



A novel approach for accounting of the use phase emissions for connected devices

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Abstract

Reducing the life cycle emissions of connected devices is essential for mitigating their environmental impact as their proliferation accelerates. These devices, including consumer electronics and Internet of Things (IoT) systems, contribute significantly to greenhouse gas emissions, with their use phase often dominating their overall environmental footprint due to high electricity consumption. Data centers, IoT edge devices, and semiconductor logic chips exemplify how operational energy use can surpass manufacturing emissions, highlighting the need for energy-efficient designs. Implementing eco-design principles, optimizing communication protocols, and integrating low-power components can enhance sustainability. This paper explores decarbonization strategies for the use phase of connected devices through four key principles: 1) enabling better measurement, 2) energy efficiency, 3) renewable energy matching, and 4) carbon offsets. It also examines the need to update carbon footprint methodologies to incorporate real-time energy monitoring, enhancing the accuracy of emissions reporting and facilitating targeted interventions for reducing environmental impact.

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Keywords: Life cycle emissions, Connected devices, Internet of Things (IoT), Greenhouse gas emissions

Introduction

Reducing life cycle emissions of connected devices is crucial for mitigating their environmental impact, particularly as the number of such devices continues to grow exponentially. These devices, which include consumer electronics and Internet of Things (IoT) systems, contribute significantly to greenhouse gas emissions and energy consumption throughout their life cycles. Connected devices, particularly consumer electronics, contribute significantly to greenhouse gas emissions. For example, operational energy consumption of devices like desktop PCs often exceeds emissions from manufacturing, highlighting the need for energy-efficient designs (Teahan, 2014) ^[1]. The proliferation of IoT devices poses substantial environmental challenges, including increased energy consumption and electronic waste. The carbon footprint of IoT edge devices can vary significantly, with worst-case scenarios potentially reaching over 1000 MtCO₂-eq/year by 2027 (Pirson & Bol, 2021) ^[2]. The use phase of data center equipment, is a major contributor to environmental impacts due to electricity consumption. This is particularly evident in the case of electronic mail services, where the energy used by data centers for data storage is significant (Farrant & Guern, 2012) ^[3]. For video projectors, the use phase dominates the life cycle impacts related to global warming potential and primary energy demand. The study suggests that energy efficiency improvements during the use phase can be beneficial, but only if they are substantial (e.g., a 10% increase in efficiency) (Cheung *et al.*, 2018) ^[4]. In the case of semiconductor logic chips, electricity consumption during the use phase is a critical factor. Reducing power consumption in this phase is identified as the most effective way to limit environmental impacts, especially for newer generations of logic chips (Boyd, 2012) ^[5] (Boyd *et al.*, 2010) ^[6]. The design parameters of electronic devices, such as the type of components used, can influence the environmental impact during the use phase. For example, the integration of more energy-efficient components can reduce the overall impact (Ochoa *et al.*, 2019) ^[7]. The intensity of use also affects the environmental impact. Professional environments, where equipment is used more intensively, tend to have a higher use phase impact compared to domestic settings (Farrant &

Guern, 2012)^[3]. In all the examples mentioned above, the use phase of connected products significantly contributes to their overall life cycle impact, primarily due to energy consumption.

This phase often dominates the environmental footprint, especially in terms of global warming potential and primary energy demand. The impact varies depending on the type of electronic device and its usage context, but electricity consumption remains a consistent factor across different studies. Implementing eco-design principles and green IoT strategies can enhance the energy efficiency of connected devices. This includes using low-power components, energy harvesting mechanisms, and optimizing communication protocols to reduce the carbon footprint (Memic *et al.*, 2022)^[8].

This paper aims to address how to decarbonize the use phase of connected products by employing four key principles: 1) enabling better measurement, 2) energy efficiency, 3) renewable energy matching, and 4) carbon offsets. Furthermore, this paper also aims to discuss how the carbon footprint methodology would need to be updated in order to account for these decarbonization actions.

