2016b; Dell, 2016a; ISO, 2006a,b; Haes and van Rooijen, 2005, p. 14; Stark, 2015, p. 7),

The proposed standardized PLC consists of the following six stages:

(1) **Product Design**: Comprises the entire product development process from the first idea to the final draft that will then be produced.

(2) **Raw Material**: Includes the extraction of all kinds of raw materials that are used to produce a product and its processing including the necessary packaging.

(3) **Transport**: Summarizes all necessary transport of raw materials, semi-finished, or finished products with their packaging from plants to manufacturing sites, to distribution hubs, the customer, and end-of-life transportation. Includes transportation by air, sea, and land.

(4) **Production**: Includes all production process steps from the first processing of the arriving raw materials to the assembling of all parts until packaging of the finished product.

(5) **Customer Usage**: Calculates the power consumption based on an average duration of use. Usage scenarios should be based on historical data. If no historical data is available, a reasonable average should be assumed. Possible could be a three-year period for products such as laptops, or smartphones. Also included are potential maintenance efforts. For them, an

average based on historical service demands or a reasonable assumption based on third-party comparison values should be used.

(6) **End-of-Life**: Reflects the possibilities of recycling, reuse or disposal. Includes all steps necessary at the end of the product's life such as mechanical separation, reprocessing, shredding of parts, or repairing activities in the case of reuse.

The necessary administrative activities such as accounting, management, or customer service e.g. by the explicitly mentioned *maintenance* at the customer use stage, are part of the respective LCS. These should also be based on historical data or reasonable demand assumptions. The Earth depicted in the middle of the PLC illustrates the by Haes and van Rooijen (2005, p. 14) described interaction of each stage with the peripheral systems. By collecting data into this life cycle, a reasonable LCS analysis is enabled.

5.2.2.3 Standardized GHG Measuring and GGE Calculation

Each GHG that is produced by any PLC activity must be recognized by measuring its emissions. These measures must then be used to calculate the GGEs in CO_2e based on each GHG's GWP, in the time period of 100 years (EPA, 2016c). Since the international standard ISO 14064-1 (ISO, 2006c, p. 19) proposes the specifications of the second Assessment Report (AR) by the IPCC (1996, p. 22) and Apple refers to the use of the ISO 14040 (ISO, 2006a) and ISO 14044 (ISO, 2006b), which for their part refer to the ISO 14064-1 (ISO, 2006c, p. 19), it must be assumed that Apple uses the old GWP values. However, as Dell (2013a, p. 1) states "[…] we support efforts to reduce global greenhouse gas (GHG) emissions to levels guided by evolving science." Since this paper holds the same opinion, it encourages following the latest scientific findings by established organizations such as the IPCC. Therefore, the generalized model proposes to use the current GWP values released by the fifth AR of the IPCC (IPCC, 2014, p. 87; Myhre *et al.*, 2013, pp. 731-737). Tab. 15 shows the GHGs listed by the ISO 14064-1 with the current GWP values and chemical formulas of the AR5.

Gas	**Chemical formula**	**GWP (100-year) based on IPCC AR5**
Carbon dioxide	CO_2	1
Methane	CH_4	28
Nitrous oxide	N_2O	265
Hydrofluorocarbons (HFCs)		
HFC-23	CHF_3	12.400
HFC-32	CH_2F_2	677
HFC-41	CH_3F	116
HFC-43-10mee	$CF_3CHFCHFCF_2CF_3$	1.650
HFC-125	CHF_2CF_3	3.170
HFC-134	CHF_2CHF_2	1.120

HFC-134a	CH_2FCF_3	1.300
HFC-143	CH_2FCHF_2	328
HFC-143a	CH_3CF_3	4.800
HFC-152a	CH_3CHF_2	138
HFC-227ea	CF_3CHFCF_3	3.350
HFC-236fa	CF_3CH2CF_3	8.060
HFC 245ca	$CH_2FCF2CHF_2$	716
Hydrofluoroethers (HFEs)		
HFE-7100	$C_4F_9OCH_3$	421
HFE-7200	$C_4F_9OC_2H_5$	57
Perfluorocarbons (PFCs)		
PFC-14	CF_4	6.630
PFC-116	C_2F_6	11.100
PFC-218	C_3F_8	8.900
PFC-31-10	C_4F_{10}	9.200
PFC-318	c-C_4F_8	9.540
PFC-41-12	n-C_5F_{12}	8.550
PFC-51-14	n-C_6F_{14}	7.910
Sulfur hexafluoride	SF_6	23.500

Table 15: Global Warming Potential of ISO 14064-1 Greenhouse Gases based on IPCC AR5 (IPCC, 2014, p. 87; ISO, 2006c, p. 20; Myhre et al., 2013, pp. 731-737)

These most commonly used GHGs are sufficient for most life cycle activities of ICT enterprises. However, for the consideration of further gases, the entire list can be obtained in IPCC (2014, p. 19) and Myhre *et al.* (2013, pp. 731-737). Based on these values, a sample calculation for the total GGEs could look like Brander (2012, p. 2) describes: "A quantity of GHG can be expressed as CO_2e by multiplying the amount of the GHG by its GWP." (Tab. 16).

GHGs	Emissions in kg	GWP	GGEs in kg CO_2e
CO_2	10	1	10
CH_4	1	28	28
N_2O	0.1	265	26.5
CHF_3	0.01	12,400	124
Total GGEs in kg CO_2e			**188.5**

Table 16: Sample Calculation of GGEs in kg CO_2e
Own Calcualtion based on (Brander, 2012, p. 2; IPCC, 2014, p. 87; ISO, 2006c, p. 20; Myhre et al., 2013, pp. 731-737)

The first column shows the chemical formulas, here, for the *GHGs*, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and hydrofluorocarbons-23 (CHF_3). The second column states conceived sample *Emissions in kg*. The third column restates the *GWP* from Tab. 15. In the last column, the calculation results by multiplying the *Emissions in kg* with the corresponding *GWP* are shown. In the last row, the *Total GGEs in kg CO_2e* are calculated by summarizing the single values. Based on this example each company can understand how to use the proposed system for their footprint calculations in the given unit of CO_2e.

5.2.2.4 Standardized (Raw) Material Definitions

A material name must always mean the same resource to ensure its comparability. Considering the Apple portfolio, the company uses following material designations in alphabetical order: *aluminum*, *aluminum and steel*, *aluminum and magnesium*, *battery*, *ceramic*, *circuit boards*, *copper*, *cords and cables*, *display*, *display panel*, *glass*, *hard drive*, *hard drive and optical drive*, *leather*, *magnets*, *main board*, *other*, *other metals*, *other plastics*, *polycarbonate*, *power supply*, *sapphire*, *solid state drive*, *speakers*, *stainless steel*, *steel*, *trackpad and keyboard* (Apple, 2016b). These specifications cause several problems. First, the general definition of some materials is inconsistent. As the iPhone SE report states: "The greenhouse gas emissions associated with the aluminum enclosure of iPhone SE are 40 percent less than those of iPhone 5s thanks to the use of less virgin aluminum and more low-carbon aluminum manufacturing." (Apple, 2016c, p. 1) This reveals that at least in model 5s (Apple, 2013a) another form of *aluminum* and also a different manufacturing process had been used, despite both reports showing the same designation. A therewith connected issue is that in some cases metalloids such as *aluminum* are stated as a material, while in other cases, components such as *battery* are shown. While *aluminum* is a basic element, which can be found in the periodic table of elements (Sólyom, 2007, p. 2), *battery* is a combination of several basic elements such as lithium and its device housing that itself consists e.g. of different plastics (Apple, 2016i). For that reason, it would be more suitable to disassemble such components in order to list their separate resources. Another problem is the concatenation of materials or components such as *aluminum and steel*, or *aluminum and magnesium*. This data can be illustrated for a single product, but it is not possible to compare it, e.g. with single *aluminum* from another product. The last problem that shall be mentioned is the listing of *other*, *other metals*, or *other plastics*. These designations are not useful for an environmental report and should be avoided. For these reasons, a standardized material definition catalog must be implemented to enable a unified material understanding as well as a comparability of the single resources. The scientific field that deals with these issues is called Materials Science. It is defined as "an interdisciplinary subject, spanning the physics and chemistry of matter, engineering applications, and industrial manufacturing processes." (University of Oxford, 2016) The creation of the standardized material catalog has to be realized individually by the analyzing organization. Each company might employ experts in this field of study who define each product by its single parts. Much information is available that already predefines basic elements such as aluminum (Sólyom, 2007, p. 2). For other parts such as internal battery or packaging compositions, new descriptions have to be elaborated. Further information on this definition process are available in Gaol *et al.* (2015) or Radder (2012).

