

JRC TECHNICAL REPORT

Development of European Green Public Procurement Criteria for Data Centres

Preliminary report

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Abstract

Development of the EU Green Public Procurement (GPP) Criteria for Data Centres, Technical report: draft criteria

Green Public Procurement (GPP), in which public authorities procure goods, services and works that have less environmental impact than comparable contracts, has the potential to accelerate the market introduction and uptake of less environmentally damaging technologies. This report forms the basis to develop the EU GPP criteria for Data Centres. The development of EU GPP criteria requires in-depth information about the technical and environmental performance of this product group as well as about the typical procurement processes. This report gathers the necessary background information for that and presents it in a structured form. Environmental improvement areas are identified thorough the life cycle of data centres Furthermore, the main elements of Life Cycle Costs of data centres are presented. The scientific body of evidence gathered will be crosschecked with sector-experienced stakeholders to find the best way to develop the criteria in order to deliver optimum environmental improvements while complying with Public Procurement law and safeguarding the Single Market.

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1. Background

1.1 Green Public Procurement

Green Public Procurement (GPP), in which public authorities procure goods, services and works that have less environmental impact than comparable contracts, has the potential to accelerate the market introduction and market uptake of environmentally less damaging technologies. In order to support GPP, the European Commission has developed harmonised EU GPP criteria for each of various products and services, in order to avoid a distortion of the single market and to reduce administrative burdens.

1.2 Aim of the study

The aim of this study is to develop EU Green Public Procurement (GPP) criteria for Data Centres; to have clear and ambitious environmental criteria, based on a life-cycle approach and a scientific evidence base. The GPP criteria will be based on the requirements addressed in EU Communication COM (2008) 400 "Public Procurement for a better Environment".

The study is carried out by the Joint Research Centre's Directorate B - Growth and Innovation (JRC) with input from the project team which is a consortium of six consulting companies: Viegand Maagøe, Operational Intelligence, Ballarat Consulting, Hansheng and PlanMiljø. The project is led by Viegand Maagøe performing the project management, lead expert consulting and the main data analysis, with close support from the rest of the team. The team of consultants has a broad understanding and experience in the areas of product policy and purchasing requirements, energy efficiency and life cycle assessment of electronic products and deep technical knowledge and understanding of data centres.

The work is being developed for the European Commission Directorate General for the Environment.

A key element is to have continuous wide consultation with stakeholders (e.g. manufacturers, supply chain industry, consumer organisations, NGOs, procurers) to engage them in the criteria development.

The development of the GPP criteria is done through a stepwise process consisting of four tasks:

- 1. Task 1: Definition of product scope
- 2. Task 2: Market analysis
- 3. Task 3: Technical analysis, including environmental, technical and functional aspects of the data centres
- 4. Task 4: Development of draft criteria proposal

¹ Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0400:FIN:EN:PDF

1.3 Aim of preliminary report

The aim of this preliminary report is to present the background technical analysis from the data centres product group to on:

- the scope of the criteria,
- the market analysis,
- an overview of the technical aspects that are relevant to consider when defining the criteria, and
- the identification of environmental improvement areas thorough the life cycle of data centres.

Furthermore, an overview of the main elements of Life Cycle Costs of data centres is provided, which will be the basis to quantify the additional costs and savings for the implementation of the GPP criteria. Finally, the results of the stakeholder survey are also presented, giving an overview of the answers related to scope as well as potential criteria.

The preliminary report is divided into 13 chapters, which relate to task 1 (scope), task 2 (market analysis) and task 3 (key environmental areas and life cycle costs structure) and the presentation of the results from the stakeholders' survey. Tasks 1, 2 and 3 are explained in more detail in the next paragraphs.

1.3.1 Aim of task 1

The aim of Task 1 is to propose the scope and definition of data centres that will be used for the development of the GPP criteria.

The first step is establishing an overview of existing statistical, technical and procurement categories of relevant legislation, standards, voluntary agreements and procurement criteria in and outside the EU, that are of relevance. These are then refined by taking account of feedback from stakeholders regarding the practicability of the proposed scope and product definition. During this process, practicability and feasibility of the proposed scope and definition will be assessed in the light of other relevant information (e.g. market data, technical analysis, procurement practices) and further modifications might be proposed in a later stage after evaluation of further information and discussions at the AHWG meetings.

1.3.2 Aim of task 2

The aim of task 2 is to compile the technical details on the product group and to collect key information on the market that affect public procurement practices, in order to assure that the criteria developed for GPP are up-to-date and relevant to the EU market.

The first step is establishing the technical state-of-play of data centres currently found in the EU market, including their physical architecture and installation, operation, management and end-of-life as well as aspects relevant for measuring data centres' sustainability. An overview of procurement practices in the EU is then established, including best procurement practices. Afterwards, the key actors in the value chain are identified focusing, as far as possible, on those involved in public procurement. Finally, the quantitative relevance of 'in scope' data centres, in terms of sales, stock and life

cycle costs is established. This analysis will assist in refining the scope further, based on insight into the market relevance of data centres in public procurement.

1.3.3 Aim of task 3

The aim of task 3 is to assess systematically and quantitatively the environmental impacts in a way that allows identifying the areas with the highest improvement potential.

This is done by reviewing existing Life Cycle Assessments (LCA) of data centres, by selecting those LCA studies which presented information about their LCA methodology according to widely accepted LCA standards, to make sure the results are credible and robust. Additional aspects, not related to LCA, but relevant to developing the GPP criteria are also identified. Finally, based on the review of the LCA studies the priority improvement options are identified. Additionally, the Life Cycle Costs (LCC) structure is defined.

2. Review of existing scope, product types, product classification and metrics

2.1 Data centres

Data centres are typically formed of three systems: IT, electrical and mechanical systems formed by individual products, and of the building infrastructure (see Figure 1).

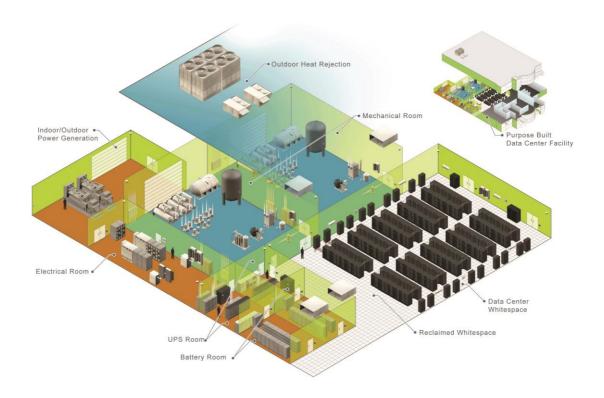


Figure 1.Typical data centre layout².

The main individual electricity consuming products that form each of the systems are:

- IT systems:
 - Server unit(s)
 - Storage unit(s)
 - Network and communications equipment e.g. switches and routers
- Mechanical system:
 - Compressors
 - Heat rejection fans
 - Pumps
 - Cooling unit fans (CRAH = Computer Room Air Handler)

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² Reproduced with permission of Schneider Electric

- Humidifiers
- Ventilation fans
- Electrical system:
 - Transformers
 - UPS³
 - Generator heaters (to enable guick start of the UPS when required)
 - PDUs (power distribution units), static switches, rack-mounted UPS
 - Lights
- Building infrastructure

Services provided by data centres such as data processing, web portals and hosting are required for many business and sectors, so data centre products and services may be purchased and operated very differently. However, data centres are often classified according the ownership of the data centre itself and/or of the service provided. This is, they are addressed differently by different schemes, voluntary agreements and EU statistical sources. An overview is presented in the next sections, and according to this overview, a proposed classification is presented in chapter 3.

2.2 Product classification in statistical sources

In this section, the product classification in statistical sources and procurement oriented sources relevant to data centres is presented. Furthermore, the classification system used in public procurement is also presented.

2.2.1 Prodcom – statistics by product

Prodcom provides statistics on the production of manufactured goods, i.e. the individual components, and single products used in the data centres such as servers, storage products and network equipment. However, it does not provide statistics on services provided by the data centres.

The relevant Prodcom categories are listed in Table 1, showing the manufacturing of servers, storage products and network equipment or other data centre related equipment, though most of them contain more product types than the ones in scope of this study.

³ Uninterruptible Power Supply

Table 1. Prodcom code and description for servers, storage products, UPS and other data centre related equipment.

Product group	Prodcom code and description
Servers	26201400 – Digital data processing machines: presented in
	the form of systems
	26201500 – Other digital automatic data processing
	machines whether or not containing in the same housing one
	or two of the following units: storage units, input/output
	units;
Storage products	26202100 – Storage units
3 '	26203000 – Other units of automatic data processing
	machines (excluding network communications equipment
	(e.g. hubs, routers, gateways) for LANs and WANs and sound,
	video, network and similar cards for automatic data
	processing machines)
Network equipment	26122000 – Network communications equipment (e.g. hubs,
and other data centre	routers, gateways) for LANs and WANs and sound, video,
related equipment	network and similar cards for automatic data processing
	machines
	26302320 – Machines for the reception, conversion and
	transmission or regeneration of voice, images or other data,
	including switching and routing apparatus
	26302370 – Other apparatus for the transmission or
	reception of voice, images or other data, including apparatus
	for communication in a wired or wireless network (such as a
	local or wide area network), other than transmission or
	reception apparatus of HS 84.43, 85.25, 85.27 or 85.28
	27901150 - Machines with translation or dITionary functions,
	aerial amplifiers and other electrical machines and apparatus,
	having individual functions, not specified or included
Uninterruptible power	elsewhere in HS 85 (excluding sunbeds, sunlamps and similar
supplies (UPS)	sun tanning equipment)
	27115040 - Power supply units for telecommunication
	apparatus, automatic data-processing machines and units
	thereof
	28251250 – Air conditioning machines with refrigeration unit
Cooling equipment	(excluding those used in motor vehicles, self-contained or
	split-systems machines)
	28251270 – Air conditioning machines not containing a
	refrigeration unit; central station air handling units; vav boxes
	and terminals, constant volume units and fan coil units
Monitoring equipment	26515271 – Electronic pressure gauges, sensors, indicators
	and transmitters

Other types of cooling equipment (e.g. free cooling) and other data centre related equipment such as switchboards, generators, data and electrical cabling are or can be part of the data centre. However, they are not listed above because Prodcom lists these products with multiple uses, not exclusively for data centres.

2.2.2 NACE - Statistical classification of economic activities

NACE⁴ provides a classification of economic activities. While Prodcom only covers the statistics of manufacturing goods, NACE includes services and businesses other than manufacturing. The NACE classification gives an indication of the services provided by data centres. See the relevant NACE classes under Section J Information and Communication in Table 2.

These classes contain data centres services but also contain for example hosting companies renting space in data centres (thus not neither owning, nor operating the data centre) and where data centres can be located outside EU.

In general, there is a need to supplement both the Prodcom and NACE categorisations to defining the scope precisely enough.

-

⁴ Nomenclature Générale des Activités Économiques dans les Communautés Européennes

Table 2. Relevant NACE clases for data centre services.

63 Information service activities

This division includes the activities of web search portals, data processing and hosting activities, as well as other activities that primarily supply information.

63.1 Data processing, hosting and related activities; web portals This group includes the provision of infrastructure for hosting, data processing services and related activities, as well as the provision of search facilities and other portals for the Internet.

63.11 Data processing, hosting and related activities

This class includes:

- provision of infrastructure for hosting, data processing services and related activities
- specialized hosting activities such as:
 - Web hosting
 - streaming services
 - application hosting
- application service provisioning
- general time-share provision of mainframe facilities to clients
- data processing activities:
 - o complete processing of data supplied by clients
 - o generation of specialized reports from data supplied by clients
- provision of data entry services

This class excludes:

o activities where the supplier uses the computers only as a tool are classified according to the nature of the services rendered

63.12 Web portals

This class includes:

- operation of web sites that use a search engine to generate and maintain extensive databases of Internet addresses and content in an easily searchable format
- operation of other websites that act as portals to the Internet, such as media sites providing periodically updated content

This class excludes:

- publishing of books, newspapers, journals etc. via Internet, see division 58
- broadcasting via Internet, see division 60

2.2.3 Common Procurement Vocabulary (CPV)

Regulation (EC) No 213/2008 for CPV establishes a single classification system for public procurement aimed at standardising the references used by contracting authorities and entities to describe the subject of procurement contracts.

Relevant categories for procurement of data centre equipment and services are listed in Table 3.

Table 3. Relevant categories in CPV.

CPV code 2007	Description
48800000-6	Information systems and servers
48820000-2	Servers
48821000-9	Network servers
48822000-6	Computer servers
48823000-3	File servers
48824000-0	Printer servers
48825000-7	Web servers
72310000-1	Data-processing services
72311100-9	Data conversion services
72311200-0	Batch processing services
72312000-5	Data entry services
72312100-6	Data preparation services
72313000-2	Data capture services
72314000-9	Data collection and collation services
72315000-6	Data network management and support services
72315100-7	Data network support services
72315200-8	Data network management services
72316000-3	Data analysis services
72317000-0	Data storage services
72318000-7	Data transmission services
72319000-4	Data supply services
72320000-4	Database services
72321000-1	Added-value database services
72322000-8	Data management services
72330000-2	Content or data standardization and classification services
72400000-4	Internet services
72410000-7	Provider services
72411000-4	Internet service providers ISP
72412000-1	Electronic mail service provider
72413000-8	World wide web WWW site design services
72414000-5	Web search engine providers
72415000-2	World wide web WWW site operation host services
72416000-9	Application service providers
72417000-6	Internet domain names
72420000-0	Internet development services
72421000-7	Internet or intranet client application development services
72422000-4	Internet or intranet server application development services

2.2.4 Summary

Prodcom categories are typically used to provide data on import, export and production in units and monetary values. However, these categories are only for tangible products in data centres. Services provided by data centres that are not physically manufactured cannot be categorised by Prodcom categories.

NACE categories covers the business categories of intangible products and services provided by data centres as well as the products manufactured. In particular, the NACE category "data processing, hosting and related activities; web portals" describes the overall services provided by data centres well, therefore it can be used to define the intangible part of the data centre products.

CPV categories have been developed for the purpose of public procurement, and in principle these categories would be suitable for defining the products and services of a data centre. However, it is unclear how the categories match with the Prodom and NACE categories and what the categories entail in practice, because two or more CPV categories can belong to one Prodom or NACE category, and the explanatory notes do not offer enough explanation. Therefore, these categories could be used for complementing Prodom and NACE where needed or where CPV categories are clearer.

In conclusion, Prodcom can be used to categorise the tangible products used in data centres, NACE classes can help defining services provided by data centres and CPV can supplement the other two where necessary.

2.3 Scope, categorisation and metrics in existing legislation, standards, voluntary agreements and procurement criteria

This section presents the scope, categorisation and environmental metrics of relevant existing legislation, standards, voluntary agreements and procurement criteria of data centres. The scope and categorisation has been investigated at the data centre level in order to get an overview of existing product and/or service definitions. This review has also looked at legislation, standards, voluntary agreements and procurement criteria focused on data centre components (e.g. uninterruptible power supply (UPS), servers, storage, cooling units) to identify suitable metrics. Table 4 presents an overview of relevant initiatives. They are applicable to all types of users unless otherwise stated.

Table 4. Overview of initiatives relevant for data centres.

Initiative	Mandato- ry legis- lation	Standards/ TR/ Certi- fication scheme	Ecolabel schemes	Guide- line	Voluntary agree- ment	Metrics	Procure- ment criteria
Ecodesign measures on servers and data storage (under development)	Х						
WEEE & RoHS Directives	Х						
EU Emission Trading Scheme	Х						
ISO 14001 & ISO 50001		Х					
Eco-Management and Audit Scheme (EMAS) - sectoral reference document on best environmental management practice of electrical and electronic equipment (EEE)		Х					
ISO/IEC 30134 series - Information technology - Data centres - Key performance indicators		Х				Х	

Initiative	Mandato- ry legis- lation	Standards/ TR/ Certi- fication scheme	Ecolabel schemes	Guide- line	Voluntary agree- ment	Metrics	Procure- ment criteria
EN50600 Data		Scheme					
Centre Standard							
series for		X				X	
infrastructure &							
facilities							
Technical Report							
series - CLC/TR							
50600-99-1:2017		.,					
Information		X					
technology - Data centre facilities and							
infrastructures							
ETSI Standard ES							
205 200-2-1							
Access, Terminals,							
Transmission and							
Multiplexing (ATTM);							
Energy management;							
Global KPIs;							
Operational							
infrastructures; Part 2: Specific		X				X	
requirements;							
Sub-part 1: Data							
centres							
ETSI GS OEU 001							
Operational energy							
efficiency for users;							
global KPI for data							
centres							
Uptime Institute's		.,					
Tier Classification		X					
system ANSI/TIA-942							
Telecommunications							
Industry							
Association's		.,					
Telecommunications		X					
infrastructure							
standard for data							
centres							
Blue Angel energy							
efficient data centre			X				
operation ENERGY STAR -							
*benchmarking of							
data centres							
*specification for							
Enterprise servers							
*specification for							
Data Centre Storage							
*specifications for			X				
large network							
equipment							
*specifications for small network							
equipment							
*specifications for							
uninterruptible power							
systems (UPS)							
The Green Grid							
voluntary standards				Χ		×	
and models							

Initiative	Mandato- ry legis- lation	Standards/ TR/ Certi- fication scheme	Ecolabel schemes	Guide- line	Voluntary agree- ment	Metrics	Procure- ment criteria
EURECA project on data centres				Х			
ITU Toolkit on environmental sustainability for the IT Sector (ESS)				Х			
European catalogue of IT standards for procurement				Х			
EU Code of Conduct (CoC) for energy efficiency in data centres				X	X		
EU Code of Conduct for AC UPS				X	X		
UK Global warming potential Agreement for colocation facilities					Х		
Finnish sustainability rating system (TIKO) for data centres developed by Ministry of Transport and Communications						Х	Х
EU Procurement guidance PrimeEnergyIT project				Х		X	Х
EU GPP Criteria for Office Building Design, Construction and Management							Х

2.3.1 Ecodesign measures on servers and data storage (under development)

Ecodesign implementing measures for servers and data storage product (DG GROW Lot 9⁵) have been proposed. The preparatory study contains some relevant findings with respect to IT hardware's environmental impacts.⁶ The process to prepare an Impact Assessment for the regulation started at the end of 2015 and a Consultation Forum meeting to discuss draft regulation took place in February 2017.

The first phase of these measures – if finally agreed on - is expected to take effect in January 2019; with subsequent phases to follow. The proposed scope for a possible ecodesign regulation includes the following products:

- Servers with up to four processor sockets regardless of form factor and types
- Data storage products as defined by SNIA⁷ taxonomy as Online 2, Online 3 and Online products

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⁵ http://ec.europa.eu/growth/industry/sustainability/ecodesign/product-groups_en

⁶ Preparatory study for implementing measures of the Ecodesign Directive 2009/125/EC DG ENTR Lot 9 - Enterprise servers and data equipment, Task 5: Environment & Economics, July 2015 - Final report

⁷ Storage Networking Industry Association

The proposed scope does not include the following:

- Servers intended for embodied applications;
- Servers classified as small scale servers in terms of Regulation (EU)
 No 617/2013;
- Servers with more than four processor sockets;
- Small data storage products defined by SNIA taxonomy as Online 1 products;
- Large data storage products defined by SNIA taxonomy as Online 5 and Online
 6 products.

'Server' is defined as: "a computing product that provides services and manages networked resources for client devices, such as desktop computers, notebook computers, desktop thin clients, internet protocol (IP) telephones, smart phones, tablets, tele-communication, automated systems or other servers. A server is typically placed on the market for use in data centres and office and corporate environments. A server is primarily accessed via network connections, and not through direct user input devices, such as a keyboard or a mouse. A server has the following characteristics:

- (a) is designed to support server operating systems (OS) and/or hypervisors, and targeted to run user-installed enterprise applications;
- (b) supports error-correcting code (ECC) and/or buffered memory (including both buffered dual in-line memory modules (DIMMs) and buffered on board (BOB) configurations);
- (c) is placed on the market with one or more power supply(ies);
- (d) all processors have access to shared system memory and are independently visible to a single OS or hypervisor."

'Data storage product' is defined as: "a fully-functional storage system that supplies data storage services to clients and devices attached directly or through a network. Components and subsystems that are an integral part of the data storage product architecture (e.g., to provide internal communications between controllers and disks) are considered to be part of the data storage product. In contrast, components that are normally associated with a storage environment at the data centre level (e.g. devices required for operation of an external storage area network) are not considered to be part of the data storage product. A data storage product may be composed of integrated storage controllers, data storage devices, embodied network elements, software, and other devices. A data storage product is a unique configuration of one or more stock keeping units, sold and marketed to the end user as a data storage product."

The proposed requirements for servers and data storage products include:

- Minimum efficiency for Power Supply Unit
- Maximum allowance for idle state power for servers
- Declaring operating conditions and maximum operational temperature
- Information requirements on server efficiency and performance calculated according to developed server metrics

- Material efficiency requirements including design for easy disassembly, recycling and reuse, Critical Raw Material contents, data deletion software and availability of firmware update.
- The information required above to be available on a public website

The servers and data storage products in scope of the potential ecodesign measure are relevant for data centres and server rooms that use standard products, which cover the majority of the market, with exception of specialised data centres that use only highly customised servers and data storage products.

The measures proposed will ensure that worst performing products regarding energy and environment will not be allowed to enter the EU market. Furthermore, the measures will provide opportunities for further energy and environmental improvements through the information provided e.g. through reducing the requirements on the data centre inlet air temperature and through being able to take into account during procurement server efficiency, server performance and possible re-use of the products.

The type of user for the ecodesign measures are legislators and Member States who have to verify the compliance and naturally the manufacturers and importers who will have to ensure compliance to place their products on the EU market.

2.3.2 WEEE and RoHS Directives

To address the problems of Waste of Electrical and Electronic Equipment (WEEE), one of the fastest growing waste streams in the EU, two pieces of legislation have been put in place: the Directive on Waste Electrical & Electronic Equipment (WEEE Directive) and the Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS Directive).

The first WEEE Directive (2002/96/EC)⁸ entered into force in February 2003. The revised WEEE Directive 2012/19/EU⁹ was adopted on 13 August 2012 and became effective on 14 February 2014. The Directive enables collection schemes where consumers return their WEEE free of charge and aims to increase the recycling and reuse and tackle the fast increasing waste stream.

EU legislation restricting the use of hazardous substances in electrical and electronic equipment (RoHS Directive 2002/95/EC)¹⁰ entered into force in February 2003. The legislation requires heavy metals such as lead, mercury, cadmium, and hexavalent chromium and flame retardants such as polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE) to be substituted by safer alternatives. In December 2008, the European Commission proposed to revise the Directive. The RoHS recast Directive 2011/65/EU¹¹ became effective on 3 January 2013.

⁹ http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32012L0019

⁸http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002L0096

¹⁰ http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002L0095

¹¹ http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32011L0065

Data centres contain many electronic and electrical devices including servers, network equipment, storage, UPS systems, air conditioners and lighting that support the delivery of data centre services, therefore when procuring data centres at component and equipment level, WEEE and RoHS Directives are relevant.

The type of user for the EU directives are legislators, and Member States who have to verify the compliance and meet the national WEEE recovery targets. The manufacturers and importers will have to ensure compliance to place their products on the EU market.

2.3.3 EU Emission Trading Scheme (ETS)

In January 2005, the European Union Greenhouse Gas Emission Trading Scheme (EU ETS) commenced operation as the largest multi-sector greenhouse gas emission trading Scheme in the world. Operators of installations that are covered by the EU ETS are obliged to monitor and report emissions of greenhouse gases from that installation and to surrender allowances equivalent to those GHG emissions. Whilst the IT and data centre sectors are not included in the scheme, there is an indirect impact of EU ETS on data centres as the permits purchased by utility providers are passed through as an indirect cost through to energy consumers and, therefore, data centres.

However, the UK implementation of the scheme also impacts large data centres with diesel generators providing standby capacity of around 7MVA and above in the event of mains power failure. The intended target of the legislation is large emitters i.e. those who burn primary fuel like oil, gas, coal, etc in order to sell electricity commercially. While these standby generators do run for a few hours a year the fact they have negligible scope 1 emissions. The cost of compliance is reported to exceed that of the EU ETS allowances.

2.3.4 UK Global warming potential Agreement (CCA) for colocation facilities

The objectives of the CCA are to improve energy stewardship without damaging growth. Participants undertake to meet energy efficiency targets and in return have the opportunity to benefit from concessions on some carbon taxes (Global warming potential Levy and Carbon Reduction Commitment). For data centres, these efficiency targets take the form of a reduction in PUE: the exact reduction required for each site depend on current performance at the start of the scheme. The scheme runs until 2023 and the targets are spread over four milestones.

UK organisations whose business activity is the leasing or licensing of a data facility which is being used as a data centre are eligible for the scheme. "Data facility" means a room, or rooms sharing the same electricity supply circuit, occupied mainly or exclusively by computer equipment which is enabled to transfer data electronically, and where in respect of the room or rooms— a) the temperature and humidity is regulated in connection with the operation of the computer equipment; b) the electricity supply is at least 200kW; and c) electricity is supplied by a back-up electricity supply when the mains supply is interrupted.

2.3.5 The Green Grid voluntary standards and models

The Green Grid¹² has developed a series of standards and models recognised by industry which include product definition and models for targeting and improving environmental performance.

2.3.5.1 Open Standard for Datacenter Availability (OSDA)

The Green Grid's No. 71 white paper OSDA¹³ proposes a development of a four-tiered approach to give greater flexibility and include energy source and IT architecture elements. This approach would be applicable for new designs and retrofits, the plan is to finalise the scoring system in the second half of 2017.

Data centre are defined by the Green Grid as "a building or portion of a building whose primary function is to house a computer room and its support areas. Data centres typically contain high-end servers and storage products with mission-critical functions"¹⁴.

2.3.5.2 The Green Grid Maturity Model¹⁵

The Data Centre Maturity Model (DCMM) provides clear goals and direction for improving energy efficiency and sustainability across all aspects of the data centre. The DCMM touches upon a data centre's major components, including power, cooling, servers, storage, and networking. The model is divided into levels that outline current best practices and provide a five-year road map for the industry.

The DCMM provides capability descriptions by data centre area so that data centre operators can benchmark their current performance. This model can be used to assess a wide range of data centre areas, from facilities to IT. Each area is assessed between levels 0-5 both for current and targeted performance. In this manner, operators can determine their data centres' levels of maturity and identify the ongoing steps and innovations necessary to include in their data centre/IT strategy in order to achieve greater energy efficiency and sustainability improvements, both today and into the future.

2.3.5.3 Green Grid Productivity Proxies Validation Study¹⁶

The Green Grid started the Productivity Proxies project as a method of approximating "useful work" in data centres. The concept was to develop metrics that were highly correlated to work being produced but that were cheaper, easier, and less intrusive to collect than counting every single transaction and combining them somehow.

In addition to the eight proxies proposed by The Green Grid, two additional proxies, IT equipment efficiency (ITEE) and IT equipment utilization (ITEU), were proposed by Japan's Green IT Promotion Council (GIPC). These became the ninth proxy.

The metrics developed by the Green IT Promotion Council (Japan) may be combined into the Datacenter Performance Per Energy metric which also includes Facility Energy

¹² https://www.thegreengrid.org/

¹³ https://www.thegreengrid.org/en/resources/library-and-tools/433-WP

¹⁴ https://www.thegreengrid.org/en/resources/glossary

¹⁵ https://www.thegreengrid.org/en/resources/library-and-tools/232-Data-Center-Maturity-Model-Handbook

¹⁶ https://www.thegreengrid.org/en/resources/library-and-tools/377-Productivity-Proxies-Validation-Study

Efficiency and Green Energy Coefficient.

This validation study was designed to test the proxies in a laboratory and determine which ones correlated to useful work most accurately, which were easiest to implement, and which showed the most promise of being a generic measure of data centre productivity.

The GPP criteria will need to select appropriate metrics including those which consider impacts beyond energy, e.g. Water Usage Effectiveness (WUE)¹⁷ and reflect their importance according to priority (highest usually environmental impact of IT equipment).

2.3.6 Telecommunications Industry Association's Telecommunications Infrastructure Standard for Data Centres

Date centre classifications are usually developed based on technical requirements, capacity, redundancy and availability. The Telecommunications Industry Association (TIA) has published *ANSI/TIA-942*¹⁸, a standard which defines four levels of data centres in terms of their relative robustness. The requirements of the four levels are given in Table 5. As this is an American standard, adoption is more common in the US.

Table 5. ANSI/TIA-942 tier levels for data centres.

Tier Level	Requirements
1 Basic Site Infrastructure	 Single non-redundant distribution path serving the IT equipment Non-redundant capacity components Basic site infrastructure with expected availability of at least 99.671%
2 Redundant Capacity Component Site Infrastructure	 Meets or exceeds all Tier 1 requirements Redundant site infrastructure capacity components with expected availability of at least 99.741%
3 Concurrently Maintainable Site Infrastructure	 Meets or exceeds all Tier 2 requirements Multiple independent distribution paths serving the IT equipment All IT equipment must be dual-powered and fully compatible with the topology of a site's architecture Concurrently maintainable site infrastructure with expected availability of at least 99.982%
4 Fault Tolerant Site Infrastructure	 Meets or exceeds all Tier 3 requirements All cooling equipment is independently dual-powered, including chillers and heating, ventilating and airconditioning (HVAC) systems Fault-tolerant site infrastructure with electrical power storage and distribution facilities with expected availability of at least 99.995%

As it is a quality standard for data centres, the owners and operators are the main type of users, and often certification according to the standard involves certified

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¹⁷ WP#35 - WATER USAGE EFFECTIVENESS (WUE): A GREEN GRID DATA CENTRE SUSTAINABILITY METRIC

¹⁸ http://www.tia-942.org/

consultants and auditors to accredit the data centre a specific Tier Level. Another type of user can be the data centre service buyers, who require a minimum level of quality according to the four tiers.

2.3.7 Uptime Institute's Tier Classification System

Uptime Institute's Tier Classification System¹⁹ also created a standard Tier Classification System as a means to evaluate data centre infrastructure in terms of business requirements for system availability (see Table 6). Many users refer to the tier systems without having their facilities certified, due to cost.

Table 6. Uptime Institute's Tier Classification System for data centres.

Tier Level	Requirements
Tier I: Basic Capacity	A Tier I data centre provides dedicated site infrastructure to support information technology beyond an office setting. Tier I infrastructure includes a dedicated space for IT systems; an uninterruptible power supply (UPS) to filter power spikes, sags, and momentary outages; dedicated cooling equipment that won't get shut down at the end of normal office hours; and an engine generator to protect IT functions from extended power outages.
Tier II: Redundant Capacity Components	Tier II facilities include redundant critical power and cooling components to provide select maintenance opportunities and an increased margin of safety against IT process disruptions that would result from site infrastructure equipment failures. The redundant components include power and cooling equipment such as UPS modules, chillers or pumps, and engine generators.
Tier III: Concurrently Maintainable	A Tier III data centre requires no shutdowns for equipment replacement and maintenance. A redundant delivery path for power and cooling is added to the redundant critical components of Tier II so that each and every component needed to support the IT processing environment can be shut down and maintained without impact on the IT operation.
Tier IV: Fault Tolerance	Tier IV site infrastructure builds on Tier III, adding the concept of Fault Tolerance to the site infrastructure topology. Fault Tolerance means that when individual equipment failures or distribution path interruptions occur, the effects of the events are stopped short of the IT operations.

