DATA CENTRE LIFE CYCLE ASSESSMENT GUIDELINES

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Executive Summary

Increasingly, both the public and private sectors are interested in determining a product or organization's environmental impact, also referred to as its environmental footprint. Whether for policy making, regulation compliance, or customer information purposes, environmental impact assessments are growing in importance and frequency.

A number of entities have developed methodologies and tools for assessing environmental impacts some can be applied in a limited way to a data centre. The current state of life cycle assessment (LCA) methodologies, the lack of applicable primary and secondary data for assessing data centre components and systems, and the complexity of the data centre create serious difficulties in performing a data centre LCA. The Green Grid—an international, non-profit consortium working to enhance data centre resource efficiency—does not seek to develop yet another methodology or calculate the environmental impacts of a particular data centre, but rather to provide a framework and rules that can be used by organizations around the world to describe the specifics of their data centres in a consistent manner, so that all the different methodologies can evaluate a data centre's environmental impacts in the same way.

The Green Grid's framework is intended to be used by data centre owners, renters, and operators as a common basis in order to harmonize environmental impact studies. This white paper introduces the framework, highlights supporting industry standards, and discusses how to identify and uniformly describe the key elements of a data centre for the purposes of conducting a complete life cycle assessment of a data centre's full environmental impacts.

Table of Contents

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I. Introduction

In response to the growing demand for environmental impact data, various standards organizations, industry consortia, and regulatory bodies have developed tools that share the same goal: accurately assess the environmental impact of a product or organization. Each tool focuses on a particular range of interest (e.g., all environmental impacts or a single impact, such as greenhouse gases), designates applicable life cycle stages (e.g., complete life cycle or just one phase, such as a use or recycling phase), and covers different product ranges (e.g., all products, including food, clothes, and electronics, or only specific product categories, such as electronics and electrical equipment). The individual tools all have their own particular requirements and limitations and, in almost all cases, provide gross estimates of the calculated impacts at best.

This white paper, produced by The Green Grid, provides a framework for identifying and describing the elements necessary to assess a data centre's complete life cycle, taking all relevant environmental impacts into consideration. The white paper focuses on defining applicable assessment boundaries and environmental concerns; it does not delve into all the economic and social aspects of sustainable data centre operations, such as the use of "conflict materials." (See Figure 1 for an illustration of the greater spectrum of sustainable data centre operations versus this white paper's environmental-only focus.) It also does not attempt to determine the level of accuracy that can be achieved in assessing the life cycle impacts of a data centre if performed within the identified framework.

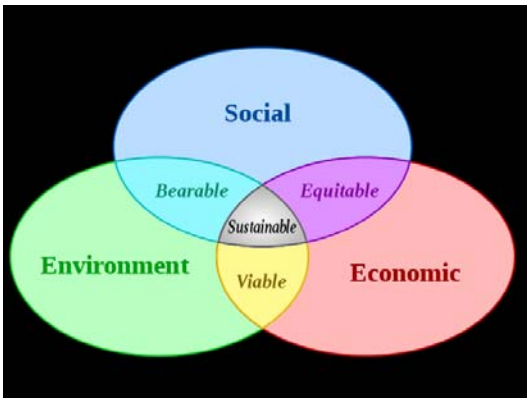

Figure 1. The three pillars commonly associated with sustainability and their areas of overlap

BENEFITS OF A LIFE CYCLE APPROACH

An effective life cycle assessment (LCA) must include a data centre's full span of operations, provide an initial assessment of *all* environmental impacts, differentiate between significant and de minimis impacts, and focus

on those aspects of the life cycle that can have a significant impact on the environment. By using a comprehensive approach that encompasses everything from the data centre's supply chain to its end-of-life elements, an organization can also assess whether reducing an environmental impact in one area may unintentionally increase an impact in another. Because LCAs address each operational phase within the data centre, they also help an organization minimize the chances that a particular area's environmental impacts will be overlooked. Knowing the impacts of every life cycle stage enables an organization to better manage and balance its data centre operational environmental impacts: energy consumption, waste generation, water use, etc.