5.2.3 Generalized BI Dataset

This step aims to gather the environmental data from all different sources into a generalized data model that defines the structure of the Power BI database. Deriving from the Apple data model, the generalization is similar but modified by possible differences at other ICT companies. These adaptations are based in particular on the Generalized Portfolio Hierarchy Classification Model that was implemented in Chapter 5.2.2.1 – Fig. 64. The adjustments are shown in blue text or bold frames (Fig. 66).

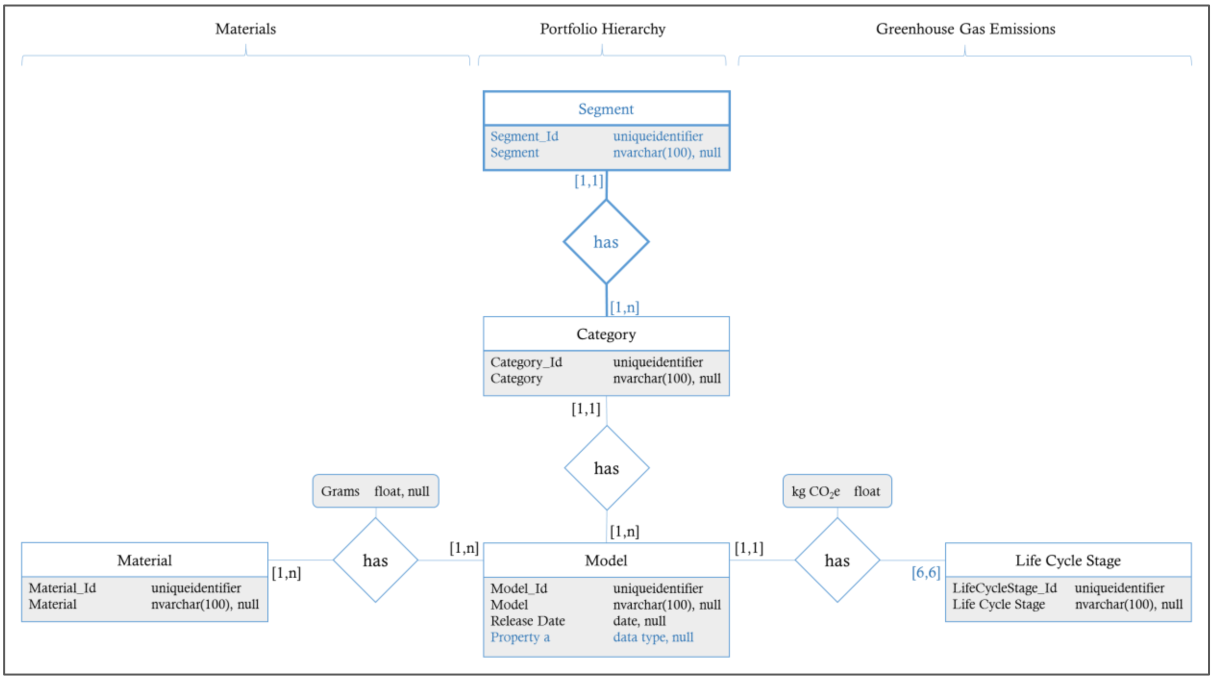


Figure 66: Generalized Environmental Data Model
Own illustration

As a new entity, the *Segment* is added since it gives companies further analysis possibilities. A segment has the attributes *Id* as *uniqueidentifier* and *Segment* as *nvarchar(100)*. One segment contains several categories, and one category belongs exactly to one segment. As with the Apple approach, the *Category* as well as the *Model* entity are still needed in the generalized approach. Within the *Model* entity, the *Release Date* is the first property. Since the products of other ICT companies could have different further properties than size and retina, those have been replaced by the placeholder *Property a*. Here a number of n properties is possible. The area of *Materials* on the left side stays the same as in the Apple approach. For the area of *Greenhouse Gas Emissions*, there are six *Life Cycle Stages* as defined in Chapter 5.2.2.2 – Fig. 65, instead of the four stages in the Apple model, which adapts the relationship cardinality to *[6,6]*.

Based on this ERD, the relational database tables are constructed as following, with the differences to the Apple Model marked in blue again (Tab. 17).

Table Name	**Key**	**Column Name**	**Data Type**	**Nulls**
Segments	PK	Segment_Id Segment	uniqueidentifier nvarchar(100)	 null
CategoriesSegments	FK FK	Segment_Id Category_Id	uniqueidentifier uniqueidentifier	
Categories	PK	Category_Id Category	uniqueidentifier nvarchar(100)	 null
CategoriesModels	FK FK	Category_Id Model_Id	uniqueidentifier uniqueidentifier	
Models	PK	Model_Id Model Release Date Property a	uniqueidentifier nvarchar(100) date data type	 null null null
Material Amounts	FK FK	Model_Id Material_Id Material in Grams	uniqueidentifier uniqueidentifier float	 null
Materials	PK	Material_Id Material	uniqueidentifier nvarchar(100)	 null
GGE Amounts	FK FK	Model_Id LifeCycleStage_Id GGEs in kg CO_2e	uniqueidentifier uniqueidentifier float	 null
Life Cycle Stages	PK	LifeCycleStage_Id Life Cycle Stage	uniqueidentifier nvarchar(100)	 null

Table 17: Tables of Generalized Environmental PLC Data Monitoring Model
Own illustration

There are nine tables listed. *Segments*, *Categories*, *Models*, *Materials*, and *Life Cycle Stages* comply with the five entities of the ERD. The tables *SegementsCategories*, *CategoriesModels*, *Material Amounts*, and *GGE Amount*s comply with the connections of the entities. Compared to the Apple database the *Segments* table and its corresponding *SegementsCategories*, which connects *Segments* with *Categories* via their Ids, are added. When this structure is displayed in Power BI, the connection table can be hidden, similar to the *CategoriesModels* table, because it also consists only of two Id-columns. The other connection descriptions stay the same as in the Apple system. With this model, all environmental PLC data of an ICT company can be structurally stored. Implementing the model in Power BI Desktop and uploading the data, results in the analyzable BI inventory.