The data centre developer, owners, operators and colocation providers as well as telecommunication companies are the main type of users for the classification system. The certification according to the standard often involves certified consultants to accredit the design and actual site of a data centre at a specific Tier Level. Another type of user can be the data centre service buyers, who require a minimum level of quality according to the four tiers.

¹⁹ https://journal.uptimeinstitute.com/explaining-uptime-institutes-tier-classification-system/

2.3.8 EN50600 Data Centre Standard Series for Infrastructure & Facilities

The EN 50600 series provides a framework for consultants, designers, installers, services providers, owners and operators that encompasses key aspects to be considered during the lifetime of a data centre²⁰:

- 1. Availability of the facilities and infrastructure to support data centre functionality
- 2. Measures to protect the data centre from unwanted events
- 3. Methods and processes to address energy efficiency and sustainability

The standard series is becoming increasingly popular in Europe. The standard describes four availability classes, similarly to the tier levels described by The Uptime Institute and TIA. Higher availability is associated with more redundancy of equipment and systems and hence increased embodied impact.

Energy efficiency includes three levels of measurement regime according to level of detail.

The standard has the following structure:

- 1. General Concepts (Part 1)
- 2. Design & Build (Part 2)
 - a. Building Construction (2-1)
 - b. Power Distribution (2-2)
 - c. Environmental Control (2-3)
 - d. Telecommunications Cabling Infrastructure (2-4)
 - e. Security Systems (2-5)
- 3. Operation (Part 3)
 - a. Management & Operational Information (3-1)
- 4. Key Performance Indicators (KPIs) (Part 4)
 - a. Overview (4-1)
 - b. Power Usage Effectiveness (4-2)
 - c. Renewable Energy Factor (4-3)

The standard also includes three best practice documents:

1. Technical Report (TR) 99-1 Recommended Practices (based on EU CoC Best Practices). These practices and their applicability are summarized in *Best Environmental Management Practices in the Telecommunications and IT Services Sector, Background Report for the development of an EMAS Sectoral Reference Document²¹ (see Table 7).*

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²⁰ http://landingpage.bsigroup.com/LandingPage/Series?UPI=BS%20EN%2050600

²¹ http://susproc.jrc.ec.europa.eu/activities/emas/documents/TelecomICT_BEMP_BackgroundReport.pdf

Table 7. Best environmental management practices in the telecommunications and IT services sector²¹.

Best practices according to CENELEC CLC/FprTR 50600-99-1	Applicability			
	Existing data centres	ICT equipment (new or replacement)	Software install or upgrade	New build or refurbishment of data centres
Data centre utilisation, management and planning	х			х
 a) Involvement of organisational groups 	Х			Х
b) General policies	Х			Х
c) Resilience level and provisioning	Х			Х
Data centre ICT equipment and services		х	x	
a) Selection and deployment of new ICT equipment		Х		
b) Deployment of new ICT services		Х	Х	
c) Management of existing ICT equipment and services		Х		
d) Data management and storage	Х			
Data centre cooling	Х	Х		X
a) Airflow management and design	Х	Х		Х
b) Cooling management	Х			
c) Temperature and humidity settings	Х			
d) Selection of cooling system				X
e) CRAC / CRAH equipment				Χ
f) Reuse of data centre heat	Χ			X
Data centre power equipment	x			x
a) Selection and deployment of new power equipment				Х
b) Management of existing power equipment	Х			
Other data centre equipment	Х			Х
a) General practices	Х			Х
Data centre building				Х
a) Building physical layout				X
b) Building geographic location				X
c) Water sources				X
Data centre monitoring	X			Х
 a) Energy consumption and environmental measurement 	Х			×
 b) Energy consumption and environmental data collection and logging 	Х			Х
c) Energy consumption and environmental reporting	Х			X
d) ICT reporting	X			

2. Technical Report 99-2 Environmental Sustainability (in development). This will be based on data centre Life Cycle Assessment research which shows that in additional to energy consumption in use, the source energy and embodied

impacts also form significant parts of a data centre's environmental impact. The technical report will complement TR99-1 and cover other environmental impacts not relating to energy efficiency, and also address lifecycle impacts outside of the operational phase.

3. Technical Report 99-3 Assessment of Conformity (in development).

2.3.9 ISO/IEC 30134

The ISO/IEC 30134 series standards define key performance indicators (KPIs) for data centre resource effectiveness. These are aligned with those defined in EN50600 Part 4.

Additional documents in this series are under development:

ISO/IEC DIS 30134-4 Information technology – Data centres – Key performance indicators – Part 4: IT Equipment Energy Efficiency for servers (ITEEsv)

ISO/IEC DIS 30134-5 Information technology – Data centres – Key performance indicators – Part 5: IT equipment utilization for servers (ITEUsv)

ISO/IEC WD 30134-6 Information technology -- Data centres -- Key performance indicators -- Part 6: Energy Reuse Factor – ERF

2.3.10 ISO 14001 & ISO 50001

ISO 14001 sets out the criteria for an environmental management system and can be certified to. It maps out a framework that a company or organization can follow to set up an effective environmental management system.

ISO 50001 is an operational energy management system which provides a systematic approach to achieving continuous improvement through measurement, documentation and reporting of performance.

Both these standards are used by organisations, including data centre operators, to demonstrate their commitment to environmental performance.

2.3.11 ETSI²² GS OEU 001 Operational Energy Efficiency for Users; Global KPI for Data Centres (Group Specification)²³

ETSI has published the DCEM (Data Centre Energy Management) indicator standard, to measure energy efficiency and compare energy management efficiency in data centres. The DCEM Global KPI specifies the coefficient or 'Global KPI' of the ecoefficiency and energy management of data centres. It combines two indicators: one taking into account different sizes of data centre (S, M, L or XL) and a second incorporating nine different levels of performance, similar to the energy classification model used for the EU home appliances energy label. The DCEM Global KPI meets a twofold objective: to assess the level of eco-efficiency in data centres, and to allow benchmarking of data centres or ITC locations in a wide range of industrial sectors.

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²² European Telecommunications Standards Institute

²³ http://www.etsi.org/deliver/etsi_gs/OEU/001_099/001/01.02.03_60/gs_OEU001v010203p.pdf

The DCEM Global KPI is based on a formula with 4 different component KPIs defined in the new ETSI Standard ES 205 200-2-1:

- 1. Energy consumption, KPIEC
- 2. Task efficiency, KPITE
- 3. Energy reused, KPIREUSE
- 4. Renewable energy, KPIREN

ETSI also publishes standards around data centre thermal management.

2.3.12 ITU²⁴ Toolkit on Environmental Sustainability for the IT Sector (ESS)²⁵

The Toolkit on Environmental Sustainability for the IT sector is an ITU-T initiative which details how IT companies can build sustainability into the operations and management of their organizations, through the practical application of international standards and guidelines.

This toolkit provides a set of agreed upon sustainability requirements for IT companies that allows for a more objective reporting of how sustainability is practiced in the IT sector in these key areas: sustainable buildings, sustainable IT in corporate organizations, sustainable products, end of life management, general specifications and KPIs, and an assessment framework for environmental impacts of the IT sector.

2.3.13 European Catalogue of IT Standards for Procurement²⁶

The European Catalogue seeks to address procurement professionalisation with the focus set on addressing questions on the specifics of digital goods and services. Such questions include: What standardised technology exists? What should you know about those standards in terms of implications to licenses and costs? How to avoid unwanted vendor lock-in? What similar experiences exist in other Member States? What are the lessons learned? What works well and what does not work? What would they have done differently? How to achieve sustainability of acquired products by integrating interoperability requirement? How to compute the lifecycle cost in a more holistic way?

2.3.14 US ENERGY STAR specifications

2.3.14.1. US ENERGY STAR benchmarking of data centres

US ENERGY STAR provides benchmarking of data centres through a tool called "Portfolio Manager" which generates a score from 1-100 relative to numerous of other data centres in the US. ENERGY STAR defines data centres as follows:

"Data centre refers to buildings specifically designed and equipped to meet the needs of high density computing equipment, such as server racks, used for data storage and processing. Typically these facilities require dedicated uninterruptible power supplies and cooling systems. Data centre functions may include traditional enterprise services,

²⁵ http://www.itu.int/ITU-T/climatechange/ess/

²⁴ International Telecommunication Union

²⁶ https://joinup.ec.europa.eu/community/european_catalogue/home

²⁷ https://www.energystar.gov/index.cfm?c=prod_development.server_efficiency

on-demand enterprise services, high performance computing, internet facilities, and/or hosting facilities.

Often Data centres are free standing, mission critical computing centres. When a data centre is located within a larger building, it will usually have its own power and cooling systems, and require a constant power load of 75 kW or more. Data centre is intended for sophisticated computing and server functions; it should not be used to represent a server closet or computer training area."

ENERGY STAR's definition of data centres excludes single servers in a server room or server closet often used by small enterprises.

2.3.14.2. Other ENERGY STAR specifications

ENERGY STAR® started as a voluntary labelling program managed by the U.S. Environmental Protection Agency and the U.S. Department of Energy in 1992. (the ENERGY STAR label is shown in Figure 1). The EU ENERGY STAR® programme for IT and office equipment results from an agreement between the US government and the European Commission in 2001 and the agreement now covers computers, displays, imaging equipment, UPS and enterprise servers. Additionally, US ENERGY STAR specifications for storage equipment, small network equipment and large equipment could be relevant to data centres.

When a manufacturer is an ENERGY STAR® partner and their products comply with the performance criteria, they may use the ENERGY STAR mark on those products after registration (EU) or a certification (US) process. Two different ENERGY STAR product specifications are in effect for the server and storage devices included in this study: Version 2.0 specification for Enterprise Servers (16 December 2013) and Version 1.0 specification for Data Centre Storage (2 December 2013). Only the specification for Enterprise Servers has been adopted in EU. The ENERGY STAR® specifications for servers include criteria on power supply efficiency, limits on idle power consumption, advanced power management features and requirements to disclose SERT²⁸ results and other data. The ENERGY STAR® specifications for storage equipment include criteria on power supply efficiency, energy efficiency features and requirements to disclose test results based on SNIA EmeraldTM Power Efficiency Measurement Specification.

Additionally, there are two specifications for respectively large and small network equipment and one specification for UPS; only ENERGY STAR for UPS is adopted in the EU. Uninterruptible Power Supplies Specification Version 1.0 includes a requirement oo minimum efficiency for AC-output and DC-ouput UPS, depending on rated power output at 25%, 50%, 75% and 100% load level and minimum power factor.

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²⁸ Server Efficiency Rating Tool



Figure 1. ENERGY STAR label.

Whenever an ENERGY STAR specification is adopted in the EU, it is required that member state national governments and the European Commission procure products that comply with ENERGY STAR requirements, if the purchase amount is over a certain limit. A similar requirement is included in the Energy Efficiency Directive although the requirement is broader, comprising all products covered by EU Energy Labelling and EU Ecodesign. The requirements are that ENERGY STAR criteria, the highest Energy Labelling class or Ecodesign benchmark values are included in the specific product procurement.

Manufacturers of the data centre equipment such as servers, storage products, UPS use the ENERGY STAR specification to stand out as energy efficient products on the market. In the EU, the public procurers are required to purchase ENERGY STAR labelled products if they are covered by the technical specifications.

2.3.15 EU Code of Conduct (CoC) for Energy Efficiency in Data Centres²⁹

The EU Code of Conduct (CoC) on Data Centre Energy Efficiency³⁰ is a voluntary scheme developed by the European Commission Joint Research Centre (JRC), Institute for Energy and Transport (IET) in collaboration with a broad range of market actors including EU Member States, hardware manufacturers, data centre consultants, data centre owners and operators. The scheme has been running since 2008 and the Best Practice Guidelines are revised on an annual basis. They largely address how to promote energy efficiency through business practices, software, operating systems / virtualisation, IT hardware, cabinets, data floor, power and cooling systems.

The scope for EU CoC on Data Centres³¹ is outlined by the term "data centres", which is defined as "including all building, facilities and rooms which contain enterprise servers, server communication equipment, cooling equipment and power equipment and provide some form of data services (e.g. large scale mission critical facilities all the way down to small server rooms located in the office buildings)."

This scope definition includes the products and components, services data centres provide as well as the facilities and buildings that support the service provision in data centres.

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²⁹ https://ec.europa.eu/jrc/en/energy-efficiency/code-conduct/datacentres

³⁰ http://iet.jrc.ec.europa.eu/energyefficiency/ict-codes-conduct/data-centres-energy-efficiency

³¹http://iet.jrc.ec.europa.eu/energyefficiency/sites/energyefficiency/files/files/documents/ICT_CoC/participant_guidelines_v2_0-final.pdf

The objectives of the EU CoC on data centres are to minimise data centre energy consumption by securing stakeholders' commitment to improve efficiency, raise awareness of energy efficiency in data centres, incentivise efficient behaviours, provide metrics to monitor progress, and share best practice.

The CoC sets voluntary requirements for owner / operators wishing to participate (Participants) around implementation of best practices and reporting of energy consumption (total facility and IT equipment). In addition to the Participants, companies (vendors, consultants, industry associations) can also promote the CoC to their clients, these are recognised as Endorsers. See labels for participant and endorser in Figure 2. Although the scheme is targeted at Europe, there are participants from elsewhere. Participants include public sector organisations. UK government organisations who make participation in the scheme a requirement in their procurement process for data centre services.



Figure 2. Labels for EU CoC data centre participant and endorser.

The Best Practice Guidelines include a minimum level of energy saving activities as well as optional specifications for the entire data centre, new software, new IT equipment and for new building or retrofitting. The Best Practice Guidelines include actions in the following areas:

- Data centre utilisation, management and planning
 - o Resilience level and provisioning of space
- IT equipment and services
 - o Selection and deployment of new IT equipment
 - o The service architecture, software and deployment of new IT services
 - Management of existing IT equipment and services
 - o Data management
- Cooling
 - Airflow and design
 - Cooling management
 - o Temperature and humidity settings, such as ASHRAE A2 A3 class
 - Type and efficiency of cooling plant
 - Computer room air conditioners
 - Reuse of data centre waste heat
- Data centre power equipment selection, deployment and management

- Other data centre equipment
- Data centre building layout and geographic location
- Monitoring
 - o Energy use and environmental measurement
 - o Energy use and environmental collection, logging and reporting

As the CoC Best Practice Guidelines include minimum practices for both the system level such as for the entire data centre, as well as for the component levels such as software, IT equipment and services, the practices in each above areas could be included in the GPP criteria for data centre and data centre services. The criteria could be weighted according to known environmental impact. There is a wide range of several orders of magnitude; the idea would be to prioritise change where it has the most impact, e.g. IT software/hardware not lighting.

The endorsers and participants of EU Code of Conduct for data centres are manufacturers, vendors, consultants and utilities, these are the primary users. Parties signing up will be expected to follow the intent of this Code of Conduct and support a set of agreed commitments.

2.3.16 EU Code of Conduct for AC uninterruptible power systems (UPS)

The products covered by the EU Code of Conduct (CoC) for AC uninterruptible power systems (UPS)³² covers UPS defined according to EN 62040-3 delivering 1-phase and 3-phase uninterruptible power above 0.3kVA at 230/400 V. The UPS are designed in different configurations and operations. Typical circuit arrangements are:

- "UPS double conversion" with or without bypass
- "UPS line interactive operation" with or without by pass
- "UPS stand-by operation"

This Code of Conduct does not cover:

- UPS designed or complying with specific customer requirements impacting efficiency such as DC/battery voltage, additional isolation, special cooling.
- UPS based on rotating machines.

The CoC include requirement on minimum efficiency depending for different UPS ratings (intervals in kVA) at 25%, 50%, 75% and 100% load level and additional maximum losses per additional device such as transformer or filter. There is also a requirement on filling a UPS data sheet for each sold UPS type.

The main users of this Code of Conduct would be the manufacturers of UPS for ensuring their UPS live up to the commitments.

2.3.17 The Blue Angel energy efficient data centre operation

The German environmental label The Blue Angel has criteria for data centre operations³³. The label is awarded to the entire building that houses the data centre

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³² http://e3p-beta.jrc.nl/sites/default/files/documents/publications/code_of_conduct_ups_16032011.pdf

³³ https://www.blauer-engel.de/en/products/office/data-center-operation

including the technical building equipment. The scope of the criteria is defined by data centres' capabilities:

"A data centre is capable of securely, permanently and centrally processing large amounts of data over a long period of time. In the process, the data centre shall still possess these capabilities even when individual capabilities are not being used e.g. operation over a long period of time. The required capabilities are described in concrete terms below:

- 1. Data processing includes e.g. the collection, transfer, calculation or storage of data
- 2. Secure data processing is described, in technological terms, as the "minimum level of security" required for a "controlled shutdown of the computers without any loss of data in the event of damage to the supply units".
- 3. The term large amount of processed data is relative to the technical capabilities of current state-of-the-art systems and thus represents a dynamic factor over time.
- 4. Operation of the data centre permanently over a long period of time requires measures to control those influences that may have critical effects beyond a certain period of time such as heat, humidity or dust."



Figure 3. The Blue Angel Label.

The requirements to qualify for the Blue Angel label (see Figure 3) include:

- An energy efficiency report documenting compliance with all requirements at the time of the application audited by the designated testing institution.
- Meeting a minimum Energy Usage Effectiveness (EUE), which is the ratio of the annual energy demand of the entire data centre to the energy demand of the IT equipment over a period of one year, depending on the time (Δt) data centre was commissioned in relation to the date the application is submitted:
 - \circ ∆t ≤ 12 months, EUE ≤ 1.4
 - \circ 12 months ≤ Δ t ≤ 5 years, EUE ≤ 1.6
 - o **Δ**t ≥ 5 years, EUE ≤ 1.8
- Requirement for an energy management system
- Requirements on electrical energy consumption
- Creation of an IT inventory list
- Monitoring of IT load
- The cooling system meeting a minimum Energy Efficiency Ratio (EER)
- Only chlorine-free and only halogen-free refrigerants may be used
- The Efficiency of UPS must meet minimum standards
- the average degree of virtualisation (number of virtual servers per physical server in the entire data centre) must be greater than two.
- Acquisition of new servers, external power supplies, cooling systems, UPS, power distribution units

The Blue Angel eco-label can provide the demand side (public sector or industry) with a means of selecting ecological criteria when calling for bids for external data center services. The main users are the public sector or the industry data centre service purchasers, but mostly in Germany. It is however the data centre owners, developer and operators and colocation providers who will apply for the label and comply with the requirements.

2.3.18 Eco-Management and Audit Scheme (EMAS)³⁴

The EU Eco-Management and Audit Scheme (EMAS) is a management tool for companies and other organisations to evaluate, report and improve their

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³⁴ http://susproc.jrc.ec.europa.eu/activities/emas/

environmental performance. The scheme has been operational since 1995; it was originally restricted to companies in industrial sectors.

The European Commission's Joint Research Centre (JRC) is developing, as an extension to the existing EMAS scheme, a sectoral reference document on best environmental management practice in the electrical and electronic equipment (EEE) manufacturing sector, to be published in 2018.

The Background Report to this sectoral reference document (October 2016), identifies a number of Best Environmental Management Practices (BEMPs), referencing the EU CoC, EN50600 TR99-1, EN50001, ETSI, The Green Grid; and identifying other BEMPs reaching beyond energy environmental aspects, e.g. waste management. These are split into the following groups:

- 1. BEMPs related to existing data centres
- 2. BEMPs related to selecting and deploying new equipment for data centres
- 3. BEMPs related to the deployment of new IT services and software
- 4. BEMPs related to new build or refurbishment of data centres

2.3.19 Finnish sustainability rating system (TIKO) for data centres by Ministry of Transport and Communications

TIKO³⁵ is a sustainability rating system for data centres. It is a weighted credit based system which acts as a systematic tool for designing, building, equipping, operating and managing data centres in an environmentally, socially and financially sustainable way.

The TIKO rating covers the data centre as a whole. TIKO emphasizes that numeric metrics should be used for communication and comparison of sustainability performance and sustainable planning. These take into consideration the life-cycle of the data centre and are based on continuous improvement without strIT rules or regulations, thus allowing and encouraging innovation.

TIKO provides guidance in seven categories: leadership, operational management, energy, sustainable site, water, waste and pollution. Each category is evaluated with a score which reflects the importance of each aspect in overall sustainability of a data centre and in relation to other categories.

TIKO is further separated into three schemes:

- TIKO for data centre new construction for building a new sustainable data centre
- TIKO for existing data centre sustainable performance development
- TIKO guide for purchasing sustainable data centre services for comparing different data centre services via the TIKO criteria.

TIKO guide can be used by a range of users, such as construction and retrofit constructor, contractors and designer to ensure the sustainability goals are met, data

³⁵ https://julkaisut.valtioneuvosto.fi/bitstream/handle/10024/77877/Publications 21-2014.pdf?sequence=1

centre owners can use the guide to set requirements and managing it, equipment suppliers can also use it for meeting the targets, the data centre clients will benefit from having the proof of sustainability as well as public authorities can use it to aid development of data centers.

2.3.20 EU Procurement guidance PrimeEnergyIT project

Procurement guidance³⁶ from PrimeEnergyIT project provides purchasing recommendations on the following server room and data centre equipment:

- Servers
- Storage devices
- Network equipment
- Cooling equipment
- Monitoring equipment, typically comprised of energy meters, sensors for measuring key variables such as temperature, flow rate, voltage, current, pressure, humidity etc. and software for collecting and analysing the data.

The scope of the procurement guidance covers the products used in server rooms and data centres well, however, it does not include the procurement of services which may be relevant in many cases nowadays.

PrimeEnergyIT's criteria for energy efficiency public procurement cover servers, data storage products, network equipment, cooling equipment and monitoring equipment, and for each product group the criteria are split into three sections:

- **Technical specifications** these define the minimum requirements for the products, those who do not meet the requirements will be rejected to compete in the tender.
- Award criteria these are sets of points awarding and weighting rules for different energy efficiency parameters, which outline how offers by suppliers can be compared, according to contracting authorities' preferences.
- **Contract clauses** these indicate how a specific contract must be carried out, which is particularly important in service contracts.

Technical specification criteria for servers and data storage products include:

- Minimum requirement for power supply corresponding to the Gold efficiency level of 80plus standard³⁷ and additional 10% load efficiency.
- Temperature requirements that servers must be able to operate on error free up to 27°C in inlet temperature. Manufacturers must provide a full warranty for the specified operation conditions.

Technical specification criteria for network equipment include the same minimum requirements on power supplies and temperature, and, in addition:

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³⁶ Procurement guidance for energy efficient server room and data centre equipment, A PrimeEnergyIT Publication February 2012

³⁷ www.80plus.org

 Power consumption information of the equipment in idle mode when all Ethernet transceivers have an active connection, i.e. when data can be transferred and received, must be supplied.

Technical specification criteria for cooling equipment specify that all cooling equipment must meet the energy requirements of Eurovent class A.

Technical specification criteria for monitoring equipment include specific requirements for portable meters, panel meters, power transducers and intelligent power distribution units and server-embodied power metering features.

These criteria can help defining the GPP requirements for equipment and products used in data centres.

2.3.21 EURECA project on data centres

EURECA is an ongoing EU H2020 funded project that aims to provide public sector organisations with quantifiable information on the environmental impact of data centres and related procurement choices³⁸. The project has analysed the market and procurement problems including incentives, and delivered training for procurement professionals to strengthen the business case and enable them to choose environmentally friendly options whilst producing robust cost-benefit analysis³⁹.

The scope for the EURECA project is mainly "data centres" and "computer/server" rooms which provide the core digital infrastructure and connectivity foundation for all users of domestic, corporate and public sector digital services. The report "Data Centres (DC) EURECA Framework and Specification" identified the relevant data centre products and services (in the EURECA market directory) with a focus on the products and services in **bold**:

- Audit/Assessment
- Cabling
- Certification
- Cloud services
- Colocation
- Consultancy services
- Contamination control
- Cooling
- Data Centre Design & Build
- DC Monitoring
- Facilities management
- Fire prevention
- Fuel solutions
- Humidifiers
- IT Hardware

³⁸ https://www.dceureca.eu/resources/Eureca-Concept-Presentation-for-DC-Industry.pdf

³⁹ https://www.dceureca.eu/mission

⁴⁰ https://www.dceureca.eu/resources/EURECA D2.1.pdf

- Servers
- Storage
- IT Software
- Legal advice
- Making business case
- Power distribution
 - o DC-level
 - Batteries
 - Transformer
 - o UPS
- Project management
- Racking & Enclosures
- Remote hands
- Security
- Training and recruitment
- Transportation services
- Virtualisation
 - o DCIM
 - Server
 - Storage

The products and services can be seen independently, or as part of products and services to improve the procurement of data centre, data centre services and products. For example, project management might not be procured, but the procurement process itself could be very complex and require project management as a service to ensure its completion.

The products and services listed above in bold provide a good overview of key elements in terms of procurement of data centre and its services and products. This can help to define the scope of GPP.

The tool is a web-based platform to help public procurers and data centre professionals self-assess the energy efficiency and profile of their data centres, and provide improvements and suggestions. The latter are based on the latest standards and research and industry outputs. In particular, the tool maps the Data Centre Maturity Model (DCMM) to the EU Code of Conduct for Data Centres (EU CoC) to provide tailored recommendations for data centres energy efficiency. This mapping connects two of the most relevant and important data centre energy related industry-class approaches in a way to increase practical usability for both. The mapping in the tool is therefore more user-friendly in real-life application as it is tailored to the specific assessment of a particular data centre. This tool has been released and pilot projects are running with data centre operators.

An important project finding is that IT performance; software efficiency, server utilisation, scalability and deployment are impact factors in optimisation.

The EURECA tool and life-cycle metrics can be useful in defining GPP criteria for data centres and data centre services.

2.3.22 Green Public Procurement Criteria for Office Building Design, Construction and Management

The approach of the existing EU GPP criteria for office buildings can partially apply to GPP criteria for data centres. Firstly, the scope from both GPP criteria covers a type of building and the services the building offers. The GPP for office buildings covers the product group "office buildings" that comprise buildings where mainly administrative, bureaucratic and clerical activities are carried out and an office building is clearly defined in the scope, without including the outside parking area. Secondly the criteria are recommended to apply to both new buildings and renovation of existing buildings, and are focusing on an office building as a system rather than individual components, as there are separate GPP criteria available for procurement of various building components such as wall panels, Combined Heat and Power (CHP) systems, water-based heating systems, indoor lighting, taps and showerheads and toilets and urinals.

The same approach can apply to data centres with a clear definition of what data centres are in this context, and criteria can apply to building new data centres and renovating existing data centres, or purchasing services for/from an existing data centre.

GPP criteria for office buildings include five main parts:

- 1. Criteria related to the ability of the tenderer, such as relevant experiences, competences.
- 2. Energy-related criteria, such as minimum energy performance, lighting requirements, Building Energy Management Systems (BEMS), low or zero carbon energy sources and facility energy management that collects data and sets limits on consumption etc.
- 3. Resource efficient construction, such as using life cycle performance, and minimum incorporation of recycled contents in construction products, wood sourcing, and waste management plans.
- 4. Other environmental criteria, such as recycling facilities, and water saving installations.
- 5. Quality of the office environment, such as thermal comfort conditions, daylighting and glare and air quality.

When creating GPP for data centres it is important to note that these are a very different building type compared with offices; energy intensity may be several orders of magnitude higher, number of occupants may be several orders of magnitude lower. Due to the high environmental impact of the materials associated with IT, power and cooling equipment and replacement during the facility lifetime, the construction materials have a relatively low impact.

Building Energy Assessment Methods such as BREEAM or LEED are well established for other building types and have adaptations for data centres, however these exclude the IT part of the facility and the weighting systems for scoring do not reflect the high environmental impact of the power and cooling systems (for example, embodied impact is excluded).

2.3.23 Summary

The presented schemes, standards, voluntary agreements and legislation define the scope either:

- At high level by including a definition for data centres (US ENERGY STAR, EU CoC, OSDA, Blue Angel) stating that all physical equipment that is set together and provides the function included in the definition is part of the scope,
- at an individual product level (PrimeEnergyIT),
- combining specific products and services (EURECA), focusing on the most important to define the criteria, or,
- at a service level (Telecommunications Industry Association and Uptime Institute's), by classifying types of data centres according to the service they offer.

All the presented schemes cover mostly the same scope, although in varying degree of detail from individual products to defining the services the data centres provide. This shows the diversity in terms of product classification.

In terms of public procurement, it is important to cover purchasing scenarios within the scope. Based on the presented schemes, the procurement of data centres can be grouped into three:

- Purchasing brand new data centres including building, equipment, infrastructure i.e. cooling system and software etc.
- Purchasing replacements for existing data centres, equipment, cooling system and software etc.
- Purchasing services provided by data centres

3 Definition of product and service scope

This chapter presents the recommended product and service scope for the GPP criteria, according to the review performed in the previous two chapters. The chapter is divided in three sections explaining:

- 1. The type of data centres according to the service they provide
- 2. The proposed definition for data centres
- 3. A high-level overview of the procurement scenarios where data centre products and services at purchased by public organisations, in order to identify the proposed scope (more details on this are presented in chapter 5)
- 4. The proposed scope

3.1 Data centre types

Data processing, web portals, hosting and related services are required for all business and sectors, so the data centre products and services are purchased and operated very differently. Data centres can be divided into three major types which can be seen in Table 8. Detailed definitions are provided below the table.

Table 8. Typical data centre types.

Туре	Description
Enterprise	A data centre that is operated by an enterprise which has the sole purpose of the delivery and management of services to its employees and customers ⁴¹ .
Colocation	A data centre in which multiple customers locate their own network(s), servers and storage equipment ⁴² .
Managed Service Providers	Server and data storage services where the customer pays for a service and the vendor provides and manages required IT hardware/software and data centre equipment. This includes the cohosting of multiple customers, which may take the form of a cloud application environment. Generic providers are those offering non-proprietary applications (such as Hosted Exchange) while specialized providers offer proprietary applications (such as G Suite).

Enterprise data centres: Where the customers, such as SMEs, larger companies and public organisations, may have their own data centres, use servers and/or storage devices owned by them and they are located in a dedicated IT equipment room or space with air conditioning or other cooling in the premises of the company. These customers usually have less focus on the energy consumption of servers and storage devices, because generally there is no dedicated electricity meter installed in the server equipment and the consumption is just one contributor of many to the overall electricity bill. There are millions of SMEs in the EU operating as few as one server to provide basic file management and e-mail functions or as many as several hundreds. This diverse range of operators means that the resources and knowledge to select, purchase, and manage the data server and storage equipment varies just as much.

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⁴¹ EN 50600-1:2012

⁴² EN 50174-2:2009/A1:2011, 3.1.8

Colocation data centres: Where the data centre owner provides the infrastructure such as area, racks, power, internet connection, secure access system, cooling etc., and the servers and/or data storage devices are owned by the customer. These are known as colocation data centres. Generally there is little focus on the energy consumption of the equipment, because the number of servers owned by a typical customer is low and the customers are not very conscious of their energy consumption. One factor that may increase energy awareness is the fact that colocation data centres often put a surcharge on the electricity price, when reselling to the server owners. However, the total size of electricity purchase may still be considered as insignificant for the customers and the invoice for electricity purchase may be less visible because it may be included in the overall bill for infrastructure (except in case where there is an agreement to charge extra for the electricity meter reading).