Organizations can use LCA results to make more informed decisions regarding design and operational activities that contribute to and can reduce a data centre's environmental impact. Such activities include determining when to retire equipment versus re-deploy it and identifying opportunities for virtualization and consolidation of lower-performing systems onto a single platform to reduce overall energy use and improve system utilization.

Benefits of LCAs include the ability to:

- Identify life cycle main impacts.
- Estimate the changes in the impacts of a product during its use period.
- Compare different technologies and supply chain opportunities.

DATA CENTRE ENVIRONMENTAL ASSESSMENT VERSUS ORGANIZATION ENVIRONMENTAL ASSESSMENT

For the purposes of this white paper, The Green Grid is considering the data centre as the entity of interest for the LCA and focusing the discussion on the assessment of the relevant data centre life cycle activities. If conducting an *organization*-level life cycle assessment, it is important to properly allocate the impacts to any companies using parts of a data centre, to aggregate different impacts from different data centres, and so on. In the case of an organization-level assessment, it is possible to have positive impacts that can be subtracted from the organization's overall global impact. For instance, heat emission from one entity can heat another entity and reduce its negative environmental effects.

II. Life Cycle Assessment Resource Materials

Certain standards organizations, industry consortia, and regulatory bodies have developed (and continue to develop) particularly useful LCA methodologies and tools. This section highlights some to consider when undertaking a data centre LCA.

LIFE CYCLE ASSESSMENT PRINCIPLES: ISO 14040

The International Organization for Standardization (ISO) created a standard called *ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework* to provide an overview of life cycle assessments to broad audience. It outlines essential questions to answer in order to conduct an accurate, effective LCA, including:

- **System boundaries:** What is included in/excluded from the particular life cycle assessment?
- **Functional unit:** What unit of reference is used?
- **Life cycle perspective:** Have all elements from supply chain to end of life been considered?
- **Comprehensiveness:** Are all aspects of the natural environment, human health, and resources included?

DECLARATION OF ENVIRONMENTAL IMPACTS: ISO 14025

ISO 14025:2006 Environmental labels and declarations -- Type III environmental declarations -- Principles and procedures further discusses the ISO 14040 series of standards and gives guidelines for how to use environmental impact data, particularly for making declarations regarding quantified environmental information about the entire life cycle of a product, known as Type III environmental declarations.

An effective life cycle assessment is based on accurate data and takes into consideration the product category rules (PCRs), which is a set of specific rules, requirements, and guidelines for developing Type III environmental declarations, as defined by ISO 14025. Figure 2 illustrates the need for both product definitions and data; the more precise those definitions are, the more accurate the data will be, and, as a consequence, the more significant the LCA's results.

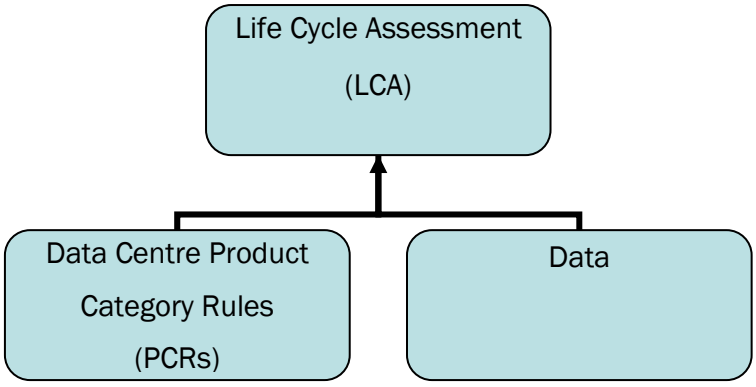

Figure 2. Depiction of the dual elements necessary for a comprehensive, accurate life cycle assessment

METHODOLOGIES FOR ASSESSMENT OF ENVIRONMENTAL IMPACT

In seeking to determine the environmental impacts of their products and overall organizations, some organizations develop their own assessment methodologies, while others prefer to wait for external entities to develop, implement, and test methodologies before choosing them as a reference. Table 1 below provides an overview of the various tools and methodologies currently available that can be used for environmental impact assessment.

