

Development of EXIGENCE Energy Consumption, Efficiency, and Carbon Footprint Metrics

Energy Measurements, Energy Metrics, Standardisation December 11, 2024



Share this post:

 LinkedIn
(<https://linkedin.com>)

Why the Focus on Metrics?

At EXIGENCE, one of our primary goals is to enable sustainable, service-level measurements across various domains while simultaneously optimising resource usage during service provisioning and invocation. Achieving these optimisations is challenging without reliable and accurate data, which is where our first ambition—defining robust metrics—becomes critical.

To support resource optimisation, we need metrics that offer insight into energy consumption, efficiency, and carbon footprint. Over the past few months, EXIGENCE has been focused on developing such metrics as part of our larger project goals. Specifically, we are addressing the energy consumption and carbon footprint challenges of ICT services in the upcoming 6G era, where the demand for sustainable technology solutions is rapidly growing.



How Are We Developing These Metrics?

The development of these metrics is deeply rooted in the requirements of real-world use cases, which will be detailed in a future blog post. These use cases give us a comprehensive view of the ICT ecosystem and its interdependencies, both in physical and virtual domains. As next-generation mobile telecommunication systems rely heavily on virtual environments (e.g., cloud-continuum), our metrics need to account for both physical components (e.g., terminals, servers) and virtual ones (e.g., VMs, containers).

Additionally, we are considering the precision and time resolution required for these metrics to be applicable in real-world scenarios. This ensures that our metrics can provide actionable data for service provisioning, resource allocation, and performance optimisation in a timely and reliable manner.

What About Existing Metrics?

EXIGENCE is not starting from scratch. We are building on existing standards and research, which can be found in our **Green ICT DIGEST** (<https://projectexigence.eu/green-ict-digest/>) repository. This includes contributions from major organisations like 3GPP, ETSI, IEEE, and IETF, alongside influential bodies such as NGMN and GSMA. However, while these existing metrics provide a foundation, our project requires specific, service-level measurements that span multiple domains. Rather than reinventing the wheel, we are adapting and refining existing metrics to better align with our goals—such as evaluating energy consumption across diverse environments.

Energy Consumption Metrics

Our energy consumption metrics are designed to evaluate both direct and indirect energy use across different ICT system components in near real time. These metrics serve two main purposes:

1. To assess energy consumption across the system and its service delivery, from various perspectives.
2. To provide input data for resource optimisation mechanisms, enabling energy-efficient system operation, especially during high-demand periods.

At the most fundamental level, our metrics measure the energy consumption of individual processes. For example, an atomic process like a running application can be monitored for energy use using tools like Running Average Power Limits (RAPL). By aggregating energy consumption data across multiple atomic processes, we can assess the energy consumption of software components and, further, entire end-to-end services.

An end-to-end service typically spans multiple components across both physical and virtual domains. To accurately assess its energy consumption, we must calculate the energy use of each individual component and aggregate them to determine the total consumption of the service. This evaluation also includes factoring in residual energy consumption, which accounts for the baseline energy used by the service, even when no users are actively engaged.

While end-to-end service energy consumption shares similarities with the energy consumption of a single (end-to-end) user session, the key difference lies in the proportion. A single user's session contributes only a fraction of the total energy consumed by the entire service, which may serve multiple users simultaneously. The primary challenge is accurately calculating the energy consumption attributed to a single user's session within the broader context of a service that serves many users.

On the infrastructure side, we also monitor the energy use of hardware devices (e.g., servers, terminals) and virtual environments (e.g., VMs, containers). Moreover, we account for renewable energy contributions, where possible.

For sustainability, it is highly recommended that infrastructure operators rely on renewable energy. For example, as reported by the **International Energy Agency (IEA)** (<https://www.iea.org/energy-system/buildings/data-centres-and-data-transmission-networks>) in July 2023, leading tech companies have made significant strides in this area. In 2021, Apple (2.8 TWh), Google (18.3 TWh), Meta (9.4 TWh), and Microsoft (13 TWh) either purchased or generated enough renewable energy to meet 100% of their operational electricity consumption, primarily in data centers.

Amazon consumed 30.9 TWh in 2021, with 85% of that from renewable sources, and has set a target to achieve 100% renewable energy by 2025. While some network operators, such as BT, TIM, and T-Mobile, have also achieved 100% renewable energy use, data transmission network operators still lag behind their counterparts in data centers in terms of renewable energy procurement.

It's important to note that matching 100% of annual demand with renewable energy purchases or certificates doesn't mean that data centers or networks are powered entirely by renewable sources at all times. To address this, Google and Microsoft have set ambitious goals to source and match zero-carbon electricity on a 24/7 basis by 2030. Similarly, Iron Mountain aims for this by 2040.

A growing number of organisations are now working towards 24/7 carbon-free energy, ensuring their electricity demand is met on an hourly basis. This shift is expected to drive the adoption of flexible technologies that will be critical for achieving net-zero transitions in the power sector.