In the case of Apple, the data has only been accessible through the PDF reports. These were transferred into an MS Excel spreadsheet, and were then inserted in the Apple data model. However, Apple could already have internal spreadsheets or any kinds of other data collections, which have not been accessible for this paper. The same could be with other companies. They could have different data sources, which contain data in diverse forms. Therefore, this step of BI dataset creation recognizes all these possibilities and proposes to either transfer all data into the data model, connect the sources to it, or to do a combination of both. To enable this, Power BI provides the opportunity to import from or connect to several different data sources and integrate them into the tool. These connection possibilities are also important when considering that emissions usually occur also at connected enterprises such as suppliers or transport companies. However, when aiming to get the entire picture of a product's footprint all data sources must be viewed together. Therefore, the tool offers connection possibilities to interfaces of cooperating enterprises, e.g. by integrating external enterprise resource planning (ERP) systems, or supply change management (SCM) systems, as well as any kinds of further databases such as MS SQL Server.

In this context, it is also important to consider how the data, e.g. for the GHGs, are collected. Several possibilities by a variety of technologies such as sensors exist (Frish, 2014). As Günther (1998, p. 9) describes: "Sensor networks have been installed and upgraded to monitor the quality of the water, the air, and the ground […]. Satellites are used increasingly to obtain environmental data, […]."[38] These technologies could also store their results in databases, which then have to be considered. Thereby, the quality of the data used is another vital factor that has to be questioned in the sources itself as well as after integrating them into the tool. As the ISO (2006a, p. 13) states: "Data quality requirements specify in general terms the characteristics of the data needed for the study. […]" Also Page (1996, p. 2) confirms: "Solutions to our environmental problems are strongly dependent on the quality of accessable [sic] information sources." Databases, for example, could already have clean and structured data, while text documents or spreadsheets have to be reviewed before their data can be transferred to the dataset. Defining data quality ensuring mechanisms is a significant task that must be reasonably implemented in order to get a useful dataset. Therefore, this concern is also reflected by this model step.

5.2.4 Building of Standardized Reports

For the analysis of the Apple data, several capabilities of the model for getting environmental insights were shown: Answering of general questions, PDF report reconstruction based on the classification hierarchy, and specific investigations of selected environmental cases. For the implementation of the generalized approach, it is also proposed to firstly ask general questions such as: which products have been released in a specific time period that is intended to be analyzed? Afterwards, it is proposed to build classification hierarchy reports with navigation possibilities to reach all levels

[38] Related topics on these fields of research are Industry 4.0 (Gilchrist, 2016; Kahn and Turowski, 2016a,b), or The Internet of Things (Stackowiak et al., 2015).

of the portfolio. Since the aim of the Apple Model in this step was to reconstruct the PDF reports, the form was close to Apple's predefined specifications. Other companies can orient on these and also show: life cycle GGEs and material usage as donut charts, lists of GGEs and materials, total GGEs, total weight, and a list of all products currently part of the report. Besides, any adjustment by the executing company is conceivable such as an extension by energy consumption or packaging data. When investigating specific environmental questions, it is also proposed to use the classification hierarchy since it enables a structured analysis among the entire portfolio. In this context, it is recommended to question the shown developments where possible, e.g. by reviewing processes, looking at the underlying dataset and finding possible anomalies, or by considering other data to find correlations. One possibility for a correlation investigation is to take the material data to search for their relation to the GGE developments. That has been demonstrated for the Apple case, e.g. by examining the relationship between total GGEs and aluminum in Fig. 53, and can be implemented in this form by other organizations as well. Deriving from these deliberations, a standardized question catalog should be used to ensure the significance of the investigated insights. In consequence of the research, the following questions are considered as central to reveal environmental insights regarding the product footprint:

- How is the development of total/LCS GGEs on the classification hierarchy layers?
- How is the rank order of total/LCS GGEs among categories/models/products?
- How is the GGE rank order of the single PLC stages?
- How are the LCS developments in percent?
- Which materials are part of the product portfolio?
- Can the total/LCS GGEs be connected to the product weights?
- Can the total/LCS GGEs be connected to a specific material?

When researching such environmental questions, the insight presentation should be based on a set of guidelines. One of the most influential roles in sustainability and thus environmental reporting is taken by the Global Reporting Initiative (GRI), which has the goal "to enhance quality, rigor and utility of sustainability reporting, particularly by developing globally applicable guidelines." (Arndt *et al.*, 2006, p. 1) As Morhardt (2002, p. 38) emphasizes: "[organizations] almost cannot avoid meeting the GRI standard in any case." Currently the fourth generation (G4) has left the multi-stakeholder feedback loops and is now in compilation and consideration to be discussed by the Global Sustainability Standard Board (GSSB) in the next step (GRI, 2016a). Therefore, the standard can be considered as a draft. Since G4 is the upcoming standard, it shall be introduced in the following as the basis for the intended environmental reporting in the framework of this paper's proposed research and in the superior context of sustainability reporting. For more information on the preceding versions, Arndt *et al.* (2006, pp. 1-3) and GRI (2006) provide valuable information.

Overviews on the transition from G3 to G4 and from G3.1 to G4 can be obtained in GRI (2013a) and GRI (2013b).

G4 is provided in two parts, the *Reporting Principles and Standard Disclosures* (GRI, 2016b) and the *Implementation Manual* (GRI, 2016c). "Part 1 of G4 has the Standard Disclosures that all organizations use to report their sustainability impacts and performance. It also details the Reporting Principles that enable effective reporting and the criteria to meet for reporting 'in accordance' with the Guidelines." (GRI, 2016a) "The Implementation Manual – part 2 of G4 – is essential for preparing a sustainability report. It explains how to apply the Reporting Principles, how to prepare information, and how to interpret the Guidelines' concepts." (GRI, 2016a) In the following, the principles of report content (1-4) and report quality (5-10) are listed with a short description from the GRI *Reporting Principles and Standard Disclosures* (GRI, 2016b). For detailed information on their implementations, the respective sources refer to the pages in the *Implementation Manual* (GRI, 2016c). The principals listing is extended by a brief review of the guideline compliance by the Apple PDFs and the improvements that come from the Apple Model in combination with the proposed reporting standards for the generalized model:[39]

- **Stakeholder Inclusiveness**: "The organization should identify its stakeholders, and explain how it has responded to their reasonable expectations and interests." (GRI, 2016b, p. 16) The Apple PDFs are generic reports, which give an unspecified general overview that is also available for the public. Although the Apple Model can also create such generic reports, its central intention is the provision of environmental product insights for different specified recipients in order to support their decision-making. Therefore, the claimed reporting balance can in particular be reached by the information tailoring capabilities of the approach that ensures the comprehensibility and usefulness of the provided information. One given example was the iPad category report exclusively provided for the iPad Team. For an implementation of the generalized model by other ICT companies, it is also proposed to consider first, whom their recipients are in order to deliver insights that comply with "their reasonable expectations and interests." (GRI, 2016b, p. 16)
- **Sustainability Context**: "The report should present the organization's performance in the wider context of sustainability." (GRI, 2016b, p. 17) The Apple PDFs as well as the Apple Model and therewith the generalized model focus on the environmental pillar in particular climate change driving GHGs with their different GWPs. Extended is this view by the material perspective that is used by the model to deliver possible GGE development explanations. The Apple Model and its generalization give space for a wider sustainability context,

[39] In this context, it is important to respect, that the final information provision is realized by the service dashboards, which are in focus of the next section.

e.g. by the expandability of the data model, which could possibly be connected to socially or economically related concerns.

