Sustainability Assessment Guidance for Digital and Energy Services Infrastructure

IPCEI-CIS MISD - Deliverable 2.8
Version 2.0

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Summary

Goal: The Sustainability Assessment Guidance for Digital and Energy Services Infrastructure (SAG-DESI) provides a comprehensive guide for assessing the environmental sustainability of data center infrastructures that offer both digital and energy services. This guidance aims to help digital service providers comply with sustainability reporting requirements, integrate ESG criteria, and innovate in delivering sustainable services. SAG-DESI is designed to support the assessment and benchmarking of sustainability improvements by building on the established Greenhouse Gas Protocol Product Standard.

Motivation: While there are existing standards and methods for assessing the sustainability of digital services, there is a lack of integrated guidance that combines digital and energy services, such as (waste) heat reuse, particularly in the context of data centers. The SAG-DESI addresses this gap by providing specific assessment guidance for these combined services.

Audience: The intended audience of this document are sustainability assessment experts, service operators in the cloud/edge services domain, and data center operators that develop heat services integrated with energy infrastructure.

Scope: The sustainability impact factors considered are greenhouse gas emissions in scope 1, 2, and 3, as defined internationally by Greenhouse Gas Protocol. The detailed guidance and key sustainability indicators are scoped to infrastructure services, being digital services that provide essential digital functionalities like compute, storage, and networking, in combination with heat energy services. Three main sources of emissions are considered in scope: data centers, end-user devices, and (telecommunication) networks.

Context: This document was developed within the IPCEI Next Generation Cloud Infrastructure and Services (IPCEI-CIS) program, specifically under the Modular Integrated Sustainable Datacenter (MISD) project. In this project, the aim is develop next-generation modular sustainable edge data centers that integrate the delivery of digital services with energy services like heat provisioning.

Publication notes:

- *The material included in this report was presented at the EnviroInfo 2025 conference in Potsdam, Germany, and will appear in the Springer Nature book series Progress in IS in the conference proceedings Advances and New Trends in Environmental Informatics – EnviroInfo 2025 [1].*
- *An earlier version of this report is available as TNO Internal 2024 R12703.*

Contents

1 Introduction

The Sustainability Assessment Guidance for Digital and Energy Services Infrastructure (SAG-DESI), described in this document, provides assessment guidance for environmental sustainability of (data center) infrastructures that offer digital services in combination with energy services.

In particular, by supporting assessment according to the Greenhouse Gas Protocol Product Standard (GHGP-ICTSG) [1] and ICT-Sector Guidance [2], the SAG-DESI is aimed at digital service providers, which, for example:

- are required by the Corporate Sustainability Reporting Directive (CSRD) [3] to deliver sustainability reporting following the European Sustainability Reporting Standard (ESRS) [4].
- include environmental, social and governance (ESG) criteria in the organizational strategy with a need to report status and progress to stakeholders.
- innovate in the delivery of digital services in combination with energy (e.g., heat) services with the goal of realizing sustainability improvements.

The SAG-DESI was developed within the context of the IPCEI Next Generation Cloud Infrastructure and Services (CIS)[1] program, and specifically within the project Modular Integrated Sustainable Datacenter (MISD), as project deliverable 2.8.

The document is organized as follows: The remainder of this section provides the scope of the assessment guidance and gives a summary of the approach. Section 2 provides general definitions and key sustainability indicators for digital and energy services infrastructures. Based on that, Section 3 provides assessment guidance for specific types of digital services. Section 4 discusses related work.

1.1 Scope and Approach

Sustainability is a broad concept comprising environmental, societal, and economic considerations[2]. The guidance in this document is limited to the assessment of environmental aspects of sustainability in digital services infrastructure following the Greenhouse Gas Protocol Product Standard [1].

The scope is further limited to reporting on the following key indicators:

- Electricity consumption and CO2-equivalent (embodied) emissions measured within data centers and its allocation to digital services.
- Useable energy production measured on data center components and its allocation to energy services. This version of SAG-DESI is limited to heat energy services, only.
- Service-specific functional outputs of digital services (e.g., users served, compute minutes delivered).

In summary, SAG-DESI first provides practical definitions of the components of a digital and heat-energy services infrastructure. These definitions apply to digital services that are

1 https://competition-policy.ec.europa.eu/state-aid/ipcei/approved-ipceis/cloud_en
2 https://en.wikipedia.org/wiki/Sustainability

relevant to the Cloud/Edge continuum: infrastructure- (IAAS), platform- (PAAS), and application services (SAAS), in combination with heat energy services. For high-level assessment and reporting, the guidance provides two key sustainability indicators for data centers, Power Usage Effectiveness with Heat Reuse (PUEHR) and Carbon Usage Effectiveness with Heat Reuse (CUEHR).

The assessment guidance builds on top of the *ICT Sector Guidance built on the GHG Protocol Product Life Cycle Accounting and Reporting Standard* [2] to offer detailed steps and reporting templates to facilitate a GHG Product Standard-compliant assessment.

The guidance should be considered a companion to GHGP-ICTSG, not a stand-alone assessment methodology. It is assumed the reader has in-depth knowledge of both the GHG Product Standard and GHGP-ICTSG.

