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Measuring 24/7 Carbon Free Energy in the context of sector coupling: *a methodology.*

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Executive Summary

This document presents an extension to the established 24/7 Carbon-Free Energy concept. nLighten, in delivering its services to the clients, proposes to build on the Carbon-Free Energy approach according to a holistic, sector coupling-based overview: this implies the recovery and use of waste heat, and its inclusion in sustainability metrics to quantify the community effect. Beginning with the known CFE indicator for electricity, also referred to as the "unit of analysis", nLighten goes on to include energy **production** and **consumption** of the data center (Figure S1) -extending the energy perimeter to account for carbon-free **heat (CFEH)**, alongside the carbon-free **electricity (CFEl)**.

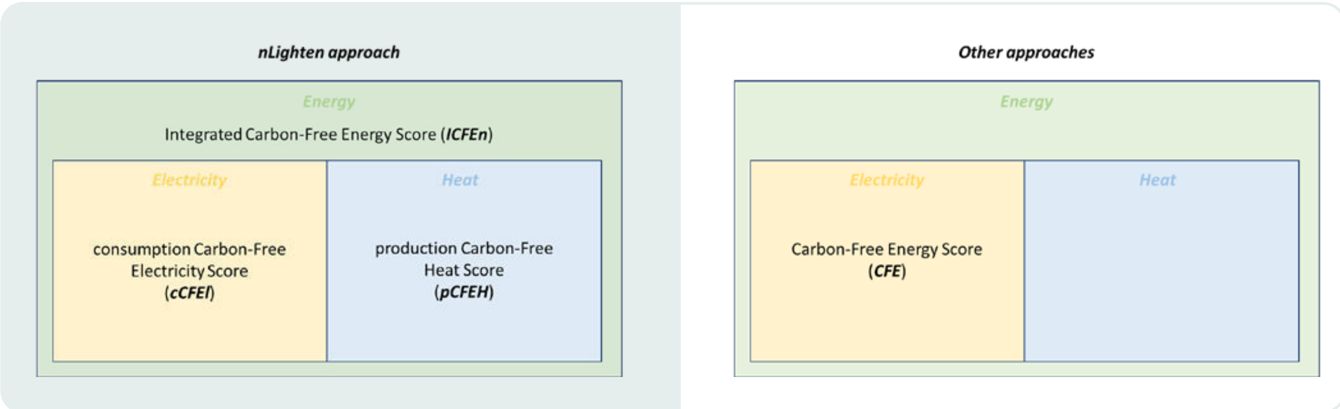


Figure S1. Differences in scores perimeters. Source: nLighten – FEEM elaboration, 2023

Where cCFEl is the consumption Carbon-Free score of electricity and pCFEH indicates Carbon-Free Heat over the DC perimeter. With this sector coupling view, a system (σ) perspective is then adopted, where entities connected to the data centers are also included in the system energy calculation for both electricity and heat (Figure S2).

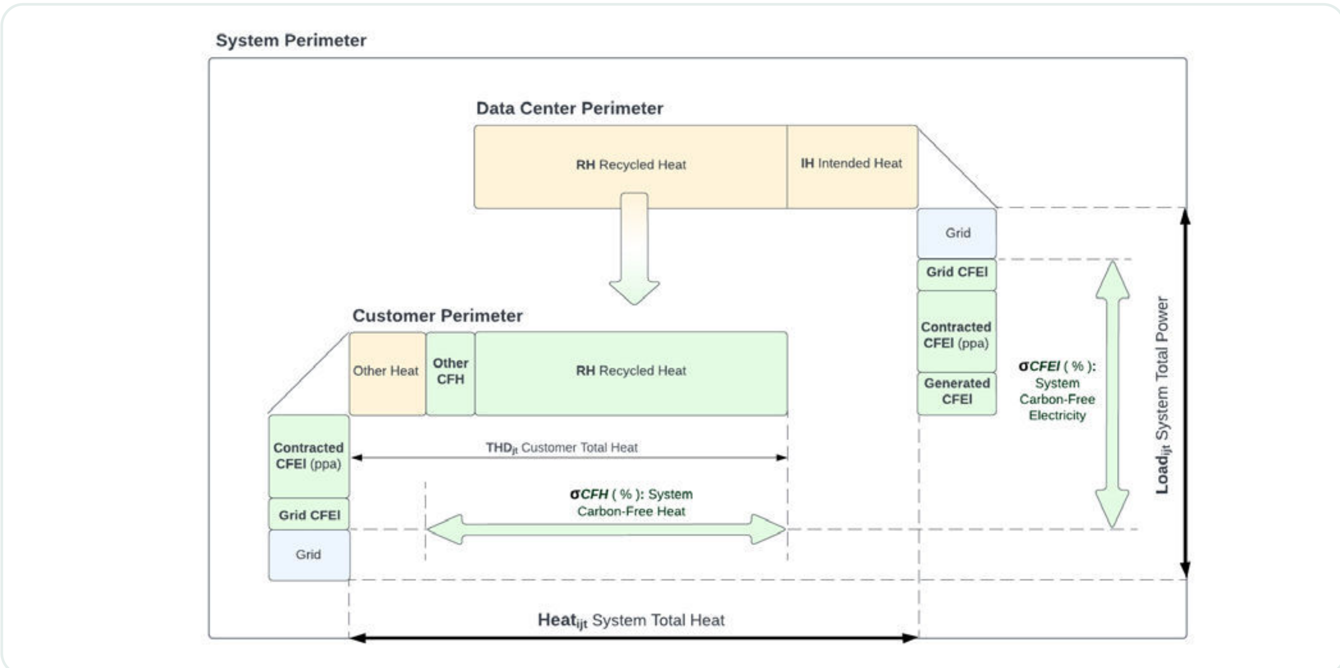
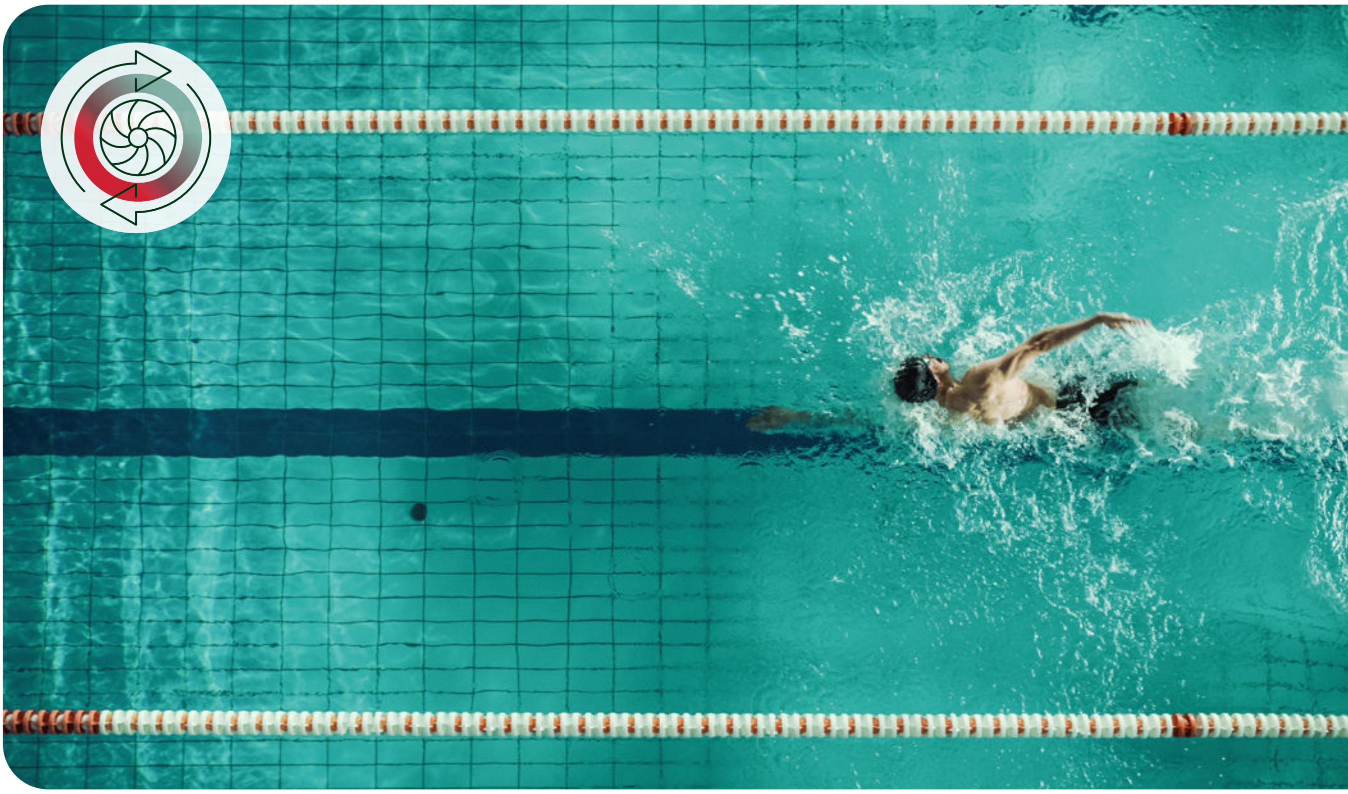


Figure S2. Diagram of the system. Source: nLighten – FEEM elaboration, 2023

This results in combined system calculations to reflect the overall performances of the sector coupled arrangement including for both electrical and heat energy. These are performed in isolation and then combined to indicate an overall system carbon free energy performance metric.

- The **System Integrated Carbon-Free Energy score** (σ ICFEn, %) (Equation S1).
- The **System Integrated Avoided Emissions** (σ I Avoided Emissions, tonnes of CO_{2e}) (Equation S2).

An application of this methodology is shown for the nLighten data center located in the town of Eschborn, close to Frankfurt, which intends to reduce the impact of its operations via high temperature heat export to an indoor swimming pool and a local government office building as recipients of its waste heat. The incorporation of Recycled Heat as a source, results in a pronounced enhancement of the system 24/7 CFE performances for both developed indicators.