Currently, there is no life cycle assessment methodology developed specifically for data centres. There are a variety of software, database, and secondary data tools available with which to perform an LCA; the practitioner should use that methodology which best suits its needs and chosen boundary conditions.

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Table 1. Methodologies, studies, and indicators for environmental assessment

Organization	Document	Publication	Geographical Scope	Product Scope	Life Cycle Impacts	Data Centre Focused?	Comments
GHG Protocol*		1998	World	Generic	Complete/GHG	No	Generic methodology
GHG Protocol « ICT Sector guidance » Chapter 8 "DataCenters"		March 2012	World	Specific chapter for data centres		Data centre only	Dedicated to data centres, only covers GHG
European Commission	Methodology for assessing environmental footprint of products (under development)	2012	Europe	All products	Complete/all impacts	Data centre is part of IT	Intended to become the reference for all European Union (EU) initiatives
IEC TC111** IEC TC111	Technical report 62725 & 62726	Expected 2013	World	Electric and electronic equipment (EEE)	Complete/GHG	Data centre considered to be EEE	Dedicated to EEE, so it covers data centre equipment
ISO TC207 ISO TC207	ISO 14067 (under development)	2013	World		Complete/GHG	Data centre is a product	GHG only, not specific to data centre or even EEE
ITU-T SG5 ITU SG5		2012	World	Telco network (includes IT)		ITU considers data centre part of a Telco network	Methodology under development; best practices for green data centre published

Organization	Document	Publication	Geographical Scope	Product Scope	Life Cycle Impacts	Data Centre Focused?	Comments
ETSI	TS 103 199 Life Cycle Assessment (LCA) of ICT equipment, networks, and services; general methodology and common requirements	2011	Europe	IT equipment, networks, and services	All	No	
Singapore Standardization	SS564	2011	Singapore	Data centre	Complete	Data centre only	Based on the ISO 50001 energy management standard; also includes some environmental requirements
JTC1 ISO/IEC***	Standardization of KPIs Best practices	Expected 2014	World	Data centre		Data centre focused	Two projects: vocabulary and metrics
CG GDC	Standards (under development)		Europe (CEN + CENELEC + ETSI)	Data centre	Use phase	Data centre focused	
The Green Grid	Power usage effectiveness (PUE™) Water usage effectiveness (WUE™) Carbon usage effectiveness (CUE™)		World	Data centre	Use phase	Data centre focused	Power, water, and carbon usage indicators (respectively) that measure a single impact during use

*GHG = greenhouse gases

**IEC = International Electrotechnical Commission, TC = Technical Committee

***JTC = Joined Technical Committee

Section III below defines LCA elements that are specific to data centres so that any methodology used for calculating environmental impact(s)—such as those shown in Table 1—can be consistently applied to data centres everywhere, according to this white paper's rules and definitions.

III. Required Criteria for Conducting Life Cycle Assessments

DATA CENTRE DEFINITION

A data centre is a structure, or group of structures, dedicated to the centralized accommodation, interconnection, and operation of information technology and network telecommunications equipment that provides data storage, processing, and transport services. A data centre encompasses all the facilities and infrastructures for power distribution and environmental control together with the necessary levels of resilience and security required to provide the desired service availability.

BOUNDARIES OF THE DATA CENTRE

Each LCA study needs to carefully define the data centre boundaries. If boundary definition is done clearly, using the criteria proposed in this white paper, the LCA will have the following attributes:

- It will set clearly defined boundaries that delineate which systems and operations are included and excluded from the LCA.
- LCA results can be compared more effectively, as the extent of the analysis will be clear.
- Organizations can better measure how their data centres' impacts evolve over time and data can be used for aggregation on a higher level.

A data centre's boundaries for any LCA should be set to include all parts of the data centre that have environmentally significant impacts. Table 2 provides the elements that such boundaries should encompass.