1.2 Roadmap

This document represents version 1.0 of SAG-DESI. At the time of writing, the following directions for further development of SAG-DESI are foreseen by the authors:

- Developing reporting tools that facilitate the completion of the various template tables that SAG-DESI provides. Potentially, an automated tool could collect data from a data center's orchestration & measurement software and pre-fill the assessment tables.
- Further detailing of the allocation methods available for platform- and application services (PAAS and SAAS). It is expected that progress in the IPCEI CIS program will impact those categories of digital services to a large extent.
- Applying the assessment guidance on several cases within the MISD project or the broader IPCEI CIS program to collect practical experiences and feedback for future iterations of SAG-DESI.
- Integrating upcoming types of energy services (in addition to heat) such as energy flexibility, grid balancing, storage, and so on. The energy transition is evolving the market for data centers and digital infrastructures, which could introduce more opportunities for data centers to offer sustainable services.
- Adding of organizational guidance that helps stakeholders within a (complex) organization to define their roles and responsibilities for specific tasks and outcomes of the assessment.
- Including other relevant environmental sustainability impact factors. SAG-DESI is limited to one impact factor: GHG emission. While GHG emission is the most pressing factor for assessment and reduction, other important factors exist such as critical materials, biodiversity, water usage, toxic emissions, and so on. For the inclusion of such impact factors the adoption of broader life-cycle assessment approaches are needed, such as *prospective life-cycle assessments*.

2 Digital and Energy Services Infrastructure

This assessment guidance combines two domains of services: the Cloud/Edge continuum and the Energy domain. The Cloud/Edge continuum is an ecosystem of digital services meant to provide compute, storage, networking, platform building, and application services, to users, and to other digital services within the continuum. The Energy domain offers services that provide heat, electricity, storage, and so on. This document only includes heat services in scope.

Figure 2.1 provides an overview of how the digital services in the Cloud/Edge continuum are connected to heat services in the Energy domain. In a nutshell, this document considers data centers that support the delivery of both types of services. Figure 2.1 indicates with arrows that digital- and heat services depend on data centers for their operation. On the right hand side the allocation done in a sustainability assessment likewise depend on actual measurement data collected within data centers.

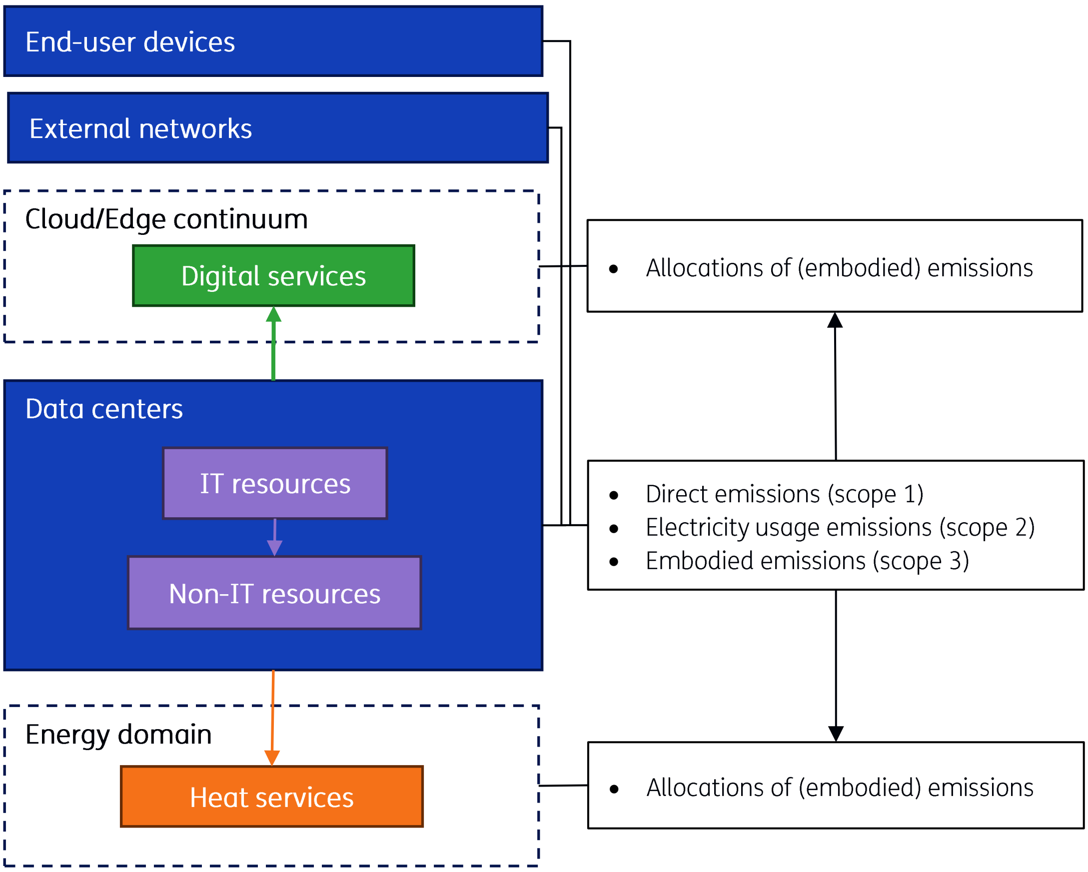

Figure 2.1: Overview of SAG-DESI infrastructure components definitions (left) and assessment guidance scope (right). The definitions of infrastructure components follow in the section below.

2.1 General definitions

The following general definitions apply across SAG-DESI:

- **Data centers** provide hosting space, electricity, cooling, and connections to Information Technology (IT) resources. To this end, data centers rely on non-IT resources.
- **Non-IT resources** are pieces of (electronic) equipment for purposes such as hosting, cooling, and monitoring, including building services such as floor space, lighting, building-heating, emergency power facilities (e.g., UPS, batteries, and diesel generators), security, and maintenance.
- IT **resources** are pieces of IT equipment (e.g., servers, routers) that are hosted in a data center, and that provide compute, storage, and networking capabilities.
- **Digital services** are services within the Cloud/Edge continuum that use IT resources or other digital services to provide digital functional outputs. As examples, digital services can provide bare metal servers, compute, storage, virtualization technology, and other components of cloud platforms, or processing service appliances and software applications-as-a-service.
- **Infrastructure services** are digital services that only uses IT resources from a data center, and no other digital services. Commonly such digital services are referred to as Infrastructure As A Service (IAAS). As an example, a service providing the use of a bare metal server is an infrastructure service.
- **Platform services** are digital services that rely on infrastructure services, or on other platform services. A common name for such services is Platform As A Service, or PAAS. They are commonly used by application services, rather than directly by end users.
- **Application services** are digital services that rely on platform- or infrastructure services and that are typically used by end users directly. A common name for such services is Software-As-A-Service, or SAAS.
- **End-user devices** are used to access digital services by users. Examples are PCs, laptops, tablets, phones, or other devices.
- **External networks** refers to the connectivity infrastructure that connects data centers to end-user devices, e.g. the internet and telecommunication networks.
- **Energy services** are services within the energy domain that leverage energy (e.g., heat) produced by data centers, e.g. by integrating into heat grids or building heating systems.

2.2 Key sustainability indicators

For overall reporting on digital services infrastructures in combination with heat energy services, the following key sustainability indicators are defined. The key indicators can be used on their own for global assessments of data centers, but their integration into a detailed assessment of digital services is discussed in Section 3.

- T Time period for reporting, e.g. calendar or financial reporting year.
- KWH_{IT} Power consumption of IT Resources during T in kilowatt-hours.
- C_{IT} The carbon intensity associated with power usage of IT Resources in $gCO2/kWh$.
- $CO2_{IT}$ Estimated tons of CO2-equivalent emissions caused by KWH_{IT}.
- KWH_{NonIT} Power consumption of Non-IT Resources during T in kilowatt-hours.
- C_{NonIT} The carbon intensity associated with power usage of Non IT Resources in $gCO2/kWh$.
- $CO2_{NonIT}$ Estimated tons of CO2-equivalent emissions caused by KWH_{NonIT}.
- KWH_{Heat} Delivered heat in kilowatt-hours equivalent, i.e. $1\ MJ = 0.278$ kWh.
- $CO2_{Heat}$ Estimated tons of CO2-equivalent emissions of KWH_{Heat}.

- C_{Heat} The carbon intensity associated with power usage of reused heat in $gCO2/kWh$.

The estimation of CO2-equivalent emissions is commonly done using emission factors applied to the amount of electricity consumed. The emission factors can depend on several variables such as location, time-of-day, and electricity production method(s). These factors are limited to scope 1 and 2 emissions and do not include (scope 3) embedded emissions. Hence these indicators do not represent a complete GHG assessment.

The two key sustainability indicators are defined as:

Eq. 2.2.1 Power Usage Effectiveness with Heat Reuse (PUEHR):

$$PUEHR = \frac{KWH_{NonIT} + KWH_{IT}}{\boldsymbol{KWH_{Heat}}}$$

Eq. 2.2.2 Carbon Usage Effectiveness with Heat Reuse (CUEHR):

$$CUEHR = \frac{KWH_{NonIT} C_{NonIT} + KWH_{IT} \cdot C_{IT}}{\boldsymbol{KWH_{Heat} \cdot C_{Heat}}}$$

The terms introduced by the heat reuse are written in green.

Note that carbon intensities can potentially be different between IT- and Non-IT Services. In practice, it is common to apply averages of carbon intensities over a time period.

Estimates of national carbon intensities at a yearly timescale are available at Our World in Data[3] or other online sites.

[3] https://ourworldindata.org/grapher/carbon-intensity-electricity

3 Sustainability Assessment Guidance

The following sections provides concrete assessment guidance to support in fulfilling the reporting requirements defined by the GHG Product Standard, Chapter 13 [1]. The assessment guidance is a concretization of the *ICT Sector Guidance built on the GHG Protocol Product Life Cycle Accounting and Reporting Standard* (GHGP-ICTSG) [2] for digital and energy services infrastructures.

This guidance should be considered a companion to GHGP-ICTSG, not a stand-alone assessment methodology. It is assumed the reader has knowledge of both the GHG Product Standard and GHGP-ICTSG.

Two important considerations for the implementation of this assessment guidance are, as mandated by the GHG Product Standard [1]:

- Consumed electricity (kWh), related emissions (CO2-equivalents), and emission factors (power-mix, kWh to CO2) should all be reported.
- Enabling effects, or avoided emissions due to digital and energy services usage should not be used to discount emissions caused by the digital and energy services.

SAG-DESI focuses on three types of digital service in combination with one or more heat energy services. Respectively, infrastructure services, platform services, and application services are covered. Heat energy services are discussed in combination with the digital services.

The assessment guidance proceeds by covering the topics required for reporting by the GHG Product Standard: scope definition, boundary setting, data collection and data quality, allocation, uncertainty, calculating inventory results, assurance. For each topic, the guidance offers references to the relevant elements in GHGP-ICTSG and provides assessment templates to help address reporting requirements.

3.1 Infrastructure services

To facilitate the assessment guidance below, Figure 3.1 depicts a common scenario involving multiple infrastructure services using multiple IT resources in a data center. The data center is also involved in offering a heat service, in this instance.