1. Introduction and Scope

The scope of this Concept Note is to present an innovation on the 24/7 Carbon-Free Energy concept pursued by nLighten[1] in their measurement and reporting of their energy operations. According to the 24/7 Carbon-free Energy Compact, a UN-Energy coordinated group of public and private sector signatories[2], *"24/7 Carbon-Free Energy (CFE) means that every kilowatt-hour of electricity consumption is met with carbon-free electricity sources, every hour of every day, everywhere. It is both the end state of a fully decarbonized electricity system, and a transformative approach to energy procurement, supply, and policy design that is critical to accelerating its arrival"*.

This objective has been advocated by participants in the 24/7 CFE Compact in their transition towards achieving zero emissions and is increasingly adopted by a wider group of entities operating in this space. nLighten, in delivering its services to the clients, plans to go further and to build on this Carbon-Free Energy concept according to a holistic, sector coupling-based perspective: this implies the recovery and use of waste heat, and its inclusion in the computation of key sustainability metrics.

Standard CFE indicators, despite their name, only take into account the electricity supplied to the asset for which the indicator is calculated, which is commonly referred to as the "unit of analysis". By expanding the CFE concept, nLighten indicators include the **consumption and production** of energy by the entity under consideration. In nLighten's approach, the perimeter of analysis is extended to the carbon-free **heat (H)** produced by the data center, representing the second essential component of the **energy** perimeter **(En)** alongside the carbon-free **electricity (El)** consumed ("Figure S1. Differences in scores perimeters. Source: nLighten – FEEM elaboration, 2023").

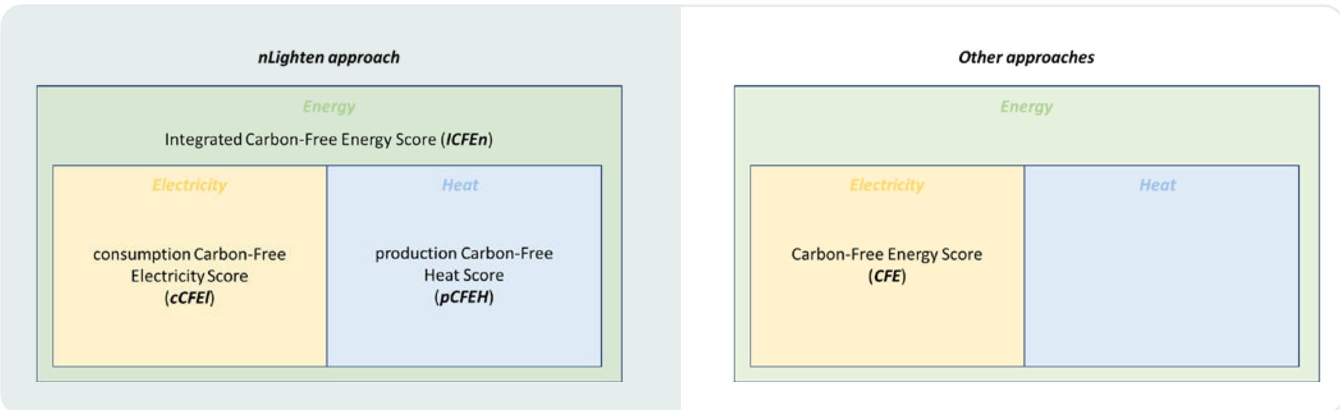


Figure 1. Differences in scores perimeters. Source: nLighten – FEEM elaboration, 2023

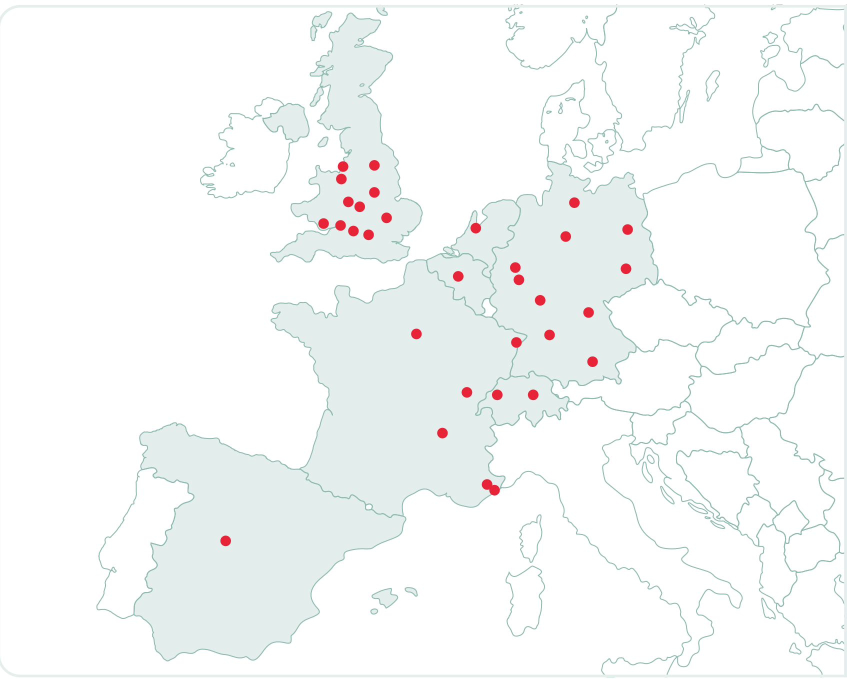
1 In this note, the name "nLighten" is used interchangeably to indicate any and all entities part of the group operating in each of the countries of operation.
2 https://www.un.org/en/energy-compacts/page/compact-247-carbon-free-energy

Furthermore, under a sector coupling perspective, the unit of analysis can be further extended to a **system (σ)** perspective, where the customers of the data centers (i.e. the entities that use the data centers' recycled heat) are also recognized for their role as electricity and heat users.

This document introduces the rationale and methodology behind this innovative approach, presents a current case study and the stepping stones planned by the business to continue moving forward.

1.1 The mission of nLighten

nLighten is a digital infrastructure platform that provides interconnected data centers for edge connectivity, data processing and exchange. With its edge data centers[3], nLighten meets the ever-increasing demand for faster and more reliable data processing and storage, while actively contributing towards decarbonization of the energy system of the countries it operates in.



FOUNDED IN 2021

10 data centers distributed in the main cities in Germany, within a 2-hour drive from any place in the country.

Three lines of service:

- → *Colocation*
- → *Connectivity*
- → *Energy and Operations*

Sector coupling integration with local energy infrastructure: collaboration between energy systems and other sectors to achieve lower community emissions.

Figure 2. Map of nLighten data centers

3 Data centers are located on the edge of the network (i.e., close; https://www.nlighten.de/close): they enable fast processing of time-sensitive data with less latency.

NLIGHTEN'S BUSINESS PROPOSITION ENCOMPASSES THE FOLLOWING FEATURES:

- nLighten is a digital infrastructure platform and a portfolio company of I Squared Capital, providing best-in-class network access to organizations, private users and the mobile workforce. Our edge data centers are designed to meet the increasing demand for regional connectivity and use this distributed model to reduce environmental impact. nLighten's goal is to set up and operate multiple leading-edge data center platforms in Europe.

- **Energy Management.** Power is increasingly procured via PPAs linked to renewable power sources. These have the potential to substantially reduce emissions while supporting power sharing with local utilities.

- **Thermal Management.** Electricity consumed in data centers is converted to heat by server and network loads. Having a data center close to main urban areas enables to locally recover and export this heat energy to the community. The latest generation of cooling systems can seamlessly upgrade server heat to directly usable temperatures – creating a carbon-free heat source to assist district heating systems. These higher operating temperatures also remove the need for evaporative cooling, conserving water across the data centers.

- **Grid Stabilization.** The energy transition requires an increasing amount of renewable power generation, which is often weather-dependent and results in variable grid capacity. Using carbon neutral on-site generation, it is possible to assist any capacity deficits via grid stabilization. This can create a further synergy between the growth of data centers and emission reductions in community infrastructure.

The combination of the abovementioned elements enables nLighten to spearhead the energy transition and leverage innovative features to deliver value to clients and local communities. In the following sections, a consistent set of metrics and key indicators is presented, to define this approach from a methodological perspective.

1.2 Data centers: rationale for 24/7 metrics

The idea of achieving 24/7 Carbon-Free Energy (CFE) is gaining momentum in some specific energy-intensive industries, such as digital infrastructure. According to the International Energy Agency (2023)[4], data centers and data transmission networks are responsible for 1% of energy related GHG emissions at global level, for an estimated electricity consumption of 240–340TWh in 2022, or around 1–1.3% of global final electricity demand.

Traditionally, energy-intensive consumers use renewable PPAs and/or Guarantees of Origin to align their energy consumption with renewable electricity generated by the underlying renewable generation assets within an annual timeframe, thus substantiating their commitment of using "100% renewable energy". This approach is widely accepted by current certificate standards and the Greenhouse Gas Protocol Scope 2 Guidance (2023)[5]. However, it has been noted that this "annual matching" approach does not accurately represent the dynamic nature of modern power

4 https://www.iea.org/energy-system/buildings/data-centers-and-data-transmission-networks
5 https://ghgprotocol.org/scope-2-guidance

grids, which exhibit significant fluctuations in variable renewable energy levels at different times. Such intraday volatility was not as relevant 20 years ago when the initial certificate systems were introduced: at the time, variable renewables such as solar and wind played a marginal role in the power sector, while constant renewable generation from hydro and geothermal was prevalent.

The current matching permits consumers to acquire all their Guarantees of Origin from any point within the established period (e.g., a 12-month period or more), such as from a solar PV plant generating in summer and apply them to their energy consumption throughout the year, including for the consumption at times of the year when renewable energy production may be at its lowest (e.g. winter night time). This discrepancy with the actual grid conditions is eroding trust in existing certificate systems and leading to allegations of greenwashing.

This seems to be further corroborated by a recent study by McKinsey (2022)[6], based on data from Germany and California, that concludes that a 24/7 renewable PPA is likely to yield an actual 100% decrease in emissions. Furthermore, advantages from a financial point of view can be achieved by 24/7 CFE as hourly matching ensures a higher certainty in price reducing exposure to spot markets. Eurelectric, that conducted the study[7] on Germany and Finland, highlights that the effectiveness depends on the price structure of the PPA and on market prices.

There is a growing consensus, within this industry and beyond, to consider 24/7 CFE as one of the most suitable indicators to monitor the effort towards a full decarbonization. Companies currently pursuing this objective, via the 24/7 Carbon-Free Energy Compact, include tech companies such as Microsoft, Google, and SAP, but also utilities like AES, Engie, EDP, Acciona, Orsted[8].