Table 2. Boundaries of a data centre

	Must Be Included in Scope of Study	Included Only if Significant Impact is Established	Included if Renewable Energy is Accounted
Power Generation or Delivery Systems and Miscellaneous Component Loads	Uninterruptible power supply (UPS) Transformers Switch gear Backup generators, including tanks Power distribution units (PDUs) Batteries Power cables	Other miscellaneous component loads, such as data centre lighting Fire-suppression system	Dedicated onsite renewable energy generator (e.g., solar panels, wind turbine, geothermal, etc.)
IT Equipment	Servers Storage equipment Network equipment (switches, routers, etc.) Racks Network cables	Keyboard, video, mouse (KVM) Monitors Workstations/laptops Printers	
Cooling System	Chillers Computer room air conditioning units (CRACs) Direct expansion air handler (DX) units Pumps Cooling towers	Heat exchange systems (e.g., equipment for using natural or industrial heat exchange) Reservoir storage for collecting rain water	

	Must Be Included in Scope of Study	Included Only if Significant Impact is Established	Included if Renewable Energy is Accounted
Building Structure		The building, or comparable system such as a container, that houses the data centre systems Any other infrastructure for the sole purpose of supporting the data centre	Regenerative architecture (e.g., vegetated roof, storm water management practices, etc.) Land use

Outside the boundaries of a data centre:

- Impacts caused by employee-related activities (commuting, offices, cafeteria, parking lot lighting, etc.)
- Impacts caused by non-data centre usage of the building
- Grid-level electricity generation and district commodity systems
- Telecommunication equipment and systems connecting the data centre to the rest of the world, including satellites, submarine cables, etc.

Currently, there are no defined rules to set data centre boundaries. The limits can be defined by the practitioner and must be clearly documented.

CUTTING RULES FOR AN LCA SCENARIO

It is important to clearly define and declare where the life cycle assessment begins and ends in relation to the broader environmental impacts of which the data centre may be part. For instance, this white paper proposes that a typical data centre LCA does not include the energy used to build the factories that manufacture the servers, construction equipment used to build the data centre, and so on. The LCA's scope must be set in a way that clearly defines the extent of the LCA usage scenario and focuses on the data centre's operation, which may include elements such as:

- Data centre equipment inventory
- Operational time frame (e.g., a data centre is running 24 hours per day, 7 days a week)
- Yearly average energy consumption, or an estimation if no measurement is available
- Expected lifetime of the equipment, building, etc. (See Table 3.)

It is important to set rules to include and exclude relevant and irrelevant environmental attributes and impacts:

- The LCA should not hide impacts. For instance, if onsite equipment provides an environmental benefit that reduces the impact of the data centre, then this benefit should be included as required by the established LCA conditions.
  - A free cooling system will reduce the energy required for cooling, thereby reducing energy use and associated CO2 emissions and improving the data centre's PUE. As the free cooling system would typically be inside the data centre's system boundary, its material impacts should be considered in the LCA.
  - Onsite renewable power generation (e.g., solar panels, wind turbines, etc.) feeding power to the data centre will reduce the total amount of energy consumed from the power grid and reduce operational CO2 emissions. If the practitioner wishes to take credit for this reduced CO2 footprint, The Green Grid recommends that the material requirements for the solar panels, wind turbines, etc. be assessed in conjunction with the data centre LCA. The benefits of the system, in terms of reduced CO2 emissions, compared with that for the electricity procured from the electricity grid use, can then be assessed against the impacts of an equal quantity of generation from the electricity grid. Otherwise, the practitioner should consider the energy produced by the onsite renewable power as out of scope for the LCA.
- Equipment or systems can be removed from the LCA's scope if it is proven that the impact is negligible compared with the whole data centre. It is considered negligible if its impact is less than 2% of the whole data centre impact and if the overall impact of the de minimis impacts is estimated at 10% or less of the total data centre impact.
- Emission reductions achieved outside of the data centre as the result of data centre operations—such as heat recovery used at a facility outside the boundary—can be credited.
- When the shell of the data centre is an existing structure, such as in the case of converting an office facility into a data centre, only the impacts from the modifications should be calculated.
- If a data centre is part of a building that hosts other functions (e.g., offices), the LCA practitioner needs to determine and apply the most appropriate ratio of the data centre's relative usage.