- **Materiality**: "The report should cover Aspects that: Reflect the organization's significant economic, environmental and social impacts; or substantively influence the assessments and decisions of stakeholders." (GRI, 2016b, p. 17, bullet points changed to sentence) For the Apple PDFs this point cannot be recognized as satisfied since they are general overviews, which are not supposed to support decision-making. On the contrary, the Apple Model and simultaneously its generalization have exactly this decision-supporting incentive by providing significant insights to ecologically related data that shall "substantively influence the assessments and decisions of stakeholders." (GRI, 2016b, p. 17)
- **Completeness**: "The report should include coverage of material Aspects and their Boundaries, sufficient to reflect significant economic, environmental and social impacts, and to enable stakeholders to assess the organization's performance in the reporting period." (GRI, 2016b, p. 17) Based on the PDF provided data, the Apple and the generalized model give a variety of environmental insights in connection with other data to deliver a preferably complete view on the product GGEs. The iPad reporting, for example, covered all the gathered inventory data by reflecting it on one page extended by the possibility of the hierarchy level navigation. Thus, within its focus area, the approaches fulfill the claim of completeness.
- **Balance**: "The report should reflect positive and negative aspects of the organization's performance to enable a reasoned assessment of overall performance." (GRI, 2016b, p. 17) The Apple PDFs only partially fulfill this claim. On the one hand, they show many marketing statements that are more about product promotion and therefore shift the focus from the data facts. On the other hand, e.g. the report of iPhone 5c (Apple, 2013c) also shows a negative insight with the use of the harmful material polycarbonate (Guerra, 2006, p. 54; Wired, 2013). The Apple Model displayed all insights without extenuations or focus shifting marketing statements. Furthermore, the approach does not favor any kind of positive or negative information since all data is displayed as it is collected in the underlying dataset. This attitude should be followed also for an implementation of the generalized model.
- **Comparability**: "The organization should select, compile and report information consistently. The reported information should be presented in a manner that enables stakeholders to analyze changes in the organization's performance over time, and that could support analysis relative to other organizations." (GRI, 2016b, p. 18) Since the PDF reports only display values combined with text for one product in one configuration at a time, this claim cannot be recognized as fulfilled to a satisfying extend by Apple's internal approach. The Apple Model and in consequence its generalization provide functionalities to fulfill the principal

e.g. by capabilities such as the examination of developments over years of releases. An analysis in relation to other organizations is in particular enabled by the generalized model. On its basis, several companies are enabled to report in the same manner, which therefore allows a benchmarking[40] between their monitored footprints.

- **Accuracy**: "The reported information should be sufficiently accurate and detailed for stakeholders to assess the organization's performance." (GRI, 2016b, p. 18) This is one major disadvantage in the Apple PDFs, which show several data errors. Therefore, the Apple Model provides a process to gather, prepare, and structure the inventory into a BI dataset that improves the delivery of correct insights. Based on this accurate dataset the reports must be accurately implemented as well. This shall be ensured e.g. by standardized reporting steps and for the generalized model additionally by a standardized question catalog that gives the framework to prevent errors.
- **Timeliness**: "The organization should report on a regular schedule so that information is available in time for stakeholders to make informed decisions." (GRI, 2016b, p. 18) For the Apple PDFs this claim is only insufficiently fulfilled since these reports are provided ones and are then never updated. That can e.g. be seen by changing PLC definitions that do not evolve with the company's view on environmental reporting. On the contrary, the Apple Model and therewith the generalized model work in real-time and deliver data as it is inserted. Moreover, with the evolving methodology also the models and their databases adapt. The real-time communication is extensively ensured by dashboards, which are described in the next chapter.
- **Clarity**: "The organization should make information available in a manner that is understandable and accessible to stakeholders using the report." (GRI, 2016b, p. 18) The Apple PDFs deliver clear information, but also show a lot of focus shifting texts. Useful text support should interpret the insights and give further explanations as demonstrated for the Dell reports (Dell, 2013a). One key incentive of this paper's environmental monitoring approach was to ensure that the data can be consumed as easily as it can be created, by each member of the company. As McCandless (2010) says: "Visual information is almost effortless to recognize, it literally pours in." Therefore, this kind of reporting is a clear way of communicating insights. Moreover, correlation investigations give further explanations on how to interpret the insights. Useful textual descriptions of the visualized data could be added if necessary depending on the use case.
- **Reliability**: "The organization should gather, record, compile, analyze and disclose information and processes used in the preparation of a report in a way that they can be subject to examination and that establishes the quality and materiality of the information." (GRI,

[40] Benchmarking will again be covered in the application of the generalized model in Chapter 5.3.

2016b, p. 18). Because of the several data error in Apple's PDFs, it can be assumed that the company may not have extensible data quality mechanisms. This paper provides a solution with the associated processes of both models that focus in all aspects on the delivery of valuable and reliable insights to support the environmental decision-making of a company.

An implementation of the generalized model should follow all of these guidelines in the framework of the model's process by considering the given explanations, in order to ensure the provision of effective environmental insights.

5.2.5 Building of Standardized Dashboards

As Malik (2005, p. 1) emphasizes: "It is a well-established management principle that you cannot manage what you cannot measure. It is equally true, however, that you cannot manage well what you cannot monitor. That is where enterprise dashboards come in." Based on the created reports, those monitoring dashboards can be implemented in order to simplify the sharing and thus the communication of the discovered insights as well as to enable further investigation capabilities. Therefore, the formally stated rules of an appropriate reporting also apply to dashboards. Those must also be material, complete, balanced, comparable, accurate, timely, clear, reliable, as well as include stakeholders, and represent a sustainability context (GRI, 2016b, pp. 16-18). Since dashboards are one level above the created reports, their reliance on the GRI principals has to be ensured separately. On the one hand, the rules of materiality, accuracy, reliability and sustainability context can already be most widely ensured by guideline conform report information. On the other hand, the rules of clarity, completeness, balance, comparability, stakeholder inclusiveness, and timeliness could suffer from information aggregations, since dashboards can lead them into a new context. It is therefore recommended to control the compliance of these rules in particular again.

In the Apple Model, the specialist CSO dashboard sample was built by the intention to follow those guidelines. To ensure that the insights are easy to comprehend, for example, the average GGEs were shown together with its sources of total GGEs and the number of products. Regarding a comparability, e.g. the yearly development of the portfolio emissions gave a possibility to consider different phases of an emission course. A balance was reached, e.g. by offering all kinds of insights, whether these are positive or negative. Therefore, the exceedance of the plastic KPI has been shown even though this information could affect consequences by the CSO. This is even fostered by the possibility of an alert function for KPIs that are out of acceptable boundaries. As described, the claim of timeliness is ensured especially by dashboards, because they emphasize the real-time communication of the environmental insights in order to foster an insights communication dialog (Günther, 1998, p. 5). Deriving from these characteristic, Malik (2005, pp. 8-9) provides additional rules that are connected to the guidelines provided by the GRI, but show further dashboard specific facets. These rules could also partially apply to the underlying reports, but unfold their full potential if clearly implemented in dashboards:

- **Collaborative**: "The dashboard should facilitate users' ability to exchange notes regarding specific observations on their dashboards. […] A well-designed collaboration would serve as a communication platform for task management and compliance control." (Malik, 2005, p. 9). This claim is the most important and unique for dashboards since their core purpose in this paper's context is exactly this environmental insights dialog enabling capability, which makes them such a valuable medium of communication. Based on the BI service tool these possibilities are given and were already demonstrated in the Apple CSO dashboard sample.
- **Interactive**: The dashboard "should allow the user to drill down and get to details, root causes, and more." (Malik, 2005, p. 8) This claim accompanies with the GRI principal of comparability (GRI, 2016b, p. 18). An example is the drill down/up into further hierarchy levels or the adaptation of insights to specific product release times. The CSO dashboard enabled this e.g. by the examination of single year GGEs. The rule also applies to the interactive reports, which also give that capability. However, in the framework of the model's process, the difference is that these reports are not shared with the stakeholder, yet.
- **Trackability**: The dashboard "should allow each user to customize the metrics he or she would like to track. Such customized tracking could then be incorporated within the default dashboard view presented to the user after login." (Malik, 2005, p. 9) This claim is connected to the principals of clarity, comparability, and especially stakeholder inclusiveness by the GRI (2016b, p. 18). In the case of Apple, the CSO dashboard demonstrated such trackability by giving a specified overview of the most pressing KPIs and developments. Therefore, the dashboard was designed differently as for example a production dashboard. Moreover, the CSO could adjust each widget to meet current requirements. Thus, also the generalized model emphasizes the need to build dashboards that fit their users' trackability needs.
- **Personalized**: "The dashboard presentation should be specific to each user's domain of responsibility, privileges, data restrictions, and so on." (Malik, 2005, p. 9) That rule must be seen in connection to the trackability claim before and therefore accompanies with the principals of clarity, comparability, and stakeholder inclusiveness by the GRI (2016b, p. 18). It aims to ensure that the aggregated and shared dashboard data relies on the person who is using it from a responsibilities and permission point of view. In the CSO example, only the CSO itself or organization members of equal status are allowed to view the dashboard. The BI tool enables this claimed restriction of all information to a specific person or group.
- **Analytical**: The dashboard "should allow users to perform guided analysis such as what-if analysis. The dashboard should make it effortless for a user to visually navigate through different drill-down paths, compare, contrast, and make analytical inferences. In this way, the

dashboard can facilitate better business comprehension within a set of interdependent business variables." (Malik, 2005, p. 9) As has been shown in the Apple analysis, the BI tool with its corresponding mobile applications offer these capabilities. It is even possible to get automated insights from scratch or by using already existing report widgets. This kind of analytical ability is a powerful functionality of the chosen BI tool and was one reason for its selection (Evelson et al., 2015, p. 9; Gartner, 2016a).

- **Responsive**: The dashboard "must respond to predefined thresholds by creating user alerts in addition to the visual presentation on the dashboard (e.g., sound alarms, e-mails, pagers, blinkers) to draw immediate user attention to critical matters." (Malik, 2005, p. 8) This is another significant unique feature of dashboards against reports in the context of the here performed approach. A sample implementation was demonstrated for the plastic target KPI as part of the Apple CSO dashboard. Here any form of alert such as email or mobile application notifications are possible. For other companies it is also proposed to set these alerts for selected KPIs in order to immediately recognize, if critical environmental values are out of acceptable boundaries.

Malik (2005, p. ix) emphasizes: "For corporate decision makers, the amount of data that must be monitored and analyzed on a given business day is anything but effortless. […] managing information is becoming more complicated by the day." Dashboards can be conducive to a solution to this information overload (Aspin, 2015, p. 3; Few, 2006, p. 107). However, to be helpful, this paper encourages to rely their implementation on the proposed six rules given by Malik (2005, pp. 8-9) in connection with the ten rules of effective reporting given by the GRI (2016b, pp. 16-18).

5.3 Application of Generalized Model

The purpose of this section is to introduce a possible application of the generalized model by using the example of the Dell Inc. product portfolio. As presented in Chapter 1.2, Dell reports its environmental data like Apple in the form of PDF reports with GGE and material data (Dell, 2016a). Thus, the company provides a comprehensive example to show in particular the benefits that derive from the generalized model compared to the Apple approach and will enable to further understand the approach's usefulness and value.

Dell Portfolio Hierarchy Classification

All products for which Dell provides environmental data can be distinguished by using only the model level (Dell, 2016a). This is because Dell uses different model designations for each product. However, in order to enable further analysis and reporting possibilities more levels shall be considered. The box diagram below illustrates the hierarchy classification for Dell's portfolio (Fig 67).

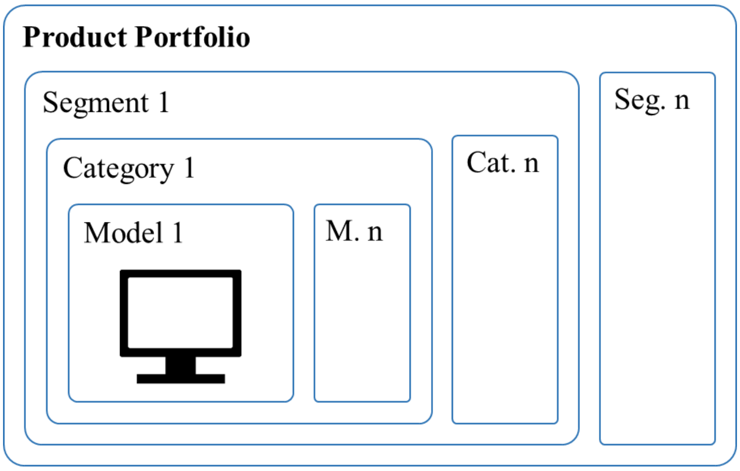


Figure 67: Dell Portfolio Hierarchy Classification
Own illustration based on data from (Dell, 2016a)

As an extension to the *Model* level, *Segment* and *Category* are added. Possible segments that are offered by Dell could be: laptop, desktop, tablet, monitor, and server (Dell 2016c). For example, the laptop segment includes the categories: Latitude, Inspiron, XPS, and Chromebook (Dell, 2016d). Fig. 68 provides three examples for Dell products in the proposed hierarchy.

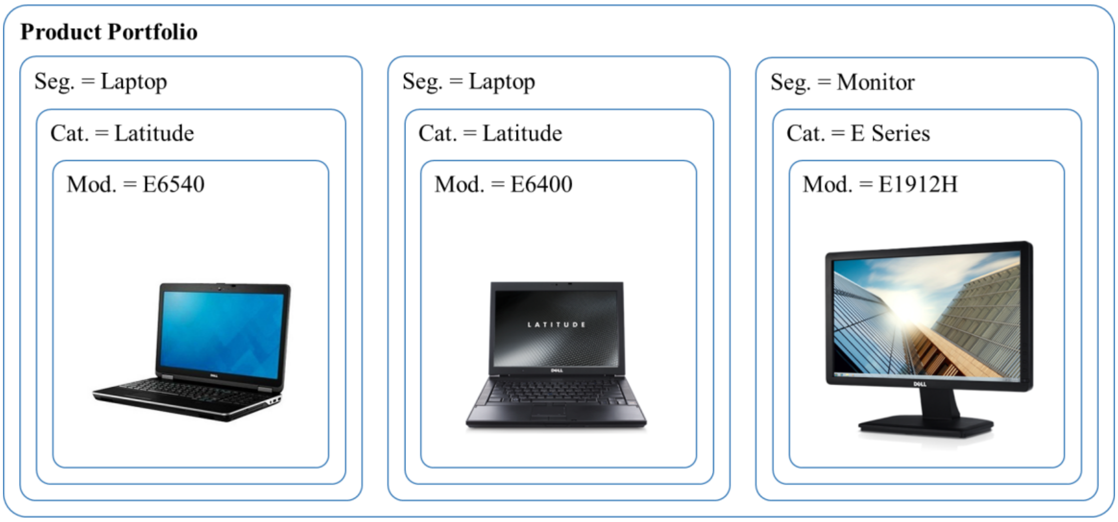


Figure 68: Dell Portfolio Hierarchy Classification – Examples
Own illustration based on data from (Dell, 2016a) with images by

As described, the examples show different unique names for each model. The additional levels enable e.g. the comparison of the two products of the laptop segment with the product of the monitor segment. Beside these hierarchy levels, several extensions are possible. For example: Dell additionally distinguishes between *Home* and *Work* in several segments such as laptop or monitor (Dell 2016c). This could therefore serve as a further level, which would be located between segment and category. Therewith, investigations would be possible to answer questions on a GGE comparison between home and work products, or on developments of each area. In addition, properties could be part of the hierarchy. Starting with the proposed use of the release date, properties such as screen size, processor, or touch screen, would be possible for Dell products (Dell, 2016d). The usefulness of these supplementary levels would have to be one necessary decision by Dell when implementing the entire approach.