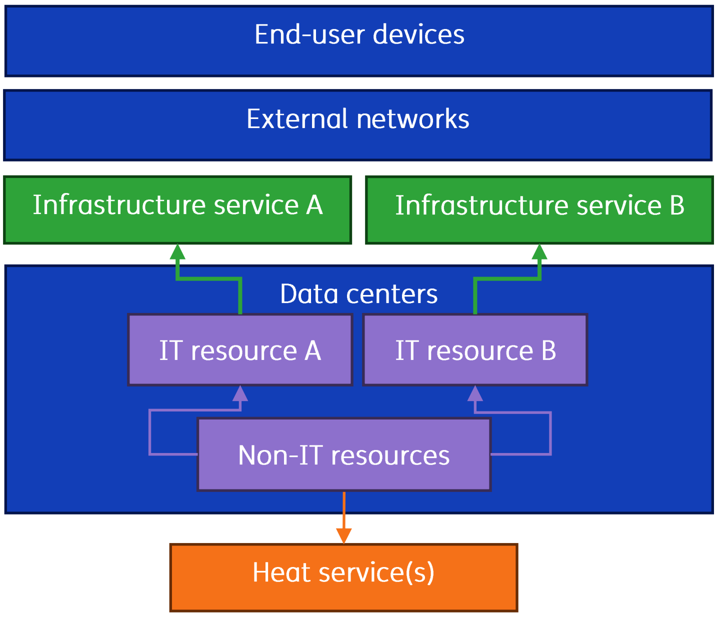

Figure 3.1: Example infrastructure services A and B use IT resources A and B, respectively. Both IT resources rely on the Non-IT resources present in the data center. The data center also offers a heat service based on its aggregated heat production of its IT and non-IT resources. To make use of the services, the user depends on end-user devices and an external networks (e.g., the Internet) for connectivity.

Scope definition

GHGP-ICTSG: 1.8.1, page 1-16, and 4.3, page 4-11.

Table 3.1 gives a scope definition template with examples for functional unit definition of infrastructure and heat services.

Infrastructure services provide low-level digital functionality. Commonly, compute, storage, and connectivity are provided as digital functionalities, either offered separately or in combinations, either as bare metal- or virtualized resources.

As part of the scope definition, an assessment should define a functional unit that covers service quantity, duration, and quality. GHG assessments depend on functional units to normalize emission calculations in reporting.

Table 3.1: Scope definition template with examples for functional unit definition of infrastructure and heat services.

Functional unit	Examples	Quantity	Period or duration	Quality
Compute	CPU, GPU, or specialized computing resources offered either as bare metal- or virtualized machines.	• Compute minutes • VMs • Servers	• Calendar year • Accounting year • Contract duration	• CPU, GPU speeds • RAM capacity • Availability • Spin-up delays • Virtualization
Storage	Persistent data storage using hard drive, flash, and other storage technology, offered either as bare metal- or virtualized storage.	• GBs stored • I/O operations	• Calendar year • Accounting year • Contract duration.	• I/O speeds • Redundancy • Encryption • Virtualization
Connectivity	Network switches, routers, firewalls, and other networking equipment.	• GBs transferred • Rules processed	• Calendar year • Accounting year • Contract duration	• Ingress/egress speeds • Network latency • Security • Virtualization
Heat	Air- or water-based heat energy from a data center's cooling system, piped to a building heating system, or residential heat grid.	• MJs heat energy	• Calendar year • Accounting year • Contract duration	• Temperatures • Availability • 1/2 Phase

Boundary setting

GHGP-ICTSG: 1.8.1, page 1-17, and 4.4, page 4-13, and Chapter 5, page 5-1.

Table 3.2 provides a boundary setting template with examples for infrastructure and heat services.

Infrastructure services create emissions in all three contexts: end-user devices, external networks, and data centers, with data centers being the most prominent. An assessment should document and justify its boundaries in each emission context by covering the following aspects:

- processes directly attributable to the service delivery,
- processes that should not be attributed, and
- details on the amortization period of equipment involved in the service delivery.

Table 3.2: Boundary setting template with examples for infrastructure and heat services.

Emission context	Attributable processes	Non-attributable processes	Amortization
End-user devices GHGP-ICTSG: Chap. 5	• User access • User side processing • Service operation and maintenance	• Non-service device operation and maintenance.	• Estimated lifetimes of involved devices, e.g. 3 – 5 years for end-user devices.
External networks GHGP-ICTSG: Chap. 2	• Connectivity • Data-transfer • Security	• Production and maintenance of capital equipment, transportation vehicles, buildings, not directly related to service delivery.	• 5-15 years for networking equipment.
Data centers GHGP-ICTSG: Chap. 4	• Hosting and operation of IT and Non-IT Resources • Cooling • Electricity provisioning • Heat upgrading	• Production and maintenance of capital equipment, transportation vehicles, buildings, not directly related to service delivery.	• 18 months – 5 years for IT equipment. • 5 – 10 years for heat production equipment.

Data collection and quality

GHGP-ICTSG: 1.8.3, page 1-19, and 4.5, page 4-14.

Table 3.3 provides a data collection and quality template for infrastructure and heat services.

The assessment needs to collect data on each of the attributable processes that belong to the infrastructure and heat services as defined within the assessment boundary, for the period specified in the assessment scope. The focus here is on documenting the data collection itself, while the next section will cover the allocation of the collected data to the service(s) under assessment.

In addition to data collection on emission contexts, data collection is needed on the number of functional units realized by the services, including reused heat energy, using the quantities defined in Table 3.1.

In practice, data collection will consist of requesting (secondary) data from service vendors, data centers owners, and other infrastructure stakeholders, that are outside of control of the assessment party. This is permitted under the GHG Product Standard. However, the data collection documentation should be accompanied by a data quality assessment as specified by the Product Standard, section 8.3.7 [1].

For the purpose of the next assessment steps, Table 3.4 provides an emissions inventory and allocation template that should be used to collect the results of data collection.

Table 3.3: Data collection and quality template with examples for infrastructure and heat services.