Managed Service Providers (MSP) data centres: Instead of owning and operating data centres directly, data processing, web portals, hosting and related server services may be purchased, commonly from cloud and hosted services providers (e.g. e-mail, file and web services) and from providers of pure server capacity (e.g. for installation of own server software and special applications). The market is growing because medium sized and larger companies are increasingly moving to cloud and hosted services. This is partly due to improved high-speed internet connections from the company to the data centre. The storage market is similarly increasing. External storage is often used even for organisations who host their own servers, where they use the external storage as remote backup. Moving services to cloud may be hindered by technical difficulties as well security and data protection concerns and the legal issues by having other countries' legal framework regulating your data. These barriers are being actively addressed because the attractions of moving to this model are considerable. For example, very large providers such as Google, Apple, Microsoft and Amazon are increasingly building data centres in EU. The foremost of these attractions are the potential increase in robustness and reliability and removing the need for a high degree of technical expertise within an organisation.

In any case, independently of the location, the criteria can be applied during procurement of services from MSPs, who are marketing the services in EU.

MSP data centres can either provide generic or specialized server services. When requiring generic services, the public procurers have the possibility to choose from different providers. When requiring specialized services, generally only one provider offers the service. When this is the case, the service may be offered by one of the global IT companies (often called hyper-scale) or by SMEs specialized in market niches. Hyper-scale providers have their own data centres and they pay the energy costs of running them, so they are aware of the energy consumption both due to the high total energy costs and due to a growing pressure to be "environmentally friendly" as part of their image; this means that they try to reduce their energy use.

Data centres also vary in size in terms of physical area, number of servers and racks, power consumption and density. Small facilities, which may be described as server closets or server rooms, are typically enterprise data centres housed in converted

space in a mixed use building, e.g. an office. Colocation and MSP facilities are usually developed on a larger scale.

Different organisations and facilities have varying requirements in terms of availability (see tier level definitions and availability classes in previous section), maintenance, staffing and site physical security.

3.2 Proposed definition

The proposed definition of data centre is a combination of the definition from EU CoC and NACE business activities, and that fits the data centre classification presented in next section.

Table 9. Proposed definition of a data centre.

Data centre definition

Data centre means a structure, or group of structures, dedicated to the centralised accommodation, interconnection and operation of information technology and network telecommunications equipment providing data storage, processing and transport services together with 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.

3.3 Procurement scenarios

In order to define the scope, it is important to take into account the processes that occur during public procurement of data centres. These processes make it clear who takes the procurement decisions on what to purchase and the purchasing decision—making. The decisions on what to purchase can be influenced by GPP criteria, and the purchasing decision—making shows how the criteria can be managed during the tendering process.

Based on the EURECA project⁴³ and on experience from the members of the consulting team, tendering approaches in public organisations may be any one of the following:

- The public institution (e.g. a municipality) makes its own tender
- Several institutions form a group and offer a common tender
- Specific purchasing organisations agree on framework contracts for specific products/services with selected suppliers, which the individual public organisations can use without further tendering
- Governmental organisations use a tender for specific product and services to select supplier(s) which the individual state institution is then obliged to use.

The purchasing may happen as:

• a one-time tender specifying the specific products or services requested

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⁴³ https://www.dceureca.eu/resources/EURECA D1.1.pdf

- a framework contract for delivery of products and services over several years (which may or may not be followed by mini tenders within the framework contract for additional requirements)
- as a direct purchase (i.e. with no tendering process) when purchasing below the tender threshold values

Typically, a larger IT tender in a public organisation involves the following types of experts:

- Procurement experts, who are experts in the tendering process, contractual aspects, etc., but with less technical knowledge of the products
- IT professionals, who know the products and services and the main technical requirements for meeting the technical needs
- Representatives of the users, who are going to be working with the products and services
- Environmental experts, especially in public institutions and/or governmental organisations that have capacity and who have environmental goals

According to outcomes from the EURECA project, the procurement officer(s) in the EU, responsible for procuring data centre related products or services are in most cases faced with a predetermined procurement scenario. During the course of our analysis, we have defined the following classification of overall procurement scenarios:

- a. Building a new data centre
- b. Expanding or consolidating the existing infrastructure
- c. Outsourcing to a hosted/cloud application environment
- d. Operation/Maintenance of an existing facility

In the first two scenarios, the procurer purchases products and, depending on the tender contract, services from the equipment supplier and/or a maintenance provider. In the third scenario, the procurer purchases services at an external data centre organisation. In the final scenario, activities such as replacement/refresh of equipment, purchase of service agreements and any service related to the operation and maintenance of an existing facility are included.

The decision on which scenario an organisation would use is most likely made by someone from IT (management) and general management, based on the valid argument they are likely to have a higher level of expertise on the subject-matter.

A schematic representation can be seen in Figure 4. The blue boxes represent how the tendering process works, while the red boxes represent where the GPP criteria can be integrated during the procurement process. Some examples of specific procurement activities that can fit in one of the classified overall scenarios in Figure 4 are:

- New data centre facility construction (scenario a)
- Project support to consolidate existing data centre estate (scenario b)
- Services to fit-out existing building with new data centre infrastructure (scenario b)
- New power or cooling equipment (scenario b)
- New IT hardware (scenario b)

- New colocation services (scenario b)
- New IT outsourced activities, e.g. provide desktop services to a new office of 100 workers via outsourcing (scenario c)
- Outsource hosting (scenario c)
- Outsource Cloud (scenario c)
- In-house or Outsource of maintenance of data centre facility (scenario d)

A more detailed assessment of the procurement practices are found in chapter 4.

- Retrofit equipment of mechanical and electrical systems (scenario b when adding new infrastructure and/or scenario d when retrofitting existing equipment)
- Acquiring new equipment (scenario b)

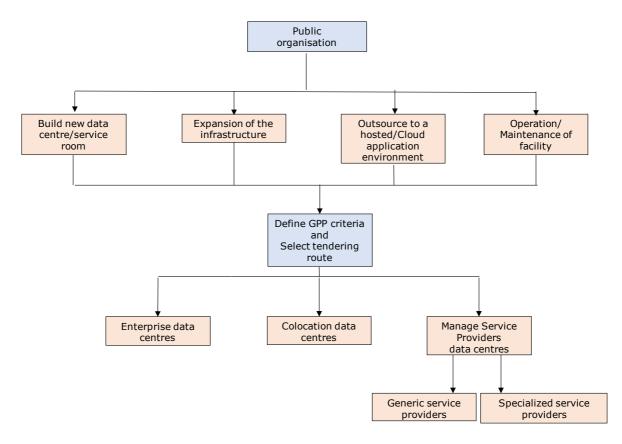


Figure 4. Schematic representation of the scope.

3.4 Proposed scope

The proposed scope of GPP criteria for data centres is limited to the boxes marked in red as:

- The procurement scenario predetermined by the public institutions and the governmental organisations.
- The data centres types as defined in section 3.1, including the IT equipment, mechanical and electrical systems.

Existing schemes identify possible criteria for some parts of the proposed scope, e.g. Best Environmental Management Practices in the Telecommunications and IT Services Sector, Background Report for the development of an EMAS Sectoral Reference Document (October 2016)⁴⁴. However, these principally relate to in-use energy; the scope in this case covers wider environmental impacts over the full life cycle.

The preliminary scope of the criteria is presented in Table 3, which encompasses the main functional components of a data centre, including the Mechanical & Electrical equipment and the IT equipment, the three being important sources of impacts to the life cycle environmental hotspots of the data centre.

As well as its components, the scope covers also the data centre performance characteristics at system level. The provision of services is included within the data centre classifications as identified in Table 2.

Table 10. Preliminary scoe of GPP criteria for data centres.

Preliminary scope of data centres

For the purposes of this GPP criteria set the scope shall encompass performance aspects of:

- The IT equipment and associated network connections that carry out the primary function of the datacentre, including the servers, storage and network equipment;
- The Mechanical & Electrical equipment used to regulate and condition the power supply (transformers, UPS) and the mechanical systems to be used to regulate the environmental conditions (CRAC/CRAH) in the white space⁴⁵;
- Data centre systems as a whole or a managed data centre service.

The building fabric (i.e. physical structure of the building and its respective building materials) is not included in the proposed scope.

⁴⁴ See section 2.3.18

⁴⁵ White space in data centres refers to the area where IT equipment are placed. Whereas grey space in the data centres is the area where back-end infrastructure is located.

4. Procurement practices

4.1 Overall mapping

4.1.1 Key public procurement practices

It is important to understand what the key public procurement practices are and how they relate to the potential application of GPP criteria when procuring data centre products and services. The procurement starts with a public organisation having a specific need, as it was explained in chapter 3.

The public organisations are usually:

- **Central governments** (i.e. federal or national government)
- **Public offices** such as ministries and departments in charge of specific areas of public concern (e.g. Environmental Protection Agency)
- Regional and/or state authorities
- Local councils or municipalities

Furthermore, in order to make the procurement process more efficient, in some EU countries public purchasing organisations exist which establish joint procurement contracts for several public institutions. Some examples are:

- SKI⁴⁶ in Denmark
- Central government procurement organisation in Denmark, which coordinates the Central Procurement Programme⁴⁷
- Crown Hosting in the UK⁴⁸

As described in section 3.3, the purchasing may happen in three different types of tenders (i.e. a one-time tender, a framework contract and as a direct purchase), and in the case of large tenders, the procurement process may involve a range of experts (i.e. procurement experts, IT professionals, representatives of the users, environmental experts).

According to the GPP handbook (3rd edition)⁴⁹, the environmental criteria or considerations in a certain tender, can be applied when the public organisations choose a procurement procedure. The procurement procedures are described in the European Commission tendering rules and procedures⁵⁰, and the GPP handbook describes some examples of how environmental criteria can be incorporated:

1. Open procedure – where the tenderers provide information about the pass/failed GPP criteria the procurer has specified in advance; no screening is done before evaluating the tenders. The advantage is that the procurer may have access to the

⁴⁶ https://www.ski.dk/Viden/Sider/Facts-about-SKI.aspx

⁴⁷ http://www.statensindkob.dk/ServiceMenu/In-English

⁴⁸ https://crownhostingdc.co.uk/

⁴⁹ Available at: http://ec.europa.eu/environment/gpp/pdf/Buying-Green-Handbook-3rd-Edition.pdf

⁵⁰ Available at: http://europa.eu/youreurope/business/public-tenders/rules-procedures/index_en.htm

maximum choice of potential environmentally friendly solutions, but there is a risk that many or none fulfil the criteria.

- 2. Restricted procedure where the tenderers can be screened out based on the procurer's initial assessment (i.e. pre-selection) on whether the tenderers may fulfil some/all of the GPP criteria. The advantage is that the procurer will have the opportunity to restrict the tender evaluation to only those potential suppliers that comply with a minimum level of performance (e.g. with core criteria), thus focusing the subsequent step(s) of the selection process to a higher level of performance (e.g. comprehensive criteria). The disadvantage is the potential exclusion of other tenderers who may present a better environmental performance at the initial stage, due to a certain degree of subjectivity in the pre-selection process.
- 3. **Negotiated procedure** where a few tenderers are selected by a public organisation and there is place for negotiation of the terms of contract, and in this case one of them could be the GPP criteria. The flexibility of negotiation can be used to assess the effect of environmental criteria on costs, both for the tenderers and the public organisation. The disadvantage is that this procedure requires a level of skill and experience in engaging with suppliers.
- 4. Competitive dialogue where the tenderers are free to participate in the definition of part of/all of the technical specifications, which may include the GPP criteria. After the first round of tenders, the public organisation invites at least three candidates to a dialogue where the final technical, legal and economic aspects of the contract are further defined. After this dialogue final tenders are submitted. Competitive dialogue cannot be used by public services providers in the water, energy, transport and postal services sectors. For other public organisations, competitive dialogue can be combined with the negotiated procedure and has similar advantages and disadvantages to the negotiated procedure.

Each of these four procedures is done through a number of procurement stages, where green considerations⁵¹ can be applied:

- 1. **Defining the scope and requirements of the contract**, where:
 - The scope is defined, e.g. data centre product and/or service⁵², functional unit, as well as the main environmental impacts are to be considered.
 - The technical specifications (i.e. requirements) are defined, which are
 measurable minimum requirements and, where environmental technical
 specifications can be defined. When defining performance or functionality it
 is important to refer to EU, international or national standards as far as
 possible; they may also refer to criteria defined in labels (e.g. EN 50600,

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⁵¹ http://ec.europa.eu/environment/gpp/pdf/Buying-Green-Handbook-3rd-Edition.pdf

⁵² According to the GPP handbook (3rd edition), contracts relevant to data centres are 'supply' contracts (product-oriented) and 'service' contracts (service-oriented)

ENERGY STAR, Blue Angel, EU sectoral guidance documents, etc.). According to the GPP Handbook (3rd edition), performance-based specifications (i.e. based on performance or functional parameters) allow more space for innovation and allow the market to develop into new technical solutions.

In the particular case of data centres, the environmental requirements may be based on workload or resilience parameters which describe their function and/or performance either at a whole data centre level or at a product level. Furthermore, this is the appropriate stage to specify desired/avoided materials/substances. Special conditions apply if the public organisation wishes to require tenderers to have an environmental label, and equivalent labels must be accepted. It is important that the procurer specifies in the tender, the evidence of compliance that the bidders shall submit to verify they fulfil the criteria.

In this context, it becomes easier for the procurer to verify if the requirements relate to environmental legislation or an environmental label, since information of compliance will be already available and/or third-party verified. However, when the criteria are not related to legislation and/or labels, a test report or a certificate from a conformity assessment which is third-party verified can be required by the procurer.

- 2. **Selection and exclusion criteria**, where the procurers select the tenderer with the best competences. This may be one step (in an open procedure) or several steps (in a restricted procedure, negotiated procedure or restricted dialogue). The typical aspects to consider include:
 - Environmental technical capacity of the tenderers. Tenderers demonstrate technical competence to comply with GPP criteria, e.g. related to the staff's and the equipment's ability to achieve/maintain a high level of efficiency concerning energy use in the operation of the data centres.
 - Environmental and/or quality management systems in place to ensure appropriate control of the environmental performance of the data centre.
 - Supply chain management measures to ensure the desired environmental performance is maintained by the suppliers and operators of the data centres.
 - Product samples, checks and conformity assessments.

3. **Defining award criteria**, providing that:

- They are related to the scope and technical specifications of the contract but that may cover additional aspects proving a better environmental performance (e.g. water consumption at the operation of a data centre, materials use at the production of one of the data centres components, etc.)
- They can be weighted and scored (while the technical specifications can only pass/fail)
- Award criteria are advertised in the tender documents, including their relative weightings and any sub-criteria

Environmental labels can be used to grant points in the award criteria, as long as they related to the scope and specifications of the contract and as long as equivalent labels are also accepted. Life Cycle Costing (LCC) can also be used as one of the award criteria, including either only direct costs (acquisition, operation and end-of life costs) or indirect (external costs such as societal costs related to CO2 emissions).

4. **Developing the specific contract clauses**, which translate the technical specifications and the award criteria into the specific clauses of the contract. This includes monitoring performance.

As a summary, the key aspects of public procurement when assessing the potential implementation of GPP criteria are:

- The **type of public organisation** performing the procurement, either as single procurement or as joined procurement
- The **type of tender** which will be set-out for the procurement procedure
- The **type of experts** involved in the procurement procedure and procurement process
- The procurement stages to follow, according to the type of public organisation, type of tender and the type of experts involved. This aspect is when the GPP scope, technical specifications and award criteria are defined, and thus it is the most essential aspect for defining and implementing a successful GPP criteria. However, this relies on all the other aspects.
- The **procurement procedure** to follow on selecting the appropriate tenderers.

4.1.2. Procurement of data centres

With the intention to understand more in detail how the public procurement of data centres happens, the procurement scenarios described in section 3.3 have been matched to the key procurement practices identified in section 6.1.1 based on own expertise and discussions with members of the EURECA team. The scenarios described in section 3.3 have been further detailed to:

- a. Building a new data centre
- b. Expansion/consolidation of the infrastructure or a new IT project, e.g.:
 - i. retrofitting such as upgrading electrical equipment or cooling optimisation
 - ii. consolidating existing data centre estate
 - iii. virtualisation of existing server capacity
 - iv. services to fit-out existing building with new data centre infrastructure
- c. Outsourcing to a hosted/cloud application environment, which means procuring a service and not a physical product
- d. Operation/Maintenance of the facility, which may include purchasing of single components or products

An IT project where a new IT service results in a new software application being rolled out to some users may trigger a requirement for additional hardware and therefore one of the preceding procurement scenarios.

Starting with the procurer's needs, the procurement scenarios have been defined. Figure 5, Figure 6, Figure 7 and Figure 8 show the typical procurement scenarios identified in the EU. They start with the definition of the procurer's need which defines what type of data centre to be procured. These have been further elaborated to what presented in chapter 3 (see Figure 4).

The type of contract, and the procurement procedure for selecting/excluding tenderers depend on the need of the procurer and the type of data centre product and/or service. These are the assumed routes based on current knowledge on the market, but they shall be corroborated with the procurers and stakeholders during the consultation process. However, by identifying separate procurement routes and matching them with data centre types, it is easier to allocate the criteria during the procurement stages.

The boxes in green are those activities controlled by the procurer, and those in orange are those specifically related to the type or product/service that the data centre provide.

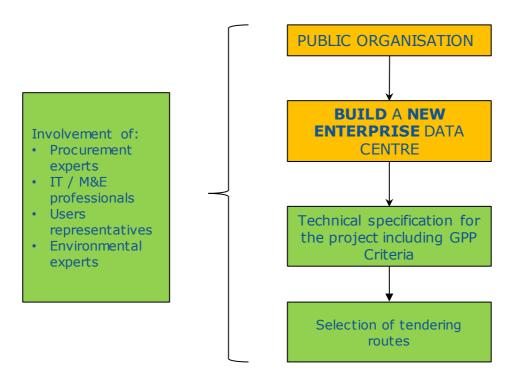


Figure 5. Mapping of potential procurement practices when public organisations build a new data centre in the EU.

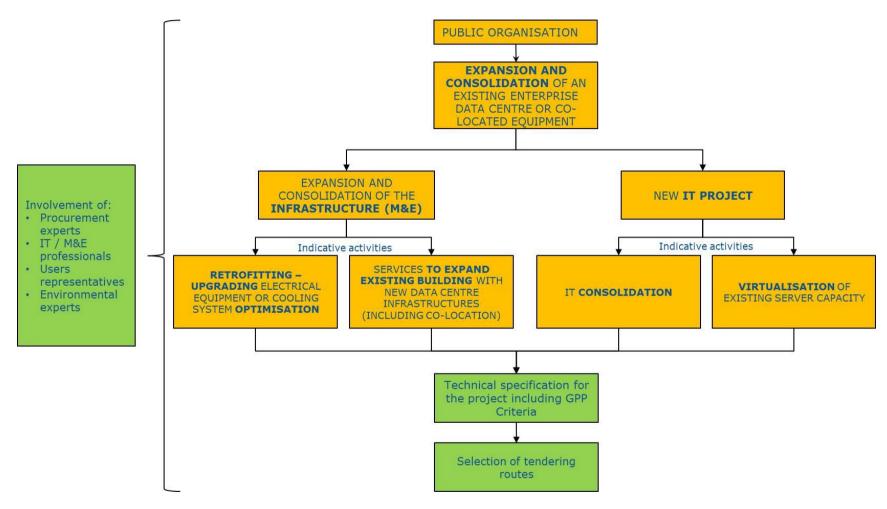


Figure 6. Mapping of potential procurement practices when public organisations expand and/or consolidate infrastructure or start a new IT project for data centres in the EU.

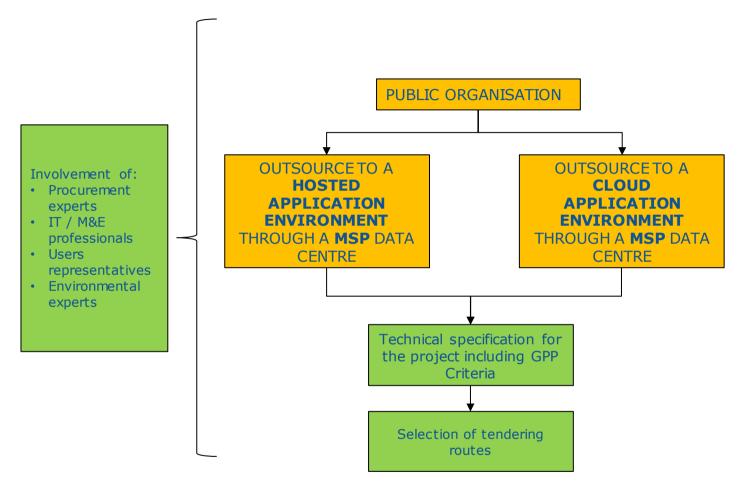


Figure 7. Mapping of potential procurement practices when public organisations outsource to a hosted or Cloud application environment in the EU.

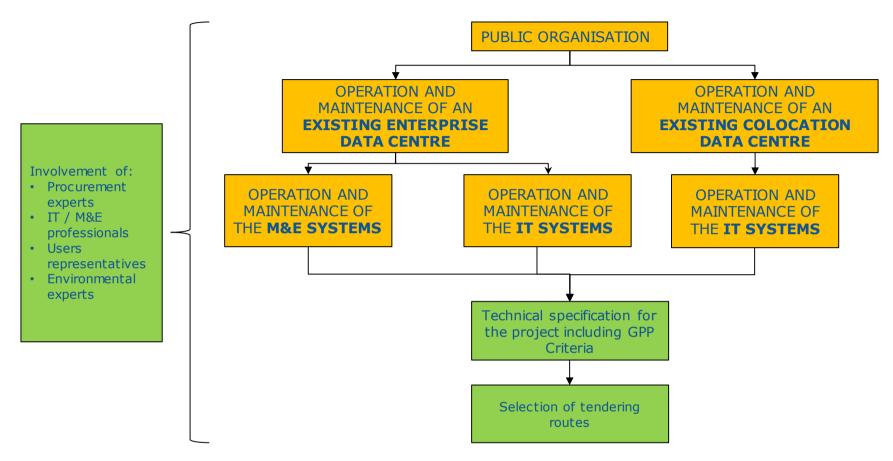


Figure 8. Mapping of potential procurement practices when public organisations purchase operation and/or maintenance services for data centres in the EU.

According to EURECA⁵³, the public procurement of data centre products and services is complex since it needs to accommodate the solution that meets the needs of a public organisation to the organisational targets and ambitions. Furthermore, due to the large array of technical systems involved it requires IT expertise which in many cases does not exist within the public organisation. EURECA also assessed the take up of technical specifications within tenders which was very low, in spite of the existence of quite a few schemes and standards as was shown in chapter 2.

Furthermore, the procurement officer responsible for procuring data centre related products/services is generally faced with a predetermined procurement scenario, meaning that it has already been decided what needs to be procured (see procurement scenarios in Figure 5). This decision may or may not have been made by someone at the IT department, but in any case it creates a disconnection between what was decided at the first step in the procurement practice and the actual procurement stages (see dark green boxes in Figure 5). In spite in this figure it appears that both procurement experts and IT professionals are involved during the definition of the scope, technical specifications, selection/exclusion criteria, award criteria and the specific contract clauses, in reality this task may have been done without their involvement.

Furthermore, EURECA highlights the importance of performing an evaluation exercise (perhaps at this stage of the procurement) where the specific need is re-evaluated through the definition of the scope and technical specifications, by triggering the procurement desire against the existing IT environment.

PrimeEnergyIT reports⁵⁴ that the size of the public organisation influences the type of data centre product/service procured. They state that smaller or highly decentralised administrations are provided by server rooms contained within administrative buildings, while larger authorities already in 2012 started to centralise at least some of their services in one or more dedicated data centres to take advantage of the significant efficiency gains in terms of space, staff and finance. This shows that for the smaller public organisations (local councils/municipalities and regional/state authorities in Figure 5), the type of data centres procured may be decentralised or fragmented colocation data centres while for larger organisations these are enterprise data centres. This is aligned to input from two experts from EURECA55. The centralisation of data centres does not necessarily have to be done by owning the data centres but can be done through colocation services. PrimeEnergyIT confirms this as another trend, where certain aspects of the larger organisation's data services are outsourced, not only because of financial reasons, but also because external service providers may be able to provide levels of data protection and security not available in smaller server rooms. EURECA confirmed that only a few public organisations

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⁵³ Report procurement practices and recommended evaluation benchmarks. Available at: https://www.dceureca.eu/resources/EURECA D1.1.pdf

⁵⁴ Procurement guidance for energy efficient server room and data centre equipment. February 2012. Available at: https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/primeenergyit_procurement_guidance_en.pdf

⁵⁵ Telephone interviews in June 2017

outsource the whole service to managed service providers data centres, but they mentioned a couple of cases in the EU where this is happening, one of them being the city of Barcelona.

Overall, most public authorities rely to some extent on contracted IT service providers to manage and maintain their IT software and hardware arrangements, which is an opportunity to establish environmental criteria as part of the contract.

4.2 Best procurement practices

Best procurement practices depend heavily on the procurement requirements. While cloud services in general offer the highest level of efficiency, there may be many other factors prohibiting this. A 'cloud first' strategy requiring cloud providers to be considered first for any service is, for example, used by UK central Government. The cloud services are delivered by public cloud but also private cloud services to address the additional security and privacy requirements needed to protect data.

The EURECA project has developed a tool for procurement which helps the public authority compare different options within their specific constraints. This offers best practice by enabling the procurer to compare and explore different service options which may not have been considered (e.g. upgrading the existing data centre to expand file sharing and email services vs. procuring cloud email and file sharing and migrating the existing data). It guides the procurer, who has limited knowledge and understanding of the data centre industry and services, to help ensure they procure the correct service.

Two practices which are becoming more common, as shown in the EURECA case studies⁵³ and UK Government⁵⁶, are to centralize procurement as much as possible and consolidate the large number of small data centres. Because of the product complexity and constant innovation in the market, procurers should involve IT staff during the definition of the scope, technical specifications and selection/exclusion/award criteria (dark green boxes in Figure 5).

However, individual local authorities are unlikely to have the budget or need for a full time IT specialist and therefore combining resources with multiple authorities is the most cost effective way to achieve this (such as it is case of SKI in Denmark or Crown Hosting data centres services in the UK). The larger procurement scale can also affect the type of service which can be delivered, particularly if new data centres are required. According to information provided by EURECA⁵⁵, any UK public organisation can join the Crown Hosting services, who often set ambitious energy performance criteria at a framework contract level.

EURECA case studies show that procurers are also starting to require data centres to declare their environmental activities and these are formalized in frameworks such as the UK Government Digital Marketplace, which include requirements such as the data centre PUE (DCiE), signatory to the EU CoC and other environmental standards, as

⁵⁶ https://crownhostingdc.co.uk/latest-news-and-blog/cabinet-office-and-ark-data-centres-launch-joint-venture-to-deliver-data-centre-procurement-framework-to-uk-public-sector/

well as use of renewables. However, many of these are very hard to verify and not yet standardized so procurement based solely on these criteria is not possible.

Concerning overall public procurement practices, there are several tools available in Denmark to ensure an efficient, social responsible and environmentally conscious procurement. Total Cost of Ownership (TCO) tools⁵⁷ ensure that the procurement of products include the in-use costs of the product and not just purchase price. The Responsible Buyer website⁵⁸ provides information, recommendations and actual formulation of tender text to ensure environmental and ethnical requirements as well other social responsibilities (working conditions are part of the tender requirements). Lastly, the Danish Energy Agency has developed Procurement Recommendations⁵⁹ which provide the most up-to-date energy efficiency and resource efficiency requirements on a range of products that public sector would purchase.

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⁵⁷ http://mst.dk/virksomhed-myndighed/groen-strategi/groenne-indkoeb/totalomkostninger/

⁵⁸ http://csr-indkob.dk/

⁵⁹ http://sparenergi.dk/offentlig/vaerktoejer/indkoebsanbefalinger

5. Key actors in data centres value chain

The design, build and operation of the data centre involves a very large number of actors. The data centre stack (see Table 11) describes the different layers within the data centre from the physical structure to the final useful IT service being provided. Within each layer are also distinct domains of operation. This gives an overview and understanding of the technical elements and dependencies which make up the data centre and influence the overall energy efficiency.

Table 11. Basic data centre stack.

Data centre aspect	User IT service/business process application			
System software	Operating system, Virtualisation			
IT equipment	Server	Networking		
Infrastructure	White space (for housing IT equipment)	Electrical system (power conditioning)	Mechanical system (environmental conditioning)	

Unlike most of the other products covered by GPP, data centres are not mass produced for a common market. Individual data centres are custom designed to meet specific geographical, business and client requirements. The major end users like the financial sector, telecommunications, and Government all have different needs of data centres in terms of IT services, reliability, and security. To achieve this level of customisation, the product selection for and operation of the data centre will differ between each data centre.

In addition, the major parts that make up the complete data centre such as the building itself, the mechanical and electrical systems, IT equipment, software and applications may be managed by separate operational teams with separate contracts. This means that different business models and markets exist for all parts of the data centres' design and operations. Table 12 shows the common actors and ownership models for the different procurement options. As a result, procurement criteria which are capable of addressing every single possible combination of products and services under the three scenarios defined in Section 1 may become extremely complex.

Table 12. Ownership and forms of procurement for data centres.

Ownership	Data centre	IT equipment	Application	Other services
Wholesale (enterprise DC)	Freehold	Customer	Customer	None
Colocation	Long term leasehold	Usually customer	Customer	Low end hardware support
Hosting (managed service)	Mix leasehold/rent	Usually provider	Website, email	Low end tech support

Ownership	Data centre	IT equipment	Application	Other services
Generic managed services	Mix leasehold/rent	Provider	Specific areas such as database, storage	Low end tech support
Specialised managed services	Mix leasehold/rent	Provider	More customised and mission critical applications	Professional services
Full outsourcing	Mix leasehold/rent	Provider	Full suite applications	Taking over staff from user

5.1 Manufacturers

The data centre is equipped with a lot of different products, produced by variety of different manufacturers. These are used in the major operations for electrical, mechanical and IT, as well as the other ancillary services such as fire suppression, and physical security. The precise number of products varies in the data centre and there are hundreds of manufacturers of data centre related equipment. The equipment can vary from specialist products designed specifically for data centres and manufactured by SMEs to more common industrial products manufactured by global companies. Identifying and listing all the product manufacturers is not an informative exercise because of the large number and wide range of products.

Furthermore, the product only dITates the design efficiency of the piece of equipment operating under specific conditions and does not necessarily indicate its suitability and efficiency in a specific system under real operating conditions.

Table 13 lists a number of large global and specialist European equipment manufacturers but is not exhaustive.

Table 13. List of some of the global and EU specialist equipment manufacturers for data centres.