6 https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/decarbonizing-the-grid-with-24-7-clean-power-purchase-agreements
7 https://247.eurelectric.org/hedging-benefits/
8 https://24-7cfe.com/our-signatories/

IN 2021, GOOGLE PROPOSED A METHODOLOGY, "24/7 CARBON-FREE ENERGY: METHODOLOGIES AND METRICS"[9], WHICH ILLUSTRATES HOW THE 24/7 CFE APPROACH ENTAILS FIVE PRINCIPLES:

- Time-based matching to the load, to ensure each hour of consumption is fully matched by carbon-free electricity generation.
- Local procurement of renewable energy, secured e.g., by a PPA.
- Technology inclusivity, to encompass all carbon-free energy technologies, e.g. hydropower and nuclear.
- Additionality, enabling the deployment of additional clean electricity generation capacity, rather than pricing out existing buyers.
- Focus on the grid, to account for the share of CFE in the electricity grid mix.

THEIR DOCUMENT PROPOSED TWO MAIN CFE METRICS OR INDICATORS:

- **CFE Score**, measuring the degree to which each hour of electricity consumption on a given regional grid is matched with CFE on an hourly basis.
- **Avoided Emissions (tCO_2)**, measuring the carbon emissions impact of procurement decisions, as an indicator to help prioritize projects across time and geography.

9 https://www.gstatic.com/gumdrop/sustainability/24x7-carbon-free-energy-methodologies-metrics.pdf

Likewise, a White Paper published by Afry, "Granular Energy and Nordpool" (2023)[10] suggests that the introduction of hourly (or lower) granularity timestamp for Guarantees of Origin (GoO) is likely to deliver a greater degree of attribution, thus enabling the achievement of nearly 100% effective infeed from renewable energy. The data used for adding a timestamp to certificates will come from smart meters and be the same as the interval metering data used in wholesale power market settlement.

According to the World Resource Institute (2023)[11], achieving 24/7 CFE requires a high level of market knowledge and sophistication, that may be out of reach for small players[12]. This calls for the introduction of new products and offers, enabling the participation of a broader range of customers.

OTHER ENABLING FACTORS INCLUDE:

- **Accessible and standardized hourly customer data.** Customers require more straightforward access to their hourly energy consumption data to understand the relationship between their energy usage and emissions content.
- **Ability to verify and track hourly transactions.** Many industry players continue to monitor renewable energy generation on an annual basis. Shifting towards hourly tracking is likely to introduce further complexities, which can be effectively managed by using more detailed data within energy attribute tracking systems.
- **New technology.** 24/7 CFE require new technologies that can help enable grids to shift to 100% clean energy. Many of these technologies are still at a premium, and there is the perceived need for expanding the offering. An example is the increase of grid flexibility the possibility to identify load-shifting opportunities.

nLighten enables the integration of a 24/7 CFE approach, thanks to its value proposition of Energy Management. The data centers managed by nLighten are supplied via renewable PPAs and integrated by state-of-the-art network and load control technology, thus effectively enabling the hourly calculation of metrics such as the CFE Score and the Avoided CO_2.

The next step, as well as the scope of this Concept Note, is to extend this approach from the electricity sector to the wider energy sector, by including the computation of waste heat in the methodology.

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10 https://www.nordpoolgroup.com/49b69a/globalassets/download-center/whitepaper/whitepaper-may-2023.pdf
11 https://www.wri.org/insights/247-carbon-free-energy-progress
12 Increasing are the efforts to accelerate the shift to 24/7 clean energy. Among those is the independent industry led EnergyTag which is supporting the development of a market for hourly energy certificates through guidelines and the coordination of a series of demonstrator projects. As underlined by this initiative (https://energytag.org/wp-content/uploads/2022/03/210830-ET-Whitepaper.pdf) building a framework for granular energy certificates can only be pursued through more and more strong collaboration within the energy industry and with regulators so that to fully exploit the potential benefits of increased time granularity of certificates.

1.3 Widening the scope: from electricity to energy

nLighten is well suited to build on the CFE score concept and extend it beyond electricity to include heat. This shift entails the definition of a new, more holistic set of metrics, covering the topics of sector coupling, that are presented in the following sections of this Concept Note.

According to the Florence School of Regulation, sector coupling can be defined as "*the process of progressively and increasingly interlinking the electricity and gas sectors – by optimizing the existing synergies in the generation, transport, and distribution of electricity and gas – with the ultimate scope to build a decarbonized and hybrid EU energy system*"[13]. The term has been further extended to the heating, transport, and industrial production, being referred to as "sector integration" or "energy system integration" (European Commission, 2020)[14].

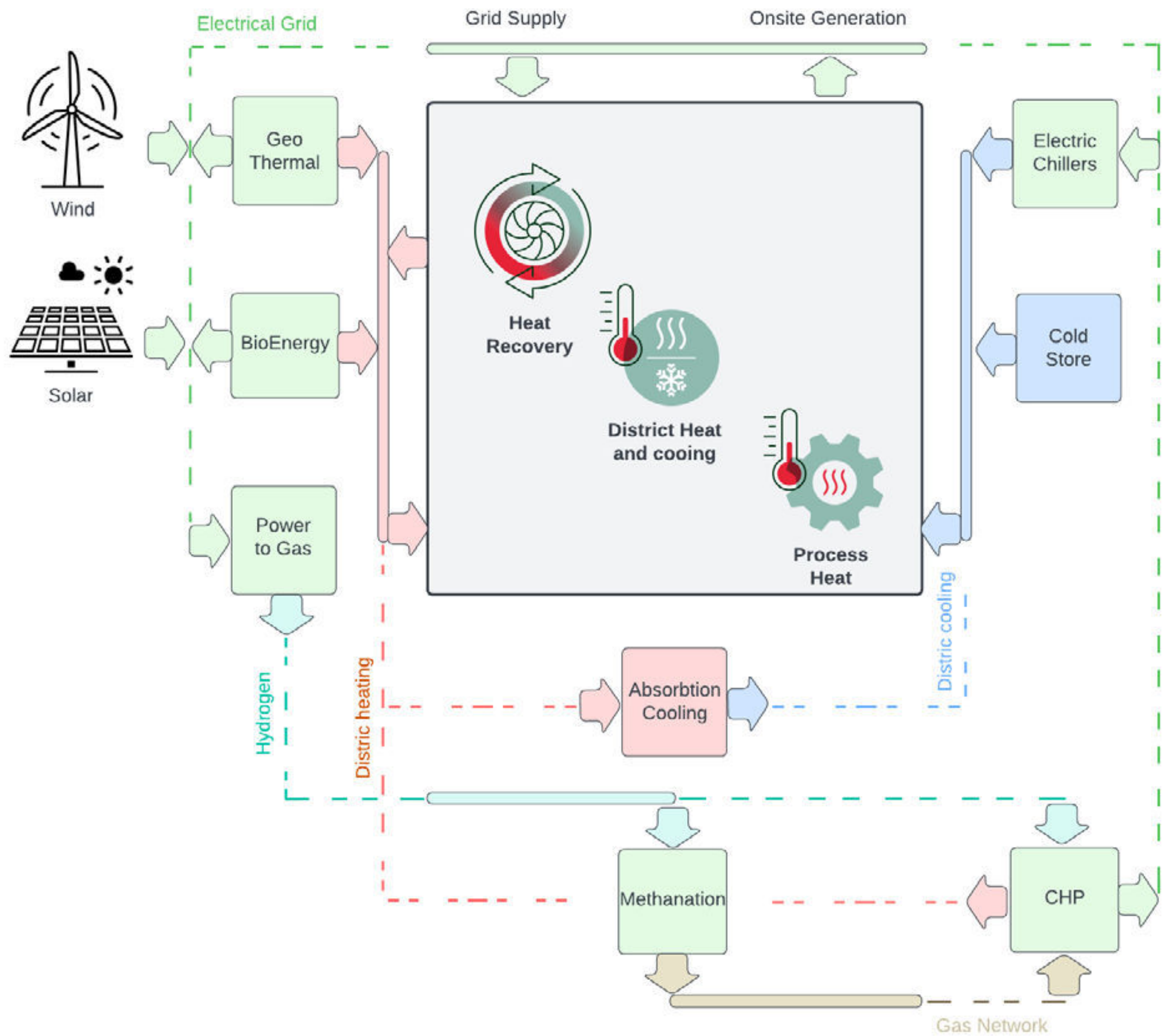

Figure 3. Diagram of the integrated energy system. Source: nLighten – FEEM elaboration, 2023

13 https://fsr.eui.eu/sector-coupling-and-energy-system-integration/
14 https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX%3A52020DC0299

A recent report from ETIP-SNET (2022)[15] highlights the importance of adopting Power-to-Heat systems to utilize excess electricity generated by variable renewable energy sources (i.e., solar, wind) which would otherwise be wasted.

HEAT PUMPS PRESENT A LIST OF ADVANTAGES:

- Possibility to work on renewable energy. If 100% green electricity is used, all heat pump applications are 100% renewable and emission-free at the operation site.
- Flexibility in the use, with the option to connect the heating, industrial and electrical energy vectors. Their inherent flexibility stabilizes the electric grid and enables higher renewable utilization factors, also providing some peak shaving and load balancing to a high-RES share dominated electric grid.

nLighten can reap these benefits thanks to i) a stable and highly predictable seasonal electric load from the data centers, ii) the procurement of green energy via PPA and iii) the seamless integration of back-up generators fuelled by carbon-netted energy, to provide grid stabilization services when required.

Consistently with the above, new legislation and policy elements are being introduced in Europe, both at country and European level, to enhance the sector coupling inclusion of efficient Power-to-Heat solutions into the energy system. In particular, the attention is centerd on the definition of waste heat, as well as on the options for its valorisation and reuse.

In Germany, the "Energy Efficiency Act" (Energieeffizienzgesetz, EnEfG, 2023)[16] has been introduced to the Parliament by the Federal Ministry for Economic Affairs and Climate Protection (Chester et al. 2023; Reubekeu & Ollech, 2023)[17]. This provision adopts a specific focus on the data centers. Among the core rules for data centers is the requirement to reduce and reuse waste heat as well as obligations to provide this heat to (municipal) heat suppliers: *"all businesses, including data centers, with an annual average end energy consumption of 2.5 GWh or more will be obliged to avoid and reduce waste heat unless technically inevitable, to reuse waste heat in their own premises and to provide it to third parties [...]"* (EnEfG-E)[18].