Emission context	Data collection	Data quality assessment
End-user devices GHGP-ICTSG: Chap. 5	• Embodied emissions • Electricity consumption	• Primary data process • Secondary data sources • Representativeness • Completeness • Reliability
External networks GHGP-ICTSG: Chap. 2	• Embodied emissions • Internet traffic • Traffic on other networks	• Primary data process • Secondary data sources • Representativeness • Completeness • Reliability
Data centers GHGP-ICTSG: Chap. 4	• Embodied emissions • Provisioned capacities • Electricity consumption of IT Resources at idle, average, and peak loads • Electricity consumption of Non-IT Resources at idle, average, and peak loads, including specific equipment for heat services, e.g. heat pumps • Direct emissions from e.g. diesel generators	• Primary data process • Secondary data sources • Representativeness • Completeness • Reliability

Allocation

GHGP-ICTSG: 1.8.4, page 1-20, and 4.6, page 4-18.

The objective of the allocation step is to allocate power consumption and emission data to the services in scope of the assessment. Table 3.4 provides a template for the outcome of this step by outlining the emissions inventory and allocations result with example items and data. The example reflected in Table 3.4 matches the scenario in Figure 3.1 where two infrastructure services A and B are supported by a data center, an external network (the internet), and end-user-devices.

The process of allocation is highly dependent on context and available data. GHGP-ICTSG section 4.6 provides allocation methods and formulas for data center and (cloud) services that can be used within the constraints of the GHG Product Standard [1], while providing multiple options depending on data availability and desired level of detail. In the following it is assumed that the appropriate allocation method for the digital services is chosen and applied.

The allocation method chosen should be clearly documented as part of the assessment.

The focus in this guidance is on the presence of heat services as additional sources of power use and emissions. The heat services are assumed to reuse heat energy from a data center's cooling system (e.g. hot water or air). In some cases heat pumps or other equipment can be necessary to upgrade or transport heat, which can consume power itself or create direct emissions.

In the section Calculating Inventory Results the final total allocations to services are done. That step re-distributes the emissions allocated to infrastructure services within the data centers emission context by allocating emissions to the heat service proportional to the heat energy it has delivered.

Table 3.4: Emissions inventory and allocation result template with example inventory items, power consumption, and emission data. The data collection process should provide fixed (idle) and variable (load-dependent) power consumption (both scope 2 emission sources), and embodied (scope 3) and direct (scope 1) emissions, e.g. from diesel generators. Allocations for each emission inventory item should add up to the total to ensure all (non-zero) emissions within the assessment boundary are accounted for or explicitly assigned to the out-of-boundary item.
* Using an example carbon intensity of 0.00039 tons of CO2 per kWh.

Emission context	Inventory item	Power consumption in kWh		Emissions in tCO2e			
	Examples	Fixed Power	Variable Power	Embodied	Direct	Fixed Power*	Variable Power*
End-user devices	Laptop	100	200	100	0	0.0390	0.0790
Allocations	Digital service A	20	40	20		0.0078	0.0156
	Digital service B	20	40	20		0.0078	0.0156
	Out-of-boundary	60	120	60		0.0234	0.0468
External networks	Internet traffic	0	10	0	0	0	0.00390
Allocations	Digital service A		2				0.00078
	Digital service B		2				0.00078
	Out-of-boundary		6				0.00234
Data centers	IT Resources	100,000	70,000	500	0	39.0	27.3
Allocations	Digital service A	40,000	30,000	50		15.6	11.7
	Digital service B	60,000	40,000	50		23.4	15.6
	Out-of-boundary	0	0	400		0	0
Data centers	Non-IT Resources	10,000	5,000	452	88	3.90	1.95
Allocations	Digital service A	4,000	1,500	50	0	1.56	0.585
	Digital service B	6,000	2,500	50	0	2.34	0.975
	Heat service	0	1,000	2	3	0	0.390
	Out-of-boundary	0	0	350	85	0	0

Calculating inventory results

GHGP-ICTSG: 1.8.6, page 1-22 and 4.7, page 4-24.

This final assessment step summarizes the inventory results and allocated emissions (Table 3.4) into an emissions summary per service, and per functional unit delivered.

Table 3.5: Calculating inventory results template that summarizes the example data in Table 3.4 for illustrative purposes. The final columns Adjusted data centers and Adjusted total are calculated using the process outlined in Figure 3.2.

Service	Functional units	CO2-equivalent emissions (tons)					
Examples	*Example quantities*	Data centers	External networks	End-user devices	Total & per unit	Adj. data centers	Adj. total & per unit
Digital service A		129	0.000780	20.0	149	122	142
Compute (minutes)	144,000				0.00103		0.000988
Digital service B		142	0.000780	20.0	162	135	155
Compute (minutes)	216,000				0.000750		0.000716
Heat service		5.4	0	0	5.4	19.5	19.5
Heat (kWh) Heat (CO2-equiv.)	50,000 19.5				0.000108 0.278		0.000390 1.00
Total emissions		276	0.00156	40	316	276	316

In the following, definitions and formulas are provided to support the completion of Table 3.5.

First define the sets S, D, and H, respectively for all services, all digital services, and all heat services in scope of the assessment, and such that $S = D \cup H$, and $D \cap H = \emptyset$.

With $s \in S$, define the following lookup functions:

- $CO2_{IT}^{Emb}(s)$ Embodied emissions of IT Resources allocated to s,
- $CO2_{IT}^{Dir}(s)$ Direct emissions of IT Resources allocated to s,
- $CO2_{IT}^{Fix}(s)$ Fixed power-related emissions of IT Resources allocated to s,
- $CO2_{IT}^{Var}(s)$ Variable power-related emissions of IT Resources allocated to s.

And specifically for heat services $h \in H$:

- $CO2_{Heat}(h)$ the heat energy delivered by heat service h expressed as CO2-equivalent.

Eq. 3.1.1 The total IT Resources emissions allocated to service s is then given by:

$$CO2_{IT}(s) = CO2_{IT}^{Emb}(s) + CO2_{IT}^{Dir}(s) + CO2_{IT}^{Fix}(s) + CO2_{IT}^{Var}(s)$$

Similarly, define lookup functions for Non-IT Resources ($NonIT$), External networks (Net), and End-user devices ($User$), and respectively the totaling functions $CO2_{NonIT}(s)$, $CO2_{Net}(s)$, and $CO2_{User}(s)$.