Manufacturer	Electrical system	Mechanical system	IT and system software
Cisco			X
CyberPower	X		
Systems	^		
Daikin		Χ	
Dell			X
Eaton Corporation	X	Χ	
EMC			X
Fujitsu		Χ	X
Hitachi		Χ	Χ
HPE			Χ
Huawei			
Technologies Co.,	X		X
Ltd.			
IBM			Χ
Intel		<u> </u>	Χ
Lenovo			X
Microsoft			X

Manufacturer	Electrical system	Mechanical system	IT and system software
Mitsubishi Electric			
Power Products,	X	X	
Inc.			
NetApp			X
Raritan (Legrand)	X	Χ	
Schneider Electric	X		
Stulz		Χ	
Trippe MFG., Co.	X		
Vertiv	X	Χ	
VMware			X

5.2 Service providers

The data centre market is not homogeneous and there are many different niches within the industry. Under the four scenarios defined in chapter 3, a distinction can be made between:

- 5. A (new facilities), B (expanded facilities) or D (operating and maintaining an existing facility) which require internal services supplied to and within the data centre such as design, operation, supplying a new data centre or expanding the infrastructure and applies to enterprise data centres.
- 6. C (An outsourced, external service, i.e. a service provided by the data centre such as colocation, cloud services, web hosting.)

Returning to the data centre stack, in Table 11, the services for scenarios A and B provide one or more of the domains of operation identified. Services provided to the data centre may be outsourced or managed in house. This is an important element to understand, since they can impact how policies might apply to the data centre. For example, product labels would primarily affect the manufacturers of the equipment deployed within the data centre, but could also influence the purchasing decisions being made by the data centre's operator. The manufacturers in the section above commonly provide services to the data centre industry to support their equipment.

In theory, the more domains within the data centre that come under one control the greater the capacity to optimise whole data centre. Conversely, shifting control of individual domains to specialists with expert knowledge means that domain subsets can be fully optimised using the best technology and operating techniques.

New data centre build and expansion of infrastructure

A new data centre can involve every aspect of the data centre stack. It often combined with a consolidation activity to close many small inefficient (both energy and cost) data centres into a larger centralised location. This includes the following services related to the operational efficiency of the data centre:

- Consultation on data centre requirements/audit of existing data centre
- Conceptual and technical data centre design
- Construction of new data centre
- Equipment supply
- Commissioning of data centre to match infrastructure operation to actual load

- DCIM (data centre infrastructure management) ongoing operation and optimisation of the infrastructure
- Migration of existing IT equipment to new location
- Consolidation/virtualisation of IT equipment and services
- Ongoing operation of IT services
- Installation of new IT services

These services may be operated by one or more different contractors and therefore the procurement criteria may be divided between contracts or the joint responsibility of different contracts. Infrastructure and IT in particular can rarely be serviced by a single contractor.

Outsourcing

Data centre/real estate management generally own (or lease) the building and land. They may also install the DC infrastructure but often will not operate or manage it and therefore have limited control of the efficiency.

Colocations will operate and manage the data centre infrastructure, and lease the managed space and electricity to clients to run their own IT equipment. They may also provide networking connecting the data centre to the internet. Colocation providers have control of the mechanical and electrical efficiency but must also meet client environmental demands.

Cloud computing converts the physical IT equipment into a large pool of data processing, storage and networking resource, which can be broken up into smaller virtual units, and which can be sold and accessed on demand by the user. By using economies of scale, the IT services are essentially commoditised and it is possible for the operator to maximise the use of the data centre and IT equipment across many users, as well as being able to scale up and down with user demands. Cloud computing is currently described at a number of levels:

- Infrastructure as a Service (IaaS) provides virtual servers
- Platform as a Service (PaaS) provides virtual applications
- Software as a Service (SaaS) provides business process/User IT services.

A company may offer a variety of services for different clients from colocation to cloud computing. Generally, 'rising up the stack' (ie operating a more complex service) creates more service providers and niches. This is because the capital costs are much lower, and companies are supplying a more diverse range of end user services.

Data Centre Map⁶⁰, a directory of colocation and cloud service providers worldwide lists 1199 colocation providers within the EU Member States and 199 cloud providers. The largest markets are in UK and Germany, followed by France and the Netherlands. However, this is a massive underestimate of the full scope of cloud service providers since the UK Government Digital Marketplace lists approximately 10,000⁶¹ registered

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⁶⁰ http://www.datacentermap.com/

⁶¹ https://www.digitalmarketplace.service.gov.uk/g-cloud

G-Cloud services (IaaS, PaaS, SaaS) from 1059 providers⁶² and further 16,000 specialist cloud services from 600 providers.

5.3 Users

Public bodies generally use services provided by the data centre both for internal operations and external services to the general public. The latter are increasing in variety as more Government services are delivered digitally and the range of end users therefore includes almost all businesses and individuals. The internal client, i.e. the procurer, can vary from large centralized Government or military contracts to small local authorities and the breadth of services required can vary similarly.

Amsterdam, Dublin, Frankfurt, London and Paris, are considered blossoming tech hubs in terms of data centre services⁶³, and this is because⁶⁴:

- Excellent connectivity, ie. Internet bandwidth capacity
- Low energy costs and/or low inflation rates
- Stable energy grid
- Fast development of software and Internet of Things (i.e. big data)
- Good infrastructure for international business

These hubs provide a platform capacity which could be utilized by public procurement, in particular regarding colocation services which data centre providers use to provide the infrastructure, and in some cases (part of) the IT equipment as indicated in Table 11.

According to information provided by EURECA, the most popular model in colocation data centres is to provide the infrastructure with an established PUE of 1.2, so the customer has to warranty a minimum level of relative energy consumption and the providers assure a minimum level of PUE.

5.4 Segmentation and expected trends in public procurement

In common with the market as a whole, it is expected that more public sector services will be delivered by larger and larger data centres and by the cloud, although there is also counter pressure due to data security issues. Public cloud services will probably be delivered by mega data centres dominated by Amazon, Microsoft and Google who have the economies and scale and expertise to design, build and deliver services at higher efficiency and lower cost. However, SMEs and private cloud services who can develop specialist services to meet the users' needs will also be important. Very large scale of operations also extends to the ability to finance and contract entire renewable energy farms to minimize environmental impacts. In line with the move to cloud computing, fewer public bodies are operating their own dedicated enterprise data centres and require services such as design, operation etc., although legacy equipment will always exist since some services are too sensitive, complex or expensive to decommission.

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⁶² https://www.publictechnology.net/articles/news/g-cloud-7-supplier-list-revealed

⁶³ According to input provided by EURECA

⁶⁴ https://www.digitalrealty.com/data-centers/europe/

Data centres are commonly segmented by their size, measured in terms of the total maximum power the IT equipment can consume while maintaining reliability etc. New data centres are generally bigger due to the economies of scale, and growing demand. However, this is not an informative measure for procurement of outsourced services and simply suggests how many other clients may be sharing the data centre.

6. Life Cycle Assessment (LCA) of Data Centres

6.1 Overview of LCA studies on data centres

Life Cycle Assessment takes a holistic view of the environmental impacts throughout the whole life of the product or system. It considers the emissions of substances and wastes and the consumption of resources from "cradle to grave", i.e. not only from the operational (so called "use") stage of the product/system but also from all processes related to the extraction of raw materials, manufacturing, waste management, final disposal as well as all related transport.

In LCA, there is an initial 'Goal and Scope' phase, where the product/system and the purpose of the assessment are defined. Then, in the Life Cycle Inventory (LCI) phase the emissions and resources consumed during the life cycle of this product/system are compiled and documented. The data collected for the LCI include elementary flows (e.g. emissions), product flows (goods and services) and waste flows. The LCI is followed by the Life Cycle Impact Assessment (LCIA) phase during which the inventory is linked to environmental impact categories and converted into quantitative impact indicators using characterisation factors⁶⁵. LCIA is either performed at a *midpoint* level (e.g. quantifying the potential contribution of various emissions to global warming potential) or at an *endpoint* level, where LCA attempts to directly model and link the emissions to impacts in three Areas of Protection (AoP) i.e. human health (includes global warming), natural environment, and natural resource use.

During LCI data collection, where there are data gaps, or where an approximation is not possible, sometimes (depending on the assessment's scope) economic input output (EIO) data can be used alongside the process- based data in a hybrid LCA. EIO looks at the total emissions produced by sectors within the economy, providing data for the entire supply chain of that product. A component manufactured within a certain sector, is then apportioned part of the environmental load based on its contribution to the total value of the sector (after purchasing has been accounted for).

In this chapter, a review of existing Life Cycle Assessment (LCA) studies on data centres has been done, in order to identify the life cycle hotspots based on the life cycle stages that show the highest environmental impacts and the identified opportunities for improvement.

Before presenting the results of this review, it is important to recall the definition of data centres presented in chapter 3:

"Data centres means a structure, or group of structures, dedicated to the centralised accommodation, interconnection and operation of information technology and network telecommunications equipment providing data storage, processing and transport services together with all the facilities and infrastructures for power distribution and

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⁶⁵ Characterisation factors of the ILCD Recommended Life Cycle Impact Assessment methods Database and supporting information, JRC 68250, EUR 25167 EN, ISBN 978-92-79-22727-1, doi: 10.2788/60825, present version updated 20/02/2013

environmental control and the necessary levels of resilience and security required to provide the desired service availability."

Based on this definition, the physical limits of a data centre's life cycle are presented in Figure 9 (i.e. the system boundaries when looking at data centres from cradle to grave). The life cycle of a data centre has the following life cycle stages:

- Raw materials extraction including:
 - The data centre's IT, mechanical and electrical systems (e.g. servers, storage units, switches, cooling, water and control systems; switchboards, cabling, generators, UPS, electrical monitoring, fire and security systems, etc.)
 - o The building where the data centre is hosted in;
 - Transport of these materials to the manufacturing sites;
- Manufacturing of the data centre and building products, incl. the construction of the building (not shown in Figure 9);
- Distribution of the products to the data centre site;
- Use phase, which is the operation of the data centre;
- Decommissioning, incl. transport to the waste transfer station and transport to landfill, WEEE treatment facilities, and to recycling and/or incineration of the products, components and/or materials;
- End of Life, incl. landfill, WEEE treatment, recycling and incineration

Data centres are complex structures with four main systems (i.e. the IT, mechanical and electrical systems, as well as the building), where a great diversity of products and materials are manufactured to fit in according to the data centre's main service to be delivered. For simplicity reasons and to consider the public procurer's needs, Figure 4 shows three overall data centre types, and according to this scope definition Figure 5 shows how these match the needs of the procurers (i.e. build new data centre/service room, expansion of the infrastructure, outsource to hosting/Cloud and operation/maintenance of the facility). The needs will determine whether the procurer buys a product (through a 'supply' contract) or a service (through a 'service' contract) and the type of data centre that will fulfil that contract, as defined in chapter 6.

Out of the ten LCA studies, seven of them focus on identifying the life cycle hotspots of data centres looking at them as products/physical systems and one of these focuses on comparing impacts between different data centre types according to the service they deliver. The other three studies assess only part of the data centre (either the IT system or the cooling system).

Furthermore, the environmental impact categories applied cover a range of different methodologies and it is therefore not possible to compare fully one study with the other. However, it is possible to identify the hotspots from each individual study and find similarities to conclude.

In contrast to other IT products, there are not many LCA studies available for data centres because the holistic focus considering their whole life cycle is a recent approach. However, by evaluating the existing studies it is possible to understand the breadth and depth of information available.

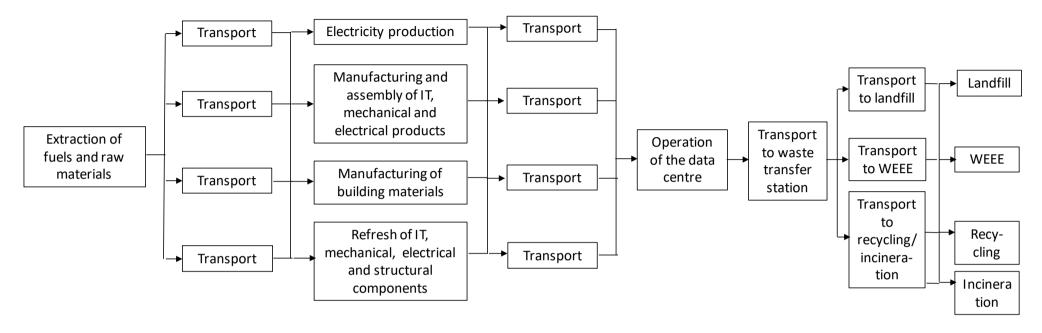


Figure 9. Life cycle of data centres represented by life cycle stages⁶⁶.

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⁶⁶ Adapted from system boundaries presented in Whitehead, Beth (2013). Life Cycle Assessment of Data Centres and the development of a software tool for its application. PhD thesis.

Table 14 gives an overview of the LCA studies assessed, together with their functional units, system boundaries, time and geographical scope and environmental impacts applied. In spite of the fact that most studies focus on the physical product/system, the fact that the studies' functional units are comparative (i.e. one year of operation or data centres total lifetime), makes it possible to use them altogether to conclude on the hotspots.

The LCA studies presented have been selected for their relevance to the current analysis, because:

- They assess the whole data centre three studies focus only on servers/storage units and on cooling systems but they are still presented since these are rather important components of the data centres and they are three of the six LCA studies that assess several environmental impacts going beyond Global Warming Potential⁶⁷.
- They do a contribution analysis showing the hotspots of the life cycle stages assessed.
- They present all necessary information on the methodological aspects a LCA shall consider, according to ISO 14040/44 and the Product Environmental Footprint -PEF- (i.e. Goal and scope definition incl. functional unit and LCA modelling principle, Life Cycle Inventory, Life Cycle Impact Assessment, Interpretation), which allows to identify the life cycle environmental hotspots.
- They present the results in life cycle impact categories which are either recommended by the Product Environmental Footprint methodology, widely recognised in the LCA academic community or which are commonly reported in the ICT sector. In spite that four studies only assess Global Warming Potential and in some cases also energy or electricity demand, these have been included in this review else only three studies covering the whole data centre would be covered.
- They are done following an accepted LCIA methodology by the LCA academic community.

Due to the limited number of LCA studies for data centres, it was not possible to only show results from studies following entirely the ISO 14040/44 standards and/or the PEF methodology. Some of the studies did not present information on important methodological aspects like when allocation or system expansion were applied, nor on the cut-off applied nor used environmental impact categories nor end of life modelling principles recommended by PEF. This is because the use of LCA is relatively new for data centres, and the diversity of methodologies applied is quite wide considering the limited number of LCA studies. Furthermore, the data centre systems are rather complex, bringing together several pieces of equipment. These may have been independently assessed in the past via a different methodological approach e.g. through a different definition of functional unit and/or system boundaries. Additionally,

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⁶⁷ Global Warming Potential is referred in this section to represent Climate Change and Carbon Footprint. Different methodologies exist to assess Global Warming Potential, but these are not assessed in detail in this review since the results are presented at LCA screening level.

caution was exercised when using/interpreting results due to their level of uncertainty and variability stemming from the modelling of complex systems, and of a continuously developing technology. Despite the challenge LCA was effective in allowing impact hotspots to be identified.

For more details on the LCA studies included in the review, please refer to Appendix 2.

Table 14. Overview of subject of the selected LCA studies, functional unit, system boundaries and time scope.

Study ID*	Subject of the study	Functional unit	System boundaries**	Time & geographical scope	Environmental impact categories
S1-DC	A typical data centre in the EU (PUE 1.42)	1 year of operation	RM+MFG+USE+ EoL	2015 EU-28	Acidification, Global Warming Potential, Photochemical ozone formation, Resource depletion, Particulate matter/respiratory organics, Ozone depletion
S2-IT	Rack-optimised enterprise servers (typical in the EU)	1 enterprise server across its lifetime	RM+MFG+ DIST+ USE+ EoL	2014 Manufacture in China, use in Europe	12 categories in the ILCD handbook ⁶⁸ and recommended by PEF ⁶⁹ , incl. Primary energy demand, Abiotic Depletion and Acidification Potential
S3-IT	Two average enterprise server technologies and one average storage unit technology in the EU	Two enterprise server technologies and one enterprise storage technology across their lifetimes	RM+MMFG+ DIST+USE+EoL	2014 Average EU-28	Total energy, Water, Hazardous/non-hazardous waste, Global Warming Potential, Acidification, VOC ⁷⁰ , POP ⁷¹ , Heavy metals to air/water, PAHs ⁷² , PM ⁷³ , Eutrophication
S4- COO	Cooling system integrating free cooling and recycling of heat (from Telia)	1 cooling technology across its lifetime with a minimal power demand of 9000 MWh per year	MFG+USE+EoL	2013 Operation in four EU cities in Finland, Sweden and Denmark	Fossil depletion, Global Warming Potential, Human health, Particulate matter formation, Human toxicity
S5-DC	Typical data centre in the UK (Tier III facility)	Provision of 1 kW of IT service per year	Full Life Cycle	2010 to 2013 Operation in	Human health, Ecosystem quality, Resources, Carcinogens,

⁶⁸ International Reference Life Cycle Data handbook. Available at: http://eplca.jrc.ec.europa.eu/?page_id=86

⁶⁹ Product Environmental Footprint. Available at: COMMISSION RECOMMENDATION of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations – Annex II Product Environmental Footprint (PEF) Guide

⁷⁰ Volatile organic compounds

⁷¹ Persistent organic pollutants

⁷² Polycyclic aromatic hydrocarbons

⁷³ Particulate matter

Study ID*	Subject of the study	Functional unit	System boundaries**	Time & geographical scope	Environmental impact categories
				UK, EU and USA, End-of-life in EU & Switzerland	Respiratory organics/inorganics, Global Warming Potential, Radiation, Ozone layer, Ecotoxicity, Acidification, Eutrophication, Land use, Minerals, Fossil fuels
S6-DC	Typical data centre in the USA (PUE 1.8)	1 year of operation	RM+MFG+USE+ EoL	2012 Operation in USA	Global Warming Potential, Ecosystem quality, Human health, Resource depletion
S7-DC	Four software applications for a typical SME in the USA (email, CRM & Web, Finance & Accounting, File storage & Sharing)	1 GB data processed service per user per year	Full Life Cycle	2012 Operation in USA	Global Warming Potential based on the GHG Protocol ⁷⁴
S8-DC	A colocation data centre in Sweden for the national insurance administration	1 year of operation	RM+MFG+DIST + USE+EoL	2010 Operation in Northern Sweden	Electricity use in operation and Global Warming Potential ⁷⁵
S9-DC	An hypothetical data centre	1 data centre through its lifetime	RM+MFG+USE	2009 Operation in USA	Total energy use, Global Warming Potential, Total toxic releases, PM10 Air pollutants
S10- DC	Installed base of data centres globally	Installed base's average energy use	RM+MFG+USE	2007 Operation in xxx	Electricity use and Global Warming Potential

^{*=} See Appendix 2 for details of the studies; **=RM: raw materials extraction, MFG: manufacturing; DIST: distribution; USE: use phase incl. electricity production; DEC: decommissioning; EoL: End of life; Sx-DC=scope was whole data centre; Sx-IT=scope was IT system (only server and storage units); Sx-COO=scope was cooling system.

Table 15 presents the main conclusions from the LCA studies, which by combining the information presented in Table 14, makes it possible to get an overview of what has been done and to identify hotspots.

⁷⁴ http://www.ghgprotocol.org/

⁷⁵ using ReCiPe characterisation factors for climate change impact

Table 15. Overview of main conclusions from LCA studies on data centres.

Study ID	Main conclusions
S1-DC	 The use phase is dominant for photochemical ozone formation, global warming potential and acidification, due to the use of electricity for the IT and M&E systems. The manufacturing is dominant for resource depletion (minerals, fossils & renewables), particulate matter and ozone depletion.
S2-IT	 The use phase is the dominant for most of the impact categories (i.e. global warming potential, marine and terrestrial eutrophication, particulate matter, photochemical ozone formation, total freshwater consumption, acidification, primary energy demand). This originates from the consumption of electricity. Manufacturing (incl. raw materials extraction and transport) are the dominant for 6 of them (i.e. all related to toxicity, freshwater eutrophication, ozone depletion and abiotic depletion of elements). Overall, this originates from the use of high impact materials and the toxic emissions from their mining. EoL is important to reduce the overall impacts, considering the Central Processing Units (CPUs), Hard Disk Drives (HDDs), memory and expansion cards are recovered and partially recycled, while batteries, cables and main board are also recovered but undergoing selective treatments which are not necessarily recycling. There are greater benefits when these components are manually recovered since more high impact materials are recycled (e.g. gold, copper, aluminium, neodymium).
S3-IT	 The use phase is dominant for the three technologies (rack and blade system servers and an average storage technology) for total energy, use of water in cooling, generation of waste, global warming potential, acidification, VOCs, eutrophication. This originates from the use of electricity. The material phase is dominant for POPs, heavy metals, PAHs and PMs. This is due to the toxic emissions from mining (i.e. from POPs, heavy metals and PMs), and the production of some electronic components (PAHs) EoL is important to reduce overall impacts if critical components are recycled or reused (the study does specify which ones). A comparison between this and S2(mentioned above), shows an underestimation of the material/manufacturing and EoL impacts by the EcoReport tool for rack servers. However, even taking this underestimation into account, the -dominant phase is still the use phase.
S4- COO	The local electricity sources could fundamentally influence the cooling system's environmental performance, considering this is a very efficient cooling system concept ⁷⁶ .

⁷⁶ https://www.seecooling.com/files/2016-02/the-teliasonera-green-room-concept.pdf

Study ID	Main conclusions
	When the data centre site is installed in an area with higher share of renewables, the use phase only becomes important several years later after start, when looking only at the environmental impacts of this cooling system.
S5-DC	 The overall impacts are dominated by the production of electricity used during the operation of the data centre and the fuels supplied to the grid. The second hotspot is the disposal of waste products from the refining of metals contained in IT components and from electricity distribution networks. Three parameters are sensitive to changes in the design of a data centre which influence the overall impact: the level of energy consumed in operation for the IT equipment, cooling, and power delivery; the energy mix used to provide electricity; the amount of IT equipment used in the facility's lifetime. Impacts to human health dominate the environmental impacts (i.e. global warming potential, ozone layer depletion, ionising and radiation emissions, respiratory effects, carcinogenic emissions), while those to resources contribute by about 33% of the total weighted environmental impact (i.e. depletion of mineral and fossil resources)
S6-DC	 97% of the contributions to the total normalised damage⁷⁷ to global warming potential originate in the use stage. Contributions to the normalized damage to human health are about 93%, to ecosystem quality are about 85% and to resource depletion are about 96%. When looking at the embodied impacts (i.e. from manufacturing and end of life), more than half of the normalized damage originates from the IT system. The contribution from IT is about 52% and overall the highest contributions come from the use stage.
S7-DC	 For the four deployment scenarios⁷⁸ and under standard conditions: The enterprise data centres w/o virtualisation as well as the colocation data centres present more than triple Global Warming Potential per application compared to enterprise with virtualisation, and to private and public cloud data centres⁷⁹.

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⁷⁷ Calculated using the Eco-indicator 99 v2.08 based on weighted life cycle impact assessment results on single score end-point damage analysis.

⁷⁸ Four software applications for a typical SME in the USA (email, CRM & Web, Finance & Accounting, File storage & Sharing).

⁷⁹ The term "private cloud" describes a cloud environment which serves a single organization. "Public cloud" refers to a SME purchasing a desired service from a cloud provider, which can be accessed from anywhere via the internet. The cloud provider may deliver their services through their own data centers, or through outsourced servers in colocation facilities.

Study ID	Main conclusions
	 For File storage & sharing as well as for finance & accounting, the public cloud performs significantly better. For email and for CRM& web, the difference between enterprise with virtualisation, private and public cloud data centres is almost negligible. Identified best practices for enterprise data centres with virtualisation show about 15x times reduction compared to worst case and about 7x times compared to average. This is due to that both the cloud and virtualization reduce IT equipment requirements, increase IT utilization and M&E part loads, and tend to have good designs, which are well managed (low PUE, etc).
S8-DC	 The procured assets (i.e. production, transport and waste management) contribute by 33% of the total global warming potential, while the use stage does by 67%. The IT platform contributes by about 67% of the total global warming potential, both from use and manufacturing. The facility (i.e. M&E systems and building) contribute by 37%, both from use and manufacturing. The environmental load associated to the procured assets of the data centre is significant and to a large extent dependent on the relatively short economic lifespan and specific configuration of IT equipment.
S9-DC	The compute infrastructure contributes to the four impact categories with a range of 45%-55%, while the cooling does within a range of 35-50%. In the case of total energy and global warming potential, the share is about 45/45%. The embodied impacts are only high for the toxic releases (about 65%) and PM-10 air pollutants (about 60%).
S10- DC	About 100 million tons of CO2-eq come from operations, compared with 25 million tons of CO2-eq that come from manufacturing.

or other public cloud facility. The hardware usage is shared by multiple customers and the individual customer only has to pay for the capacity they need

6.2 Analysis of key environmental areas and improvement options of selected LCA studies

Based on the main conclusions presented on Table 15, it can be concluded that the main life cycle environmental hotspots are, in order of importance:

- 1. The use stage due to the electricity consumption, first by the IT system (primarily based on server and storage consumption) and second by what is referred to in many cases as 'infrastructure' or 'facility' or the 'power and cooling systems" or 'Mechanical and Electrical (M&E) systems'. The building can be excluded due to its low operational contributions, which leaves the M&E system as the second contributor. One of the studies showed that virtualisation is an important practice when aiming to reduce the life cycle global warming potential of a data centre. Furthermore, one study showed that when looking only at the cooling system, the integration of renewable energy with free cooling and reused heat can reduce the environmental impacts of the use stage.
- 2. The manufacturing of the IT system and M&E system. One study shows that the contribution of network equipment to the global warming potential of the manufacturing stage is only 1%, reassuring the focus on servers and storage. Two studies show that the end of life can reduce the servers and storage overall life cycle environmental impacts if key components are recycled. These are Central Processing Units (CPUs), Hard Disk Drives (HDDs), memory and expansion cards, batteries, cables and main board. Furthermore, one shows that the benefits are greater if the waste sourcing is done manually before recycling, although the benefits may be marginal when comparing these to the overall life cycle environmental impacts of a whole data centre (the study only looked at servers and storage units in the EU-28).

Table 15 shows also that the main environmental impacts related to the use stage of data centres are, in order of importance:

- 1. Global warming potential
- 2. Acidification
- 3. Eutrophication
- 4. Primary energy demand
- 5. Others like fresh water use, waste generation, emissions of VOC and PM which are assessed in only a couple of studies.

The main environmental impacts related to the manufacturing of the IT system are, in order of importance:

- 1. Global warming potential
- 2. Toxicity, both human toxicity and ecotoxicity
- 3. Resource depletion, focusing on mineral resources

Two studies present the option of normalizing the life cycle impact categories based on damage analysis (i.e. end point analysis). These normalized results can be later weighted by a single score point system which prioritizes the importance of each of

these damage categories. In this way it is possible to come to a single score rather than presenting results in a range of environmental impact categories. This convenience is counteracted by the validity and wide use of this point system, which is not the only system used when reporting life cycle environmental impacts. Thus, care should be taken when interpreting the single score results. However, most of the studies concur on the environmental impact categories that are important.

Concerning data centre types, only one of the studies shows a comparison between the global warming potential of four services delivered by different data centre types under standard conditions but also considering worst and best practices (focusing on the operation of the data centre and the embodied impacts of the IT system). The results show that the enterprise data centres w/o virtualisation as well as the colocation data centres present more than triple Carbon Footprint per application compared to enterprise with virtualisation, private and public cloud data centres. For File storage & Sharing as well as for Finance & Accounting, the public cloud performs significantly better, however for email and for CRM & Web, the differences between enterprise with virtualisation, private and public cloud data centres are almost negligible. Identified best practices for enterprise data centres with virtualisation show about 15x times reduction compared to worst case and about 7x times compared to average. This is due to that both the cloud and virtualization reduce IT equipment requirements, increase IT utilization and M&E part loads, and tend to have good designs, which are well managed (low PUE, etc.).

6.2.1 Summary

The life cycle assessment of data centres has indicated that the main environmental impacts stem from the IT and cooling systems, in particular from:

- 1. The energy mix used to supply electricity, which can be greatly reduced the more renewables are used in the grid mix and the less waste is generated from the mining of fuels and production of electricity
- 2. The energy consumption and related energy efficiency of the overall data centre including IT and the mechanical and electrical (M&E) systems, which determines the amount of energy consumption.
- 3. The manufacture (incl. raw materials extraction and transport) of the IT and M&E systems (i.e. their embodied impacts), and in particular due to the disposal of waste products from the extraction and refining of metals used to manufacture printed circuit boards of IT components
- 4. The end of life of the equipment, specially focusing on the possibilities for reuse and recycling that are alternative to other routes and that can avoid some of the environmental impacts from manufacturing.

Global warming potential, Resource Depletion (minerals), Acidification, Eutrophication, Primary Energy Demand, Human toxicity and Ecotoxicity are the most important environmental indicators to be considered for measuring the life cycle environmental performance of data centres.

Only one study showed a comparison between different data centre types and practices for specific applications in the USA. The results show that the impacts from manufacturing (only IT) and operational carbon footprint of enterprise data centres

with virtualisation for delivering email and CRM/Web applications are around the same order of magnitude to those of Cloud data centres (i.e. managed service providers). For File storage & Sharing as well as for Finance & Accounting, the public cloud performs significantly better. Furthermore, that best practices for enterprise data centres with virtualisation can reduce their carbon footprint about 8-15 times. This is due to that both the cloud and virtualization reduce IT equipment requirements, increase IT utilization and M&E part loads, and tend to have good designs, which are well managed (low PUE, etc).

6.3 System-oriented analysis

Measures to improve data centre sustainability must not compromise reliability. There can be a perception that the two are mutually exclusive, however it is important to demonstrate that measures to improve environmental performance do not necessarily increase risk. This unawareness may hamper efforts to implement best practices, e.g. through resistance to change legacy practices and designs such as low operating temperatures. Presenting the business case for sustainability can also support improvements.

One way in which the environmental impact of data centre cooling systems can be reduced is through operating at higher internal temperatures. Provided the air delivered to the ICT equipment is managed and kept within recommended and allowable environmental ranges, this does not adversely affect hardware failure rates⁸⁰. ICT hardware increases its fan speed at higher temperatures; it is important to consider the potential increase the ICT fan energy, flow rate and noise level in addition to the decrease in cooling system energy consumption. In some installations this can also lead to operators working at uncomfortable temperatures, although it is possible to avoid / mitigate through design / management.

There has been in data centres an inherent assumption that the data hall is like an air conditioned room, at a constant temperature which is cooled and used to keep IT equipment cool. Given that IT equipment have much higher loads than people in offices, the temperature differences in the hall can vary from 10°C to 50°C. For legacy data centres, no one was responsible for how cold air was delivered to IT equipment. How this air is managed, has a very big impact on reliability (IT equipment temperatures) and cooling efficiency. The LCA studies do not specifically address the importance of air management. In practical terms, to improve energy efficiency of a data centre, it is normally the most cost effective enabler to start with, allowing maximum savings for minimum investments, when compared to other energy efficiency measures. It is very important to properly differentiate between the temperature of the cooled air supplied to the data hall (affects cooling efficiency) and the temperature of air entering IT equipment (affects IT reliability), which is always higher (1C to up to 20C higher) than cooled air supplied.

A common theme to both reliability and energy efficiency in data centres is the impact of the human element, as the majority of failures and inefficiencies are down to

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⁸⁰ 2011 Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage Guidance, ASHRAE TC9.9 (2011)

human errors / unawareness. The best mitigation is to create a learning environment culture⁸¹.