OTHER IMPACTFUL PROVISIONS OF THIS NEW LEGISLATION ARE THE FOLLOWING:

- Introduction, by the operators of data centers, of an energy management system, regardless of their energy consumption and by July 1, 2025. These systems will allow to continuously measure performance and energy demand and take measures to continuously improve energy efficiency.
- Redefinition of Power Usage Effectiveness (PUE) and introduction of mandatory levels.
- Definition of mandatory levels of Energy Reuse Factor (ERF).

The European Commission, through the Recast RED Article 2[19], defines a taxonomy for waste heat and cold as *"unavoidable heat or cold generated as by-product in industrial or power generation*

15 https://op.europa.eu/en/publication-detail/-/publication/919a8405-6ed7-11ed-9887-01aa75ed71a1/language-en?WT.mc_id=Searchresult&WT.ria_c=37085&WT.ria_f=3608&WT.ria_ev=search&WT.URL=https%3A%2F%2Fenergy.ec.europa.eu%2F
16 https://www.dentons.com/en/insights/articles/2023/september/25/energy-efficiency-act-relevance-for-data-centers
17 https://www.lexology.com/library/detail.aspx?g=2f2a4262-7d32-462f-b896-935529af3dbd
18 https://dserver.bundestag.de/btd/20/068/2006872.pdf
19 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001

installations, or in the tertiary sector, which would be dissipated unused in air or water without access to a DHC network, where a cogeneration process has been used or will be used or where cogeneration is not feasible".

THIS DEFINITION IMPLIES THE FOLLOWING (SEE ALSO FIGURE BELOW):

- Only unavoidable losses are counted as waste heat.
- Waste heat and cold should be a by-product.
- Waste heat or cold must be used via District Heating and Cooling (DHC), public of private, for environment temperature control to count as waste heat eligible for the heating and cooling target (Galindo et al. 2021; Lyons et al., 2021)[20].

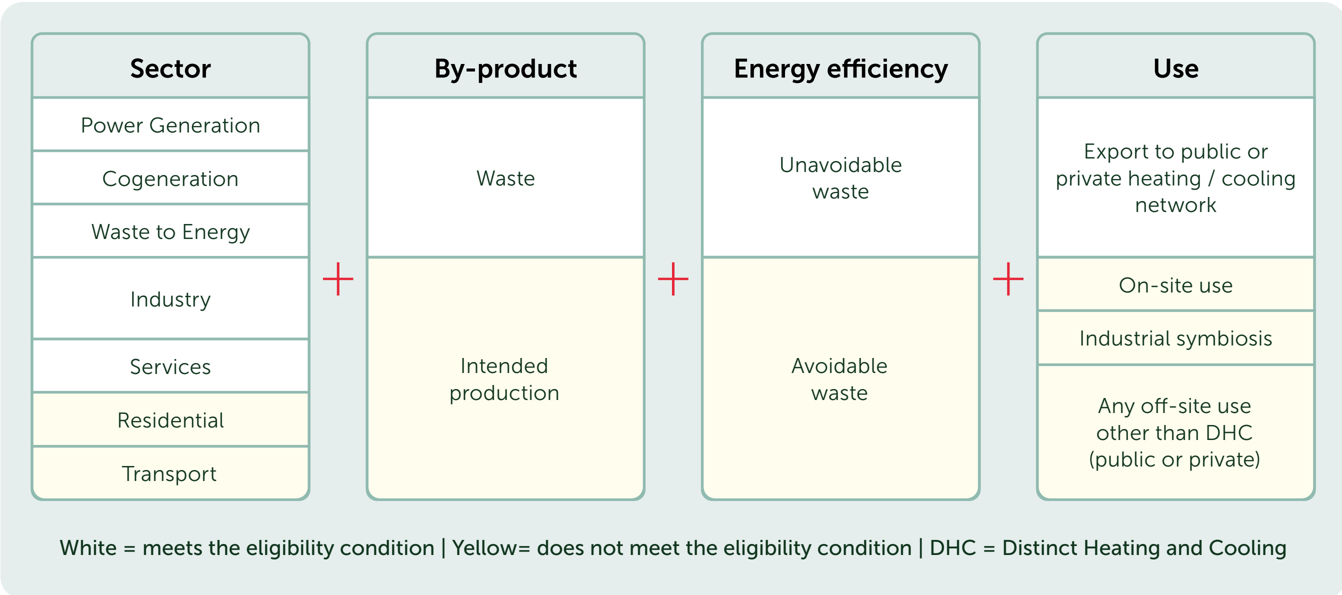

Figure 4. Taxonomy of waste heat. Source: Lyons et al. (2021)[22] and FEEM elaboration.

It is noteworthy mentioning how modern low-temperature DHC systems are more energy efficient than previous generations, and can integrate daily or seasonal storage, particularly where the heat sources are of an intermittent nature e.g., industrial waste heat, solar thermal and heat pumps. This allows for a more varied range of options to recover and reuse waste heat.

NLIGHTEN ACKNOWLEDGES THE OBJECTIVES OF THE GERMAN LEGISLATION, AND AIMS TO COMPLY WITH IT BY DELIVERING:

- commitment to procure green energy for its operations, via renewable PPAs.
- Fit for purpose technology and monitoring solutions.
- Improved set of metrics and indicators to monitor the energy efficiency of operations and the reuse of waste heat on hourly basis (see the proposed methodology in 2.2).
- Incorporation of options for the valorisation and reuse of waste heat in its business proposition to perspective customers (see the business case of the Eschborn data center in Section 3).

20 https://publications.jrc.ec.europa.eu/repository/handle/JRC123771
21 https://publications.jrc.ec.europa.eu/repository/handle/JRC126383

2. Methodology: the approach of nLighten

2.1 Existing metrics and applications in industry

One of the most comprehensive pieces of literature in this field is 'New performance indicators for fully integrated and decarbonized data centers' Bergaentzlé & Madsen (2021)[22]

Their work advocates for the adoption of new metrics that offer in-depth insights into the decarbonization endeavours of data centers. The objective is to instigate changes that break the link between sector growth and CO_2 emissions, emphasizing aspects beyond energy efficiency, such as flexibility and waste heat utilization. The concept of an integrated data center is mentioned several times in the text, and this terminology, which inspired the creation of 8 new indicators to measure their environmental and energy performance, and the 24/7 CFE approach of Google mentioned above, positively reinforce the construction of the new methodology developed in this report.

SOME IMPORTANT KPIS INCLUDE:

- **Power Usage Effectiveness (PUE)**, which measures the efficiency of energy use needed to operate the IT system during a given year. The lower the PUE, the higher the efficiency level.
- **Renewable Energy Factor (REF)**, which indicates the share of owned and controlled renewable energy used by the data center, compared with the overall energy consumption (concept embedded in nLighten's indicators).
- **Carbon Usage Effectiveness**, which captures the carbon intensity of data centers in relation to the energy consumption of their IT equipment (concept embedded in nLighten's indicators).

22 https://backend.orbit.dtu.dk/ws/portalfiles/portal/258762990/New_KPIs_for_decarbonised_and_integrated_data_centers.pdf

2.2 Our approach and revised metrics

NEW METRICS FOR SECTOR COUPLING

This methodology introduces a pair of pivotal innovations in the realm of Key Performance Indicators (KPIs), with the primary objective of synthesizing the valuable insights derived from both the 24/7 CFE and the sector coupling approach into a consolidated metric. This paradigm shift is designed to align and build upon advancements in existing literature, peaking in the development of a novel indicator that incorporates the most comprehensive information attainable. The overarching aim is to establish a metric that transcends the individual contributions of the 24/7 CFE and sector coupling approach, thereby constructing a more all-encompassing measure. In this sense, data centers can be conceptualized from the perspective of energy prosumers, which considers both integration of the upstream green energy supply and downstream waste heat reuse, allowing to unlock the potentials for improving performances[23].

Usual CFE indicators, despite their name, only take into account the electricity perimeter that the unit of analysis is supplied with. By expanding the concept, nLighten's indicators bring together both the **consumption side** and the **production side** of a single entity. In this sense, the proposed metrics are the **Integrated Carbon-Free Energy score (ICFEn)** – which comprises both the **Carbon-Free Electricity score (cCFEl)** and the **Carbon-Free Heat score (pCFH)** – and the **Integrated Avoided Emissions (I Avoided Emissions)** which comprises both the **Electricity Avoided Emissions (cEl Avoided Emissions)** and the emissions from heat. The heat perimeter (H) is this way included in the integrated analysis as the second essential component of the energy perimeter (En) along with the electricity one (El). As a final result, the hourly carbon intensity for the whole energy balance of the data center is also calculated.