- **Example 1: Cooling.** An appropriate ratio could be power consumption in the data centre versus consumption in the rest of the building.
- **Example 2: Raw material consumption for manufacturing the data centre.** In this case, the relative surface or volume of the data centre versus the rest of the building could be an appropriate ratio.

By purchasing equipment with longer expected lifetimes and using maintenance best practices, average component lifetimes with a requisite reduction in lifetime material requirements. Table 3 illustrates typical equipment lifetimes.

Table 3. Expected lifetime of data centre components

Component	Average Lifetime (Years)
IT Equipment	
High-end servers	5-8
Low-end servers	3-5
Storage	3-5
Network equipment (switches)	3-5
PCs/laptops	3-5
Other IT (screens, phones, mouse, keyboards, etc.)	3-5
Power Equipment	
Switch gear	20
Generators	20
PDUs	20
UPS	20
Batteries	3-5
Lighting	3-5
Solar panel	20
Wind turbine	20
Cooling Equipment	
Chiller	20
CRAC	20

Component	Average Lifetime (Years)
Direct expansion air handler (DX) units	20
Pumps	20
Cooling tower	20
Building Structure	
Building	20
Container	5-10

Currently, there is no effective methodology by which equipment lifetimes can be factored or distributed across an LCA analysis, and current standards and assessment methodologies are largely silent on how to compare impacts and attributes with different time frames. Although the benefits are not typically quantifiable, the use of more robust and upgradable equipment will reduce the overall impact of the data centre.

FUNCTIONAL UNIT OR UNIT OF PERFORMANCE

Precisely identifying what is being assessed in an LCA—the "functional unit"—provides important insight into the operational variables and a way to categorize data centre operations to assist comparisons of different operations, regardless of the methodologies used. The functional unit contributes by defining the scope of the system that will be evaluated by the LCA methodology and quantifying the service delivered by the data centre system.

While conducting the LCA, all data (inputs and outputs of the system) should be linked to the functional unit that is defined in the scope of the data centre LCA. The functional unit's role is to quantify the performance of a product system and serve as a reference unit.

The functional unit should be categorized based on the answer to these three questions:

- What combination of information technologies (IT) and facilities equipment is used to provide a given service or group of services?
- What are the variations in system utilization across the day? Is it steady and continuous or is it varied with periods of idleness?
- Does the equipment require special resiliency, serviceability, or availability characteristics that affect its operational characteristics?

In the case of a data centre, a functional unit will help to define the context and the goals. It may include some of the following criteria:

- **Which type of data centre?**
  - Usage: production, research & development, disaster recovery
  - Category: high-performance computing, commercial usage
  - Full building or mixed-use building that contains offices and data centre
  - Data centre housed in a container or modules
  - Geographical area
  - The mix and capabilities of the data centre equipment
    - Are systems optimized for performance delivered per unit of power consumed for the supported workload?
    - Does the equipment have the ability to reduce energy use when no work is present?
- **Does the data centre use renewable energy resources?**
    - Is the data centre equipped to utilize free cooling?
    - Does it use renewable energies (e.g., solar, wind, free cooling, etc.)?
- **What activities, attributes, and metrics are measured in the data centre, and what are the amounts? (I.e., "How much?")**
  - Energy consumption, metrics such as PUE
  - Non-IT measurements, including temperature and humidity
    - Does the data centre operate to the ASHRAE A2 standards or higher?
  - IT equipment measurement, such as calculating compute and storage-capacity utilization
  - Transactions per second
  - Other metrics
- **What is the expected lifetime of the data centre and its components, and what is the duration of the service that is provided? (I.e., "How long?")**
  - Is equipment with longer life expectancies specified for the data centre systems?
  - In cases where the service provided is time-related, provide specifications. For instance, how long should the data be kept? Is there a guaranteed data-storing period?
- **What are the data centre's specifications regarding the quality of the service provided? (I.e., "How well?")**
  - System availability (e.g., 99,999%), reliability, etc.
  - Certification, tier-level approach, etc.
  - Criticality, capacity, growth plan, etc.