➔ Energy Efficiency Metrics

Energy efficiency in ICT, particularly in telecommunications, is often measured by the energy needed to transmit or process a certain amount of data—such as Joules per bit or kWh per bit. As mobile network technologies advance (e.g., 5G), energy efficiency continues to improve. For example, according to **"A holistic approach to address RAN energy efficiency, Ericsson Blog"** (<https://www.ericsson.com/en/blog/2021/12/a-holistic-approach-to-address-ran-energy-efficiency>) published in December 2021, while mobile traffic grew by a factor of almost 300 between 2011 and 2021, the total energy consumption to handle this traffic only increased by 64%, showing significant gains in efficiency.

Energy efficiency metrics also consider the use of renewable energy, which leads us to define a Renewable Energy Factor (REF). This ratio compares the energy consumed from renewable sources to the total energy consumed by the system. The goal here is to maximise the share of renewable energy in ICT operations, ensuring that sustainability is built into the system's very foundation.

These metrics are invaluable for optimisation purposes, helping identify energy wastage and areas where efficiency can be improved. For example, by understanding the energy consumption of a device or component under varying loads, we can pinpoint energy-saving opportunities and guide better resource allocation. It may be also noted here that the definition of this metric is inspired by the Energy Waste Factor definition based on network measurements as defined in T.S. Rappaport, et.al., "Waste Factor and Waste Figure: A Unified Theory for Modeling and Analysing Wasted Power in Radio Access Networks for Improved Sustainability", IEEE Open Journal of the Communications Society", Vol. 5, 2024.

➔ Carbon Footprint Metrics

Carbon footprint metrics are designed to assess the environmental impact of services across multiple domains, quantifying the greenhouse gases emitted due to energy consumption. These metrics are an extension of our energy consumption measurements, providing insight into the carbon emissions associated with various ICT activities.

Carbon footprint can be measured at different levels:

- The footprint of a hardware device (e.g., server or terminal).
- The footprint of a software component.
- The footprint of an entire service chain.
- The footprint of a single user's session or data flow.

For services involving multiple domains (such as cloud-based applications or multi-user services), the challenge lies in accurately calculating the carbon impact based on the energy used, the type of energy (renewable vs. fossil fuel), and the location of the energy sources. To calculate the carbon footprint of a single traffic flow, the energy consumption must first be calculated based on the devices used and the time of use. This data can be provided by the corresponding energy consumption metric, while the challenge is then to calculate the emission factor, i.e. the carbon intensity of the electricity used (e.g., measured in grams of CO₂ per kWh). For example, the carbon intensity of electricity varies by geographic region, depending on the mix of energy sources. This variability is factored in to calculate the carbon footprint, ensuring a more accurate representation of a service's environmental impact.

Conclusions

The metrics we have developed so far reflect the current status of our work and the ongoing evolution of the EXIGENCE project. As the project progresses, we expect these metrics to be refined, and we may introduce new ones or discard those that are no longer relevant. The goal is not only to address the current challenges but also to anticipate the future needs of a rapidly changing technological landscape.

Stay tuned for further updates on our metrics development and insights into how EXIGENCE is shaping the future of sustainable ICT systems.

Read EXIGENCE D4.1 – Assessment Plan full report: [HERE](https://projectexigence.eu/wp-content/uploads/2025/04/D4.1-Assessment-Plan.pdf) (<https://projectexigence.eu/wp-content/uploads/2025/04/D4.1-Assessment-Plan.pdf>)

Authors



Internet Institute Ltd

Rudolf Susnik, manages research and innovation-oriented projects at Internet Institute, focusing on 5G/6G, IoT, edge-cloud continuum, sustainability in ICT and ICT for sustainability. His background includes over 15 years in the ICT industry (network operators and vendors) and research/teaching experience at the University of Ljubljana, where he earned his PhD in 2007. He also actively volunteers as a firefighter.



TNO

Ljupco Jorguseski received a Dipl. Ing. degree in electrical engineering from the University Cyril and Methodius, Skopje, Republic of Macedonia in 1996, and a Ph.D. degree in 2008 from the Aalborg University, Aalborg, Denmark. From 1997 to 1999 he worked as applied researcher at TU Delft, The Netherlands on the ETSI WCDMA proposal for 3G, followed by research position on wireless 3G and 4G systems at KPN Research, The Netherlands till 2003. Since 2003 he is a senior consultant on wireless access at TNO, the Dutch national institute for applied research, focusing on radio planning and (self-)optimisation of wireless networks. From 2008 he is involved as RAN and SA groups delegate in 3GPP and from 2021 he also follows O-RAN Alliance standardisation activities. He has authored and co-authored over 30 publications in conferences, journals, book chapters and patent applications.

Funded by the European Union. The project is supported by [Smart Networks and Services Joint Undertaking \(https://smart-networks.europa.eu/\)](https://smart-networks.europa.eu/) (SNS JU) and its members. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or SNS JU. Neither the European Union nor the granting authority can be held responsible for them.

Copyright © 2024 EXIGENCE Consortium. All Rights Reserved.

Terms & Privacy

Terms of use (<https://projectexigence.eu/terms-of-use/>)
Privacy policy (<https://projectexigence.eu/privacy-policy/>)
Cookie policy (<https://projectexigence.eu/cookie-policy/>)

Write us a message

✉ hello@projectexigence.eu(mailto:hello@projectexigence.eu)

Connect with us

[in](https://www.linkedin.com/company/projectexigence) LinkedIn(<https://www.linkedin.com/company/projectexigence>)