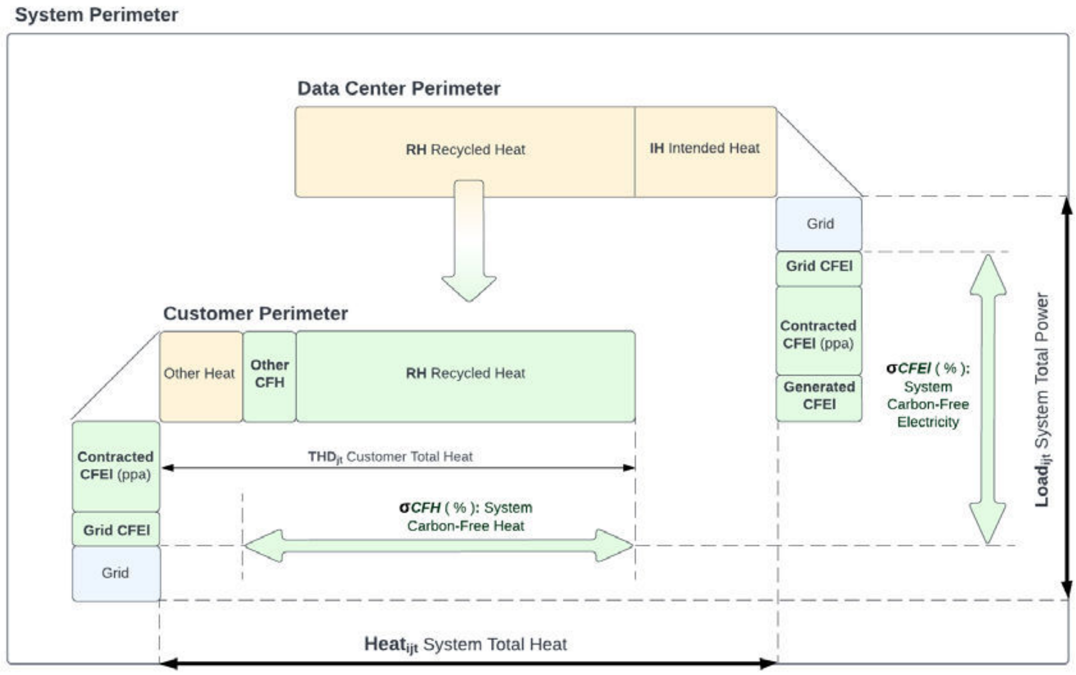

Figure 5. Diagram of the system (σ). Source: nLighten – FEEM elaboration, 2023

23 https://www.sciencedirect.com/science/article/abs/pii/S0306261919317969

Upon establishing the primary indicators, this methodology extends its scope by exploring various perimeters of applications. Recognizing the importance of sector and business coupling, the integration of potential customers utilizing the waste heat generated by the data center was considered. Consequently, an additional set of indicators has been defined, further expanding the metric framework previously outlined. This expansion encompasses the broader Industrial System, incorporating both the data center (nLighten) and its associated customers. The **System Integrated Carbon-Free Energy score (σ ICFEn)** and the **System Integrated Avoided Emissions (σ I Avoided Emissions)** bring together the consumption and production side of two businesses looking at the perspective of a unified system where both electricity and heat are accounted for.

Together with the KPIs just mentioned, referring to the perimeters of the diagram, nLighten also defines:

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DATA CENTER PERIMETER

cCFEl (%)	*consumption Carbon-Free score referring to Electricity perimeter.*
pCFH (%)	*production Carbon-Free score referring to Heat perimeter.*
ICFEn (%)	*integrated Carbon-Free score referring to Energy (electricity and heat) perimeter.*
cEl Avoided Emissions ($kgCO_{2e}$)	*consumption Avoided Emissions score referring to Electricity perimeter.*
I Avoided Emissions$_{it}$ ($kgCO_{2e}$)	*Integrated Avoided emissions score referring to energy (electricity and heat) perimeter.*
cCI ($kgCO_{2e}$/kWh)	*consumption Carbon Intensity referring to Electricity perimeter.*
I CI	*Integrated Carbon Intensity referring to Energy (electricity and heat) perimeter.*

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SYSTEM PERIMETER

σ CFEl (%)	*system Carbon-Free score referring to Electricity perimeter.*
σ CFH (%)	*system Carbon-Free score referring to Heat perimeter.*
σ ICFEn (%)	*system Carbon-Free score referring to Energy perimeter.*
σ El Avoided Emissions ($kgCO_{2e}$)	*system Avoided Emissions score referring to Electricity perimeter.*
σ I Avoided Emissions$_{it}$ ($kgCO_{2e}$)	*system Avoided Emissions score referring to energy (electricity and heat) perimeter.*

RECYCLED HEAT AND INTENDED HEAT

Building on the taxonomy for waste heat at European level (as explained in 1.3) nLighten departs from it and proposes to identify two types of heat, inspired by two eligibility criteria "By-product" and "Energy efficiency" as framed in the EU taxonomy:

a data center can generate heat as a by-product of its core activity (henceforth "Recycled Heat" or RH) at a grade compatible for re-use outside its boundaries for those activities requiring heat with specific characteristics (e.g. within required temperatures) or it can generate heat in an energy optimized mode not suitable for direct resuse on grounds of energy efficiency or limited demand (henceforth "Intended Heat" or IH).

EMISSIONS ALLOCATION METHODOLOGIES AND DEFINITION OF DATA CENTERS' WASTE HEAT

In a data center, GHG emissions generated (including carbon dioxide (CO), methane (CH) and nitrous oxide (NO)) can be allocated to the consumption of electricity; however, data centers also produce waste heat, that is a by-product of their functioning. Taking inspiration from CHP system where multiple forms of energy (most often electricity and steam) are generated simultaneously in an integrated system, emissions generated by data centers, can also be allocated to either electricity consumption or heat production. Methodologies for emission allocation between two products resulting from the same process have indeed primarily been used for co-generation systems, and those are the ones that this work refers to and departs from.

THERE IS MORE THAN ONE WAY TO DETERMINE WHAT SHARE OF EMISSIONS IS ATTRIBUTABLE TO EACH PRODUCT, BETWEEN ELECTRICITY AND HEAT, THERE ARE METHODS USED WHICH APPORTION THEM DEPENDING ON OPERATIONAL PROCESS; FOR GUIDANCE, WE NOTE EMISSIONS CAN BE ALLOCATED TO HEAT OR ELECTRICITY ACCORDING TO (DITTMAN ET AL 2023[24]; ROSEN, 2008[25]; WRI/WBCSD, 2006[26]):

- heat first/electricity first: 100% emissions are allocated to one of the two products.
- method of alternative supply: emissions savings are allocated to one of the two products.
- energy content of products.
- exergy content of products.
- contractual agreement or other understanding between the affected parties.
- the economic value of products.

Having two different types of heat allows the opportunity of accounting for them with the method which best suits the underlying concept.

The Recycled Heat (RH) (IZES, 2023)[27], by-product of the main service provided by nLighten and energy that would otherwise be lost, is accounted for with the method of alternative supply at the customer's end. This method prescribes the allocation to co-generated heat of those costs – either emission costs (Rosen, 2008[26]; WRI/WBCSD, 2006[27]) or variable and fixed costs (World Bank, 2003)[28] – that would have been incurred into by producing the same amount of heat with an alternative production technology. This method delivers one of the highest scores when CO_{2e} allocation methods are compared (criteria of evaluation: simplicity of the method; widest area of application; recognition and proven application; appropriate way of allocating emissions; thermodynamic plausibility; accessibility of data) (BSR LTDH Project; ARERA)[29]. The alternative technology considered will be based on data centers' specific customers (gas boilers, or gas boiler and small CHP, or DHC).

Intended Heat instead – i.e., heat dissipated in the atmosphere as no export to the customer can be performed – is accounted for with the method of heat first[30].

24 https://tudresden.de/ing/maschinenwesen/iet/gewv/ressourcen/dateien/veroefftlg/alloc_co2?lang=en
25 https://www.sciencedirect.com/science/article/abs/pii/S0959652606003362
26 https://ghgprotocol.org/sites/default/files/2023-03/CHP_guidance_v1.0.pdf
27 https://www.izes.de/en. (In particular, Hoffmann, P., https://ee-ip.org/en/article/waste-heat-recovering-a-valuable-renewable-resource-6990)
28 https://documents1.worldbank.org/curated/en/948891468771619606/pdf/272010paper.pdf
29 https://www.arera.it/it/index.htm
30 As data center (i) load used in the production of IH coincides with IH expressed in energy units, in the calculation it is possible to simplify the allocation to 100% heat to an allocation to load used in the production of IH.

The nLighten electricity supply mix will be used to recognize IH emissions (i.e., if nLighten electricity supply mix is 100% carbon-free, IH will be considered 100% carbon-free and so on).

Given the need to define two calculation perimeters, namely heat and electricity, the terminology referring to them is given here, all of which have kWh as unit of measurement:

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HEAT PERIMETER

Intended heat (IH)	*data center heat generated and dissipated in the atmosphere (not exported to the customer).*
Recycled heat (RH)	*data center heat generated and exported to the customer.*
Heat	*Intended Heat plus Recycled Heat (i.e. total heat produced).*
Total Heat Demand (THD)	*Total Head Demand of the system (comprises RH).*
otherCFH	*Other Carbon-Free Heat of the customer.*

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ELECTRICITY PERIMETER

$Load_i$	*data center Load.*
$Load_J$	*Customer Load.*
Contracted CFEl	*Carbon-Free Electricity supply contracted through a renewable energy Purchasing Power Agreement (PPA).*
Consumed Grid CFEl	*Carbon-Free Electricity supplied from the grid.*
Generated CFEl	*Carbon-Free Electricity produced by onsite generation.*
CFEI	*Resultant Carbon-Free Electricity (total of PPA, generated and contracted Carbon Free grid electricity).*

Where: i = data center; t = hour / day / month / quarter / year; j = customer.

AVOIDED EMISSIONS SCORES

Grid CI	*Grid carbon Intensity.*
Alternative CI	*emissions associated with heat production with the alternative technology*

2.2.1 Available Data

DATA CENTERS AND CUSTOMERS DATA

To calculate the indicators and measure progress towards stated goals, data collection is performed for:

- electricity consumption of any given hour (t) at any given data center (i).
- heat production of any given hour (t) at any given data center (i) (detailed in IH and RH).
- carbon-free electricity supply under contract (PPA) of any given hour (t) at any given data center (i).
- energy production from back-up onsite generators of any given hour (t) at any given data center (i).
- total heat demand of any given hour (t) for any given customer (j).
- other carbon-free heat supply at any given quarter of a year (t) for any given customer (j).
- electricity consumption of any given quarter of a year (t) for any given customer (j).

GENERATION AND IMPORTS

Data on generation and imports should be collected from available sources that depends on the site-specific application of the methodology. For what concerns the production mix of the electricity grid where nLighten data centers are located, these following two pieces of information are collected on ENTSO-E Transparency Platform[31]:

- Actual Generation per Production Type [16.1.B&C][32] reflects the actual aggregated net generation output (MWh) per market time unit and per production type. The information considered is collected at country level with 15 minutes granularity and, for the purpose of the calculation of the indicators, aggregated with an hourly granularity.

- Cross-Border Physical Flow Physical Flows [12.1.G][33] reflects physical flows between bidding zones per market time unit as close to real-time as possible and at the latest H+1 after the end of the reference period. Physical flow is defined as the measured real flow of energy between neighbouring bidding zones across the country borders. The information considered is collected at country level, every 15 minutes, or every hour (depending on the country's accounting system); for the purpose of the indicators calculation, when data is provided with 15 minutes granularity, it is then aggregated to an hourly granularity.