Eq. 3.1.2 Data center emissions allocated to service s are then given by:

$$CO2_{DC}(s) = CO2_{IT}(s) + CO2_{NonIT}(s)$$

Eq. 3.1.3 The total of emissions of all types allocated to service s is then given by:

$$CO2(s) = CO2_{DC}(s) + CO2_{Net}(s) + CO2_{User}(s)$$

Eq. 3.1.4 The totals of data center emissions allocated to services S, D, and H are then defined as, respectively:

$$CO2_{DC}^{S} = \sum_{s \in S} CO2_{DC}(s)$$

$$CO2_{DC}^{D} = \sum_{d \in D} CO2_{DC}(d)$$

$$CO2_{DC}^{H} = \sum_{h \in H} CO2_{DC}(h)$$

Eq. 3.1.5 The total amount of heat energy delivered by heat services H, expressed as CO2-equivalent:

$$CO2_{heat}^{H} = \sum_{h \in H} CO2_{heat}(h)$$

Adjusting emissions based on heat delivered

The heat delivered by heat services is a joint result of digital and heat services, co-located in the same data center. Most of the heat energy will typically originate from the data center's cooling systems. In some cases, the heat services may also employ some further equipment that upgrades or transports heat, while creating some additional emissions. An example situation has been depicted in Figure 3.2.

The heat production can give rise to a fairness concern regarding the digital services. Their allocated emissions, from power usage and cooling, have contributed to the production of heat. Hence, this guidance suggests an approach to adjust allocated data center emissions in a proportional way. In short, the data center emissions allocated to digital services are partly moved to the heat service(s), while keeping the total data center emissions equal. and the following equations further detail the calculations.

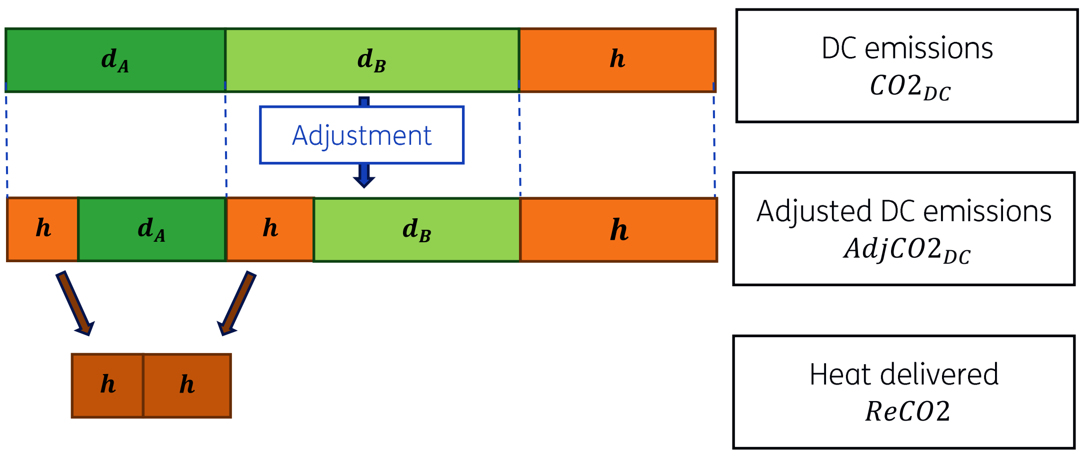

Figure 3.2: Overview of the equivalent CO2 emission adjustment approach for digital and heat services, based on delivered heat. The first row illlustrates the data center emission allocated to two digital (d_A and d_B) and one heat (h) services. The second row illustrates the reallocation of emission after adjustment. The third row highlights the equivalent CO2 emissions of the delivered heat.

Eq. 3.1.6 Define the amount of heat delivered that is used to reduce data center emissions of digital services, taking into account any emissions already allocated to the heat services. Such emissions can be caused by e.g. heat pumps or generators used specifically for the heat services. These definitions assume that heat services should not be “punished” twice for their emissions. Furthermore, heat services that have already caused more data centers emissions than their respective heat productions do not get additional emissions allocated in the adjustment.

$$ReCO2(h) = max(0, CO2_{heat}(h) - CO2_{DC}(h))$$

$$ReCO2^{H} = \sum_{h \in H} CO2_{heat}(h)$$

Eq. 3.1.7 Then, we define the adjusted data center emissions for a digital service $d \in D$ as follows:

$$AdjCO2_{DC}(d) = CO2_{DC}(d) - ReCO2^{H} \cdot \frac{CO2_{DC}(d)}{CO2_{DC}^{D}}$$

Intuitively, the adjustment entails that the emissions of each digital service are reduced by a proportional fraction of the heat energy delivered by the heat services (minus the emissions allocated to the heat services themselves).

Eq. 3.1.8 And finally, the data center emissions of the heat services $h \in H$ are increased with the adjustement amounts that were previously defined:

$$AdjCO2_{DC}(h) = CO2_{DC}(h) + ReCO2(h)$$

Note that the total amounts of data center emissions before and after adjustment are equal, i.e., $\sum_{s \in S} AdjCO2_{DC}(s) = \sum_{s \in S} CO2_{DC}(s)$, because data center emissions that are moved away from digital services S are added in equal amount to heat services H, not discounted from the total.

Uncertainty

GHGP-ICTSG: 1.8.5, page 1-21.

The GHG Product Standard (Chapter 10) requires that assessments include a qualitative statement that documents (known) sources of uncertainty in the inventory and due the methodological choices. In addition to the guidance included in GHGP-ICTSG, assessment including heat services should assess the parameter uncertainty related to measurement of heat production, and the actual delivery amount to clients of the heat services.