- Type of cooling, power architecture, etc.
- Best practices

LIFE CYCLE STAGES

A given product system consists of consecutive, interlinked stages that begin with either raw material acquisition or generation from natural resources and progress to final disposal.[1]

Table 4 provides typical names for life cycle stages, which can be used when conducting a product environmental assessment.

[1] *ISO 14040 Environmental management -- Life cycle assessment -- Principles and framework* (2006) www.iso.org/iso/catalogue_detail?csnumber=37456

Table 4. Life cycle phases of a data centre

General life Cycle Phases	Data Centre Life Cycle Phases
Manufacturing/Construction	Construction of the physical structure of the data centre (e.g., building, container, other structure, etc.) Manufacturing of the IT and facilities equipment used at the data centre Additional power, telecommunications, and transportation infrastructure (e.g., roads) constructed for the sole purpose of supporting the data centre
Transportation	To site and onsite transportation of materials for data centre physical construction Transportation of the equipment
Use or Operation	Use and operation of the data centre, equipment, and structure
Equipment Upgrade **End of Life of Equipment Inside the Data Centre**	Maintenance of equipment and structure, including upgrade and addition of equipment Upgrade of equipment, which counts as new equipment, with the removed equipment being managed through a reprovisioning process that can include reuse/ redeployment, dismantling for parts, recycling, and final disposal
Decommissioning	Closing of the data centre

DATA QUALITY AND UNCERTAINTY

Completing a LCA for a data centre is a complex undertaking, requiring significant effort to develop the assessment. Developing a credible assessment requires:

- Highly skilled people to conduct LCAs
- Data describing the data centre equipment, systems, and operations, with numerous decisions made regarding the use of primary, secondary, and proxy data
- A large amount of resources to gather and process the data

Data collection is complex; an extensive amount of data and information is required to assess the CO2 emissions inventory and the broader environmental life cycle impacts of a highly complex system such as a data centre. Complications extend from the following factors:

- The facilities and IT equipment are individually highly complex systems with tens and hundreds of parts manufactured by hundreds of entities.
- There is a limited quantity of primary or secondary data available on the equipment and systems used in a data centre.
- The equipment and materials have varied life spans, as depicted in Table 3. The highly varied life spans make it difficult to combine the analyses of the various systems.

The practitioner who undertakes a data centre LCA needs to balance the cost of collecting relevant data against the accuracy of the final life cycle assessment. Data sources are limited, and the data must be extracted from various sources to construct a complete picture of the data centre. The preferred hierarchy of data that can be used is described below:

1. **Primary data:** Collected data that is measured or calculated
2. **Secondary data:** Data derived from other sources such as literature or databases
3. **Proxy data:** Primary or secondary data related to an input, process, or activity that is similar (but not representative) to the one in the inventory, which can be used in lieu of representative data if unavailable

The type of data available will influence the relevance and usability of the LCA. One that consists largely of primary and relevant secondary data will offer a workable assessment of the system impacts. At the other end of the spectrum, an LCA that relies on some relevant secondary data and a large amount of proxy data will be useful in identifying systems with a high level of impact deserving of focused reduction efforts in the design and operations phase, but it will not provide a relevant assessment of the system impacts.

Currently, primary data on equipment and system-level CO2 emissions and environmental impacts is very limited. The majority of available data is secondary process-based or economic input/output data that is generalized both in geographical space and time. As an example, studies on IT equipment have shown uncertainties of 20% to 30% in estimates of emissions impacts on a single, high-volume server system. Given the current limitations on available data, the main purpose of a data centre LCA will be to assess the components and systems that provide the most design and operating leverage with which to reduce the impacts of the data centre.