This source is selected due to the availability and transparency of the data. The latter *"has improved markedly in Europe over the past few years, culminating in Regulation (EU) No 5 43/2013 of 14 June 2013 on submission and publication of data in electricity markets. Through this Regulation, it has now become mandatory for European Member States data providers and owners to submit fundamental information"* to the ENTSO-E Transparency Platform that collects it "*from data providers such as TSOs, power exchanges or other qualified third parties*" (SOURCE: ENTSO-E TP)[31].

31 https://transparency.entsoe.eu/
32 https://transparency.entsoe.eu/generation/r2/actualGenerationPerProductionType/show
33 https://transparency.entsoe.eu/transmission-domain/physicalFlow/show

2.2.2 Data center cCFEl

Limited to the data center perimeter, the **consumption Carbon-Free Electricity Score (cCFEl Score)** (%) measures the degree to which each hour of electricity consumption is matched with CFE on an hourly basis; the indicator is structurally akin to the CFE score in the literature[9]. The name of the indicator, cCFEl, precise that, in the extent of widening the perimeter from a sector-coupling point of view, this score only accounts for the consumption (c) side of the energy a data center deals with.

The cCFEl Score (%) of any given hour (t) at any given data center (i) is calculated as (Equation 1):

$$cCFEl_{it} = \frac{Contracted\ CFEl_{it} + Consumed\ Grid\ CFEl_{it} + Generated\ CFEl_{it}}{Load_{\ it}} * 100$$

Equation 1

Where Consumed Grid CFEl (MWh) is expressed as Equation 2 and it is calculated by taking into account energy per production type, among which Biomass, Geothermal, Hydro Pumped Storage, Hydro Run-of-river and poundage, Hydro Water Reservoir, Marine, Nuclear, Solar, Waste, Wind Offshore, Wind Onshore and Other renewable are considered carbon-free.

$$Consumed\ Grid\ CFEl_{it} = [Load_{\ it} - Contracted\ CFEl_{\ it} - Generated\ CFEl_{it}] * \ Grid\ CFEl_{it}$$

Equation 2

2.2.3 Data center pCFH & ICFEn Score

Limited to the data center perimeter, **production Carbon-Free Heat Score (pCFH Score)** (%) represents the share of carbon-free heat over the data center heat perimeter. The pCFH Score of any given hour (t) at any given data center (i) is calculated as (Equation 3):

$$pCFH_{it} = \left(\frac{RH_{it}}{Heat_{it}}\right) + \left[\left(1 - \frac{RH_{it}}{Heat_{it}}\right) * cCFEl_{it}\right] * 100$$

Equation 3

Where the components RH and IH (here expressed as 1-RH) are multiplied by their percentage component of CFE (respectively 100% and cCFEl). As the Intended Heat carries the carbon intensity of the power that has been used to generate it, it is multiplied by that factor.

Once the pCFH is also defined, the Integrated Carbon-Free Energy score (ICFEn) (%) can be outlined for any given hour (t) at any given data center (i) (Equation 4). It is a weighted average of the two CFE scores, namely consumption and production. It represents the carbon-free energy over the data center energy (electricity and heat) perimeter and fulfills the first innovation mentioned in the paragraph 2.2 bringing together the consumption and production side of a business maintaining the accuracy and detail level of a 24/7 CFE score.

$$ICFEn_{it} = \frac{(pCFH_{it} \times Heat_{it}) + (cCFEl_{it} \times Load_{it})}{Heat_{it} + Load_{it}} * 100$$

Equation 4

Simplifying the equation:

$$ICFEn_{it} = \frac{(pCFH_{it} + cCFEl_{it})}{2} * 100$$

Equation 5

2.2.4 System ICFEn scores: widening the perimeter

Expanding the control perimeter to include the customer utilizing the recycled heat (RH) from the data center allows for the calculation of similar indicators. The calculation methodology remains consistent, starting with the electricity perimeter. In this instance, the electricity perimeter no longer reconciles with the consumption perimeter, as the customer relies on heat supply. Subsequent steps involve calculating the indicator within the heat perimeter, which is no longer overlapping with the production perimeter due to the aforementioned adjustment. The process concludes with the calculation within the integrated perimeter, accounting for both heat and electricity.

The σ **CFEl Score** (%) represents the share of Carbon-Free Electricity over the System (data center and customer) electricity perimeter and can be calculated for any given quarter of the year [34](t) at any given data center (i) and with any given customer (j) (Equation 6).

$$\sigma\, CFEl_{\,ijt} = \frac{(Contracted\ CFEl_{it} + Consumed\ Grid\ CFEl_{it} + Generated\ CFEl_{it}) + (CFEl_{jt})}{Load_{\,it} + Load_{jt}} * 100$$

Equation 6

Where Consumed Grid CFEl is calculated as 2 and CFEljt represents the carbon-free electricity supply of the customer). CFEljt as well as for the data center, can be detailed into its single components which can vary depending on the specific customer. However, it can be assumed that they are as follow:

$$CFEl_{\,jt} = Contracted\ CFEl_{jt} + Consumed\ Grid\ CFEl_{jt} + Generated\ CFEl_{jt}$$

Equation 7

Once the System CFEl (electrical perimeter) has been defined it is possible to proceed with the σ **CFH** (%) which represents the share of Carbon-Free Heat over the System (data centre and customer) heat perimeter. It is defined for the period (t) at any given data centre (i) and with any given customer (j) (Equation 8).

$$\sigma\, CFH_{ijt} = \left[\left(\frac{RH_{it} + otherCFH_{jt}}{THD_{jt} + IH_{it}}\right) + \left(\frac{otherHeat_{jt} * CFEh_{jt} + IH_{it} * CFEl_{it}}{THD_{jt} + IH_{it}}\right)\right] * 100$$

Equation 8

34 All system scores in this methodological note are determined with quarterly time granularity due to difficulties in retrieving data. As the collaboration between nLighten and the customer evolves, the collection of source data for indicator calculations may allow for finer time granularity.

Where the heat used by the customer is split into three components depending on its source: recycled heat from the data centre (RHit), other carbon free heat such as solar thermal or produced with a heat pump (otherCFHjt) and otherHeatjt which may still be produced with carbon rich energy vectors. The carbon free heat score (CFEhjt)of otherHeat becomes 0, if any carbon free proportion of it is moved to "other CFHjt". On that basis, Equation 8 can be simplified into Equation 8a:

$$\sigma\, CFH_{ijt} = \left[\left(\frac{RH_{it} + otherCFH_{jt}}{THD_{jt} + IH_{it}}\right) + \left(\frac{IH_{it} * CFEl_{it}}{THD_{jt} + IH_{it}}\right)\right] * 100$$

Equation 8a

Where the carbon-free heat (left hand side term) and the remaining carbon intensive heat (right hand side term) are multiplied by their percentage component of CFE (respectively 100% and CFEl). THD and IH represent the sum of the whole heat perimeter, with THD already including the RH exported by the data centre.

Or consolidating the Heat terms simplifies to:

$$\sigma\, CFH_{ijt} = \left[\sigma\, CFEl_{ijt} + \left(\frac{RH_{it} + otherCFH_{jt}}{THD_{jt} + IH_{it}}\right)(1 - \sigma\, CFEl_{ijt})\right] * 100$$

Equation 9

Finally, one can conclude by calculating the σ **ICFEn** (%) by averaging with a weighted average the previous two scores where the weights being the respective perimeters of action of the two scores. The σ ICFEn is defined for any given quarter of the year (t) at any given data center (i) and with any given customer (j) and represents the carbon-free energy over the system (data center and customer) electricity and heat perimeter (Equation 10).

$$\sigma\, ICFEn_{ijt} = \frac{(\sigma\, CFH_{ijt} \times Heat_{ijt}) + (\sigma\, CFEl_{ijt} \times Load_{ijt})}{Heat_{ijt} + Load_{ijt}} * 100$$

Equation 10

2.2.5 Data center Avoided Emissions Scores

The calculation of the second metric provides an indication of the amount of avoided emissions resulting from nLighten's decarbonization efforts. This KPI includes the calculation of CO_2 and CO_2 equivalent emissions from methane (CH) and nitrous oxide (NO) and is obtained using carbon indexes.

Remaining within the data center consumption perimeter, it is possible to calculate the emissions (kg) resulting from the core activity of the data center through Equation 11 (cEl Emissions) and the related avoided emissions by subtracting the latter from the theoretical emissions generated by the data center if it were supplied solely by the grid.

The consumption Electricity Avoided Emissions Score (cEl Avoided Emissions) ($kgCO_{2e}$) of any given hour (t) at any given data center (i) is calculated with Equation 12 and takes into account the avoided emissions within the data center electricity perimeter.

$$\boldsymbol{cEl\ Emissions_{it} = [(Load_{it} - Contracted\ CFEl_{it} - Generated\ CFEl_{it}) * GridCI]}$$

Equation 11

$$\boldsymbol{cEl\ Avoided\ Emissions_{it} = (Load_{it} * GridCI) - cEl\ Emissions_{it}}$$

Equation 12

By including also the production side, and thus the heat perimeter of the data center data center as a source to district heating system, it is possible to calculate the **Integrated Emissions Score (I Emissions)** (in kg, for heat and electricity perimeter) again starting from the calculation of the actual emissions dispersed into the atmosphere by the data center electrical consumption (Equation 13). The heat recovered at the data center is emission free and a zero term within the data center perimeter, because the emissions are accounted for in the electrical supply.

$$\boldsymbol{I\ Emissions_{it} = cEl\ Emissions_{it} = [(Load_{it} - Contracted\ CFEl_{it} - Generated\ CFEl_{it}) * GridCI]}$$

Equation 13

The recycled heat is carbon-free and valued, in the following calculation for avoided system emissions, at the Carbon Intensity of the system it is replacing (Alternative Carbon Intensity).

The avoided emissions cannot be attributed to the data center as the decision of a replacement of a carbon rich technology with renewable heat is within the decision powers of the heat customers. The impact of the emission avoidance therefore can only be accounted for in the System Avoided emissions measurement.

2.2.6 System Avoided Emissions: widening the perimeter

By adding to the data center consumption perimeter the customer perimeter it is possible to calculate the emissions resulting from the electricity consumption of the system through Equation 14 (σ **El Emissions**) (kg) and the related avoided emissions by subtracting the latter from the theoretical emissions generated by the system as if it was supplied solely by the network.