6.4 Identification of priority improvement options for products and services

Based on the analysis presented in the last three sections, key improvement options for products and services have been elaborated, together with key recommendations. The improvement options and recommendations are based on the physical boundaries of the data centre and focus mostly on the product. A couple of additional options/recommendations are provided in the case the data centre service is provided fully as a service (i.e. by Managed Service Providers data centres).

The key areas of improvement (presented in section 6.2) and subsequent recommendations are, in order of importance:

- 1. The energy mix used to supply electricity
 - o Use a more renewable energy source/grid
- 2. The energy efficiency and utilisation of the IT system
 - Improve the efficiency of servers reducing power consumption when idle and increasing utilisation (via consolidation and virtualisation)
- 3. The energy consumption of the M&E systems
 - Minimise PUE. The largest opportunities for M&E systems may be found in optimizing of cooling systems and scalability at part loads
 - Allow higher cooling temperatures so to reduce energy required for cooling and allow more free cooling
 - Design for actual loads to be achieved to avoid oversupplying IT and M&E equipment
- 4. The manufacture (incl. raw materials extraction and transport) of the equipment (i.e. their embodied impacts) of IT and M&E systems
 - Reduce the embodied impact of IT equipment (predominantly through the product design and manufacturing and end-of-life processes) – facilitate the design for disassembly to increase share of reuse/recycling
 - Reduce the total quantity of materials used in IT and cooling components, because of the frequency with which they are replaced, or design the components to last longer (i.e. to prolong their lifetime)
 - Reduce the use of heavy metals in the production of IT components, to decrease the carcinogenic effects of the manufacturing stage
 - Research the reduction of gold and copper in components, and the processes used in their refining, to reduce long-term emissions
 - Design for extended refresh periods, rather than incorporating planned obsolescence into the process
 - Design for staged decommission, allowing for the replacement of only the parts that have come to their end of life
 - Improve manufacturing processes to become less reliant on carbon-based fuels which produce carcinogenic PAHs

⁸¹ Duffey R and Saull J, Managing Risk: The Human Element, 2008

- Make information on equipment utilisation and efficiency freely available to the whole industry to allow for standardisation to drive down impact
- o Provision of information concerning critical raw materials
- o Consider zero refrigeration systems

5. The water discharged from the cooling system

One of the reviewed studies find that the electricity mix used to provide power to the data centre and those parameters which directly impact the IT equipment operational power — such as equipment utilization, peak power, and idle power — also have a significant impact. The level of standby redundancy and influence of parameters related to facility thermal management are also non-trivial across most impact factors. This may be addressed by considering overall resilience and removing excessive levels across IT and M&E systems and operating at higher temperatures.

It is important to consider when IT equipment refresh results in a reduced overall impact. This topic is explored in a paper scheduled for publication⁸².

One study showed a comparison between different data centre types and practices for specific applications in the USA. The results show that the impacts from manufacturing (only IT) and operational global warming potential of enterprise data centres with virtualisation for delivering email and CRM/Web applications are around the same order of magnitude to those of Cloud data centres (i.e. managed service providers). For File storage & Sharing as well as for Finance & Accounting, the public cloud performs significantly better. Furthermore, that best practices for enterprise data centres with virtualisation can reduce their carbon footprint about 8-15 times. This is due to that both the cloud and virtualization reduce IT equipment requirements, increase IT utilization and M&E part loads, and tend to have good hyperscale designs, which are well managed (low PUE, etc).

Recent research also indicates that the impact of water usage and particularly water discharge is of growing significance in data centres. This is an area which has not previously received much attention, in part due to the lack of data. Data centres which are designed to be energy efficient often have increased water consumption through use of adiabatic cooling (i.e. through evaporative coolers) to avoid refrigeration. As this is currently an underestimated and growing area of concern it is proposed to include it in the GPP criteria.

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⁸² A Comprehensive Reasoning Framework for Hardware Refresh in Data Centres, Rabih Bashroush, scheduled for publication in IEEE TRANSACTIONS ON COMPUTERS

7. Data Centre energy consumption in the EU market

7.1. Overall energy consumption for data centres

Figure 10 shows the global power demand of data centres, including the CAGR (Compound Annual Growth Rate) in the different regions of the world from 2015 to 2020. According to the authors of this report (Yole Développement⁸³), with no slowing down in new facility construction, data centres worldwide will have an increasing need for power. Figure 10 shows about 58 GW of total power demand in 2020, with Europe demanding approximately 20 GW, which is ca. 34% of the total worldwide power needs.

WORLDWIDE DATA CENTER FACILITIES - POWER NEEDS IN GW



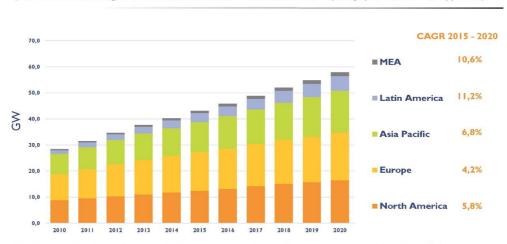


Figure 10. Worldwide data centre facilities' power needs in GW83.

According to this report, data centres are huge electricity users representing around 1.62% of the world's consumed energy in 2014. In Europe, the data centres account for approx. 2% of the total energy consumption. In a conservative scenario with an average Power Usage Efficiency (PUE) of 1.8, worldwide data centre energy consumption will reach 507.9 TWh by 2020. However, in a more optimistic and efficient scenario, there is a possibility for achieving a 12.4% decrease of this number by implementing some new technologies such as modular Alternative Current and Direct Current grid, silicon photonics and Wide Band Gap (WBG)⁸⁴.

Data published on some market figures and pricing in Europe⁸⁵ cover the statistics over 1512 date centre facilities across the 24 European markets by 2015 with a total capacity of 3024 thousand m² and total customer power of 3.4 GW. These countries cover 21 of the EU-28 Member States including Norway, Iceland and Switzerland.

⁸³ http://www.yole.fr/Datacenter_Silicon_Photonics.aspx#.WRrA8oiGO71

⁸⁴ https://www.i-micronews.com/power-electronics-report/product/new-technologies-and-architectures-for-efficient-data-center.html

⁸⁵ Data Centre Pricing in Europe 2015 to 2020 (extract). Published July 2015. See: http://www.datacentre.me/downloads/Documents/Data%20Centre%20Pricing%20in%20Europe%202015%20to%202020%20-%20table%20of%20contents.pdf

Considering an average PUE of 1.8 and assuming 80% IT equipment efficiency⁸⁶, the total power demand is calculated to be ca. 7.4 GW, (approx. 50% of the total 15 GW shown in Figure 10). A rough estimation for a total ca. 3000 data centres in Europe can be derived based on above statistics.

Borderstep Institute has carried out a study on EU's data centre energy consumption⁸⁷. It shows that in the last few years, data centres sector in European countries have followed the global incline trend, more rapidly from 2014 to 2015. Compared with other countries in Europe, energy consumption by servers and data centres (2015) are highest in Germany (approx. 12.5 TWh), the United Kingdom (approx. 10.8 TWh), France (approx. 8.6 TWh), and the Netherlands (approx. 4.3 TWh) (see Figure 11). Taken together, they account in 2015 for 55 % of the electricity consumption of all servers and data centres in Europe (approx. 66 TWh). In 2010 this figure was approx. 55 TWh, which means that in 5 years the energy consumptions of data centres in EU has increased by 10 TWh.

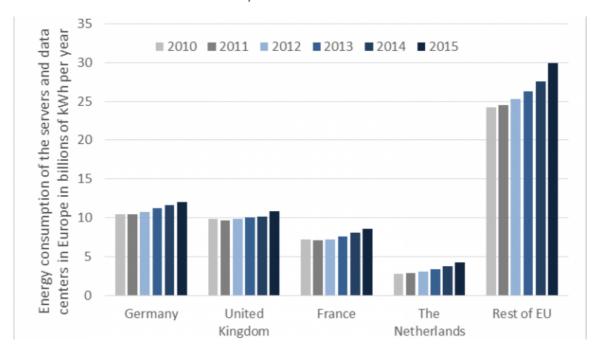


Figure 11. Energy consumption of servers and data centres in Europe in billions of kWh per year for 2010 - 2015⁸⁷.

According to JRC's figures on the European Programme for Energy Efficiency in the Data Centres Code of Conduct⁸⁸, in 2007 the data centres total energy consumption was already 56 TWh (2% of total electricity consumption in Western Europe) and at the time it was projected to increase to 104 TWh per year by 2020⁸⁹. This is line with the US consumption of data centres representing 1.7% to 2% of US total electricity

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⁸⁶ Assumptions made for the ongoing work on EU ecodesign for enterprise servers and storage

⁸⁷ https://www.dotmagazine.online/issues/powering-and-greening-IT/Sustainable-Energy-Transformation

⁸⁸ Presented by Paolo Bertoldi in November 2016.

⁸⁹ EU Code of Conduct for data centres presentations, November 2016.

consumption⁹⁰. The numbers for the EU presented by Yole Développement were thus observed underestimated. The estimates from Borderstep Institute and JRC were therefore used to interpolate the total EU data centre energy consumption up to 2020, and the growth in energy consumption after 2020 is assumed to slow down due to increasing efficiency of servers and storage equipment⁹¹.

The total EU data centres energy consumption was estimated from 2010 and projected up to 2030, reflecting the slower growth of energy consumption in the period of 2020 to 2030 (see Table 16). The energy consumption of the data centres in the EU can be compared with the US data consumption as estimated by Lawrence Berkeley National Laboratory⁹⁰. It can be seen in the table, that historically the US has had a larger data centre consumption, however due to the bloom of data centre sector in Europe as well as in the rest of world, the data centre energy consumption is increasing in Europe and surpassing the US level around 2015. Meanwhile the data centre development has slowed down in the US in the recent years. The US energy consumption made by Lawrence Berkeley National Laboratory was only predicted up to 2020, and therefore the comparison of energy consumption for the period of 2020 to 2030 was not possible. As seen in the table, the annual growth of energy consumption is expected to slow down from the current level.

Table 16. Estimated EU data centre energy consumption 2010 – 2030 compared with US data centre energy consumption.

	2010	2015	2020	2025	2030
Total EU DC energy consumption,	55	74	104	134	160
TWh/ year					
Annual growth, %	-	9%	6%	5%	3%
Total US DC energy consumption,	66	69	71	No	No
TWh/year				projection	projection

It can be concluded from the information presented above that the energy consumption of data centres in the EU is significant, with an annual electricity consumption of approx. 74 TWh in 2015. It is projected based on the historic trend and the increasing demand for data centre capacities and services, the annual energy consumption from data centres in the EU will increase to 160 TWh per year by 2030, considering the slowing down of growth of data centres capacity on the market. However, the actual energy consumption in 2020 – 2030 period could be substantially less than projected due to increase in energy efficiency of data centres.

7.2. Energy consumption per data centre type

Based on the total energy consumption in the EU, the consumption per data centre type was estimated (see Figure 13). This was done in order to identify the energy consumption by enterprise and colocation data centres in the EU, considering these are widely used by the public organisations as discussed in chapter 6. Furthermore,

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⁹⁰ US Data Center Energy Usage Report. Ernest Orlando Lawrence Berkeley National Laboratory. June 2016.

 $^{^{\}rm 91}$ In line to assumptions made at the ongoing ecodesign work on servers and storage.

since it is the understanding so far that MSP data centres are usually operated under more optimised conditions and thus bringing more opportunities for reducing energy consumption. The split projections by data centre type up to 2030 are done to identify the best practices due to the fact that each of the data centre types may have different ways of increasing their efficiency and thus reduce energy consumption.

The share of the energy use by MSP data centres is based on the ratio of electricity consumption of unbranded servers in relation to the total in the US, provided in the Lawrence Berkeley National Laboratory report. In this report, it is stated that unbranded servers are usually bought directly from the manufacturing companies that build servers (e.g. Quanta, Wistron and Foxconn) for use in hyperscale data centres. This share is used to calculate the MSP DC electricity consumption in Europe up to 2020, based on the total EU DC energy consumption presented in Table 16.

The colocation share is found using the ratio of colocation power demand and total data centre power needs based on power supply power demand presented in a CBRE market view report^{Error! Bookmark not defined.} and power demand shown in Figure 10 and Figure 12. In spite of the rapid growth the colocation market has observed in the last 10 years, its electricity consumption share in relation to the total EU DC energy consumption is still relatively small as shown in Figure 13.



Figure 12. Europe colocation supply and 2017 year-end projection as at Q1 201792.

Lastly, the share of enterprise data centres is estimated as the remainder after MSP and colocation data centres.

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⁹² CBRE Marketview. Europe Data Centres, Q1 2017.

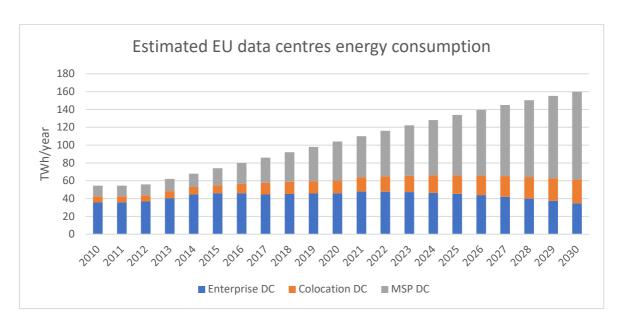


Figure 13. Estimated EU data centres energy consumptions divided by types.

Data centre energy consumption in the EU is historically estimated to be dominated by enterprise data centres according to the data available, up to 62% in 2015. However, the data also shows to be rapidly decreasing up to 2020, due to the shift to MSP assuming this development follows that of the US. Given the data, colocation data centres electricity consumption is also increasing but slower in comparison to MSP data centres. Table 17 shows the energy consumption by data centre type, including their share in relation to the total energy consumption of data centres in the EU.

Table 17. Projected Energy consumption and shares in % by data centre types.

Data centre type	2010	2015	2020	2025	2030
Enterprise DC, TWh/year	35.5	46.0	45.9	45.3	34.7
Enterprise DC % of all DC	65%	62%	44%	34%	22%
Colocation DC, TWh/year	7.0	8.9	14.3	20.7	26.5
Colocation DC % of all DC	13%	12%	14%	15%	17%
MSP DC, TWh/year	11.9	19.1	43.8	67.9	98.7
MSP DC % of all DC	22%	26%	42%	51%	62%

7.3. Data centre electricity consumption internal breakdown

Based on data available, it was possible to establish a breakdown of the share of electricity consumption by the IT equipment and the infrastructure (i.e. the mechanical and electrical systems). This breakdown was established for the whole EU, making possible to establish the significance of the IT, the cooling and the electricity supply systems at an EU level.

Establishing the significance of IT and infrastructure electricity consumption could help identifying where the largest savings could come from. Knowing that new data centres can already achieve a PUE of 1.3 or 1.2, this means that their infrastructure such as mechanical HVAC and electrical systems etc. consumes approx. 23% or 17% of the total data centre electricity consumption. From procurement point of view, the tender

criteria for data centre services could include a maximum PUE or energy consumption of infrastructure to facilitate the increase in energy efficiency of data centres.

The percentage of electricity consumption for the IT equipment was calculated from the percentage of IT and infrastructure in the US for period 2010 to 2020 estimated by the Lawrence Berkeley National Laboratory report. In the period of 2020 to 2030, this was calculated based on an interpolation considering a PUE factor of 1.5 in 2030. This PUE factor was estimated by EU impact assessment for servers and storage equipment as a moderate policy scenario. See Table 18 for the consumption by IT, such as servers, storage equipment and network equipment and consumption by the rest of data centres i.e. the infrastructure, including cooling, ventilation, UPS, etc., as well as the percentage share of the total data centre electricity consumption.

Table 18. Energy consumption and shares in % by data centre systems.

	2010	2015	2020	2025	2030
IT (servers, storage and	52%	57%	65%	66%	67%
network equipment etc.)					
Infrastructure (mechanical and	48%	43%	35%	34%	33%
electrical systems)					
Enterprise DC IT (TWh/year)	18.3	26.2	29.7	29.8	23.2
Enterprise DC infrastructure	17.2	19.8	16.1	15.5	11.6
(TWh/year)					
Colocation DC IT (TWh/year)	3.6	5.1	9.3	13.6	17.7
Colocation DC infrastructure	3.4	3.8	5.1	7.1	8.8
(TWh/year)					
MSP DC IT (TWh/year)	6.1	10.9	28.4	44.6	65.8
MSP DC infrastructure	5.8	8.2	15.4	23.3	32.9
(TWh/year)					
Total EU DC (TWh/year)	54.5	74.0	104.0	133.9	160.0

As seen in the table above, that IT and infrastructure (i.e. M&E) accounts each for nearly half of the total energy consumption of data centres, slightly more in IT. The improvement potential for data centres depends on the base case of the data centre, the type of the contract, and how the savings and costs are assigned to IT and M&E. However, as also seen in the trend that as the energy efficiency of data centres over the past years has improved, the M&E consumption share is declining and it is expected to continue, it can be concluded that the improvement in M&E is more achievable and less disruptive to technology and resilience and reliability.

Improvement strategies for M&E could include the use of efficient HVAC products, and more vitally better design and management of the infrastructure such as cooling system optimisation, use of free cooling, air flow management etc. These improvement strategies are very promising, as they can directly contribute to a lower PUE.

Nevertheless, the M&E consumption is indicated by the IT consumption, it is more important to improve the energy consumption by IT, however it is more complex. Better IT utilisation, such as consolidation or virtualisation could potentially improve

significantly the energy consumption, as it is assumed relatively poor currently. However, the use of efficient IT equipment is not very promising in terms of energy consumption improvement, because it highly depends on the suitability of the equipment to its end application and the operation of the IT equipment regardless of its efficiency level, an efficient product selected for an inappropriate task could still end up consuming more energy.

7.4. Quantity of data centres facilities

The number of data centres facilities was not possible to estimate at EU level. The only available data was for colocation data centres. However, this number cannot be used to estimate the data centres facilities for enterprise and managed service providers, since the diversity in size, utilisation and efficiency is quite high to be able to derive the number of facilities based on colocation facilities and energy consumption figures.

Figures for colocation facilities were found for 2016 (see Figure 14), showing that in 2016 there were 9540 colocation facilities in the world, and total number of colocation data centres in the EU-27 countries was found to be 1188, and 1220 if including Iceland and Norway⁹³ in the same year. Comparing the estimated energy consumption of 2016 for the for colocation data centres in the EU based on what presented in the previous section, the data show that 4.75 TWh were consumed in 2016.



Figure 14. Worldwide reported number of Colocation facilities94.

7.5. Relevance for public procurement

Considering information and data presented in chapter 6, the relevance of the electricity consumption overview presented in this chapter related to public procurement concerns mainly enterprise and colocation data centres. However, this is

⁹³ http://www.datacentermap.com/datacenters.html

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⁹⁴ http://www.datacenterdynamics.com/research/reports/worldwide-colocation-data-center-investment/96030.article

as of today. A possibility to shift towards managed service providers exists, although as discussed in chapter 7, legacy equipment will always exist and there may be issues to deal concerning data security when moving towards cloud services by public organisations. There exists a trend of shifting towards managed service providers in the private sector, but the public sector is more conservative. Therefore it is important to focus efforts, when developing GPP criteria, on the shift towards more efficient technologies and best practices in the public organisations, in particular for enterprise and colocation data centres. Furthermore, it is also important to investigate whether shifting towards MSP data centres could be another possibility for public organisations, as it is the apparent shift happening overall on the data centre market in the EU. The future share of the colocation market assumed in this chapter is somewhat conservative considering available data. But a possibility also exists that more public organisations shift towards colocation data centres, moving the responsibility to keep the facilities efficient from the client to the operator, who may have better knowledge on how to apply best practices.

8. Data Centres market volumes

Market volumes on data centre white space and estimated number of EU data centres have been provided by Data Center Dynamics⁹⁵. The data market data is broken down per data centre type according to the data centre classification shown in chapter 3. The estimated white space and number of data centres in the EU can be seen in Table 19 and Table 20.

The initial data was collected for data centre whitespace, and from that the number of data centres was derived. The data shows that most of the data centres in the EU are Enterprise (i.e. 96% of the total number of data centres in the EU). However, when looking only at data centre white space, colocation data centres are also important of the total white space in the EU (i.e. 57% of total white space for Enterprise and 40% for Colocation). These numbers show Enterprise data centres are much smaller than Colocation and MSP. The average white space for Enterprise is of 60 m2/data centre, while for Colocation is 1152 m2/data centre and for MSP is 1123 m2/data centre. Enterprise data centres exclude small server rooms as the criteria for establishing this quantification was to have an IT capacity equal or greater than 25 kW, have provision for power and environmental management separate from other areas and a dedicated building. However, Enterprise data centres include often legacy IT equipment according to information from data centre experts. Quantitative forecasts were not available, as according to experts issues on data centre definition, scope and nomenclature have prevented to establish future predictions. Although data centre experts assume that public organisations often have their own legacy products, but that the future is to expand, consolidate or build new IT projects outside their property boundaries. The preliminary conclusion is thus that Enterprise still represent a significant share of the present number of data centres operated by public organisations, but that the trend is to move towards more Colocation data centres and/or services. Concerning MSP, data centre experts have a conservative assumption that this type of data centre service may be still quite restricted at public level due to data security issues.

There is a general trend towards managed service providers in the private sector, but the public sector is more conservative so the amount of white space serving public authorities may still be greater within enterprise data centres. It is therefore important to focus efforts when developing GPP criteria, on the shift towards more efficient technologies and best practices for enterprise data centres.

With regards to cloud services, there are examples of public facing cloud services now being delivered by mega data centres dominated by large dedicated service providers who have the economies and scale and expertise to design, build and deliver services at higher efficiency and lower cost. It is expected that more public sector services will be delivered by larger and larger data centres, which may include managed services such as the cloud, although there is also counter pressure due to data security issues

⁹⁵ http://www.datacenterdynamics.com/

and public acceptance. Moreover, legacy equipment will always exist since some services are too sensitive, complex or expensive to decommission.

Table 19. EU total data centres in square meters – white space.

Market	Enterprise	Colocation	Managed Service
			Provider
Austria	52500	22100	2200
Belgium	61500	31900	3700
Bulgaria	32550	13700	1500
Croatia	19350	17500	1320
Cyprus	10800	11000	800
Czech Republic	31500	19200	1050
Denmark	36000	40300	3600
England	772500	474500	24000
Estonia	13200	8100	1000
Finland	48750	83200	8900
France	577500	305500	21000
Germany	825000	409500	27900
Greece	41250	29900	2600
Hungary	30900	31900	2400
Ireland	43500	188500	10300
Italy	201000	84500	5700
Latvia	30750	12800	300
Lithuania	50250	21000	2050
Luxembourg	15300	62400	5100
Malta	12900	11700	700
Netherlands	210000	351000	15800
Poland	70500	61100	2400
Portugal	33000	16900	1200
Romania	40500	17200	1200
Slovakia	34500	14600	640
Slovenia	15750	9700	700
Spain	270000	136500	14600
Sweden	48000	75400	8000
Total	3629250	2562000	170660
% of total	57%	40%	3%

Table 20. Estimated number of EU total data centre facilities Error! Bookmark not d efined..

Market	Enterprise	Colocation	Managed Service Provider
Austria	330	60	4
Belgium	345	65	6
Bulgaria	265	20	2
Croatia	160	15	1
Cyprus	90	15	0

Czech Republic	450	40	2
Denmark	680	40	5
England	11500	450	25
Estonia	135	10	1
Finland	220	35	4
France	8700	270	20
Germany	13200	410	30
Greece	330	20	2
Hungary	260	15	1
Ireland	350	40	2
Italy	6500	95	7
Latvia	160	20	0
Lithuania	220	10	0
Luxembourg	115	25	3
Malta	80	10	0
Netherlands	5600	250	15
Poland	1600	70	3
Portugal	275	25	2
Romania	650	30	2
Slovakia	260	15	0
Slovenia	140	10	0
Spain	6300	100	10
Sweden	1300	50	5
Total	60215	2215	152
% of total	96.2%	3.5%	0.3%

9. Technical state-of-play of data centres

9.1. Physical architecture and installation approaches

Data centre facilities may be categorised as one of the following building types:

- 1. Greenfield purpose built
- 2. Brownfield existing building fit-out e.g. conversion of warehouse, room within office space
- 3. Containerised, e.g. housed within a metal shipping container, typically 6 m or 12 m length.

The construction itself may be traditional 'bricks and mortar' or offsite prefabricated modular build, where the elements are joined together on site. Each option has its own merits and is chosen according to the specific project requirements.

Greenfield buildings typically have the highest capital cost and construction time, however this approach allows the building dimensions to be optimised for the facility's needs, for example, taller slab to slab height to better facilitate air flow for air side free cooling systems. A larger air flow area allows lower pressure drop, thereby reducing fan power requirements.

Any type of facility may employ a scalable, modular approach, where the installation is conceived in (usually independent) blocks, which are constructed and go live only in line with demand. The opposite of this is to build a large monolithic facility for the final design load; usually this gets filled up with IT equipment over a number of years (and never reaches its full design load). A modular approach allows costs to be spread / deferred and future phases to benefit from technology which may not be available at the start of the first phase. It also allows the systems to be better optimised for part loads. Power and legacy cooling systems operating at low load tend to have relatively high losses. Smaller module sizes can allow the systems to operate at more efficient, higher loadings for more of their lifetime and are easier to commission.

9.2. Mode of operation

Optimisation of software and applications management have a crucial role in determining how much energy a data centre requires to deliver its output.

Most IT equipment operate at very low loads. The Green Grid have several reports on this, nevertheless the average utilization is below 10%. This is because traditionally users tend to prefer their applications on different servers. When a server operates at around a 10% load, their energy consumption is typically above 50% (used to be 60-70%) of the full load condition, i.e. they have very poor scalability. This creates many servers operating at very low utilization and bad energy performance. It also creates the need for many more servers than necessary and therefore poor embodied environmental impact.

Virtualisation, utilisation and consolidation are all important factors which can significantly reduce the IT power requirements and CAPEX. This in turn has a knock on effect for the power and cooling systems.

Data centres may be optimised in operation, particularly when operating at part load. Legacy designs may not include a modular approach to provisioning power and cooling equipment for example, hence it may be appropriate to reconfigure plant for the actual operating load. For example if the UPS system has five modules and is designed to be N+1 (one spare), at low loads only one module may be needed to support the load and a further module to provide the spare. The additional modules could be offline, therefore increasing the loading of the live modules, allowing them to operate in a more efficient range with reduced losses.

However, for mechanical systems, operating at part loads may be more efficient. Fans for example, follow the affinity laws where the requirement of mechanical power varies with the cube of the speed (which may or may not affect the demand of electrical power depending on the design of the product). This means that for a given total airflow, operating more fans at a slower speed uses less energy than operating fewer fans at a faster speed, depending on the efficiency curve of the fans. Application of this principle allows operators to reduce their cooling energy requirements. This solution is also more reliable as the redundant fans are already live; failure of one fan does not require a changeover, only that the remaining fans ramp up their speed.

Low energy new designs incorporate free cooling, by taking advantage of higher operating temperatures and optimisation of data hall air segregation (for air cooled IT equipment) and providing compressor-free cooling. In many climates it is possible to design cooling systems without refrigeration systems, giving reduced capital cost, embodied impact, maintenance and energy costs.

Where a free cooling system exists this may only operate at lower ambient temperatures, often due to undersizing of plant and poor air management. Optimisation is possible to ensure the number of free cooling hours is maximised.

Many facilities may not benefit from an optimised mode of operation due to a lack of knowledge transfer between the designer, contractor and operator, which may be due to contractual limitations. Designs do not always cater for part load operation and operators often do not often have a clear understanding of the design intent or the skills to analyse and challenge this.

9.3. Management

In most facilities the team which manages the IT services (software & hardware of servers, network and storage, cabling etc.) is separate to that which manages the facility systems (power, cooling, fire alarm, physical security, etc.). Although both influence the same environment, their responsibilities, backgrounds and experience are different and they usually report through different departments in the business. This creates challenges when collaboration is required to achieve energy savings, for example.

In colocation facilities, the IT services are managed by the external client or managed services provider, whereas the facilities services are managed by the "colo" (i.e. colocation) business. Hence colocation providers have a very limited influence over IT systems.

The operational team may be direct employees of the owner operator or an outsourced team with a contract which is tendered on a three – five year basis for example.

Although all stakeholders have a role in supporting the data centre, not all stakeholders may be incentivised to reduce energy consumption, operating cost or improve sustainability. Energy costs are not always visible to the individuals who are able to influence consumption, e.g. those who procure hardware. Often outsourced maintenance providers find it more profitable to employ a strategy of plant replacement rather than optimisation. This means that there are often energy efficiency opportunities achievable through optimisation of existing systems which are not exploited.

Where colocation companies charge customers for their energy consumption with a mark-up, lower customer energy consumption impacts profitability. However, reducing facility energy consumption allows operational overheads to be reduced and improves profitability and competitiveness. Also, customers may consider environmental performance when choosing one provider over another.

9.4. End-of-life practices

According to one of the studies presented in chapter 7⁹⁶, end of life scenarios of enterprise servers are not usually described in detail in LCA studies, as most concentrate on defining the life cycle stages with the greatest impact which are the use stage and the manufacturing stage. This is undermining the fact that this life cycle stage can significantly contribute to reduce the overall environmental impacts. Typically, IT manufacturers do not report on end of life practices, so based on own expertise and experience on the data centre industry, it is observed that IT hardware is refreshed at varying rates depending on the business requirements. IT hardware follows Moore's law: trend of increasing performance, and Koomey's law: trend of improving energy efficiency. Hence businesses may derive a benefit from replacing older hardware with newer devices which have higher performance for a given power consumption. This is particularly significant for enterprises such as banking where speed of performance allows a competitive advantage.

According to JRC⁹⁶, since enterprise servers are Business to Business (B2B), a large number of the equipment are managed by OEMs all the way until their end of life rarely reaching recycling facilities and mostly having reusable parts harvested and tested for their possible reuse for second-hand equipment before the rest of the server parts reach the waste treatment sites. Based on experience with industry, it is seen that servers which are refreshed may be redeployed for less critical applications or sold second hand to other businesses, particularly in less developed markets. This allows consumers of secondary-market products to purchase hardware at a much lower cost than new, often with a short lead time. Some resellers report that companies purchase secondary-market products to keep as spares which are stored on site. They report that some end users may also choose to add / replace an older

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⁹⁶ Environmental Footprint and Material Efficiency Support for product policy - Analysis of material efficiency requirements of enterprise servers. EC JRC Science & Policy Report, Perio & Ardente (September 2015)

device rather than pay the additional cost of a new device with the associated business disruptions and knowledge gap when upgrading. Secondary market buyers often sell back the equipment they are replacing. Warranties are available for second-hand equipment, however resellers operate outside of the established OEM sales channels and don't have a formal relationship with manufacturers, which can make support problematic. Resellers may not provide software updates as standard which come with normal manufacturer maintenance.

Servers high metal content also means they have a scrap value. Furthermore, OEMs are aware of the economic value of their products even when they are technologically obsolete or no longer function. Therefore, most OEMs have developed their own EoL policies to optimise the reuse and recycling of components, and to prevent the remanufacturing of new parts, thus helping to save natural resources and reduce waste generation.

A DIGITALEUROPE survey from 2014 found that globally roughly 118,000 tons of IT equipment and spare-parts is shipped cross-border annually for OEM repair and remanufacturing; roughly 28,000 tons in Europe. An estimated 70% or more of this volume is repair of nonprofessional (B2C) products and 40% are 'out of warranty' repairs.