Deriving from this example, this paper recommends giving each product a unique identification number. One-step further, each configuration of a product with its specific properties should have such an Id in order to collect their specific environmental data. Other levels of the classification hierarchy would still be necessary to enable further analysis possibilities e.g. by considering the configuration properties, but a single good or even a single good with its unique configuration could be identified more easily since no level concatenation would be needed anymore. Moreover, a wider range of product data could be collected under these conditioning.

Life Cycle and Total GGEs in CO_2e

As an example, the further examination is performed for the Dell laptop Latitude E6540. Therefore, the PDF report *Carbon Footprint of a Dell Latitude E6540* (Dell, 2013b) provides the data. Although Dell uses a PLC other than the one proposed by the generalized model, the values of the stages build, use, ship, and recycle (Dell, 2013b, p. 1) are used for the model stages of production, customer usage, transport, and end-of-life. The values for the stages of design and raw material are conceived in a reasonable relation to the other data. This shall ensure an authentic example. Tab. 18 shows the LCS and the total GGEs in kg CO_2e.

Life Cycle Stages	**LCS GGEs in kg CO_2e**
Product Design	3
Raw Material	55
Transport	38
Production	259
Customer Usage	110
End-of-life	1
Total	**466**

Table 18: LCS and Total GGEs of Dell Latitude E6540
Own illustration based on data from (Dell, 2013b)

Since there is no access to Dell's measurement of the caused GHGs and their calculation of GGEs, the values are taken as provided. For other companies it is recommended to calculate their GGEs as shown in the sample calculation of Chapter 5.2.2 – Tab. 16.

(Raw) Materials

This step demands a company to define all elements of a product in a uniform manner. Materials provided by Dell for the Latitude E6540 are in alphabetical order: *assembly*, *battery*, *chassis*, *display*, *hard drive*, *mainboard and other boards*, *optical drive*, *packaging*, and *power supply* (Dell, 2013b). As can be seen, the step of a uniform material definition and usage had not been performed for these material listing. Several similar problems of Apple's approach also apply to Dell. For example, *battery* is listed, which is a component not a material. Further, Dell also combines materials, here *mainboard and other boards*. In this context the term *other boards* is also not useful. Moreover, Dell adds *assembly* as a material, which is actually a part of the production process and should therefore be added to the life cycle emissions. The problem that shall be mentioned lastly, is the listing of *packaging* as a material. Despite the consideration of the packaging is important since e.g. its weight influences the footprint of PLC stages such as transport or production, it should be considered separately. Moreover, *packaging* can mean a wide range of elementary resources such as plastics and is therefore not a useful designation. Since there is no access to better material data, the solution is to delete those parts that would cause problems in the analysis such as *assembly* and *packaging* in order to obtain a more useful material listing.

BI Dataset

The GGE as well as the material data can then be stored in the Generalized Environmental Data Model as implemented in Chapter 5.2.3 – Fig. 66 and Chapter 5.3.2 – Tab. 17. Deriving from a Dell specified ERD through the resulting table structure, Fig. 69 shows the final data model in Power BI Desktop, which constitutes the Dell BI database.

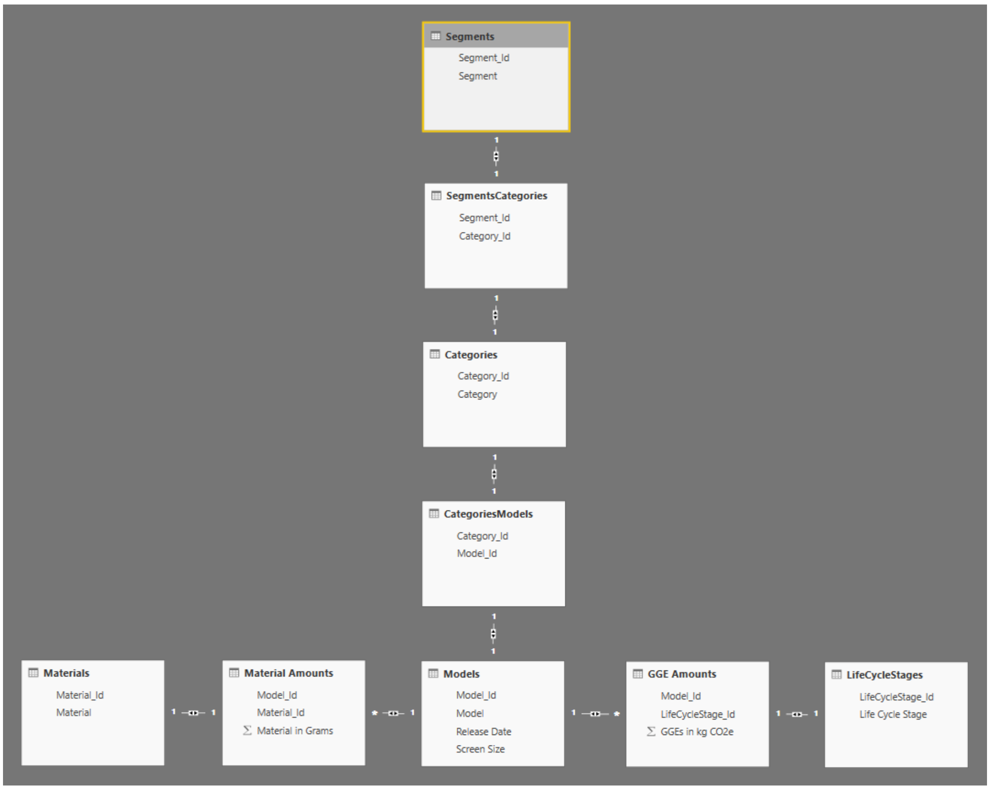


Figure 69: Dell Data Model in MS Power BI Desktop
Own illustration

On top, the structure shows the S*egments* table, which was added for the generalized approach. Thereby, also the *CategorySegments* table results. The second adjustment by the generalized model was made for the attributes/columns of the *Models* table. For this example the properties, *Release Date* and *Screen Size* are added (Dell, 2016d). All other parts are identical with the Apple data model as shown in Chapter 4.3.5 – Fig. 33. In this structure, the entire Dell portfolio data can be stored. For this sample application, the inventory consist of the data for the Latitude E6540 (Dell, 2013b).

Reporting

Based on the dataset the report for the Latitude E6540 can be created. Inspired by the Apple PDF report reconstruction, this single product report can answer questions such as: how much GGEs does the product cause in total?, how are the GGEs of the product distributed to the single LCSs?, or: which materials does the product uses in which amounts? (Fig. 70).