MAPPING OF ENVIRONMENTAL IMPACTS AND LIFE CYCLE STAGES

In the case of a data centre, it is useful to define the environmental impacts under consideration. What are the data centre's most significant impacts and what are the other impacts that can be ignored? Table 5 below shows the data centre life cycle stages arrayed against a typically accepted set of LCA environmental impacts. There is no standardized list of impact categories, and even if different methodologies are similar in approach, they do not use exactly the same categories. It is therefore up to the LCA practitioner to justify the choice of impacts. Keep in mind that a data centre is an integration of complex systems, therefore environmental impacts can be difficult to assess when considering the data centre life cycle stages.

Table 5. Data centre life cycle stages and range of environmental impacts

Environmental Impacts	Life Cycle Stages					
		Manufacturing and Design Components + Construction of Structure	Installation and Commissioning	Use	Maintenance and Updates	End of Life
	Climate change (GWP)					
	Ozone depletion					
	Human toxicity					
	Particulate matter/respiratory inorganics					
	Ionising radiation					
	Photochemical ozone formation					
	Acidification					
	Eutrophication, terrestrial					
	Eutrophication, aquatic					
	Ecotoxicity, freshwater aquatic					
	Land transformation					
	Resource depletion					

To optimize time and resources for evaluating a data centre's environmental impacts, The Green Grid has identified a set of specific impacts to analyse when evaluating any data centre. These impacts incorporate the more typical impacts listed in Table 5 but define them through the functions and operations of the data centre. It is up to the LCA practitioner to determine whether the impacts are relevant to the LCA, depending on the type and environment of the data centre. By focusing on these impacts, an LCA can be conducted with less data and effort yet still generate an acceptable result.

- **Primary impacts** (shall be considered for all data centres):
  - Energy consumption during operation
  - Raw material depletion for construction of the data centre structure
  - Raw material depletion for manufacturing of IT and facility equipment
  - Land use and environmental impacts of the facility
  - Mix of energy-generating sources used to support operation
  - Water consumption during operation
  - Reuse, recycling, and/or disposal of IT and facility equipment and materials
- **Secondary impacts** (should be considered if relevant to a given facility):
  - Hazardous substance content of data centre building and equipment
  - Air pollution during operation

The current state of LCA methodologies and the lack of reliable primary and secondary data for the complex equipment and systems used in a data centre will require the LCA practitioner to expend considerable time in performing even a simple assessment and introduce a significant degree of uncertainty and approximation into any final results.

Studies indicate that, to facilitate clear communications, stakeholders expect a single number representing a product or organization's global environmental impact. As discussed above, the complexity of the data centre and the lack of credible data and methodologies do not lend themselves to the creation of a single aggregate number describing the environmental impact of the data centre. Instead, The Green Grid recommends assessing metrics or use values for each of the impacts listed above and identifying system or operational approaches to optimize the metric or reduce the use of the resources. A list of available metrics is provided in Table A-1 in Appendix A. Mapping of Studies and Standards.

IV. Suggestions for Future Work

The following are recommended actions for The Green Grid to take to further refine this white paper's guidelines and improve data centre environmental impact assessment as a whole:

- Implement one or several case studies to evaluate this white paper's use in a real-world data centre scenario and determine what needs to be updated or added.
- Establish more links within The Green Grid to harmonize and bring consistency to the different works related to environmental aspects of data centres.

- Collaborate with the other organizations developing environmental assessment methodologies that apply, or can be applied, to data centres.
- Observe and analyse published studies that cover environmental aspects of data centres in order to improve the current LCA guidelines included in this white paper.
- Extend LCA considerations to include sustainability, both economic and social.

V. Conclusion

This white paper represents the first step toward establishing a framework for studies and assessments on the environmental impacts of data centres. With time, The Green Grid's framework will evolve and improve, with the goal of defining product category rules for data centres that can be used to complement any environmental assessment methodology.