Bitkom's Product Reuse European Working Group⁹⁷ came to the conclusion that the remanufacturing/refurbishment business in the EU for IT has a turnover of \$6.9bn (includes printer cartridges). UNEDA (United Network Equipment Dealers Association) representatives estimated the networking equipment portion of the secondary market at about \$2 billion worldwide in 2007.

WEEE regulations mean that manufacturers must provide take-back schemes. However, the general comment in the market is that there is market for reuse and recycling and old servers have a resale value (most are used an estimated two to four times), in practice a very small proportion returns to the manufacturers for disposal.

From market sources who specialise in refurbishing and recycling IT hardware used in data centres reported a 90% and 10% split between refurbishment and recycling, with hardware between two to three years old being ideal for refurbishment. It is still economically viable to refurbish three to four year old equipment but the value is less.

Power and cooling products also contain a high proportional of metal content which has a recovery value. However, the components that are most frequently reused are not necessarily those greater in terms of mass as it has been shown by a study done by $JRC.^{98}$

research-reports/environmental-footprint-and-material-efficiency-support-product-policy-analysis-material

 ⁹⁷ https://www.bitkom.org/Bitkom/Organisation/Gremien/Product-Reuse-European-Working-Group.html
 98 JRC Science and policy report. Environmental footprint and material efficiency support for product policy.
 Analysis of material efficiency requirements of enterprise servers. Laura Talens Peiro and Fulvio Ardente.
 September 2015.Can be accessed via https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-

9.5. Primary and secondary energy demand

Data centre energy consumption is principally electricity, which is in most cases provided from the national electricity grid and hence has an associated environmental impact.

Electricity generation tends to be more efficient on a larger scale, thus although local generation is possible, this may be less favourable in terms of cost and environmental impact. Dedicated (small scale) Combined Heat and Power plants are not well suited to this application when compared with well-designed free cooling systems, which are simpler and have a reduced environmental impact and operating cost.

Purchasing renewable energy is usually more practical than installing local renewable generation.

Most data centres also have diesel fuelled emergency generation for when grid power is not available. In many locations, grid power outages are rare, however the generators may be tested on a regular basis to ensure their availability in the event of a mains failure. In any event, most facilities are diesel powered for a relatively small number of hours in the year (diesel also has a relatively high cost). Operating on generators has a higher environmental impact than using grid mains because of the higher embodied impact from using only fossil fuels like diesel to power the generators.

In the UK, generator emissions are subject to EU ETS legislation aimed at large emitters i.e. those who burn fuels like oil, gas, coal, etc. Large facilities, with standby capacity of around 7 MVA and above, are captured although they have negligible scope 1 emissions and are not the intended target of the legislation. The UK interpretation of the Directive states that standby generation is included in EUETS if a) units of 3 MW thermal and above add up to 20 MW and b) it is technically capable of being operated simultaneously with the main power supply. Facilities which the legislation applies to may have to pay up to £1,000 in EU ETS allowances in addition to a much high compliance cost for administration (reported at up to 100 times the cost of allowances). There are concerns that this may cause negative environmental impacts because:

- It discourages the consolidation of computing resource into large purpose built facilities and instead encourages a less efficient distributed model where energy use is usually far less transparent or accountable.
- A company may avoid EU ETS by replacing few large generators with many small, generators.
- It discourages data centres from participating in STOR or other demand response programmes that allow periods where peak demand exceeds supply to be managed without having to invest in additional generating capacity on the grid

9.6. Material resources

Data centre life cycle assessment (LCA) has identified that the embodied impact of IT equipment and that of mechanical and electrical (M&E) equipment has a significant environmental impact. The embodied impact of the building itself is two to three

orders of magnitude smaller (i.e. less than 1% of that of IT and M&E equipment); this differs from other commercial building uses such as offices which have far lower energy densities.

As concluded in chapter 7 from the review of LCA studies, the contribution to the embodied environmental impacts from manufacturing is mostly originating from servers and storage units, although this is based on the very few studies that analysed the contribution from network equipment. Whiteheadl⁹⁹ found a significant impact from the disposal of metal refining waste products during the manufacture of IT components and electricity distribution networks. Sulphidic tailings are a by-product of the mining and refining of gold and copper used to manufacture printed wiring boards, which can (in aerobic conditions) oxidise to an acid and dissolve metals from the tailings material. The disposal of tailings results in intensive land use, and if they are not disposed of responsibly, can leach into surrounding water and soil, releasing carcinogens (waterborne arsenic and cadmium and emissions to air of carbon dioxide, nitrogen oxides, PM-2.5 and sulphur dioxide). The use of gold and copper, and the complex disposal of their waste, therefore represents a significant environmental concern.

Other metals such as steel and iron are also environmental impact hotspots. Phthalates and halogen-containing materials—including brominated flame retardants (BFRs), chlorinated flame retardants (CFRs), and polyvinyl chloride (PVC) have been identified as substances of concern in IT products.

LCA is often applied to product design, however there is limited data available for IT hardware and power and cooling equipment. LCA data available for server and storage equipment is seldom available; perhaps because it is rarely a requirement in tender requests. LCAs which examine carbon only for consumer IT products, e.g. PCs and printers, indicate that 97.5% of emissions are during the operational phase, with 2.5% during the embodied phase. Full LCAs typically show 80% of impacts in operational phase versus 20% in the embodied phase, however it is much closer to a 50:50 operational versus embodied split when renewable sources of energy are used in operation. The LCA study done by JRC of enterprise servers shows a ratio of 84:16 use vs. manufacturing for primary energy demand and of 77:23 for global warming potential (excluding biogenic carbon) under average disposal conditions in the EU and using an grid electricity with average emissions in operation¹⁰⁰.

With an increased awareness of impacts from material and manufacturing, designs can be developed which reduce or eliminate the amounts of hotspot items. Currently, it is not possible to compare two brands of server due to lack of data available (which would need to be assessed on same basis/with the same data and methodology). It is

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⁹⁹ Whitehead B, Andrews D, Shah A, The life cycle assessment of a UK data centre, The international journal of life cycle assessment, 2015.

¹⁰⁰ JRC Science and policy report. Environmental footprint and material efficiency support for product policy. Analysis of material efficiency requirements of enterprise servers. Laura Talens Peiro and Fulvio Ardente. September 2015. Can be accessed via https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/environmental-footprint-and-material-efficiency-support-product-policy-analysis-material

thought that there is reluctance by manufacturers to share information, which may expose them to a commercial risk. However, it is notable that other industries, such as the food, metals, chemical and construction material industries, have successfully applied LCA.

9.7. Space requirements

As mentioned previously, greenfield builds usually have a larger footprint and the flexibility to increase the plant room space for a given load density. The height of each floor is usually 1.5-2.0 times more than a standard storey. As a general principle, cooling systems use less energy with larger heat exchange areas (evaporators, condensers, cooling towers, plate heat exchangers, air to air cross flow or counter flow heat exchangers).

Best practice low energy designs using (direct or indirect) air side free cooling, require large Air Handling Units (AHUs) to move air into to the data hall for cooling IT equipment. This type of layout is difficult to achieve with an existing building. Some zero refrigeration designs use water cooling (with cooling towers), again the layout for plant and pipework distribution is easier with a new build.

For brownfield facilities, space restrictions often limit the choice of cooling system, and chilled water is used instead of air to transfer heat outside of the building. This requires another heat exchange process (to reject heat from the water) which thus has additional energy losses. Cooling towers or dry coolers allow compressor free cooling, however in many cases chillers are used which are less-efficient but occupy less space.

With an optimised cooling design and good air management, relatively high IT equipment load densities can be supported with air cooling. However, for very high load densities, for example those used in High Performance Computing (HPC), bespoke rack liquid cooling is often used. The liquid may be water, and is in some cases directly plumbed to the IT hardware; other solutions use immersion cooling with oil. These solutions do not necessarily have a lower environmental impact; it depends on the operating temperatures and system used to provide cooling; the same best practice principles apply.

9.8. Durability, repairability and reusability aspects

As mentioned in section 9.4, servers are typically refreshed every 2-5 years¹⁰¹ depending on the business requirements and 5- 7 years for data storage products. A shorter refresh time results in a higher embodied impact, however this is offset (not necessarily 100%) by the improved performance of the newer and more efficient IT hardware. More detailed analysis is needed to optimise the refresh time with respect to environmental performance.

According to JRC⁹⁶, obtaining data on failure rates of specific components of enterprise servers and storage units is difficult as data is mostly proprietary. They, however,

¹⁰¹ Roadmap for Datacom Cooling, ASHRAE Journal, Vol. 47, No. 12, December 2005.

found data on servers refurbishing from a UK company¹⁰² showing that the spare parts most frequently replaced are HDDs and Solid State Disk (SSD, shown by JRC as 'memory card') (up to 88% of the times when reusing a server), and in minor extent the CPU and the motherboard (up to 8% of the times). See Figure 15.

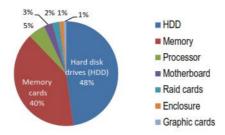


Figure 15. Spare parts most frequently replaced in servers (from JRC report, UK figures¹⁰²).

Product lifetime can be extended through reuse, repair, refurbishment and remanufacturing – hence avoiding premature wastage. Manufacturers may prioritise durability over repairability, i.e. designed not to be repaired, therefore difficult to diagnose fault, access components, obtain spares etc. Manufacturers may provide repair services (extended warranty) and in some cases offer a leasing model, i.e. purchase the ability to operate a product to deliver an output rather than the product itself. For mission critical applications, users tend to choose the option with the least perceived risk; this often means purchasing new high-specification equipment, maintaining it and replacing it before end of life. The additional cost of these choices is offset against the high cost of downtime.

According to JRC, the main limitations for reusing servers apart from their obsolescence are the lack of availability of firmware updates, which are updates to a set of micro-instructions that activate hardware functions in the server and that are designed by OEMs, and of data deletion for storage units such as the HDDs and the Solid State Disk (SSD, shown by JRC as 'memory card'). By requiring the OEMs to make these available at the product design level, the servers lifetime could be prolonged either by updating firmware or by replacing key components.

JRC has developed reusability benefit rates of enterprise servers for parts that are frequently reused (i.e. hard disk drive, Solid State Drive (SSD, shown by JRC as 'memory card'), CPU, main board, RAID card, chassis, expansion card/graphic card, internal power supply)¹⁰³. These rates consider the benefits of reusing these parts over the manufacturing and operational impacts across 15 different environmental impacts. The benefit rates vary between 6.7% (fresh water consumption) to 41.5% (human toxicity cancer). For primary energy demand of fossil fuels the benefit rate is 7.7% and for global warming potential excluding biogenic carbon this is 11.2%. These

¹⁰² http://www.re-tek.co.uk/

¹⁰³ EC JRC Science & Policy Report, Environmental Footprint and Material Efficiency Support for product policy, Analysis of material efficiency requirements of enterprise servers, Laura Talens Peiró, Fulvio Ardente, September 2015

rates were derived assuming environmental impacts from EU average electricity grid and end-of-life conditions, and they show still the relatively low benefit of reusing the most common parts of enterprise servers in the EU market.

The facility itself may be designed for a 15-25 year life, with (mechanical) plant items perhaps being refreshed once in this period. The maintenance regime reflects the mission critical nature of the application, with M&E assets looked after in order to ensure their continued reliability and performance. Due to the pace of IT hardware change, at the end of its life, the facility may have seen seven generations of IT equipment. It is difficult to predict the requirements of IT hardware even one generation ahead and a challenge to design a facility for unknown future needs.

Again, a modular design approach allows greater flexibility in this respect.

9.9. Key performance indicators (KPIs)

The design redundancy of a facility's power and cooling infrastructure is usually described by its tier level; many facilities have redundant plant and systems (for example Uptime tier 2-3, see section 2.3.7 for details).

Energy efficiency of the facility (but not the IT equipment) may be measured using PUE (power usage effectiveness), the annual ratio of total facility energy to IT energy. Although this was never conceived as a metric to compare facilities, it is frequently cited in marketing literature to demonstrate energy efficient operation or 'green' design. PUE can be a useful tool when used correctly, with caution exercised around how and where it is measured and analysis of its range.

Other KPIs are used by some operators often to describe environmental performance, such as CUE (carbon usage effectiveness) or WUE (water usage effectiveness).

EN 50600-4-X documents specify requirements and recommendations for key performance indicators (KPIs) used to assess and improve the resource usage efficiency and effectiveness, respectively, of a data centre. These currently include PUE (EN 50600-4-2:2016) and Renewable Energy Factor or REF (EN 50600-4-3:2016), which provides a quantitative metric for the use of renewable energy, in the form of electricity, in a data centre.

A Global Taskforce has been formed to agree on standard approaches and reporting conventions for key energy efficiency and GHG emission metrics for data centres. Members are: the U.S. Department of Energy's Save Energy Now and Federal Energy Management Programs (March 2009 – October 2012); the U.S. Environmental Protection Agency's ENERGY STAR Program; the European Commission Joint Research Centre Data Centres Code of Conduct; Japan's Ministry of Economy, Trade and Industry; Japan's Green IT Promotion Council; and The Green Grid Association.

The taskforce has reached agreement on measurement guidelines for PUE, green energy coefficient (GEC), energy reuse factor (ERF), and carbon usage effectiveness (CUE) and that data centres begin to define attributes and measure data centre energy productivity (DCeP). DCeP is defined as Useful Work Produced / Total Data Center Source Energy Consumed producing this work. Each user defines what useful work constitutes for their own business so they will have a custom metric which is

meaningful to them (but difficult to compare across facilities). The challenges in defining and measuring useful work means that uptake of DCeP is limited.

In order to make decisions based on lifecycle impact, analysis which incorporates suitable metrics is needed. This allows the relative impact of embodied and operational phases to be understood and trade-offs to be considered. Some life cycle assessment (LCA) work on data centres has been completed, this is examined in more detail in Chapter 8.

9.10. Overview of metrics

Table 21 provides an overview of main, relevant metrics, mostly relating to the energy use in operation, published by various standards institutions and industry bodies. Note that metrics for subsystems, such as Coefficient of Performance for refrigeration systems, are excluded.

Table 21. Overview of metrics.

Metric	ISO	CENELEC	ETSI	Green Grid
Power Usage Effectiveness (PUE) Ratio of total energy and IT energy (measure of power and cooling efficiency)	ISO/IEC 30134:2016 Part 2: Power usage effectiveness (PUE)	EN 50600-4-2:2016 Part 4-2: Power Usage Effectiveness	ETSI ES 205 200-2-1 V1.2.1	The Green Grid White Paper 49 – PUE – A Comprehensive Examination of the metric
Renewable Energy Factor (REF)	ISO/IEC 30134:2016 Part 3: Renewable energy factor (REF)	EN 50600-4-3:2016 Part 4-3: Renewable Energy Factor	ETSI ES 205 200-2-1 V1.2.1	
Energy Reuse Factor (ERF)	ISO/IEC 30134:2016 Part 6: Energy Reuse Factor		ETSI ES 205 200-2-1 V1.2.1	
Water Usage Effectiveness (WUE)				The Green Grid White Paper 35 – WUE – Usage Guidelines
Carbon Usage Effectiveness (CUE)				The Green Grid White Paper 32 – CUE – Usage Guidelines
IT equipment efficiency (ITEE)	ISO/IEC 30134:2016 Part 4 (under development): IT Equipment Energy Efficiency for servers (ITEEsv)			
IT equipment utilization (ITEU)	ISO/IEC 30134:2016 Part 5 (under development): IT equipment utilization for servers (ITEUsv)			

Metric	ISO	CENELEC	ETSI	Green Grid
Proxy #1 - Useful Work Self-Assessment And Reporting Proxy #2 - Dcep Subset By Productivity Link Proxy #3 - Dcep Subset By Sample Workload Proxy #4 - Bits Per Kilowatt-Hour Proxy #5 - Weighted Cpu Utilization - Specint_Rate Proxy #6 - Weighted Cpu Utilization - Specpower Proxy #7 - Compute Units Per Second Trend Curve Proxy #8 - Operating System Workload Efficiency		CENTELEC		The Green Grid White Paper 17 – Green Grid Proxies
KPIEM Global Key Performance Indicator of energy management			ETSI ES 205 200-2-1 V1.2.1	

10. Life Cycle Costs structure of data centres

Typically, life cycle costs of products are the sum of the acquisition costs, running costs (i.e. operational/maintenance/repair costs) and end-of-life costs. However, for data centres an additional step is generally included between OPEX and end of life - decommissioning¹⁰⁴. CAPEX refers to the purchase and installation of the IT, mechanical and electrical equipment in the building, together with the building infrastructure. OPEX refers to the running costs, decommissioning refers to switching down the facility once it reaches its end of life, and the end-of-life costs are related to disposal, recycling and WEEE treatment.

This chapter's focus is on establishing an overview of the relative costs ranges between the different data centre types, as well as differences between CAPEX-OPEX-Decommissioning-End-of-life. Furthermore, according to input from experts the IT costs differ to those for the rest of the equipment (mechanical and electrical) and the building infrastructure, so this overview has been split into IT and facilities (see Table 22). Finally, we have attempted to establish differences between the costs for data centre owners and those to customers, since those for customers, especially concerning colocation and managed service provider data centres, are expected to be different. This assessment has been done qualitatively as a starting point, with the aim to understand the data centres' life cycle costs structure. A quantitative analysis will be carried out in task 4, in order to determine the additional expected costs from potential GPP criteria.

Table 22. Overview of main Life Cycle Costs for data centres owners and customers.

Cost category	Cost range for DC owners			Cost for DC customers		
	Enterprise	Colocation	MSP	Enterprise	Colocation	MSP
CAPEX facilities	Medium	High	Medium	Medium	Low	Zero
CAPEX IT	Medium- High	Low	Medium- High	Medium- High	Medium- High	Zero
OPEX facilities	Medium	Medium- High	Medium	Medium	Medium	High
OPEX IT	Medium	Low- Medium	Medium	Medium	Medium- High	High
Decommissioning	Low- Medium	Low	Low	Low- Medium	Low	Zero
Facilities end of Life	Low	Low	Low	Low	N/A	N/A

From the data centre owner's perspective, CAPEX of purchasing and building facilities is medium to high and this is universal for all data centre types. The CAPEX for purchasing IT hardware, including installation and testing, is medium to high for enterprise and MSP data centre owners, as they could be purchasing mainframe servers and more specialised servers customised for their applications, depending on the services the data centre should provide. At the same time, the requirement for

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¹⁰⁴ Input provided by industry experts during interviews in July 2017

resilience for colocation data centres is often high and therefore much more expensive facilities are needed. CAPEX for IT would be lower for colocation data centres

Table 23. Life Cycle Costs of data centres owners.

Cost category	Type of costs	Cost range			
,	17,000	Enterprise	Colocation	MSP/Cloud	
CAPEX	Facilities purchase	High	High	High	
	IT hardware purchase	High	High	Low - medium	
	Installation and testing of IT hardware and services	Low	Low	Low	
	Facility building services (HVAC etc.)	Medium	Medium	Medium	
	Redundancy and designing for resilience (UPS etc.)	Medium	High	Low	
	Licensing (one-off)	Low	Low	Low	
	Backup generators and data security	High	High	High	
	Renovation of facilities	Medium to high	Medium	Medium	
	Refreshing IT hardware	Medium	Medium	High	
OPEX	Staffing costs (training, salaries, etc.)	Medium	Medium	Low	
	Cost of failure compensation (downtime, service disruption)	Low	High	High	
	Operation of facilities	Medium	Medium	Low- medium	
	Operation of IT hardware	High	High	Low- medium	
	Energy consumption	Medium - High	High	Low – medium	
	Maintenance	High	High	Medium	
	Licensing (annual)	Low – medium	Low	Low	
	Estate rental cost	Medium	Medium	Medium	
	Network access	Low	High	High	
Decommissioning	Uninstallation, decommissioning services Data deletion	High	Low - Medium	Low - Medium	
Facility End of Life	Recovery of materials Decommission of building Recovery of materials Disposal of materials	High	N/A	N/A	

OPEX for facilities in enterprise and colocation data centres is similar, but there is a margin of 7- 12% to be obtained by colocation data centres by charging it to the customers¹⁰⁵. OPEX for IT in enterprise and colocation data centres is similarly high, due to the lack of standardisation and uniformity of servers.

OPEX for facilities and IT in MSP or cloud data centres is significantly lower, due to the standardisation of servers, automation of the IT services, and less physical labour is required. Also, the uniformity of servers enables easier implementation of best practice, therefore operation phase is more efficient and the energy consumption is also lower.

Decommissioning is high for enterprise, but lower for colocation owners because the clients are mostly responsible for the decommissioning of their IT. Decommissioning is also lower for MSP data centres- as the IT hardware is more standardised, it is easier and cheaper to uninstall and decommission, as racks and cablings can be reused, only servers themselves are changed.

Facilities end of life is high for enterprise as it involves the decommissioning of the data centre building. However, it is less relevant for colocation and MSP data centres; because they are usually designed for data centres, they will be upgraded or transferred to a different ownership but the building is not decommissioned until the design lifetime of the building is reached, in principal a century later. At this point the final decommission cost of the building would be high.

From data centre customers' perspective, see Table 24, enterprise data centre has the same LCC as for data centre owners. For colocation customers, the CAPEX of IT is high, rather than CAPEX of facilities which is almost zero, as they purchase their own IT hardware and data centre provide the facilities. OPEX of facilities is rather high because of the margin data centre charge to the customer, where the OPEX for IT is slightly lower than they are being managed by colocation data centre, they mainly pay for energy consumption and a fixed fee for maintenance. Decommission of IT hardware is the same as enterprise data centre.

Table 24. Life Cycle Costs of data centres customers.

Cost category	Type of costs	Cost range			
		Enterprise	Colocation	MSP/Cloud	
CAPEX	Facilities purchase	High	Zero-low	Zero	
	IT hardware purchase	High	High	Zero	
	Installation and testing of IT hardware and services	Low	Low	Zero	
	Facility building services (HVAC etc.)	Medium	Zero-low	Zero	
	Redundancy and designing for resilience (UPS etc.)	Medium	Zero-low	Zero	

¹⁰⁵ Interview with industry expert, July 2017.

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Cost category	Type of costs	Cost range		
		Enterprise	Colocation	MSP/Cloud
	Licensing (one-off)	Low	Low	Zero
I I	Backup generators and data security	High	Zero – Iow	Zero
	Renovation of facilities	Medium to high	Zero – Iow	Zero
	Refreshing IT hardware	Medium	Medium	Zero
	Staffing costs (training, salaries, etc.)	Medium	Zero	Zero
	Cost of failure compensation (downtime, service disruption)	Low	High	High
	Operation of facilities	Medium	High	High
I I	Operation of IT hardware	High	Medium	High
	Energy consumption	Medium - High	High	Low – medium
	Maintenance	High	High	Medium
	Licensing (annual)	Low – medium	Low	Low
	Estate rental cost	Medium	Zero	Zero
	Network access	Low	Zero	Zero
	Uninstallation, decommissioning services Data deletion	High	Low - Medium	Zero
I	Recovery of materials			
Facilities end of life	Decommission of building Recovery of materials	High	N/A	N/A
_	Disposal of materials			

MSP data centre customers pay zero costs for CAPEX, as they do not own any facilities or IT hardware, they only pay fixed fees for the services, which means that their OPEX for facilities and IT are much higher, as they could be charged by hour or minute or per GB memory, these OPEX costs can add up to a number times higher than the OPEX of colocation customers. As for CAPEX, the customers pay nothing for the decommissioning as they have no ownership of facilities and hardware.

CAPEX, the capital expenditure for enterprise data centres includes purchasing the facilities and equipment, installation of the equipment, services and testing services associated with the equipment. Part of the reliability cost is also included in the CAPEX, such as redundancy, designing for more resilience which implies higher investment cost for more equipment and the design services associated with it. Colocation data centres have often high cost in the CAPEX due to the high redundancy and resilience level, often colocation data centres can provide up to Tier 4 level (see Table 5 for details of what this means).

According to BSRIA 106 the CAPEX of the building services installation costs for data centres, regardless of types, is around 8300 BGP/ m^2 (ca. 9400 EUR/ m^2). 62% of the costs goes to electrical installations and 17% goes to space heating, cooling and air treatment.

High redundancy and resilience often means high CAPEX for data centre owners, as there are many more back-up servers, UPS and generators as well as better system design would be needed. Redundancy and resilience is usually the lowest in MSP and cloud data centres, as they mostly purchase standardised servers for the similar applications used by the mass population, extreme high level of redundancy and resilience is not necessary. However, depending on customers' needs, cloud and MSP data centres can also deliver high redundancy. Enterprise is also lower than colocation as it depends on the solution chosen, but colocation data centres provide high resilience and redundancy to build customers' trust in their facilities.

The cost of refreshing IT hardware is high for MSP date centres - the cost per server is low, but they rotate twice as fast as enterprise or colocation data centres, therefore this part of the CAPEX is high for MSP.

The OPEX of facilities for enterprise data centres can be a factor of 3 - 6 times higher than the initial investment in facilities in a period of 20 years, however the OPEX for IT hardware can easily be almost 10 million euros for 300 - 500 m² data centre if mainframe servers are involved. An average enterprise data centre currently could have an annual operating cost of 14,000 euros per server¹⁰⁷, this can be used as a benchmark.

The LCC for enterprise data centres customers is the same as for owners, because the same organisation usually owns and operates it.

The costs of colocation data centres services vary depending on the geographic location; this could be due to the climate, electricity prices and/or real estate value. The cost for consumer is generally charged as a cost per m² floor area occupied, cost per kW or cost per kWh energy consumption. A fixed reliability fee may be added to ensure resilience. The cost of hosting a rack of server in colocation data centre is around 14,650 euros¹08; this is higher than the annual operating cost of one server in a typical enterprise data centre.

The LCC is different for the enterprise, colocation and MSP or cloud data centres, furthermore it is also different for owners and customers when it comes to colocation and MSP data centres. The CAPEX is usually very high for data centre owners, especially for data centres that are highly specialised, customised and provide high resilience and redundancy. The OPEX is much higher for customers who rent facilities or purchase only services. The decommissioning costs of IT hardware is lowest in MSP data centres for customers, and the end of life of facilities is not applicable for

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¹⁰⁶ BSRIA Rules of Thumb 5th ed, page 78.

¹⁰⁷ ICLEI, Interview with data centre expert, July 2017.

¹⁰⁸ Interview with industry expert, July 2014.

customers of colocation and MSP data centres. It can be concluded from the customer's point of view that colocation and MSP data centre solution are the cheaper options when compared to enterprise data centres, as in enterprise data centres, there are more types of costs to bear in a life cycle than colocation and MSP data centres.

Based on the information presented, overall quantitative ranges for the three data centre types in scope can be established, both for data centre owners and for data centre customers (see Table 25).

Table 25. Overview of Life Cycle Cost ranges for data centres owners and customers.

Cost category	Cost range for DC owners			Cost for DC customers		
	Enterprise	Colocation	MSP	Enterprise	Colocation	MSP
CAPEX facilities	15-20%	40-50%	15-20%	15-20%	1-5%	0%
CAPEX IT	30-40%	1-10%	30-40%	30-40%	35-45%	0%
OPEX facilities	10-15%	35-45%	10-15%	10-15%	15-20%	35-50%
OPEX IT	25-35%	1-10%	25-35%	25-35%	30-40%	50-70%
Decommissioning	5-10%	1-5%	1-5%	5-10%	1-5%	0%
Facilities end of Life	1-5%	1-2%	1-2%	1-5%	N/A	N/A

11. Main outcomes from stakeholders' survey in relation to proposed criteria

11.1 Questionnaire feedback analysis – stakeholders involvement in environmental initiatives

As of 27 April 2017, which was the end of the survey period, we had received 52 responses. The distribution of responses by organisation type is shown in Table 26.

Table 26. Number of responses by organisation type.

Number	Organisation type
13	Consultant and/or research institution
1	Laboratory testing organisation
8	Manufacturer of IT products for the data centres (e.g. servers, network, storage, cabling)
3	Manufacturer of the electrical system of the data centres (e.g. UPS, transformers, generators, lights)
4	Manufacturer of the mechanical system of the data centres (e.g. compressors, fans, pumps)
6	Non-governmental organisation (NGO)
4	Public procurer from a local, regional, national or continental authority
11	Supplier of services for data centres (e.g. colocation services, managed service providers, operators, maintenance providers, building contractors)
2	Trade associations and professional bodies

Of the 13 organisation classifications in the survey four types had no respondents:

- Decommissioning services
- Environmental labelling scheme
- Market surveillance authority
- Policy maker at a Member State level or representing the European Union

From these organisations, 37 said they are or have been involved in environmental initiatives, which in many cases were related to the EU Code of Conduct, development of sustainability criteria such as The Blue Angel, ENERGY STAR, EPEAT and EMAS sectoral reference documents on IT equipment, development of the EN 50600 series standard and implementation of energy reduction programmes. (Seven of them said they were involved in sustainability initiatives more related to circular economy, life cycle assessment methodologies for IT products and decommissioning and disposal). Most of these organisations measure the benefits of these initiatives as energy savings from more efficient technologies, with only one looking at embodied energy savings. Some provided estimates of the costs of these initiatives with values varying from 300,000 EUR to 1.5 million EUR. In some cases, the energy savings have exceeded the costs.

Of the four public procurers participating in the survey, two said they had used environmental criteria in their procurement processes. These were mostly related to changes in product design to achieve higher efficiencies, but it is unclear how they

have integrated this in their procurement tasks. However, another 25 organisations use or have used legislative and/or voluntary schemes to label or purchase data centre products and services. The most popular is the EU Code of Conduct, while a few respondents reported using ENERGY STAR, The Blue Angel and Green Grid's maturity models. For more details on stakeholders' involvement in environmental initiatives, see Table 27

11.2 Stakeholders' opinion on proposed scope and definitions

44 respondents gave an opinion when on the proposed scope and definitions (see chapter 3). 35 agreed with what was proposed, but a couple suggested: separate categories for size (small/large) and physical location (climate) of the facility. A further suggestion was to harmonise with the work of CENELEC TC 215, which is expected to implement the Green Maturity Model as a European standard. Of the nine respondents who did not agree, most of them suggested using the definitions in the EN 50600 series standards. The full responses to these questions are given in Table 32 and Table 33.

11.3 Approaches to assess environmental aspects of data centres in GPP criteria

All the respondents to the survey (i.e. 52) answered to the questions regarding potential GPP criteria. 29 provided recommendations for the developments of criteria, while 40 listed key challenges of this development. For some questions, multiple answers were allowed, resulting in more than 52 answers to one question (see the number of answers for each question in Appendix 1). Therefore, in some cases the percentages do not sum 100%.

The main answers provided by stakeholders about the environmental aspects to be considered in GPP criteria are shown in Figure 16. For more details on suggested aspects see Table 34.

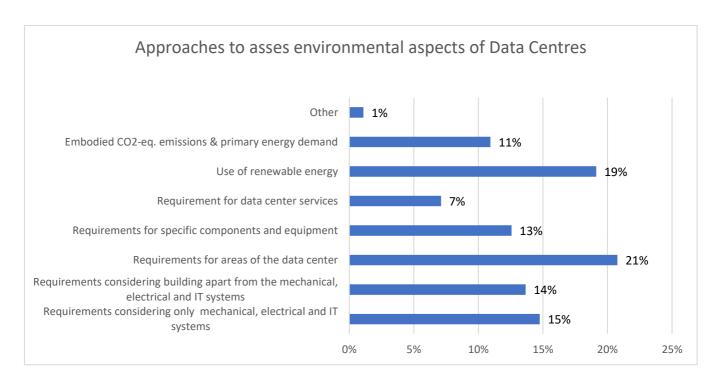


Figure 16 Approaches to assess environmental aspects of Data centres.