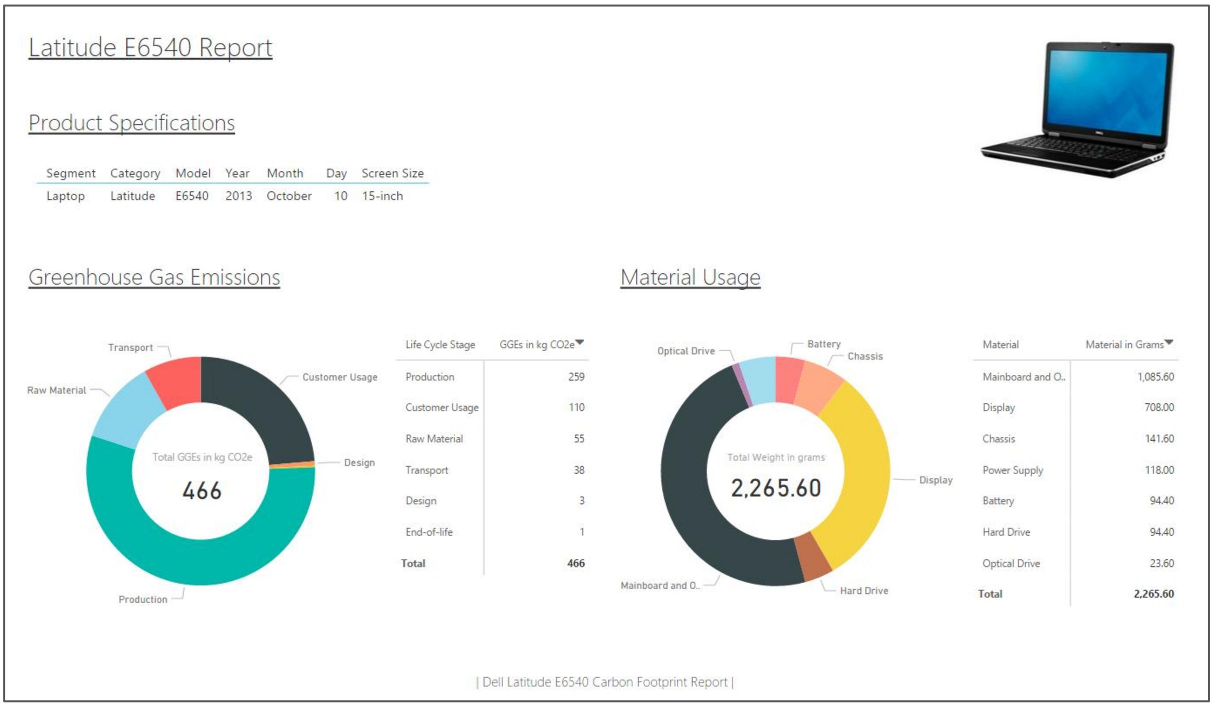


Figure 70: Dell Latitude E6540 Report
Own illustration based on data from (Dell, 2013b,c)

The report shows in the upper left the name *Latitude E6540 Report*. Below this, the product specifications are listed. These show that the Latitude E6540 is part of the laptop segment. The release date is separated into year, month, and day. It shows that the product was introduced on 10 October 2013. Further, the screen size is given as 15-inch. In the bottom half, the report contains on the left side total and life cycle GGEs in the form of a donut chart supplemented by a list of LCS emissions sorted from most emission-causing to least. This list shows the six stages of the standardized PLC of the generalized model. The GGE values could also be extended by comparison data as demonstrated in Chapter 1.2 and Chapter 4.4.3.2. Those would give the possibility to even better comprehend the GGE values. On the right side of the bottom half are the materials as a donut chart, with the total weight that results from all materials in grams listed on the right. The report is concluded by the footer *Dell Latitude E6540 Carbon Footprint Report*.

By considering more products, e.g. yearly examinations for the GGE developments would be possible as demonstrated for the Apple portfolio. Since this reporting uses the generalized model and a design inspired by the Apple PDF reconstruction, the already for the Apple Model confirmed compliance with the GRI guidelines can also be confirmed for this case (2016b, pp. 16–18). In a last step, the report data could be upload in the service tool. Since there is only one report, this would be exactly mirrored by a dashboard. Therefore, this step will be spared. However, all stated advantages of interactive dashboard supported insight communication would also apply to the Dell sample, so e.g. automated insights could be obtained.

Result and Further Applications

As demonstrated, the model works well also for another company scenario by collecting and presenting the environmental data as intended in a structured and meaningful way, while following the provided guidelines. Implemented by several companies, this kind of standardized environmental reporting could further enable benchmarking among these companies as mentioned in the remarks on the comparability claim of the GRI (2016b, p. 18). In this paper's context, benchmarking refers to a continuous comparison of the environmental product impact between two or more companies (CUP, 2016e). The goal is to close the performance gap to better performing competitors, hence companies that release similar products with lower environmental impacts. One example could be to compare the Dell Latitude E6540 to an Apple laptop to get answers on which laptop has the lesser footprint. Afterwards, reasons for the results must be searched to deduce actions that intent to influence the product footprints positively. This comparison could eventually lead to an environmental labeling that reflects a possible rank order of products and companies regarding their environmental impacts. Such "eco-labeling of IT products" (Murugesan, 2008, p. 26) has been introduced as one focus area of Green IT in the foundations part of this paper (Chapter 3.2). Its implementation is also described by ISO (2006a, p. v) and should in particular consider the ISO 14021 *Environmental Labels and Declarations — Self-declared Environmental Claims* (ISO, 2016e). This benchmarking and eco-labeling would than enable to verify claims such as: "Apple's ultracompact product and packaging designs lead the industry in material efficiency." (Apple, 2016c, p. 2) Showing proof for statements like this based on a recognized method of a standardized Environmental PLC Data Monitoring Model, would help companies to be more credible about their environmental responsibility.

6 Conclusion and Future Research

The relevance of a sustainable acting is becoming ever more important in peoples' and companies' thinking (Gartner, 2015b; ISO, 2009, p. 3). In particular, the protection of the environment is a vital factor since social and economic aspects can be considered only with a healthy planet to live on (Hilty and Aebischer, 2015, p. 12). Today, human greenhouse gas emission-caused climate change is held to be the most threatening problem to the environment (Dahiya and Ahlawat, 2013, p. 6.4). As the IPCC (2014, p. 8) states: "Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems." Especially companies emit a large range of those gases while manufacturing their products (EPA, 2016c). This also applies to goods of the ICT industry (GeSI, 2012; Greenpeace, 2010). Throughout their entire life cycle, from design to raw material, transport, production, customer usage, and end-of-life by recycling, reuse or disposal, ICT products and their processes should strive for a preferably low environmental impact. Accurately analyzing and reporting environmental PLC data would help companies to monitor their footprints and support them in their environmental decision-making (ISO, 2006a, p. v). As Günther (1998, p. 131) confirms: "The collection and monitoring of environmental data is an essential component of any environmental management and protection strategy. [...] The purpose is to recognize unusual developments early on to avoid serious damage." Besides, proactive environmental monitoring could reveal saving potentials, e.g. by finding new low impact materials that could also be cheaper or easier to process and therefore lower production costs. To enable such monitoring, this paper's objective target was to constitute a model to gather, prepare, analyze, report, and appropriately communicate environmentally related ICT life cycle data by using state-of-the-art BI technologies. This solution should in consequence support the LCA methodology, which provided the main scientific basis for the conducted research.