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VII. About The Green Grid

The Green Grid Association is a non-profit, open industry consortium of end users, policy makers, technology providers, facility architects, and utility companies that works to improve the resource efficiency of information technology and data centers throughout the world. With its member organizations around the world, The Green Grid seeks to unite global industry efforts, create a common set of metrics, and develop technical resources and educational tools to further its goals. Additional information is available at www.thegreengrid.org.

Appendix A. Mapping of Studies and Standards

For each of the potential impacts of the various life cycle stages, there are related standards, metrics, and studies that help determine the nature and relative weighting of the impact in relation to the overall LCA. Table A-1 and its corresponding list below provide examples of the connections between impacts, stages, and available resources.

Table A-1. Environmental impacts and data centre life cycle stages with relevant resources, including numbers that correspond to the resources listed below the table

Possible Environmental Impact	Data Centre Life Cycle Stage				
	Manufacturing and Design Components	**Transportation**	**Construction, Installation, and Commissioning**	**Use/ Maintenance**	**End of Life**
Raw Material			Packaging directive	8	WEEE, 5, www.stepinitiative.org, EPEAT/IEEE 1680.x
Air				8	
Water				WUE, energy reuse effectiveness (ERE™), 8	
Energy	PUE, 2		PUE, 2	PUE, unused servers, ERE, data centre compute efficiency (DCcE™), 8	3
Global Warming Energy Efficiency				CUE, server power management, ERE, 8	
Ozone				8	1, 4
Toxic Waste	RoHS, EPEAT/IEEE 1680.x		Packaging directive	N/A	WEEE, 1, 2, 3, 4, www.stepinitiative.org, EPEAT/IEEE 1680.x
Substances	RoHS, JIG EPEAT/IEEE 1680.x, SIN list		Packaging directive	8	WEEE, 1
Recycling	WEEE, EPEAT/IEEE 1680.x		Packaging directive	N/A	Unused servers, WEEE, 1, 3, 5, 7
Biodiversity	9	9	9	9	
Noise	ISO 9298				

1. Atlantic Consulting; IPU. LCA Study of the Product Group Personal Computers in the EU Ecolabel Scheme, Version 1.2.1; London, 1998 (Comment: very old study).

2. Lifecycle-based Data Center Design, HP Laboratories, Justin Meza; Shih Rocky, Amip Shh, Parthasarathy Ranganaathan, Jichuan Chang, Cullen Bash, Proceedings of the ASME 2010 International Mechanical Engineering Congress, IMECE 2010.

3. W. Scharnhorst et al. / Environmental Impact Assessment Review 25 (2005) 540–566 "It has also been shown that advanced fractionation, i.e. a material-specific separation of electronic scrap prior to material recovery neither significantly contributes to the environmental impact of EOL treatment nor significantly improves the material recovery processes."

4. Life cycle assessment of a personal computer and its effective recycling rate; Choi, B-C, Shin H-S, Lee S-Y, Hur T; International Journal of Life Cycle Assessment, 2006, p122.

5. Life cycle assessment of second generation (2G) and third generation (3G) mobile networks; Scharnhorst, W, Hilty LM, Jolliet O, Environmental International, 2006, online.

6. A hybrid life cycle assessment method for construction; G. J. Treloar, P. E. D. Love, O. O. Faniran, U. Iyer-Raniga; Construction Management & Economics. 2000, volume 18, 5-9.

7. Economic sustainability of reuse as an end-of-life management tool for computers and televisions ISEE '04 Proceedings of the International Symposium on Electronics and the Environment; L. Rubinstein, Northeast Recycling Council Inc. (NERC), Brattleboro, USA.

8. Singapore Standard for Green data Centres - Energy and environmental management systems (SS564:2010). (See www.singaporestandardseshop.sg/data/ECopyFileStore/110131114327SS%20564-2010_Preview.pdf.)

9. See www.total-ep-canada.com/upstream/documents/application/CR15_Biodiversity_Report.pdf as an example.