Assurance

GHGP-ICTSG: 1.8.7, page 1-25.

The GHG Product Standard (Chapter 12) requires that assessments are assured by a first or third party, including in scope of review the methods’ application, data sources and quality, calculation methods, and documentation.

3.2 Platform- and application services

The cloud/edge continuum consists of interconnected services that built upon each other. While infrastructure services are defined to depend only on IT Resources hosted in a data center, two types of more abstract services are commonly used. Figure 3.3 provides an illustration of the interplay of digital services within the cloud/edge continuum.

In this section, assessment topics specific to platform- and application services are discussed, while noting that this section serves as a starting point for further development of the SAG-DESI:

- *Platform services*. In the IPCEI CIS context, the overall architecture framework 8ra-VirtMO defines yet further platform service types, i.e. Northbound services, which connect to application services, and Southbound services, which connect to infrastructure services [5].

- *Application services.* In the 8ra-VirtMO architecture, SAAS is further differentiated into software appliances, which are pre-configured software packages with an automation focus, and software applications, which focus on end-users [5].

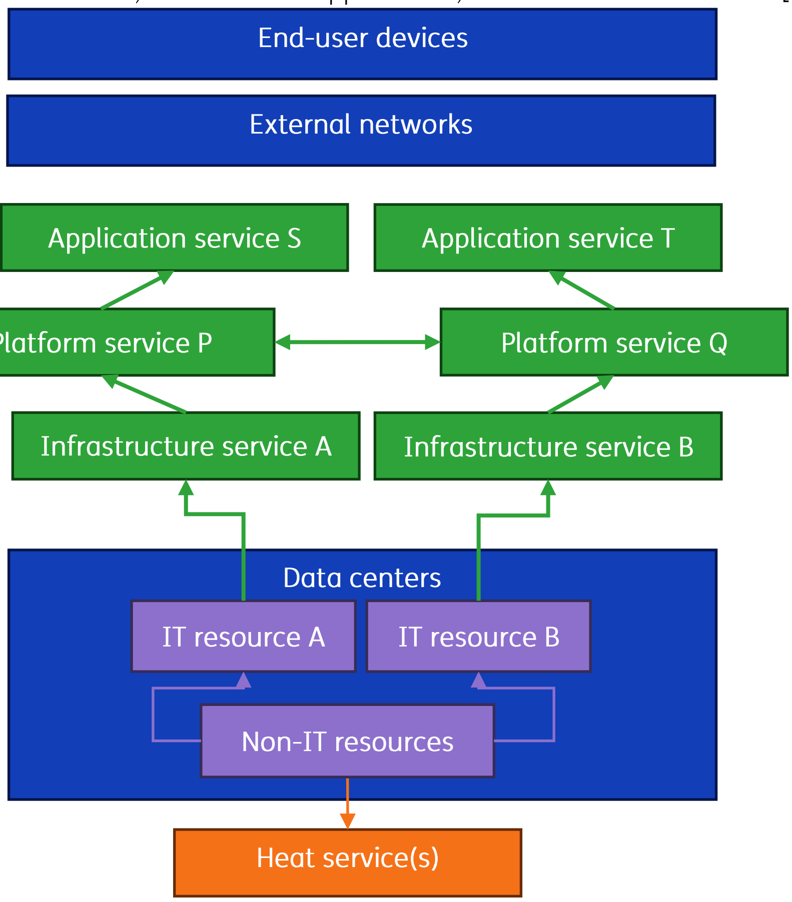

Figure 3.3: Illustration of the cloud continuum consisting of multiple infrastructure, platform, and application services. To make use of the services, the user depends on end-user devices and external networks (e.g., the Internet) for connectivity.

Assessing application- and cloud services is more complex than infrastructure services due to a potentially large number of interdependencies among services. A platform service such as a managed Kubernetes cluster, for instance, depends on infrastructure services offering either virtual machines or bare metals. At the same time, application- and platform services are often creating functional outputs in collaborative fashion.

In perspective of the GHGP-ICTSG, most assessment steps should be applied similar to how infrastructure services are treated above. However, two assessment steps will entail more effort and complexity in case of platform- and application services:

- **Scope definition.** The functional unit definitions of platform- and application services will vary wildly in practice. From Docker containers hosted, to user requests serviced, an assessment will depend on clear definitions and documentation created at the time of assessment, within the specific context of the services and the surrounding infrastructure.

- **Allocation.** As services interdepend on each other, the allocation of emissions should aim for a fair distribution. Definitions of fairness depends on context and be motivated from societal, organizational, or even personal sustainability goals. For each emission context, i.e. end-user devices, networks, and data centers, additional effort of measurement and fine-grained allocation methods are needed, which are highly context-driven and reliant on the availability of data. Where possible, measurement tools should be employed that can allocate variable and/or fixed power usage directly to specific digital services. However, embodied, direct, and/or fixed power emissions related to services should also be included in the emissions inventory.

4 Related Work

This section discusses the relevant initiatives and implementations related to sustainability assessment in software and datacenters and their relation with SAG-DESI.

Blue Angel for data centers [6].

Blue Angel data centers (DE-UZ 228) is a label provided by the German environment agency to data centers and rewarding data centers that: implement short and long term energy efficiency strategy for their IT and Non-IT Resources, and empower customers to measure and improve their energy efficiency.

Sustainable Digital Infrastructure Alliance (SDIA) life cycle assessment [7].

SDIA proposes a full life cycle assessment of digital environments. This holistic approach allows for a fine-grained analysis of all components contributing to any environmental impact (e.g., ozone depletion, water use, human toxicity). SAG-DESI has a more restricted scope compared to a life cycle assessment. By focusing solely on CO2 emissions, SAG-DESI offers an easy-to-implement method that can be used within a broader framework of carbon accountability.