The replies from stakeholders were diverse covering a range of approaches to assess environmental aspects. They cover energy management, data centre construction, and LCA related indicators, but also existing assessment methodologies such as Blue Angel and the Code of Conduct for Energy Efficiency of Data Centres. One respondent emphasised the importance of the criteria being simple and clear while also comprehensive.

11.4 Regulatory and voluntary schemes

When the stakeholders were asked about regulatory and voluntary schemes to be used as starting point for development of GPP criteria, the answers were also quite diverse. However, most were aligned to the schemes reviewed in chapter 2 as shown below in Figure 17.

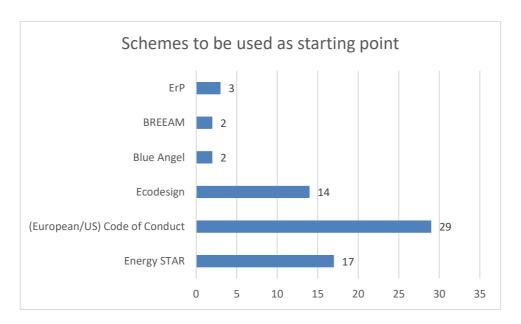


Figure 17. Schemes to be used as starting point (number of stakeholders).

Some additions are:

- ANSI/ASHRAE Standard 90.4-2016
- CEN/CLC/ETSI CG GDC The CEN/CENELEC/ETSI Coordination Group on Green Data Centres (CEN/CLC/ETSI CG GDC).
- ETSI EN 303 470 Environmental Engineering (EE); Energy Efficiency measurement methodology and KPI/metrics for Servers.
- GHG Protocol Product Life Cycle Accounting and Reporting Standard IT Sector Guidance – Chapter 5 – Guide for assessing GHG emissions of Cloud Computing and Data Centre Services¹⁰⁹.
- EPEAT Electronic Product Environmental Assessment Tool¹¹⁰.
- EICC¹¹¹ (Electronic Industry Citizenship Coalition
- SCTE 2020¹¹², a network hub on technical and applied science for the cable telecommunications industry having a set of goals concerning energy management.
- 80 PLUS¹¹³, a voluntary certification program intended to promote efficient energy use in computer power supply units, including servers.
- The Product Environmental Footprint Category Rules (PEFCR) for UPS¹¹⁴ and the PEFCR pilot project on storage units¹¹⁵.

111 http://www.eiccoalition.org/initiatives/environmental-sustainability/

113 https://plugloadsolutions.com/80PlusPowerSupplies.aspx

¹⁰⁹ https://www.ictfootprint.eu/en/ghg-protocol-ccdc-factsheet

¹¹⁰ http://www.epeat.net/about-epeat/

¹¹² http://www.scte.org/energy2020/

¹¹⁴ http://ec.europa.eu/environment/eussd/smgp/pdf/pilots/PEFCR_UPS.pdf

¹¹⁵ http://ec.europa.eu/environment/eussd/smgp/pdf/pilots/PEFCR_UPS.pdf

- EN15804 standard¹¹⁶ on construction products.
- BREEAM¹¹⁷ is an international voluntary sustainable building certification scheme.
- LEED¹¹⁸ is an international voluntary sustainable building certification scheme.
- ISO 14062¹¹⁹, UN Global Compact¹²⁰ and the Energy Efficiency Directive 2012/27/EU¹²¹.

11.5 Criteria and metrics to be included in the GPP criteria

Replies regarding criteria and metrics have been merged due to an overlap in the answers. The percentages shown below are based on the total number of responses for both questions. The stakeholders' main answers about criteria and metrics to be included in the GPP criteria are shown in Figure 18 below.

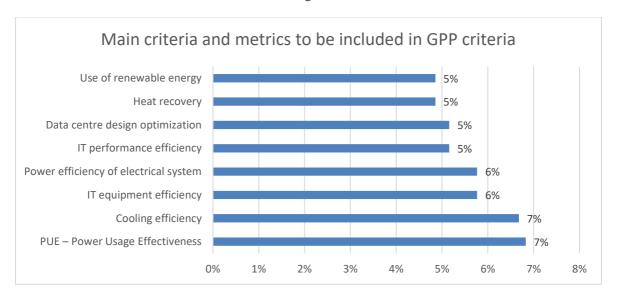


Figure 18. Main criteria and metrics to be included in GPP criteria according to stakeholders.

Please see Table 35 and Table 36 for a full overview of stakeholders' additional suggestions.

The stakeholders provided a wide range of additional suggestions for criteria and metrics. Five respondents mentioned water consumption in connection to water scarcity and suggested including a water footprint as a metric. Three respondents suggest including CO_2 -emissions as a metric, one also mentioning aspects beyond embodied CO_2 -equivalents such as ozone depletion potential and acidification potential. One respondent pointed out that WUE¹²² should only be used in countries

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¹¹⁶ http://shop.bsigroup.com/ProductDetail/?pid=00000000030279721,

¹¹⁷ http://www.breeam.com/

¹¹⁸ http://www.usqbc.org/help/what-leed

¹¹⁹ https://www.iso.org/obp/ui/#iso:std:iso:tr:14062:ed-1:v1:en

¹²⁰ https://www.unglobalcompact.org/

¹²¹ http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:315:0001:0056:en:PDF

¹²² Water Use Efficiency

where water is an issue, implying that there should be country-specific GPP criteria. Some respondents are critical towards the current set of metrics commonly used in the industry, deeming them misleading and calling for them to be replaced, while one respondent said that indicators suggested in the questionnaire would weaken the existing set of indicators. One respondent felt that the basis of any criteria should be founded on the work already undertaken by JRC, in particular the EU Code of Conduct for Energy Efficiency. These include component efficiency and LCA indicators, which are proposed as both metrics and criteria. Likewise, Blue Angel is proposed as both a regulatory scheme and an approach.

11.6 Life Cycle stages to be included in GPP criteria

When stakeholders were asked about the life cycle stages they preferred to be included in the scope of the GPP criteria, most agreed in the use, manufacturing, repair and maintenance and end of life (see Figure 19).

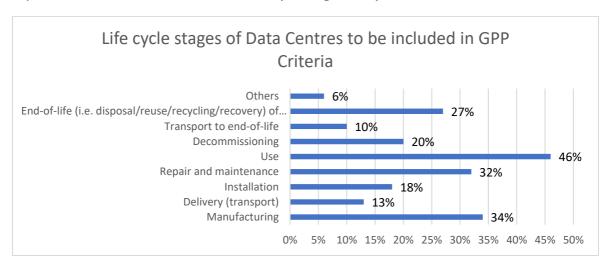


Figure 19. Life cycle stages to be covered by the GPP criteria.

11.7 Key challenges for development of GPP criteria

When the stakeholders were asked about key challenges for development of GPP criteria, the answers were:

- Identifying the correct/agreeable standards to be used as benchmarking
- Creating criteria and metrics that can be flexible enough to remain relevant for 15+ years
- Balancing reliability with energy effectiveness in the eyes of users
- DC's have to work with design values (difficult to prove) or show bad ratio's
- Find a proper definition of the performance of a data centre
- Specify data for embodied carbon emissions
- Dynamic power management
- Get sufficient/some minimum support from stakeholders to overcome the PUE "lock-in" and preference of other principally unsuitable, old indicators.
- GPP criteria should be so flexible that good efforts to improve the efficiency of data centres can be rewarded (or mandated)
- Trade-offs between Equipment Energy Efficiency and Data centre SLA (Service Level Agreements) requirements

- Companies who in one way or the other will try to stop the process
- To make it simple enough and not too heavy for the data centres to measure and report
- Legacy installation limitations prevent a holistic approach to improvements
- Not to get lost in a bureaucratic result. The key challenge will not be the development but the use of the criteria
- Obtaining data. Testing of assumptions.
- Determining scope. Accounting for virtualization. Developing criteria that apply to, and will be adopted by, large proprietary providers
- Make them realistic but at the same time challenging
- Risk of scope creep
- Consider Colo's as equals when looking at these guidelines (and not just green field)

See Table 40 for a full list of additional challenges. This table shows that the stakeholders see numerous challenges associated with developing new GPP criteria for data centres. Two public procurers responded that *agreeing* on standards for use of benchmarking will pose a key challenge to the development, as will navigating the bureaucracy in which these criteria will be used. Furthermore, one respondent implied that the industry as well as stakeholders are reluctant to change. Another respondent stated that GPP criteria should allow for good efforts towards improvement to be rewarded. A different challenge is pointed out by a respondent naming the difficulty of creating criteria that can maintain relevance for a decade or more, thus avoiding having to use new procurement criteria at short intervals. Many respondents said that data centres' performance cannot be properly assessed currently; there is a need to create a satisfactory metric(s) for the performance of a data centre.

Appendix 1. Results from stakeholder survey

This appendix shows the questions and answers of the stakeholders survey which was available online from the 20^{th} of February to the 27^{th} of April 2017. The results were collected on the 27^{th} of April.

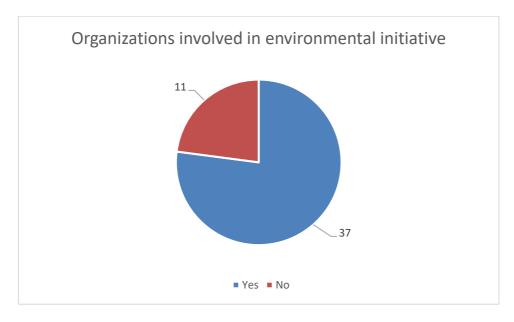
There were 52 participants in the survey. However, not all the questions received 52 answers. Furthermore, some questions are linked and depend on each other but it was observed that in some cases not all the participants responded the following dependent questions. Finally, since some questions are multiple choice, the answers for these questions exceed 52. For these reasons, the number of answers is stated after each question to get an idea on the amount of answers, and thus information, available.

The results are presented as tables when the question is open and thus the answers are open text. They are presented in figures when the question is closed (yes/no) or multiple choice.

The first four questions are not presented because they present private information about the respondents. An overview of the type of stakeholders answering the survey has been presented in chapter 4.

1.5. Is or has your organisation been involved in any environmental initiative for the manufacturing, use and/or decommissioning of data centres and/or data centre products and/or services you offer?

Number of answers: 48



1.5.1. If **yes**, please say what they are

Number of answers: 37 (please see Table 27).

Table 27. Environmental initiatives.

Stakeholder type	Environmental initiative
Consultant and/or research institution	 Server Compute Efficiency metrics Data centre operators, Energy or carbon-footprint reduction initiatives EUCOC ISO14001 EURECA PROJECT Product Environmental Footprint Pilot Design of low energy data centres in the UK, Sweden and Norway, New, more sustainable processes and technologies for datacentres, R&D on smart grid integration of DC's, eWaste and circular approaches to DC's, Climate friendly air-conditioning of data centres Energy efficiency of datacentres FIWARE network computation Node "European Standardisation Mandate and Lifecycle Inventory Databases" CONTRACT NUMBER - 30-CE-0518625/00-10, "Technical Assistance In The Monitoring Of Standardisation Efforts Developing Methodologies For The Environmental Footprint Of IT And Compatibility Assessment With Product Environmental Footprint Methodology Of The European Commission" Ares(2012)790803 for DG CONNECT Development of eco-label schemes (Blue Angel) for data centres, UPS, Room Air Conditioners IT equipment + GPP criteria for data centres and other IT equipment
Laboratory testing organization	 Life cycle analysis and carbon audit service to manufacturers, provide environmental system advisory to our customer
Manufacturer	 Combined heating and cooling Energy re-usage Factor, SCTE2020 ErP Lot 9 Endorser of de EU CoC on data Centres ENERGY STAR programs for servers, storage and networking products, and data Storage Equipment EPEAT for servers, "free cooling" in datacentres, WEEE and battery directives CEN/CENELEC Circular Economy Standards EMAS, Codes of Conduct Product design initiatives Build data centres with pUE at 1.15 Energy Conservation of products and Operation of DC

Stakeholder type	Environmental initiative
Non-governmental organization (NGO)	 CLC EN 50600-2: design of data centre infrastructures and facilities CLC EN 50600-4-2: fully-standardised approach to PUE - aligned with ISO/IEC 30134-2 CLC EN 50600-4-3: fully standardised approach to renewable energy factor (REF) - aligned with ISO/IEC 30134-3 CLC EN 50600-99-6: fully standardised approach to energy reuse factor (ERF) - aligned with a future ISO/IEC 30134-6 CLC/TR 50600-99-1: Data Centres - Resource Management - Recommended practices CLC TR 50600-99-2: Data Centres - Environmental sustainability - Recommended practices CENELEC TC215 expected to implement the Green Grid Maturity Model as a European Standard in 2018 Green power, datacentre lifecycle: design, construction, use.
Public procurer	
Supplier of services for data centres	 Data Centre Energy Improvement Initiatives EU Code of Conduct for Data Centre Energy Efficiency ISO50001 ISO14001 EMAS Sectoral Reference Document on Best Environmental Management Practices for the Telecommunications and IT services Sector Energy conscious design Development of data centres EMAS sectoral reference document for the Telecommunications and IT services sector Decommissioning of end of life IT infrastructure Responsible disposal of IT products zero waste to landfill
Trade associations and professional bodies	 CoC, EMAS Standardization bodies CGGDC

1.5.2. If **yes**, what is the impact and do you think they are working properly?

Number of answers: 35 (see Table 28).

Table 28. Impact of environmental initiatives.

Stakeholder type	Impact
Consultant and/or research institution	 Regulatory support required Procedure to evaluate products in line with PEF method is too complicated Working to the clients' specification Impact is huge, initiation of large-scale DC heat reuse at Schiphol rijk Impact so far mainly in Germany Large impact as we operate a 200kw datacentre Mainly publications, increase the awareness of energy consumption in the node customers Definition of benchmarks for best available technology Reduction of energy and resource consumption and refrigerant fluids relevant for global warming potential (GWP)

Stakeholder type	Impact
Laboratory testing organization	Still not popularly implemented in this industry
Manufacturer	 Reduce power consumption in data centres The data centre gets free cooling and the community gets low carbon heating Too early to tell, indications are the process is successful Reduction of energy use, improvements in energy efficiency Very high efficiency and over 1,000,000 uptime hours without failure Encourage greener behaviour Reduced material consumption
Non-governmental organization (NGO)	 Only partially The impact is large and important Whitepapers have been published and supported by many organisations and other associations at the European level and in Quebec
Public procurer	• -
Supplier of services for data centres	 To a degree, but could be improved Substantially lower energy overhead The use of the good practices set out in the CoC is resulting in a lower PUE in our DC Work properly Impact is demonstrating responsibility The ISO 50001 certification that we as an organisation have is founded on the prinicples and practices of the EU Code of Conduct for Energy Efficiency in Data Centres and in turn the focus through participation on the EMAS Sectoral Reference Document on Best Environmental Management Practices for the Telecommunications and IT services Sector Working Group was to identify and align EU Code of Conduct for Energy Efficiency in Data Centres to reflect the learnings of the EU Code of Conduct for Energy Efficiency for Data Centres and the practicalities associated with current and future practices
Trade associations and professional bodies	 Good visibility Impact of this data centre design is not only the actual facility and using free cooling but also causing servers to run 15% more efficiently and up to an increase of 50% in service-ability. Facebook DC's run at a PUE in the region of 1.04

1.5.3. If **yes** and you have any indication of the environmental and/or cost benefits achieved through implementing these initiatives (e.g. tons of CO2 savings, energy savings, business competitive advantage, brand benefits) please give them below

Number of answers: 26 (see Table 29).

Table 29. Environmental and/or cost benefits.

Stakeholder type	Environmental and/or cost benefits
Consultant and/or research institution	 Energy saving potentials about -40% Metrics do not have any direct impact on CO2 reduction or energy savings, but have led to specific and predITable reductions in power consumption and CO2 equivalent emissions Use phase energy savings and use of electronic parts e.g. printed circuit board and HDD, 2500 tCO2. Estimate until end of 2016. Reduction of costs and energy waste Difficult to measure as only indirect impact For EURECA, as it is an ongoing project, the target is 110 GWh primary energy saving /year and reporting on other savings, for a selected number of data centres the project is directly interacting with / advising, while this might not use the full set of GPP indicators that we have proposed.
Laboratory testing organization	 In carbon audit programme, will indicate the comparative result in term of tons of CO2, energy savings in kWh and some best benefits
Manufacturer	 No. The regulations are incomplete and therefore benefits are not calculable, target is 25% energy saving over BAU by 2020 Typical chiller performance is COPc 5.0 We have achieve over 15. (1/3rd of cooling power), Less Energy Consumption and less capital and operating costs, N/A
Non-governmental organization (NGO)	 Equinix has achieved 80% green power utilisation in EMEA and is target 100% by the end of 2018, currently saving over 400,000 metric tons of CO2 annually and expect this to break 1,000,000 metric tons, energy efficiency measures have reduced our consumption of power to enable us to save a further 100,000 + metric tons of CO2 per year
Public procurer	-
Supplier of services for data centres	 Yes PUE data Energy savings, business advantage AND brand benefits No Zero waste to landfill
Trade associations and professional bodies	 Overall decrease in the embodied energy within the ingredients (servers, rack and power, storage & networking), lighter footprint and more efficient (at scale) DC's

1.5.4. Can you give an estimate of costs associated with this initiative (if any)?

Number of answers: 22 (see Table 30).

Table 30. Costs associated with initiative.

Stakeholder type	Costs associated with initiative
Consultant and/or research institution	 0.3 million euros Same cost as a traditional facility but increased risks of IT service availability taken by clients 200k-300k annually EURECA: 1.5 Mio EUR No, depends on the specific measure
Laboratory testing organization	-
Manufacturer	 \$200,000.00 per product for test and registration Community pays for the heat pumps so it has no cost to the data centre No No cost or reduced cost to consumer anticipated Depends on size of facility but as running costs are 70% of cooling costs, saving 1/3rd is much more valuable than buying cheaper equipment Saved 0.5M in equipment and installation costs for a 200 KW data centre
Non-governmental organization (NGO)	 Equinix has invested in solar power facilities in the US, procured at a cost premium 100% green power in EMEA and spends several million USD per year on efficiency measures
Public procurer	-
Supplier of services for data centres	 \$M's Exclusively internal costs. not quantifiable No costs as equipment recycled by the recycling company
Trade associations and professional bodies	 Varies based on the configuration of OCP ingredients and deployment facility

1.6 Have you ever used environmental criteria in your procurement activities for this product group?

Number of answers: 4. Yes: 2, No: 2

1.6.1 If **yes**, please say what they were

Number of answers: 5

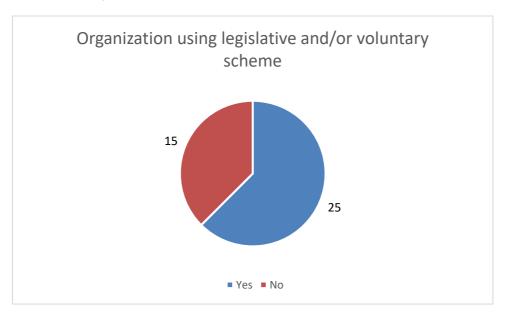
- 1. Product test and product registration
- 2. Efficiency ratios of equipment such as UPSs, Air conditioning, ISO14001 Certifications
- 3. Design changes for higher efficiency power supplies, 3rd party test labs to qualify products, systems required for initial testing and audits.
- 4. Removed 2 Static Transfer Switches and 1 UPS, incurring less losses.
- 5. In the selection and award criteria, the technical specifications and some clauses of our contracts

There were no answers for questions regarding guidelines for GPP criteria. As a result, these questions have been omitted from the appendix.

1.7 Has your organization used any legislative and/or voluntary scheme (e.g. EU Code of Conduct for Energy Efficiency, EU ENERGY STAR, Blue Angel, Green Grid Data

centre Maturity Model, etc.) for labelling your product or for purchasing data centres products and/or services?

Number of replies: 40



1.7.1 If **yes**, please write which one(s) your organization has used

Number of answers: 23 (see Table 31).

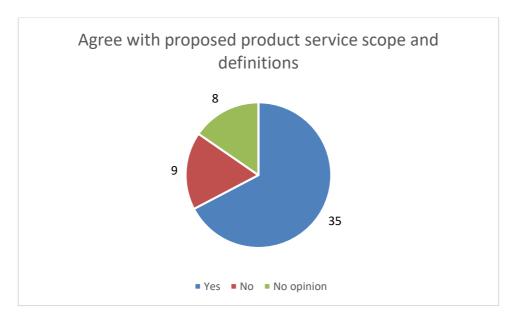
Table 31. Legislative and/or voluntary scheme.

Stakeholder type	Legislative and/or voluntary scheme
Consultant and/or research institution	 EU CoC EU ENERGY STAR Blue Angel/DCMM CEEDA For own procurement: adopted GPP-criteria for server, storage, energy
Laboratory testing organization	EU ErP and Energy Label
Manufacturer	 EU Code of Conduct for Energy Efficiency ENERGY STAR Green Grid Data centre Maturity Model Codes of Conduct for UPS and data centres
Non-governmental organization (NGO)	 CLC/TR 50600-99-1: standards-based implementation of EU CoC Best Practices CENELEC TC215 expected to implement the Green Grid Maturity Model as a European Standard in 2018 TCO Development Blue Angel
Public procurer	 EU CoC EU ENERGY STAR Blue Ange

Stakeholder type	Legislative and/or voluntary scheme
Supplier of services for data centres	 EU Code of Conduct for Data Centre Energy Efficiency ISO50001 ISO14001 US EPA Energy Star LEED SS 564 BCA-IDA Green Mark
Trade associations and professional bodies	 EU CoC on DC and UPS The Green Grid IEC/ISO SC 39 TC 215

2.1 Would you agree with including the proposed product service scope and definitions?

Number of answers: 52



2.1.1 If **yes**, are there any other elements you would like to add to the product scope and definitions?

Number of answers: 18 (see Table 32).

Table 32. Elements to add to product scope and definitions.

Stakeholder type	Elements to add to product scope and definitions
Consultant and/or research institution	 No For Enterprise category, there are significant differences in scope for large and small facilities. For all categories, there can be significant differences is cost and efficiency metrics based on the physical location (climate) of the facility In 'enterprise' include Governmental and Security/Military Unclear question Having the definition of DC "buildings, facilities and rooms" is really unclear For comparisons, the server application type (Email, HPC, Video streaming, and combinations thereof) needs to be considered when defining the useful work, which is indispensible for comparisons. Moreover, Data centres will see multiple replacement of its main hardware, particularly servers, but also UPS, possibly cooling, why criteria sets for such hardware are needed - the data centre as initially established may be half empty in the begining and GPP criteria be distorted / not meaningful and later lacking when "only" the hardware is purchased to fill the space; correspondingly, the most relevant product clases of these hardware (possibly also certai sot ´ftware, such as virtualisation?) need to be defined for use in GPP context as well The Ecodesign Legislation on the related ecquipment should be also included in the proposed criteria Own dedicated facility with external staff to run the IT-equipment (it must be ensured that outsourcing the staff does not lead to inefficient data centre management)
Laboratory testing organization	-
Manufacturer	 No Heat recovery/harvesting How relevant are server closets, server rooms to the targeted audience
Non-governmental organization (NGO)	-
Public procurer	Security standards
Supplier of services for data centres	NoData centre interconnections
Trade associations and professional bodies	 Complying with the current definitions of DC as per Cenelec TC 215 and IEC / ISO SC 39 and CGGDC

2.1.2 If **no**, please explain why and give your proposal for this product group (e.g. CPV codes, NACE classification, Prodcom codes)

Number of answers: 9 (see Table 33).

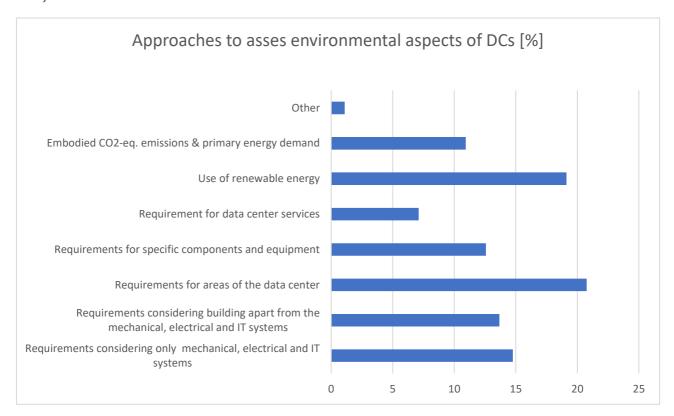
Table 33. Alternative proposals of product scope and definitions for this product group given by stakeholders.

Stakeholder type	Proposal for this product group
Consultant and/or research institution	Add datacentre type related to Edge or Fog services, such as micro data centres
Laboratory testing organization	-
Manufacturer	 Use the European EN 50600 classification not the Uptime Tiering. The European EN 50600 series of standards is in the process of being incorporated in the work of ISO/IEC JTC1 SC 39 Sustainability for and by Information Technology and will probably have a global coverage in the future. The EN 50600-99-1 Data centre facilities and infrastructures - Recommended practices for energy management is the standards equivalent of the EU Code of Conduct for Energy Efficiency best practice guide and fits perfectly in Mentioning the Uptime Tiers by name is an endorsement of that proprietary scheme, and The Green Grid's new OSDA availability model may be a better way to design and evaluate the availability of data centres
Non-governmental organization (NGO)	 Definitions of data centre, enterprise and co-location does not match that already agreed in CENELEC, ETSI and ISO/IEC Do not believe that the Uptime Institute is impartial nor do I feel their classification metrics are appropriate for this proposal The GPP scope shall refer to the classification of data centres as per series EN 50600 (developed and published by CENELEC under EU standardization Mandate M/462). Uptime Institute is a US based profit-oriented commercial enterprise (offering data centre certification services) rather than a neutral reference and as such irrelevant for the European Market in this context A colocation datacenter can have many usage, for exemple hosting entreprises, managed services provider and hyper scale. Definition is more linked to the usage of the datacenter than to the datacenter itself
Public procurer	-

Stakeholder type	Proposal for this product group
	 Uptime Tiers should not be used. They are not a true standard and the statement that they represent different levels of reliability is incorrect. They actually define the opportunity for maintenance without interrupting service availability. In a European initiative it would be better to use the CEN/CENELEC EN 50600 series as a reference point The Tier rating classifications are run by a commercial organisation and not in line with a number of data centre operators requirements and are very prescriptive, they do not consider business requirements and can result in inappropriate designs which are;-
	a) not practical for the business,
Supplier of	b) not considering the effective stewardship of energy,
services for data centres	 c) facilities who either existed prior or were unfamiliar to the standard would require significant investment to be assessed and or retorfit to achieve the standard,
	d) this could be seen as the Project endorsing another organisation resulting in financial gain to that organisation
	e) These are in conflIT with the definitions defined in EN 50600 where there are 5 levels of classification and there are variations/overlaps between the respective levels
	f) EN 50600 series of Standards has links into other recognised International Standards e.g ISO/IEC 30134, ISO14046
	f) In Germany there is another form which is also a hybrid standard TuV IT (TSI) with selected sections of UTI Tier, TIA842 & EN 50600 and again is in conflIT with UTI and its classifications
Trade associations and professional bodies	 Overall data centre requirements: the environmental impact of delivering a certain amount of data centre work, using existing and new metrics, considering only the mechanical, electrical and IT systems.; Requirements for areas of the data centre: e.g. Power Usage Effectiveness, principles such as free cooling, heat recovery and temperature setpoints for ITE (IT Equipment), inlet air temperatures.; Use of renewable energy; Embodied CO2-eq. emissions and primary energy demand Requirement for data centre services: based on the same requirements as for component products, just reformulating the criteria so that the service provider should deliver the services using only products complying with the product requirements. Criteria may be on use of principles or compliance with specific metric levels

3.1 Which of the following approaches do you think should be used to assess the environmental aspects of data centres in the GPP criteria (more than one choice allowed)?

Number of answers: 52 (some answered more than once, total number of answers is 183)



3.1.1 If 'Other', please give your suggestion(s)

Number of answers: 10 (seeTable 34).

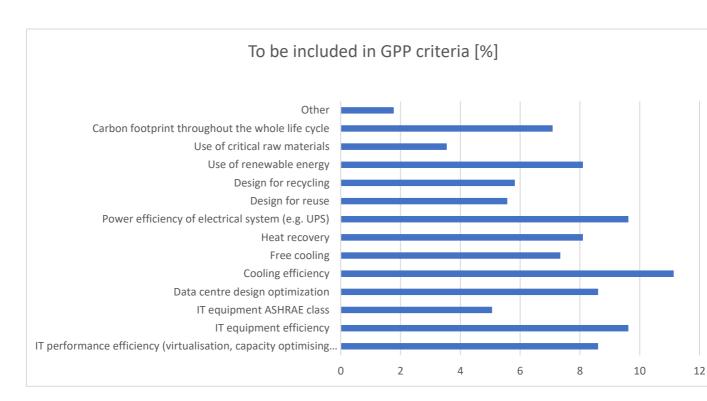
Table 34. Alternative aspects to be covered by GPP criteria suggested by stakeholders.

Stakeholder type	Suggestions for approaches
Consultant and/or research institution	 Use of electronic parts e.g. printed circuit board and HDD Metrics related to the (avoided) energy consumption within the DC area, such as heat reused by third parties (e.g., ERF) Use of natural refrigerants for cooling Combination of performance-based, technical criteria that have been derived using life cycle information and – where harmonised approaches such as the PEF or EN 15804 exist, e.g. for UPS, hard disks, buildings – quantitative life cycle results. The environmental impacts that should be considered are global warming potential potential, ozone depletion potential, acidification potential, eutrophication potential to land, photochemical oxidant creation potential, land use, water scarcity, and particulate matter. As additional indicator primary energy demand could be added. Note that we deliberately leave out here and throughout the questionnaire some impact categories, such as Resource depletion, as these are not of environmental concern and/or have so large impact method weaknesses, that they would cloud the more robust other life cycle results energy management, information about efforts to reduce energy and resource consumption. Extension of lifetime and degree of capacity utilization (=resource reduction)
Laboratory testing organization	-
Manufacturer	Heat recovery should be mandatoryData centre construction
Non-governmental organization (NGO)	 Datacentres are inherently VERY efficient as compared to: (1) Businesses use of computing power in standard office environments - by several factors and (2) the business process that has been digitised. Any attempt to penalise datacentres without recognising these two core fundamental facts is flawed Environmental aspects should be considered with the functional unit of what is really bought; is it housing services, cloud services, IT services, network services
Public procurer	-

Stakeholder type	Suggestions for approaches
Supplier of services for data centres	• The basis of any criteria should be founded on the work already undertaken by JRC, in particular EU Code of Conduct for Energy Efficiency of Data Centres and laterly followed up by JRC with EMAS Sectoral Reference Document on Best Environmental Management Practices for the Telecommunications and IT services Sector. These areas of work when supported by ISO50001 - Energy Management System and ISO14001 - Environmental Management System collectively support the stewardship of Energy and Environmental management of an organisation. These also complement the work already completed by the European Commission and member states in the delivery of the Energy Efficiency Directive 2012/27/EU Whereas each of the above selection criteria in 3.1 has a level of relevance, but no single or combination is achievable to either individual or multiple business in the delivery of services to/from a data centre. The assessment of data centre work is subjective and in most cases not available to the data centre operator and or IT consumer, as this is often specific to the IT Systems / business sub unit using/consuming the input/output, The management of the supporting data centre infrastructure is often operated and managed by parties who have no control or visibility over the other business units activities
Trade associations and professional bodies	-

3.2 Which of the following examples of criteria do you think should be included in the GPP criteria (more than one choice allowed)?