Enabling better measurement

Current State

The Greenhouse Gas Protocol (GHGP) provides guidance for measuring and reporting Scope 3 emissions, which include all indirect emissions that occur in a company's value chain. Category 11 of Scope 3 specifically addresses emissions from the use of sold products. This category is crucial for companies whose products, when used, result in significant greenhouse gas emissions such as connected devices. Scope 3 Category 11, often constitute a substantial portion of a company's total greenhouse gas emissions, sometimes exceeding direct emissions significantly (Bettenhausen, 2022)^[9]. Measuring emissions from the use of sold products involves significant complexity and uncertainty, as it requires assumptions about how products are used by consumers (Patchell, 2018)^[10]. This complexity can lead to variability in reporting and challenges in achieving accurate assessments. Companies often rely on industry average emission factors and input-output models, which may not accurately reflect their specific supply chains or product use scenarios. This can limit the precision and actionability of the data collected. The GHGP guidance emphasizes the importance of understanding and managing these emissions to achieve comprehensive carbon footprinting and effective emissions reduction strategies. While the focus on Scope 3 Category 11 emissions is crucial for comprehensive carbon management, it is also important to consider the broader implications of such reporting. The complexity and resource intensity of measuring these emissions can divert attention from more immediate and impactful environmental actions. Additionally, the responsibility for reducing these emissions often falls on third parties, which can complicate accountability and action. Therefore, while detailed Scope 3 reporting is essential, it should be balanced with practical strategies that enable companies to make meaningful progress in reducing their overall carbon footprint (Patchell, 2018)^[10].

Proposed Future State

A significant concern with this method is its dependence on projected lifetime energy consumption figures that are based

on the year a product is sold, instead of using actual energy consumption data that can be derived from yearly product usage. To improve the accuracy of emissions reporting and reduce greenhouse gas emissions, it is necessary to adopt real-time energy monitoring systems. By using technology that monitors how devices are used and their energy consumption in real time, companies can gather detailed data that reflects actual operating conditions, rather than depending on fixed estimates based on initial sales figures. This method supports findings from life cycle assessments, which show that the energy used during operation often exceeds the emissions produced during manufacturing for connected devices. This highlights the need for accurate measurement during the use phase accounting. (Teehan, 2014)^[1]. Embracing innovative measurement strategies will not only improve accountability but also empower organizations to implement targeted interventions that significantly mitigate the use phase footprints of their devices over time. Additionally, it would also eliminate the need for estimating the lifetime of the devices in order to account for all the lifetime energy consumption in the year that the device was sold.

This fundamental shift in how the use phase accounting will enable the following:

1. Accurate carbon reporting that uses actual data about the usage of the device which removes estimations and guesstimates about energy consumption.
2. Accurate understanding of how new features and updated software leads to a change in energy consumption.
3. Increased accountability for the use phase emissions of the device on an annually rather than accounting for all the use phase emissions in the year that the device is sold.
4. Enable credible and additional renewable energy matching to mitigate the use phase emissions associated with devices.

For many connected devices, there is no need to modify hardware for accurate energy measurement. If a device recognizes its current operating state, it can retrieve the energy consumption data for that state from a pre-established internal database.

Energy Efficiency

Energy efficiency is crucial for reducing use phase emissions of connected devices. As the number of connected devices continues to grow, optimizing energy consumption becomes essential to minimize environmental impact and operational costs. Energy-efficient technologies and strategies not only extend the lifespan of devices but also contribute to significant reductions in greenhouse gas emissions. Improving energy efficiency in connected devices not only reduces emissions but also offers economic benefits by lowering energy costs for end customers. This is particularly important as energy prices rise and the demand for sustainable solutions increases (González *et al.*, 2012)^[11] (Quittek *et al.*, 2011)^[12].

The Energy Star program, initiated by the Environmental

Protection Agency (EPA) in 1992, is a well-known initiative that identifies and promotes products that use energy efficiently. Since its inception, Energy Star and its collaborators have assisted American households and businesses in saving 5 trillion kilowatt hours of electricity,

reducing energy expenses by over \$450 billion, and lowering carbon emissions by 4 billion metric tons (Sanchez *et al.*, 2008) ^[13]. It is observed that many products consume more energy than necessary for their intended use in spite of years of voluntary and regulatory efforts to promote energy efficiency. For numerous connected devices, energy efficiency standards are either absent or have not kept pace with industry developments. These standards are established by creating a simplified model of a product, which includes specific usage scenarios and benchmarks. However, these standards may not accurately reflect real-life situations as the complexity of device features and operations increases. Thus, there is a chance to utilize connectivity to enhance energy efficiency in a more immediate and data-informed manner. Energy efficiency is crucial for achieving a net-zero carbon future, as it allows for meeting the growing global energy demands with reduced overall energy production. This decrease in total energy consumption helps lessen the need for additional renewable energy resources. Moreover, as energy efficiency standards evolve, the role of consumer behavior in driving demand for sustainable technologies cannot be overlooked. Consumers increasingly prioritize eco-friendly products, which places pressure on manufacturers to innovate and adopt greener practices. This shift aligns with findings that suggest operational energy consumption often surpasses emissions from device manufacturing, underscoring the importance of addressing use-phase impacts (Teehan, 2014) ^[14].