Metrics from the Horizon CATALYST project green data center [8].

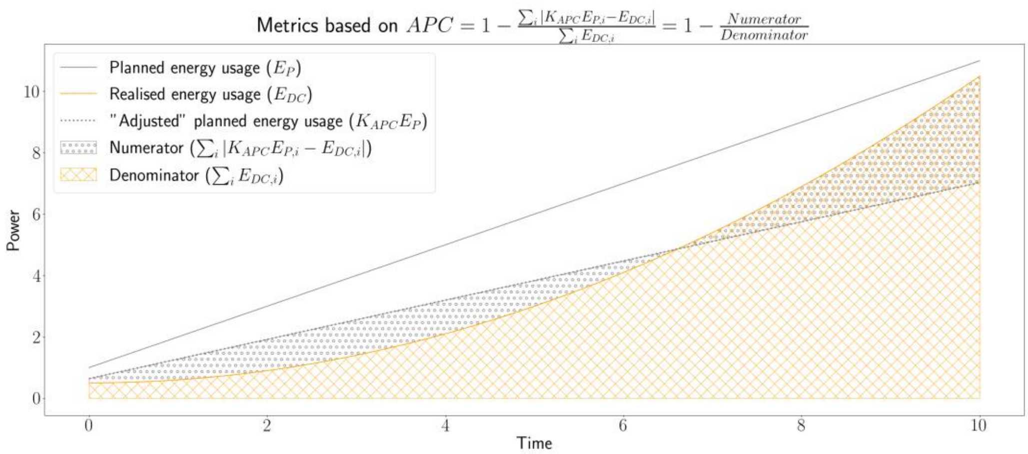

Figure 4.1: Example of adaptive power curve (APC) illustrated for the *planned energy* and the *realized energy*. When adaptation is good (small discrepancy between the *planned energy* and the *realized energy*) the grey dotted area is small compared to the orange hatched area. Conversely adaptation is bad (meaning a large discrepancy between the *planned energy* and the *realized energy*) the grey dotted area is large compared to the orange hatched area.

The Horizon CATALYST project green data center (DC) assessment toolkit presents eight metrics that assesses the environmental impact of data centers. Four of those metrics can be used when reporting the environmental performances over a period of time of time considering:

- the effectiveness of the power usage, computing the PUE as presented in section 2.2

- the energy reuse, computing the Energy Reuse Factor (ERF): $ERF = KWH_{Heat}/(KWH_{NonIT} + KWH_{IT})$
- the proportion of renewable energy, computing the Renewable Energy Factor (REF): $REF = RenewableEnergy/(KWH_{NonIT} + KWH_{IT})$
- The effectiveness of the water usage, compute the Water Usage Effectiveness (WUE): $WUE = AnnualWater/(KWH_{NonIT} + KWH_{IT})$ ($AnnualWater$ being the operational water usage associated with the DC)

Two metrics focus on evaluating the adaptability of an energy use pattern to another energy use pattern and are based on adaptive power curves (illustrated and explained in Figure 4.1) The Adaptability Power Curve at Renewable Energy Sources (APC-RES) measures the adaptability of *the data center energy consumption pattern* to the *available renewable energy to be consumed* while the (DCA) measures the adaptability of *the DC energy consumption after adapting to an operational mode* pattern and the *DC energy consumption before adapting to an operational mode* pattern.

The last two presented metrics assess the energy and CO2 savings when changing operational modes that alter the energy profile of the data center:

- Primary Energy Savings (PES): The saving in terms of primary energies between the DC consumption after adapting to an operational mode and DC consumption before adapting to an operational mode.
- CO2 Savings (CO2S): The saving in terms of CO2 between the DC consumption after adapting to an operational mode and DC consumption before adapting to an operational mode.

Although not directly applicable to SAG-DESI, the APC-RES, PES, CO2S, and DCA metrics could monitor the impact of decisions based on its findings. The ERF, REF and WUE bring different insights on sustainability beyond the scope of the proposed assessment which focusses on the CO2 emissions.

Software Carbon Intensity ISO standard [9].

The Software Carbon Intensity ISO standard provides a practical guide leading to the measure software carbon intensity (SCI) score. The proposed assessment specializes the approach making it more practical in the context of data center and reuse of heat. The proposed approach is fully compatible with the procedure defined by the Software Carbon Intensity ISO standard as Section 3 provide guidance on software boundary, functional units, and allocation method.

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Glossary

SAG-DESI	Sustainability Assessment Guidance for Digital and Energy Services Infrastructure
CSRD	Corporate Sustainability Reporting Directive
ESRS	European Sustainability Reporting Standard
ESG	Environmental, Social and Governance
CIS	IPCEI Next Generation Cloud Infrastructure and Services
MISD	Modular Integrated Sustainable Datacenter
IAAS	Infrastructure As A Service
PAAS	Platform As A Service
SAAS	Application As A Service
PUEHR	Power Usage Effectiveness with Heat Reuse
CUEHR	Carbon Usage Effectiveness with Heat Reuse
GHGP-ICTSG	Greenhouse Gas Protocol Product Standard
GHG	Greenhouse gas
VM	Virtual machine
CPU	Central Processing Unit
GPU	Graphics Processing Unit
GB	Gigabytes
PES	Primary Energy Savings
CO2S	CO2 Savings
APC-RES	Adaptability Power Curve at Renewable Energy Sources
DCA	Data Center Adapt
DC	Data Center
KEPLER	Kubernetes-based Efficient Power Level Exporter
ERF	Energy Reuse Factor
REF	Renewable Energy Factor
WUE	Water Usage Effectiveness
PUE	Power Usage Effectiveness
SCI	Software Carbon Intensity

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