Number of answers: 52 (some answered more than once, total number of answers is 395)



3.2.1 If 'Others', please give your suggestion(s)

Number of answers: 7 (see Table 18).

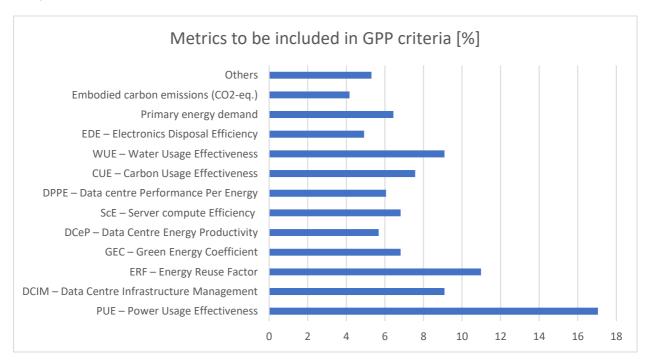
Table 35. Suggestions for GPP criteria.

Stakeholder type Su	 Use of natural refrigerants for cooling CO2 emissions should replace renewable energy use a combination of performance-based, technical criteria that have been derived using life cycle information and – where
Consultant and/or research institution	harmonised approaches such as the PEF or EN 15804 exist, e.g. for UPS, harddisks, buildings – quantitative life cycle results. The environmental impacts that should be considered are global warming potential potential, ozone depletion potential, acidification potential, eutrophication potential to land, photochemical oxidant creation potential, land use, water scarcity, and particulate matter. As additional indicator primary energy demand could be added. The specific set of criteria may vary, depending whether a data centre as a whole is subject, or also components (e.g. servers, UPS,) for replacement and software (e.g. virtualisation) • Henergy management and information (e.g. public metrics) • all these criteria are examples to reach the same goal: the reduction of environmental impacts. GPP criteria should not reduce the options to reach that goal. Better give requirements for the goal (e.g. efficiency) and leave it to the operator of the data centre to choose the appropriate option
Laboratory testing organization	

Stakeholder type	Suggestions for GPP criteria
Manufacturer	 Weighted environmental footprint as defined by PEF methodology (DG Environment and JRC)
Non-governmental organization (NGO)	 Water consumption (direct and indirect), Water footprint throughout the wole life cycle, waste management (rate of recycling, rate of reuse), lifetime of ITC equipments
Public procurer	-
Supplier of services for data centres	 Each of these items a covered in varying levels in the various sections below and as with the subsequents responses the basis of any criteria should be founded on the work already undertaken by JRC, in particular EU Code of Conduct for Energy Efficiency of Data Centres and laterly followed up by JRC with EMAS Sectoral Reference Document on Best Environmental Management Practices for the Telecommunications and IT services Sector. These areas of work when supported by ISO50001 - Energy Management System and ISO14001 - Environmental Management System collectively support the stewardship of Energy and Environmental management of an organisation. These also complement the work already completed by the European Commision and member states in the delivery of the Energy Efficiency Directive 2012/27/EU
Trade associations and professional bodies	-

3.3 Which of the following examples of metrics should be included in the GPP criteria (more than one choice allowed)?

Number of answers: 52 (some answered more than once, total number of answers is 264)



3.3.1 If 'Others', please give your suggestion(s)

Number of answers: 14 (see Table 36).

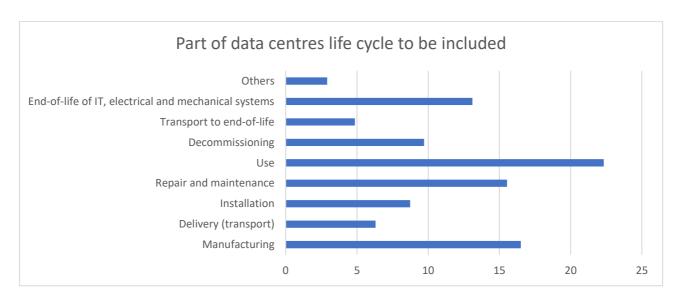
Table 36. Alternative metrics suggested by stakeholders.

Stakeholder type	Suggestions for metrics to be included
Consultant and/or research institution	 Resource depletion potential Total CO2 emissions (including direct (by refrigerants) and indirect (by energy use and embodied energy) Remark:
Laboratory testing organization	-
Manufacturer	 Weighted Environmental Footprint effectiveness Energy re-usage standard Design PUE see ISO/IEC 30134-2:2016 Information technology Data centres Key performance indicators Part 2: Power usage effectiveness (PUE) (Annex C4) ISO/IEC 30134-3:2016 information technology Data centres Key performance indicators Part 3: Renewable energy factor (REF) The Green Grid just published the capacity and utilization metrics that will help to understand how much IT is deployed and its %utilization

Stakeholder type	Suggestions for metrics to be included
Non-governmental	Renewable Energy Factor (REF) as per EN 50600-4-3:2016
organization	(instead of GEC)
(NGO)	ÎTC equipments lifetime, water footprint throughout life cycle
Public procurer	-
Supplier of services for data centres Trade associations	Current metrics are misleading and in many cases not helpful. New metrics are required. The basis of any criteria should be founded on the work already undertaken by JRC, in particular EU Code of Conduct for Energy Efficiency of Data Centres and laterly followed up by JRC with EMAS Sectoral Reference Document on Best Environmental Management Practices for the Telecommunications and IT services Sector. These areas of work when supported by ISO50001 - Energy Management System and ISO14001 - Environmental Management System collectively support the stewardship of Energy and Environmental management of an organisation. These also complement the work already completed by the European Commission and member states in the delivery of the Energy Efficiency Directive 2012/27/EU, where metrics are referenced they should where practical be based on ISO/IEC 30134 Standard or equivalent or from organisations such as The Green Grid where a significant number of metrics have already been developed and published With the exception of DCIM (which is a tool not a metric) the above (in section 3.3) are variable by data centre and are significantly impacted by;-a) size b) location c) age, d) maturity, e) business requirements f) resilience/availability level to name but a few influences, as such were they to be included they would be inappropriatle used by customers seeking to utilise these services to compare providers. The intent of the respective metrics is to allow trending of individual data centres for enablement of good energy and environmental stewardship by the owner operator. Noting that the improvement of one or more metrics listed can have a detrimental impact on other metrics. Energy and environmental management is about the optimisation of the appropriate metrics that meet the business needs and objectives
and professional	_
bodies	
Dodies	

3.4 Which parts of the life cycle of data centres do you think should be included in the GPP criteria (more than one choice allowed)?

Number of answers: 206



3.4.1 If 'Others', please give your suggestion(s)

Number of answers: 6 (see Table 37).

Table 37. Other life cycle stages of data centres to be included in GPP criteria suggested by stakeholders.

Stakeholder type	Suggestions for part of DC Life Cycle to be included
Consultant and/or research institution	 Material and energy carrier production (i.e. upstream of "Manufacturing") needs to be included, where quantitatively relevant.
Laboratory testing organization	-
Manufacturer	 Design criteria regarding scalability related to the expected use of the data centre i.e. Designed PUE Construction. Use to include server management programs, e.g. efforts to minimize "zombie" servers.
Non-governmental organization (NGO)	 comparative metrics are great but there is also the metric of comparing to (1) computing costs outside of a datacentre and (2) the cost of a non-digitised business process (eg: an online survey form processed in a datacentre like this versus the environmental cost of a paper and mail based survey It depend of the scope considered, if you included th ITC equipment, the manufacturing, use and disposal stage should be considered
Public procurer	-

Stakeholder type	Suggestions for part of DC Life Cycle to be included
Supplier of services for data centres	 The following is a extract from The Green Grid members area where White Paper #62 is described as; - Editor: Christophe Garnier, Schneider Electric Contributing Editor: Billy McHallum, Equinix Contributors: Jay Dietrich, IBM Markus Stutz, Dell Conducting life cycle assessments (LCAs) to determine a product's environmental impacts has become relatively mainstream. Applying that same methodology to a data centre and its systems is far more challenging due to the variety of data centre types and their numbers of suppliers, the lack of applicable component and system data, and the sheer complexity of a data centre. To begin to address the difficulties surrounding data centre LCAs, The Green Grid, an international, nonprofit consortium working to enhance data centre resource efficiency, set out to identify the main environmental impact categories for the typical data centre. Drawing on a combination of results from previous studies and the expertise of its members who are experienced in this area, The Green Grid compiled a range of data centre environmental impacts, organized them into five main categories, and defined objectives, measurements, and key performance indicators for some of them. The ranked levels provided follow the same 0-to-5 progression as is used in the widely adopted Data centre Maturity Model (DCMM). Using this information, data centre owners and operators can better determine their most critical environmental impacts, evaluate those impacts, and take steps to mitigate them. In response to the strong interest expressed by recent participants in The Green Grid Forums, a proposal will be put forth to translate the results of this white paper into a new "Environmental" or "Life Cycle" section in the DCMM. The key areas, which had subsets within, gave consideration to:-a) Energy consumption - minimise energy consumption b) Green house gas emission - Global impact of GHG, local impact on air quality C) Environmental resource usage - "What do we have?" and "How effic
Trade associations and professional bodies	-

3.5 What regulatory and voluntary schemes do you think should be used as a starting point for the development of the GPP criteria (e.g. US/EU ENERGY STAR, European Code of Conduct, Ecodesign ongoing work on servers and storage) and in what aspects?

Number of answers: 52 (see Table 38).

Table 38. Regulatory and voluntary schemes suggested by stakeholders to be used as starting point for development of GPP criteria.

Stakeholder type	Suggestions for regulatory and voluntary schemes to be used as starting point for developing GPP criteria
Consultant and/or research institution	 ASHRAE 90.4 80 PLUS CENELEC CN50600 CG GDC EUCOC - All Ecodesign EN50600 ISO/IEC 30134 ENERGY STAR Blauer Engel für Energieeffizienten Rechenzentrumsbetrieb RAL UZ 161 BREEAM/LEEDS PEF initiative: PEFCR guide, and PEFCRs on UPS, IT (hard disks) Ispra EN15804 on Construction products for the data centre building GPP guidelines for data centres from the German Environment Agency (UBA)
Laboratory testing organization	 US/EU ENERGY STAR Ecodesign ongoing work on servers and storage (ErP Directive)
Manufacturer	 Weighted Environmental Footprint method from DG ENV – JRC Ecodesign European Standardisation Organisations BB code of Conduct SCTE 2020 European Code of Conduct Energy Star ErP Lot9 Efficiency of components should be considered Evaluate how ecodesign initiatives would contribute to overall reduction data centre environmental impacts Evaluate initiatives from other jurisdITions on UPS or other data centre equipment.

Stakeholder type	Suggestions for regulatory and voluntary schemes to be used as starting point for developing GPP criteria
Non-governmental organization (NGO)	 ETSI EN 303 470 based on LOT 9 for servers Ecodesign ENERGY STAR European Code of Conduct EICC EPEAT Code of Conduct CLC/TR 50600-99-1:2017 ISO 14001 ISO 50001 Global Compact ISO 14062
Public procurer	US/EU ENERGY STAREU CoC
Supplier of services for data centres	 BREEAM EU Code of Conduct EN 50600 Standard EMAS BEMP ETSI IT Standards JRC with EMAS Sectoral Reference Document on Best Environmental Management Practices for the Telecommunications and IT services Sector ISO50001 - Energy Management System ISO14001 - Environmental Management System Energy Efficiency Directive 2012/27/EU Ecodesign Energy Star
Trade associations and professional bodies	 European Code of Conducy US/EU Energy Star

4.1 Do you have any recommendation for the development of the criteria for this Product Group?

Number of answers: 29 (see Table 39).

Table 39. Recommendations by stakeholders by stakeholders.

Stakeholder type	Development of the criteria for this Product Group							
Consultant and/or research institution	 Engage the industry Use experts not generalists Don't underestimate the IT hardware use fase energy use Focus on innovation readiness Link to German Project KPI4DCE standardisation body work on the subject (i.e., ETSI, ITU-T,) Blue Angel criteria development: the "energy aware" data centres 							
Laboratory testing organization	3rd party measurement and verification on GPP							

Stakeholder type	Development of the criteria for this Product Group								
Manufacturer	 Only objectively measureable criteria Semi-qualitative and qualitative criteria Work done within the EU: Best Environmental Management Practice for the Electrical and Electronic Equipment Manufacturing work together with CEN/CENELEC/ETSI Coordination Group on Green Data Centres (CEN/CLC/ETSI CG-GDC PUE Approach in combination with LCC International standards 								
Non-governmental organization (NGO)	 Avoid re-invention Simple and clear but measure many specific things 								
Public procurer	-								
Supplier of services for data centres	 Sannot be prescriptive Best Practice that builds on work previously completed Reflect capability of existing data centre stock Set aspirational and stretch goals for expansion/newbuild/retrofit EU Code of Conduct for DCs as a starting point Keep approach as complete as possible while delivering a framework which can easily applied Use metrics that are already standardized 								
Trade associations and professional bodies	GEC does not exist and its use is very dangerous								

4.2 What do you think will be the key challenges in developing GPP criteria for data centres?

Number of answers: 40 (see Table 40).

Table 40. Key challenges identified by stakeholders for developing GPP criteria.

Vov. challenges
Key challenges
 Creating criteria that can be flexible enough to remain relevant for 15+ years Engage with the industry How to simplify the procedure and methodology Balancing reliability with energy effectiveness in the eyes of users DC's have to work with design values (difficult to prove) or show bad ratio's Technology prescriptiveness will keep sneaking back into the process Find a proper definition of the performance of a datacenter Specify data for embodied carbon emissions Agreement on widely accepted criteria Precise definition of scope and of IT efficiency Dynamic power management Define useful work for fair comparison across offers, differentiated to some degree per type of DC service Find right balance when to ask for more complete and accurate but also to some extent more costly to develop life lycle based data during procurement, and where technical criteria that are derived from life cycle based studies suffice. (E.g. for PPI and PCP, full LCA studies may be advisable, while not for regular GPP, unless endorsed and reproducible schemes such as PEF exist for selected product groups). Get sufficient/some minimum support from stakeholders to overcome the PUE "lock-in" and preference of other principally unsuitable, old indicators. The resistance to change/advancement of the industry (and of many academics and consultants active in the domain) is "impressive". The total increament of energy management processes GPP criteria should be so flexible that good efforts to improve the efficiency of data centres can be rewarded (or mandated)
 Reorganization of the scheme and technical measurement method
 in GPP criteria Trade-offs between Equipment Energy Efficiency and Data centre SLA (Service Level Agreements) requirements Face off companies who in one way or the other will try to stop the process To make it simple enough and not too heavy for the data centres to measure and report Legacy installation limitations prevents a holistic approach to improvements Not to get lost in a bureaucratic result. The key challenge will not be the development but the use of the criteria Definition of scope and Limits that cover usage in various climatic situations Obtaining data. Testing of assumptions. Multi-Tier. Efficiency vs Reliability

	D. L. II
Stakeholder type	Key challenges
Non-governmental organization (NGO)	 Determining scope. Accounting for virtualization. Developing criteria that apply to, and will be adopted by, large proprietary providers such as Amazon Web Services and Google True success comes in efficient software, running on efficient servers and related equipment, operating at 60-80% utilisation, residing in efficient datacentres, who use a proactive mix of green energy. This represents five completely different industries (software vendors, hardware vendors, IT system integrators including cloud, datacentre operators, and energy suppliers) Not all criteria might be applicable to all types of data centres To choose several KPI, not only based on energy efficiency, and consider all the lifecycle of the datacentre and the IT equipment
Public procurer	 Identifying the correct/agreeable standards for use of benchmarking Make them realistic but at the same time challenging
Supplier of services for data centres	 Useful and relevant metrics / KPIs Establishing a common set of metrics that are fair and relevant across different Data Centre types Every data centre is different, consider 5 people who buy the same make, model and specification of a vehicle on the same day, each will use (operate) and maintain the car differently dependent on their individual needs and requirements and although the standard metrics from the manufacturer and requirements for operation and maintenance are the same the needs are different and the impact on fuel consumption and the environmental will consequently vary for each use case. a) size b) location c) age, d) maturity, e) business requirements It is therefore necessary to understand what Best Practice should be and then measure against delivery of that with assessment of application of the best practices. The standardization framework as of now is fuzzy, even the simplest metrics not being universally adopted/accepted. Granted that metrics/KPIs are the most important indicators of the DCs efficiency, this fuzziness can turn out to play a significant role Accurate, consistent, comparable assessment of existing product Embodied carbon, if included, will be very difficult to quantify accurately (with primary data) Get the right available indicators over the lifecycle of the different DC components
Trade associations and professional bodies	 Measuring useful work of Data centres Risk of scope creep on these type of guidelines Important to consider colo's as equals when looking at these guidelines (and not just green field)

4.3 If you have any data concerning the overall market and the public procurement market share of the product group (volume of sales, % of the public procurement sector, etc.) please either upload the relevant information here

Number of answers: 0

4.3.1 or enter the link to it here

Number of answers: 4 (see Table 41).

Table 41. Links to market share of data centres in public procurement.

Stakeholder type	Links
Consultant and/or research institution	 http://www.eceee.org/ecodesign/products/enterprise-servers/
Laboratory testing organization	-
Manufacturer	https://www.youtube.com/watch?v=GT3SzGn_w_g
Non-governmental organization (NGO)	 http://alliancegreenit.org/wp-content/uploads/Doc%20AGIT/LB-ecoconception-numerique.pdf
Public procurer	-
Supplier of services for data centres	 http://www.equinix.com/company/green/ http://www.equinix.com/company/green/green-data-centers/ http://www.equinix.com/company/green/green-certifications/ http://www.equinix.com/company/green/green-awards/
Trade associations and professional bodies	-

Appendix 2. Detailed overview of reviewed LCA studies.

Study ID	Title/authors of the study and year of publication	Subject of the study and data centre type ¹²³	Functional Unit	Time and geographi- calscope	LCA methodology	Impact categories	Data quality aspects ¹²⁴	Main conclusions
S1-DC	Environmental burdens of data centres – not only the use stage matters. Makiconsulting, 2016.	A data centre with 160 server racks, 500 m2 floor space, packed with 2U servers, virtualisation and a PUE 1.42	One year of operation	2015	Attributional LCA with system expansion for end of life	Acidification, global warming potential incl. biogenic carbon, photochemical ozone formation (human health), resource depletion (water), resource depletion (mineral, fossils & renewables), particulate matter/respirator organics, ozone depletion	Data based on data centre life cycle assessment guidelines (the Green Grid), JRC report on servers, Lot 27 on UPS and PEF rules for IT equipment (storage)	The use phase is dominant for resource depletion (water), photochemical ozone formation, global warming potential and acidification. The production is for resource depletion (minerals, fossils & renewables), particulate matter and ozone depletion.
S2-IT	Environmental Footprint and Material Efficiency Support for product policy - Analysis of material efficiency requirements of enterprise servers EC JRC Science & Policy Report, Perio & Ardente	Rack-optimised enterprise servers used in the three data centre types	One enterprise server	Four year operation during use phase (i.e. lifetime of the server)	Attributional LCA with system expansion for end of life modelling using GaBi software	The 12 categories in the International Reference Life Cycle Data (ILCD) handbook and recommended by Product Environmental Footprint (PEF) ¹²⁵ , plus Primary energy	Life cycle inventory data from Ecoinvent, PE-GaBi, Stanford Research Institute, International Aluminum Institute and a journal article ¹²⁶	The use phase is the dominant for 9 of the 15 impact categories. Manufacturing (incl. raw materials extraction and transport) are the dominant for 6 of them (i.e. all related to toxicity, freshwater eutrophication, ozone depletion and abiotic depletion (elements)

¹²³ Enterprise, Colocation or Managed Service Providers as defined in chapter 3

¹²⁴ Data quality assessment, external critical review and/or article in peer reviewed journal

¹²⁵ COMMISSION RECOMMENDATION of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations – Annex II Product Environmental Footprint (PEF) Guide

¹²⁶ Hischier, R., M. Classen, et al. (2007). Life cycle inventories of electric and electronic equipment: production, use and disposal. Final report Ecoinvent data v2.0. No 18/Part II. Duebendorf and St.Gallen., Swiss Centre for Life Cycle Inventory, ETHZ.

Study ID	Title/authors of the study and year of publication	Subject of the study and data centre type ¹²³	Functional Unit	Time and geographi- calscope	LCA methodology	Impact categories	Data quality aspects ¹²⁴	Main conclusions
	(September 2015)			Manufacture in China, use in Europe		demand (gross cal. value) [MJ], Abiotic Depletion (elements) [kg Sbeq.] and Acidification Potential [kg SO ₂ -eq.]	have been used for the life cycle modelling	
S3-IT	Preparatory study for implementing measures of the Ecodesign Directive 2009/125/EC. DG ENTR Lot 9 - Enterprise servers and data equipment. Task 5: Environment & Economics. Final report, Bio by Deloitte and Fraunhofer IZM for European Commission, DG Internal Market, Industry, Entrepreneurship and SMEs (July 2015)	Enterprise servers and enterprise storage (i.e. rack servers, blade systems with 8 blade servers, storage hybrid system in the SNIA Online 2-3 category), used in three data centre types	Three average servers and storage units technologies used in the EU-28 market (i.e. base cases) with a technology level of 2012	2010-2012 4/6 year product life Servers and storage units used in the EU (average EU-28)	Attributional LCA with system expansion for end of life using EcoReport tool (MEErP)	Total energy (gross energy requirement), water (process) water (cooling) waste (hazardous and non-hazardous), GWP100 ¹²⁷ , acidification, volatile organic compounds (VOC), persistent organic pollutants (POP), heavy metals into air, polycyclic aromatic hydrocarbons (PAHs), particulate matter (PM, dust), heavy metals into water, eutrophication	Emission factors for life cycle inventory from EcoReport tool - some data may be outdated since they cover a time period of 2005 to 2010	The use phase is dominant for the three technologies for total energy, water for cooling, GWP100, acidification and VOCs. The material phase is dominant for POPs, heavy metals, PAHs and PMs. A comparison between this and JRC study (mentioned above), shows an underestimation of the material/manufacturing and EoL impacts by the EcoReport tool for rack servers. However, even taking this underestimation into account, the -dominant phase is still the use phase.
S4- COO	Further study of Life Cycle Assessment of a high density data center cooling system – Teliasonera's "Green	Teliasonera "Green Room", which is a cooling system incorporating free	The lifespan of a "Green Room", which is 20 years	Up to 20 year lifespan Comparison of four	Attributional LCA with system expansion to model end of	Fossil depletion, global warming potential human health, global warming potential	Average datasets for electricity grid mix of Sweden, Finland and UK from 2011. Not	The local climate and local electricity sources could fundamentally influence the Green Room's environmental Performance. When the site is

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¹²⁷ Global Warming Potential impact evaluated in a 100 year period

Study ID	Title/authors of the study and year of publication	Subject of the study and data centre type ¹²³	Functional Unit	Time and geographi- calscope	LCA methodology	Impact categories	Data quality aspects ¹²⁴	Main conclusions
	Room" concept, Wang 2013	cooling and internal recycling of heat. Applicable to the three type of data centres.	consuming90 00+ MWh electricity	European cities (in Finland, Sweden, UK)	life	ecosystems, particulate matter formation and human toxicity	specified for manufacturing (although mentioned data was limited). Simapro 7.2 (2012) with EcoInvent database v2.0 plus ReCiPe for Impact Assessment.	installed in an area with higher share of renewables, the utilization phase only becomes important at the 8 th -9 th year after start using the Green Room. The use of a natural coolant is confirmed as a key for sustainable cooling innovation since it could substantially reduce both energy consumption and environmental impact.
S5-DC	Life Cycle Assessment of Data Centres and the Development of a Software Tool for its Application, PhD thesis, LSBU 2013, Whitehead	Wynyard Enterprise 13 MW Data Centre, classified as Tier III, which is a concurrently maintainable data centre (see Table 6) with a PUE of 1.17	Provision of 1kW of IT per year in a Tier III facility	Building structure 60 years, IT refresh 3 years, batteries 10 years, facilities 20 years Manufacturin g datasets from different regions of the world, end of life mostly from ecoinvent (EU and Switzerland based), operation datasets from UK, Europe and USA	Eco-indicator 99, hybrid LCI and EIO	Human health, ecosystem quality, resources, carcinogens, respiratory organics, respiratory inorganics, global warming potential, radiation, ozone layer, ecotoxicity, acidification / eutrophication, land use, minerals, fossil fuels	PhD thesis: external critical review, articles in peer reviewed journal – not to be used for comparative assertions intended to be disclosed to the public – data was considered generally representative, consistent and reproducible (modelled in SimaPro)	The overall impacts are dominated by the production of electricity and the fuels required for it and the second is the disposal of waste products from the refining of metals in IT components and from electricity distribution networks – as a conclusion, three parameters are sensitive to changes in the design of a data centre and influence the overall impact: the level of energy consumed in operation for the IT equipment, cooling, and power delivery; the energy mix used to provide electricity; and the total IT equipment used in the facility's lifetime
S6-DC	Sources of Variability in Data Center Lifecycle	Representative US baseline	One year of operation,	Facilities & building	Impact 2002+	Global warming potential,	Peer reviewed, published in 2012	The majority of the contributions to the total normalised damage to

Study ID	Title/authors of the study and year of	Subject of the study and data	Functional Unit	Time and geographi-	LCA methodology	Impact categories	Data quality aspects ¹²⁴	Main conclusions
	publication Assessment, Shah et al 2012	entre type ¹²³ enterprise data center with a PUE of 1.8 (raised- floor, air-cooled, data centre incl. the building and a chiller), which is a traditional data centre in the USA	including embodied impacts at a compute, storage, and networking equipment ratio of 80%, 10%, and 10%	calscope lifetime 20 years, IT system lifetime 4 years USA		Ecosystem Quality, Human Health, Resource Depletion	IEEE International Symposium on Sustainable Systems and Technology (ISSST) – Embodied emission factors from Ecoinvent 2.0 data from 2007	global warming potential, ecosystem quality, human health and resource depletion are coming from the IT and facilities, those from the building are almost non- visible; the contribution from IT is about 52% and overall the highest contributions come from the use stage
S7-DC	The carbon emissions of server computing for small to medium sized organisations. A Performance Study of On-Premise vs. the Cloud, WSP Environment & Energy LLC, Natural Resources Defense Council (2012)	The study compares the estimated efficiency of four commonly used small-to- medium-sized organizations (SMO) software applications (email, CRM & Web, Finance & Accounting, File storage & Sharing) against five computing deployment scenarios: Enterprise (virtualised and not virtualised), Colocation (not virtualised), Private cloud and Public cloud.	Carbon emissions per user per year, carbon emissions per GB storage per year	Time period considered: a one-year application use, licensing, or subscription agreement.	Aligned to the assessment methodology developed by the Global e-Sustainability Initiative (GeSI) following the development of the Greenhouse Gas (GHG) Protocol ICT Sector Guidance for Cloud Computing and Data Center Services.	Carbon footprint based on the GHG Protocol declaring six primary GHG gases: carbon dioxide (CO2), sulphur hexafluoride (SF6), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons, (HFCs), and perfluorocarbons (PFCs).	Only the IT facility included with life cycle data from different industry sources, and electricity grid based on US average from 2012 published by US EPA.	For the four deployment scenarios and under standard conditions, the enterprise data centres w/o virtualisation as well as the colocation data centres present more than triple Carbon Footprint per application compared to enterprise with virtualisation, private and public cloud data centres. For File storage & sharing as well as for finance & accounting, the public cloud performs significantly better, however for email and for CRM& web, the difference between enterprise with virtualisation, private and public cloud data centres is almost negligible. Identified best practices for enterprise data centres with virtualisation show about 15x times reduction compared to worst case and about 7x times compared to average.
S8-DC	Environmental Performance of Data Centres - A Case Study of the Swedish National	Swedish National Insurance Agency colocation data centre in	One year of platform operations in the year	2010 For disaster recovery	Attributional LCA with system expansion for	Electricity use in operations and lifecycle accumulated green	Conference paper at Electronics Goes Green conference 2012.	The procured assets (i.e. production, transport and waste management) contribute by 33% of the total carbon footprint, while

Study ID	Title/authors of the study and year of publication	Subject of the study and data centre type ¹²³	Functional Unit	Time and geographi- calscope	LCA methodology	Impact categories	Data quality aspects ¹²⁴	Main conclusions
	Insurance Administration, Honee et al 2012	Sundsvall, Sweden (x2 locations). The centre is operated on a 7x24 basis, equipped with redundant Power Distribution Systems (PDS) fitted out with battery run uninterruptable power supplies (UPS) and diesel fuelled electric generation sets.	2010	reasons, it is situated at two physically separated locations around Sundsvall in northern Sweden.	end of life	house gas emissions indicated as 'Carbon footprint' using ReCiPe characterisation factors for global warming potential impact	For the foreground datasets, ecoinvent 2.2 (2007) was used, electricity supply was modelled using the Swedish grid mix from 2005, and the rest of the data (mostly materials data) was sourced from Environmental Product Declarations from vendors.	operation does by 67%. The IT platform contributes by about 67% of the total carbon footprint, while the facility by 37% (from this, 38% is from the procured assets). The environmental load associated to the procured assets of the data centre is significant and to a large extent dependent on the relatively short economic lifespan and specific configuration of IT equipment.
S9-DC	The Environmental Footprint of Data Centers, Shah et al 2009	An hypothetical data center (type not specified)	The data center through its lifetime	3 year lifetime USA	Hybrid LCA (Process LCA and Economic Input-Output)	Total Energy Use (TJ), GWP (mt CO2- eq.), Total Toxic Releases (kg), PM- 10 Air Pollutants (mt)	Data based on macroeconomic data in the USA. For the IT system, process LCA data was used. Peer reviewed, published by ASME (InterPACK'09)	The compute infrastructure contributes to the four impact categories with a range of 45%-55%, while the cooling does within a range of 35-50%. In the case of Total energy and GWP, the share is about 45/45%. The embodied impacts are only high for the toxic releases (about 65%) and PM-10 air pollutants (about 60%).
S10-DC	Greenhouse Gas Emissions and Operational Electricity Use in the ICT and Entertainment & Media Sectors, Malmodin et al (2010)	ICT and Entertainment & Media Sectors (all data center types)	Installed base of data centres used mid year 2007 using an average of energy use	2005/2007 Global	The GWP was calculated based on multiplying stock and equipment with emission factors found from literature.	Electricity use and CO2-eq.	Installed base, electricity consumption and emission factors from manufacturing of equipment gathered from available studies. The estimate for data center infrastructure	About 20 million tons of CO2-eq out of 170 come from manufacturing and business overhead. The rest come from operation of the network (incl. data centers).

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