The σ **El Avoided Emissions Score** (Kg) of any given hour (t) for the data center (i) and customer (j) is calculated with Equation 15 and takes account of the avoided emissions within the system electricity perimeter.

$$\sigma\, El\, Emissions_{ijt} = \left[(Load_{it} - Contracted\, CFEl_{it} - Generated\, CFEl_{it}) + (Load_{jt} - CFEl_{jt})\right] * GridCI$$

Equation 14

$$\sigma\, El\, Avoided\, Emissions_{ijt} = (Load_{ijt} * GridCI) - \sigma\, El\, Emissions_{ijt}$$

Equation 15

By including the production side, and thus the heat perimeter of the system, it is possible to calculate the σ **Integrated Avoided Emissions Score** (in kg, for heat and electricity perimeter) again starting from the calculation of the electrical emissions dispersed into the atmosphere and adding those for heat sources (Equation 16).

$$\sigma\, I\, Emissions_{ijt} = \sigma\, El\, Emissions_{ijt} + \left[(Heat_{jt} - otherCFH_{jt} - RH_{it}) * AlternativeCI\right]$$

Equation 16

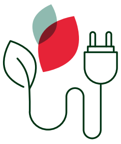
Then it is possible to calculate the σ **Integrated Avoided Emissions Score** ($kgCO_{2e}$) of any given hour (t) at any given data center (i) by applying Equation 17. It takes into account the emissions within the data center and customer electricity and heat perimeters, allowing for a non-electrical heat source in the customer facility.

$$\sigma\, I\, Avoided\, Emissions_{ijt} = (Load_{ijt} * GridCI) + (Heat_{jt} * AlternativeCI) - \sigma\, I\, emissions_{ijt}$$

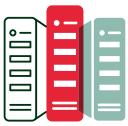
Equation 17

3. Supporting the energy transition

nLighten builds on the 24/7 CFE concept in both the electricity and heat sectors, supporting the energy transition by seamlessly combining:



Access to **contracted carbon-free, renewable energy** via PPA



Integration of **data centers and perspective off-takers** of waste heat

Provision of **back-up and grid stabilization services**, via carbon-netted or carbon-neutral in situ generation

These elements require state-of-the-art metering and monitoring equipment to i) enable the calculation of the under-lying KPIs, ii) effectively communicate the latter to the clients and iii) take advantage of favourable market conditions and pricing signals.

nLighten is fully committed to the implementation of 24/7 CFE metrics and the integration of sector coupling solutions into its business model, indeed, the company is working to bring this concept to fruition at one of its major data centers in Germany. The data center located in the town of Eschborn, close to Frankfurt, is the ideal case study of this new approach of nLighten.

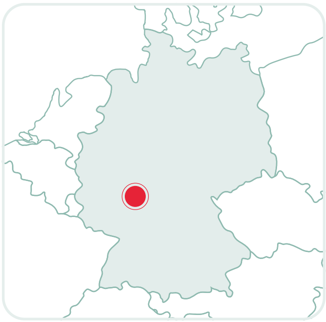


Figure 6 – Location of Eschborn. Source: nLighten

nLighten has been looking for ways to decarbonize its operations and have positive impact on the community it is located in. For that reason, it has been looking for perspective clients that could be interested in using the heat produced by the data center. The data center is operational since 2001, it includes 1500m^2 of data halls for a total IT server load of up to 3MW. Customers for the waste heat of Eschborn have been identified in a public indoor swimming pool and an office building. The swimming pool is particularly fitting, thanks to its all-year heat demand with nLighten's constant heat production.

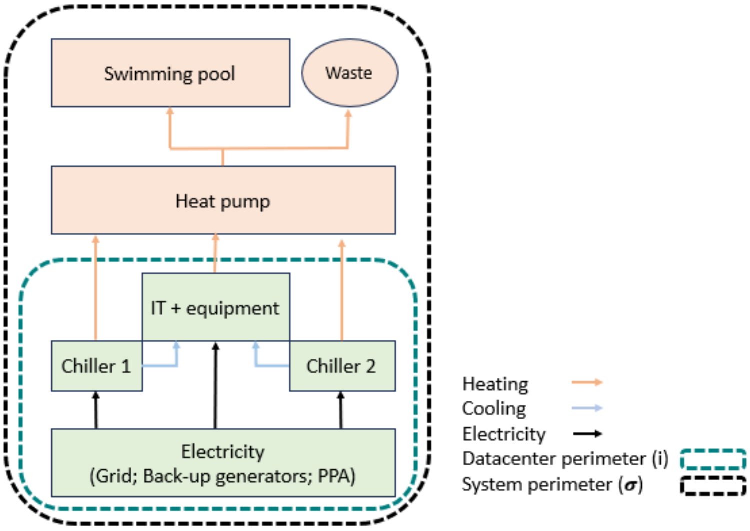


Figure 7 – Simplified example of data center integrated energy system. Source: nLighten-FEEM elaboration, 2023

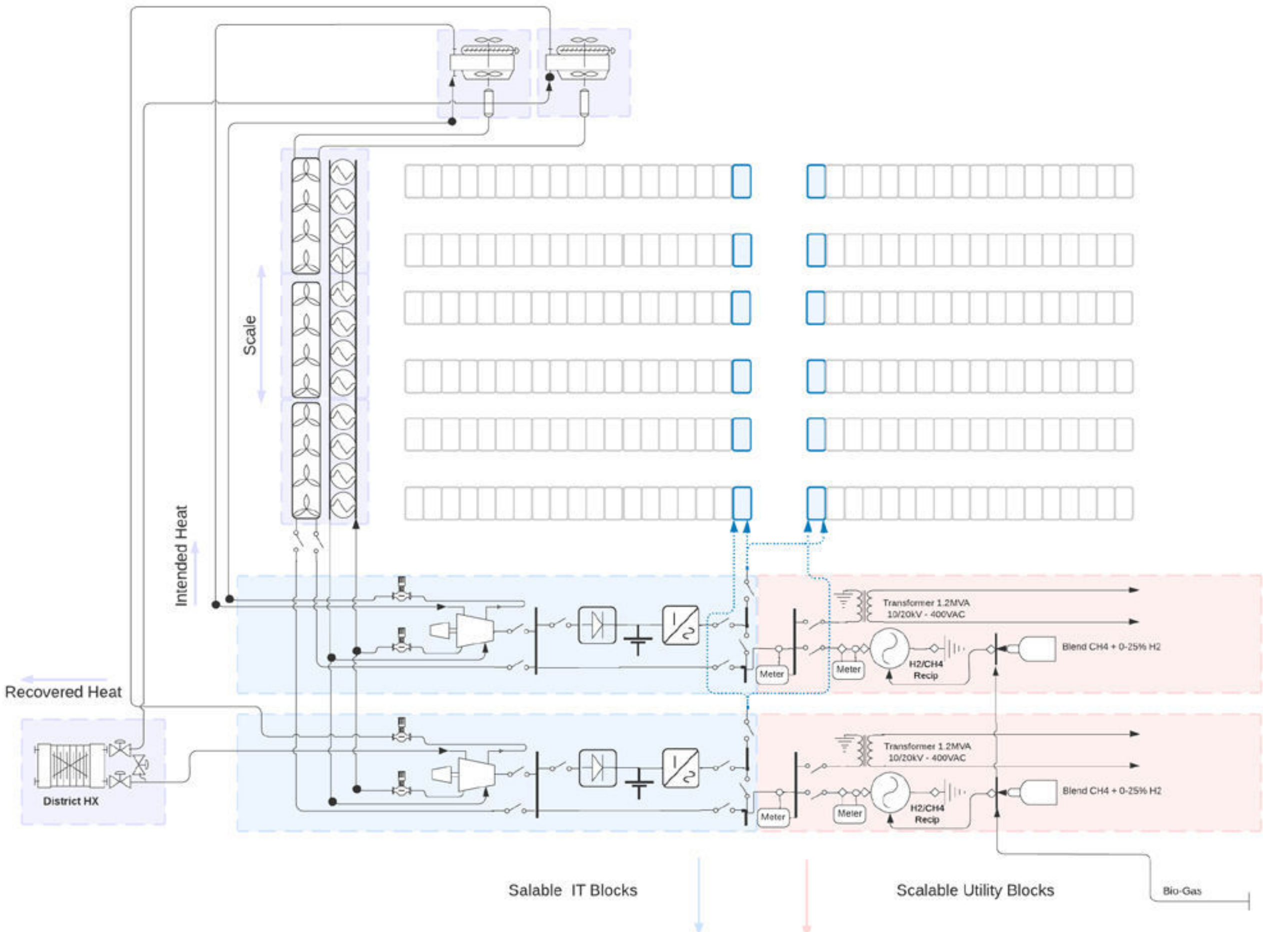


Figure 8 – Diagram of Eschborn integrated energy system. Source: nLighten-FEEM collaboration, 2023

Currently, the two customers are supplied by gas boilers. By connecting their heating centrals to a heating grid, the consumption of natural gas can be partially replaced, and CO_2-emissions can be reduced. The gas boilers will only be serving for peaks in demand and as back-up option.

Some of the Heat pumps are controlled to meet the heating load and run at higher temperatures to produce a hot water circuit to a level of about 60 °C. At the data center a heat transfer station conveys heat onwards to a heating grid ring, connected to the two clients and the office of nLighten. The remaining heat pumps are running energy optimized to meet the remainder of the data center cooling load (intended heat).

This approach can be potentially scaled-up and integrated in a more comprehensive local network and/or district heating, as more clients and heat sources are gradually connected.

The following charts present some of the main KPIs introduced in the previous section, with reference to the case of Eschborn in year 2023[35].