. Additionally, integrating smart technology into devices can facilitate real-time adjustments based on usage patterns, further enhancing energy savings and reducing overall carbon footprints.

Renewable Energy Matching

Renewable energy matching can significantly mitigate the use phase emissions of connected devices by aligning energy consumption with additional renewable energy. This method involves one of two approaches. The first approach entails integrating renewable energy sources into the power grid and optimizing their use through advanced technologies and strategies. The second approach involves corporate procurement of renewable energy and allocating it to the end use of the devices that they sell. By doing so, emissions associated with the energy consumption of connected devices can be mitigated. Prior to renewable energy matching, energy efficiency needs to be maximized. Following which, investments need to be made in additional renewable energy capacity. Additionality in renewable energy refers to the concept of ensuring that renewable energy projects provide benefits beyond what would have occurred under a business-as-usual scenario. Additionality is often used to assess whether a project contributes to genuine emission reductions or other positive outcomes that would not have happened without the project (Gillenwater *et al.*, 2014) ^[14].

. Investing in additional renewable energy matching can ensure that the emissions reductions are credible.

Carbon offsets

Since there are embodied emissions with any renewable energy projects, the use phase emissions can never truly get to zero. Carbon offsets are a critical tool in the pursuit of net zero emissions, serving as a mechanism to balance out GHG emissions that are difficult to eliminate entirely. By investing in projects that either remove carbon dioxide from the

atmosphere or prevent emissions, net-zero can be achieved. It is important to note that offsets should be used as a last resort when all other options have been exhausted. Despite the potential of carbon credits, challenges such as verification costs, small project scales, and double counting of credits need to be addressed to fully realize their potential (Friess *et al.*, 2022) ^[15]. However, these risks are small compared to the benefit of achieving net zero for the use phase emissions of connected devices.

Proposed changes to the carbon accounting methodology

The method proposed here departs from what is suggested by the GHGP, however, it makes the accounting of Scope 3 Category 11 emissions more accurate and enables companies to take decarbonization actions. This method incentivizes maximizing energy efficiency, renewable energy purchases, shifts to an annual accounting approach instead of a lifetime accounting approach, and finally, enables accountability for already sold devices.

The use phase calculation for connected devices needs to be calculated per month per country. Power measurements obtained from lab based measurements or field based power measurements. These measurements can then be combined with aggregated data that looks at how much time each device spends in a power state. Accounting for renewable energy matching can be done by taking the percentage of matched energy consumption for each country, month, and device. This matched energy consumption needs to be multiplied by an average transmission and distribution loss factor, and an average upstream embodied emission factor for each renewable energy type. The unmatched consumption can then be multiplied by the grid emissions along with an average transmission and distribution loss factor.

Finally, the overall Scope 3 Category 11 emissions can then be calculated by taking the sum of use phase emissions per country per month for all the geographies per annum. This approach can be adapted to suit particular locations and timeframes that align with the specific data related to a product and its renewable energy purchasing methods.

Conclusion

In conclusion, the urgent need to address the life cycle emissions of connected devices is underscored by their increasing prevalence and the significant environmental impacts associated with their use phase. This research highlights the critical role that operational energy consumption plays in contributing to greenhouse gas emissions, particularly as the demand for energy-efficient designs and sustainable practices grows. By focusing on the use phase, which often dominates the overall life cycle impact of devices, this study proposes a comprehensive approach to decarbonization that includes enhanced measurement techniques, energy efficiency improvements, renewable energy matching, and the strategic use of carbon offsets. The proposed methodology aims to refine carbon accounting practices, particularly within the framework of Scope 3 emissions, enabling companies to better quantify and manage their environmental footprints. Ultimately, the findings of this research advocate for a shift towards more accurate and actionable emissions reporting, fostering accountability and encouraging the adoption of eco-design principles that align with global sustainability goals. Through these measures, stakeholders can work collaboratively to mitigate the environmental impacts of connected devices,

paving the way for a more sustainable future.

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