Leading to this goal, the paper first introduced the state of the art to show currently available approaches, which already contribute to environmental PLC data monitoring. Thereby, the Apple Environmental PDF reports were introduced as the origin for the intended research. As identified, these reports show several issues such as inaccurate data, inconsistent life cycle definitions, or a misleading understanding of materials. Beside these reports, available LCA software was presented. These also show improvement potentials because of disadvantages such as difficult handling of confusing interfaces, insufficient quality of report presentations, or inadequate information sharing possibilities. Because of the identified problems of the available LCA software and in particular within the research foundation of the Apple PDF reports, a better solution was recognized as required. Therefore, first, the fundamentals of sustainability, environmental protection, and climate change were shown to impart the precedence and the consequences of the issue. Furthermore, several statistics were presented to evidence the growing environmental awareness in peoples' and companies' thinking. Afterwards, environmental protection in the context of the ICT industry was discussed by initially illustrating the sectors' growing importance as well as the increasing consciousness for ICT environmental thinking. The explanation continued by introducing the fundamentals of the research fields of Environmental Informatics, Green IT, and LCA as well as the basics of BI analysis and reporting. Furthermore, the utilized BI tool landscape, consisting of MS Excel and the MS Power BI suite, was described to transfer significant basic handling information in order to understand its application in the further sections. Afterwards, the analysis of the Apple PLC environmental data was performed by implementing the Apple Environmental Monitoring Model to question the footprint of the entire Apple product portfolio. This approach was subsequently evaluated by identifying its limitations and issues in order to implement a generalized model with a standardized process that provides further solutions. Therefore, several steps were taken such as the creation of a more substantiated PLC that covers a broader range of environmentally related data and offers more analysis possibilities. Finally, the applicability of the generalized model was demonstrated on the example of the Dell product portfolio and a selected Dell laptop. Thereby, the further utilization of the generalized approach for insights benchmarking and eco-labeling purposes was introduced.

Finally, the question of possible future work for the concept remains to be answered. The model already gives data-driven insights to significant environmental questions. By expanding it, further valuable business insights could be revealed. One possibility is to extend the model by other enterprise perspectives. A sales point of view, for example, could characterize that a product is sold in a store, which is located in a country or a region. Based on this extension e.g. the number of sold products of a category in a country could be set in relation with the single product emissions in order to create a filled map that shows, where the category causes the most GGEs. This would enhance the product release viewpoint by actual sales numbers, and thereby connect the model's environmental focus to an economic perspective. Based on these further KPIs such as the emissions per revenue are feasible. An example could be: The iPhone SE emits 75 kg CO_2e (Apple, 2016c). Assuming 800.000 iPhone SE have been sold in Q2/2016 in the USA, 60 Mio. kg CO_2e would have been emitted by the iPhone SE on the U.S. market. Assuming the iPhone SE would cost 600 USD, the revenue would be 480 Mio USD. Thus, the emissions per revenue would stand in relation 1:8, what signifies that for 8 USD revenue 1 kg CO_2e had been produced. From a life cycle perspective, these considerations could be further separated. The production emissions, for example, should not always be applied to the country in which the product was sold since the production usually takes place in a few countries that are only in some cases the point of sale. Also, the transport is a problem, which should be viewed from a more global perspective to obtain insights in more detail. In addition to these sales related enhancements, there are several other possible extensions of the concept. One would be a fully autonomous working detection of wrong, incomplete, or inaccurate information. This is already implemented basically, so that a user can correct mistakes, e.g. in the case of materials that are misspelled. In this context, the proposing of alternative materials could be another functionality. If an analysis reveals that a material causes numerous emissions in a specific LCS, it would be an option to replace it. The model could show possible materials that have similar properties based on the implemented standard material catalog. However, the consideration to replace a material should also rely on further deliberations such as its utility for recycling or similar purposes since higher emissions in one stage could be compensated by saving emissions through other advantages.

A further valuable system extension would be a correlation calculation e.g. between PLC stage emissions and a specific material. Currently, the research is restricted on total correlations, so a significant impact is indicated, if increase and decrease of two graphs are compatible in each case. This could be enhanced by the implementation of a correlation indicator as described by Sedgwick (2012). A calculation like this would enable the user to get granular statements on possible relationships. Since the current model concentrates on the environmental indicator GWP for the purpose of climate change prevention, several other subjects that could lead to detailed footprint insights and further correlations could also be considered. These include the consumption of energy or the contamination of water. Also, the packaging could be taken into account since it also influences the life cycle, e.g. by design, production, or transportation needs. The enrichment of the LCI with external knowledge could be another extension. Therefore, the solution could be connected with environmental databases, such as *ecoinvent* (Ecoinvent Association, 2016). In this regard, also the extension by comparison data e.g. for the emissions, by databases such as the *Environmental Data Explorer* of the UNEP (2016b), would be possible. Regarding the data assessment and interpretation, a wide range of further investigation cases basing on the already conducted researches could be examined. An example is the investigation, if a particular material combination might influence the total or single life cycle emissions. In this context, also the enhancement of the models interpretation possibilities would provide a valuable extension. Last mentioned implication shall be the adjustment of the entire model for a use in other industries. Upcoming research should question, which adaptations, e.g. of the life cycle, would be necessary to implement such cross-sector solution. These mentioned cases are some possibilities to extend the model and its monitoring capabilities, which could be utilized by further research efforts to create an even more valuable approach.

As the Climate Group (2008) says: "To help, rather than hinder, the fight against climate change, the ICT sector must manage its own growing impact [...]." Gartner (2015b) confirms: "[the] awareness among organizations [..] [for] green technology and climate change issues is growing." This trend is also evidenced by several environmental mission statements of ICT enterprises such as Apple (2016a), Dell (2016b), or Microsoft (2016a). The central challenge for all these companies is to manage the amounts of environmental data that are produced along the PLC of each product in their portfolio. Only the reliable insights that can be gained from this data enable a reasonable decisions making and a substantiated controlling of a company's environmental product impacts. Therefore, the ISO (2006a, p. v) confirms: "The increasing awareness of the importance of environmental protection, and the possible impacts associated with products [...] has increased interest in the development of methods to better understand and address these impacts." The model implemented by this paper, provides such a solution that helps to better understand and address environmental product impacts by providing meaningful and reliable ecological data insights. Therefore, the approach supports the methodology of LCA from the accurate collection of an environmental data inventory, through the comprehensive assessment of the data, to the interpretation of the explored insights. In addition, the model provides several more advantages such as the real-time communication of the obtained information or the possibility to generate automatically data insights, which are enabled by the utilized BI tool landscape. With all the demonstrated capabilities of the Apple Monitoring Model and eventually of its generalization, the new approach offers the intended flexible, fast to implement, and easy-to-use solution, which presents significant environmental insights that can be effortlessly shared among all stakeholders. The thereby initiated environmental insights dialog enables a unique decision supporting possibility that will help each company to achieve their footprint goals. Thus, the model provides a substantial progress and a significant business value for the environmental data monitoring efforts of ICT companies and therewith supports the environmental protection aspect of sustainability.

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Acknowledgment

First, I like to thank my family, especially my girlfriend, for being so supportive over the months of writing this thesis. I also want to thank my advisors Prof. Dr. Hans-Knud Arndt and Prof. Dr. Klaus Turowski who helped me with every question I had. Furthermore, I like to thank the Otto von Guericke University Magdeburg for enabling and supporting my academic career.

Declaration of Originality

I hereby declare that this thesis is my own work, which I have independently prepared, without assistance and only by using the specified tools. The thesis has not been submitted in any form for another degree or diploma at any university or other institute of tertiary education. Information directly or indirectly used from the work of other authors has been acknowledged in the text and in the references.

Magdeburg, September 12, 2016

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Monitoring of Life Cycle Data to Determine the Environmental Impact of Information and Communication Technology Products.

Master's Thesis, Otto von Guericke University Magdeburg, 2016.