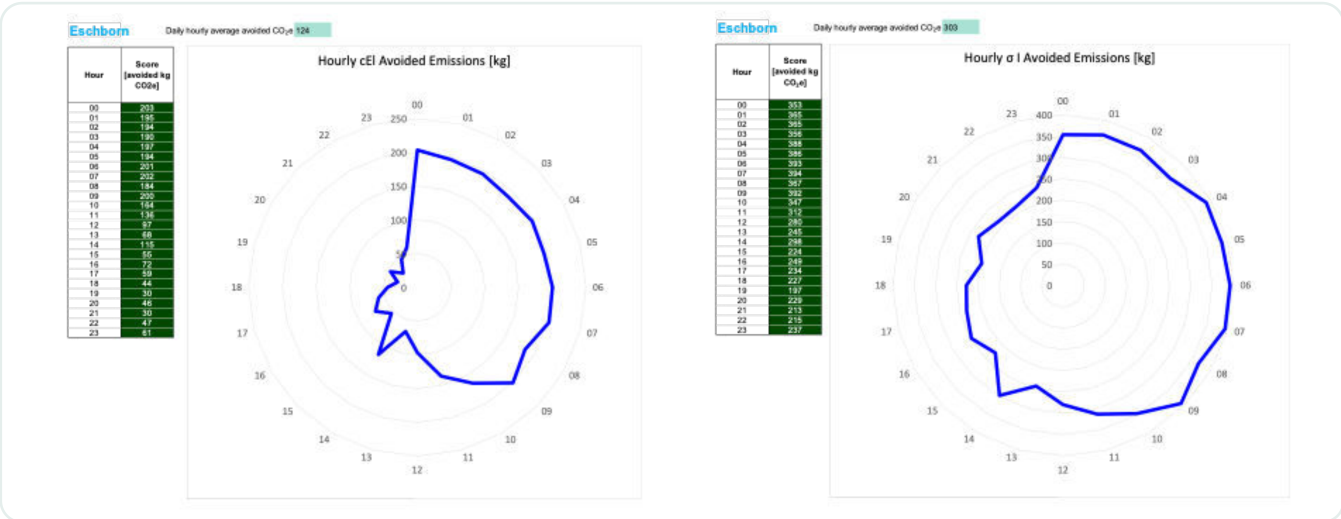


Figure 9 – Hourly data center cEl avoided emissions (Eschborn) and system avoided emissions (Eschborn)

In Figure 9 – Hourly cEl Avoided Emissions (Eschborn) the daily emissions avoidance from the data center is presented with hourly granularity, for 20th December. Notably, during the nocturnal and morning periods, the data center exhibits a pronounced deviation from emissions savings. The graphical representation also highlights the difference in the aggregate values, showcasing an average hourly daily emissions production of 124 kg of CO_{2e} in the case of the **cEl Avoided Emissions** and 300 kg of CO_{2e} in the case of the **I Avoided Emissions**. This depiction underscores the data center's effectiveness in mitigating emissions, particularly when heat is integrated into the indicator.

35 The case study is used as a preliminary example of the methodology; wherever data for 2023 are not available, those have been assumed as the last available year (data on Generated CFEl refer to 2022) or forecasted (Contracted CFEl).

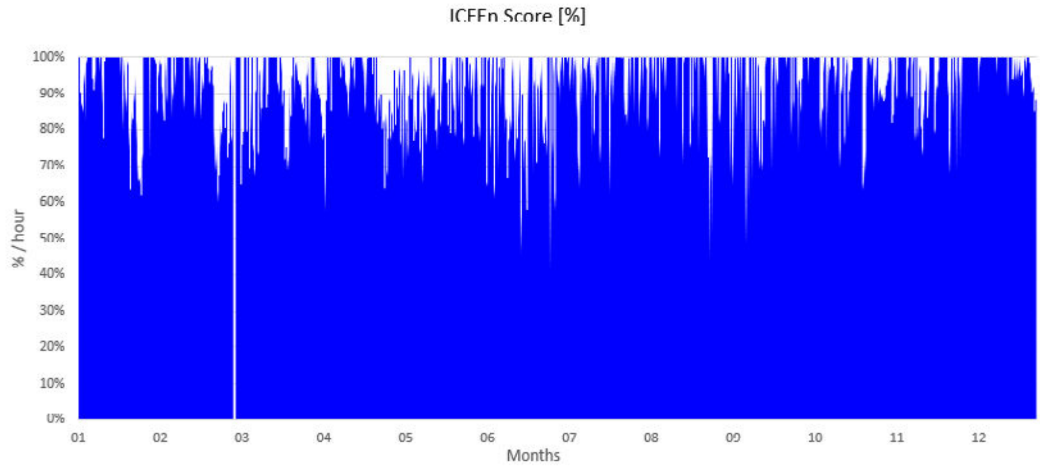


Figure 10 – ICFEn score (Eschborn)

On the other hand, an annual analysis of the integrated Avoided Emissions score (Heat and Electricity perimeter) is presented, featuring hourly granularity. The data reveals notable peaks during winter periods, surpassing the annual average. This distinctive pattern is attributable to the higher carbon intensity of the German grid during colder seasons. Consequently, the data center exhibits a valuable capability for emissions avoidance during these specific temporal intervals. The observed variability underscores the influence of seasonal factors on the data center's efficacy in mitigating emissions, with colder months presenting optimal opportunities.

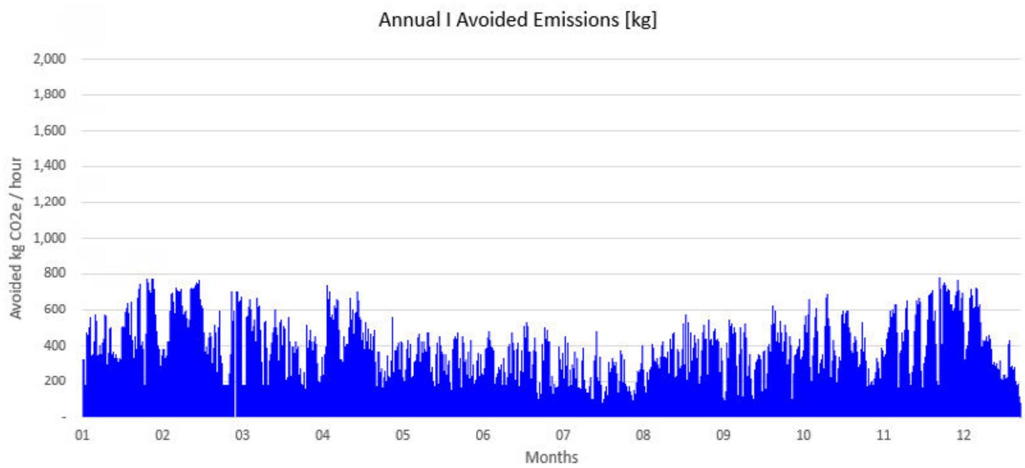
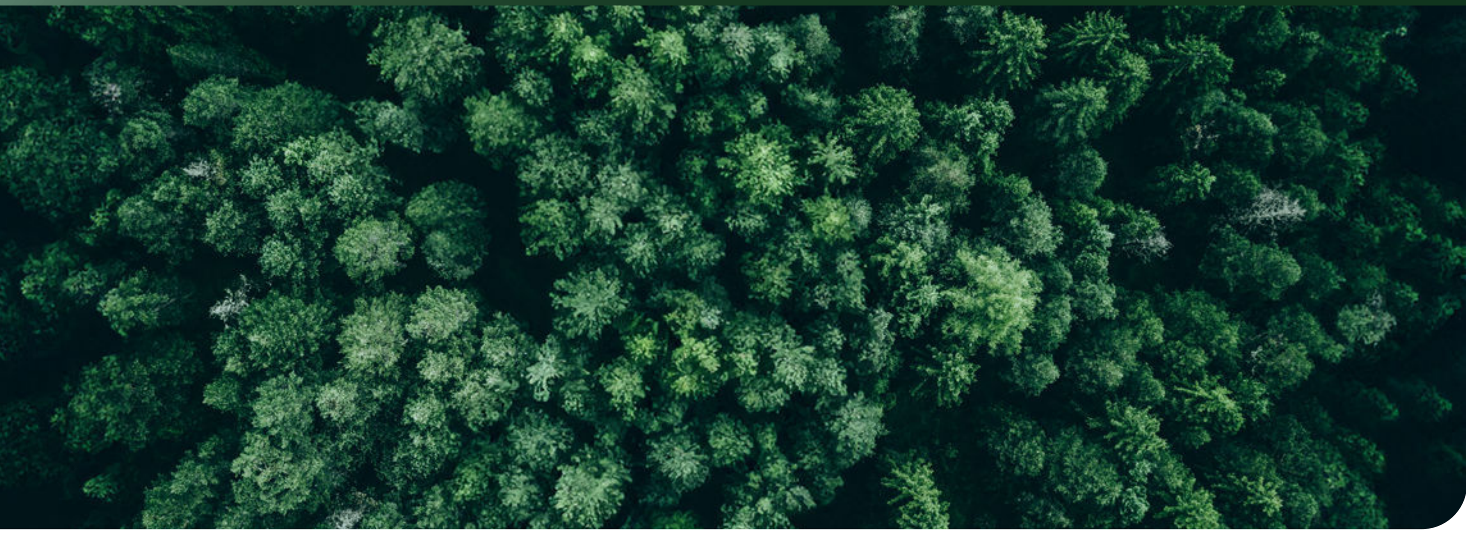


Figure 11 – Annual I Avoided Emissions (Eschborn)

In Figure 10, the annual Integrated CFE score of the data center (electricity and heat perimeter) is displayed with an hourly granularity.

The average ICFEn score hovers around 93%, notably exceeding the average annual value of the indicator solely per-taining to the electricity perimeter (cEl CFE score), which stands at a comparatively lower 88%.

This indicates that the incorporation of Recycled Heat, coupled with the calculation of the Integrated CFE score, results in a pronounced enhancement of the data center's 24/7 CFE performances.



4. Conclusions

This extension of the established 24/7 Carbon-Free Energy concept represents a goal to transparently show decarbonisation via sector coupling and advance energy practices in procurement, supply, and policy. The expansion of the original 24/7 CFE methodology outlined in this note, incorporating waste heat recovery and utilization, and enlarging the perimeter to all of the actors involved, showcases a holistic sector coupling-based perspective on data center operations.

The rationale outlined here provides a systematic framework already applied to a Frankfurt data center presented as a case study; the introduced Key Performance Indicators (KPIs) reveal the efficacy of this new environmental and energy accounting mechanism, with the example data center achieving notable emissions reductions and enhanced 24/7 CFE performances, particularly when considering the integration of recycled heat.

This empirical evidence substantiates the viability and potential scalability of nLighten’s 24/7 CFE methodology, providing valuable insights for advancing sustainable and carbon-free energy models within the data center industry.

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