A PRELIMINARY ASSESSMENT OF HANDPRINT METHODOLOGIES FOR INFORMATION AND COMMUNICATIONS TECHNOLOGY GRID MANAGEMENT SOLUTIONS

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White Paper

Smart Energy. Clean Planet. Better Lives.

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About ACEEE

The **American Council for an Energy-Efficient Economy** (ACEEE), a nonprofit research organization, develops policies to reduce energy waste and combat climate change. Its independent analysis advances investments, programs, and behaviors that use energy more effectively and help build an equitable clean energy future.

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Executive Summary

ACEEE research has found that current GHG protocols are limited in their ability to address and account for downstream scope 3 emissions that occur when goods and services are delivered to end users. The *carbon handprint* has emerged as an approach for assessing and enabling reductions in these downstream scope 3 emissions, complementing the more common *carbon footprint*. We also found that approaches to the treatment of these corporate emissions are in flux as companies and stakeholders seek to implement protocols assessing companies' exposure to climate risk and their fulfillment of their environmental and social responsibilities.

Information and communications technologies (ICT) offer the potential to significantly reduce energy and greenhouse gas (GHG) emissions by value chain players and end users through improvements to system efficiency. These ICT-enabled impacts can be viewed as offsetting the energy and emissions footprints that result from the production of emissions-reducing goods and services by companies (figure ES-1). While simple in concept, the estimation and attribution of these handprint effects is complicated by the diverse and interconnected networks of companies that enable and deliver ICT solutions to their end users.

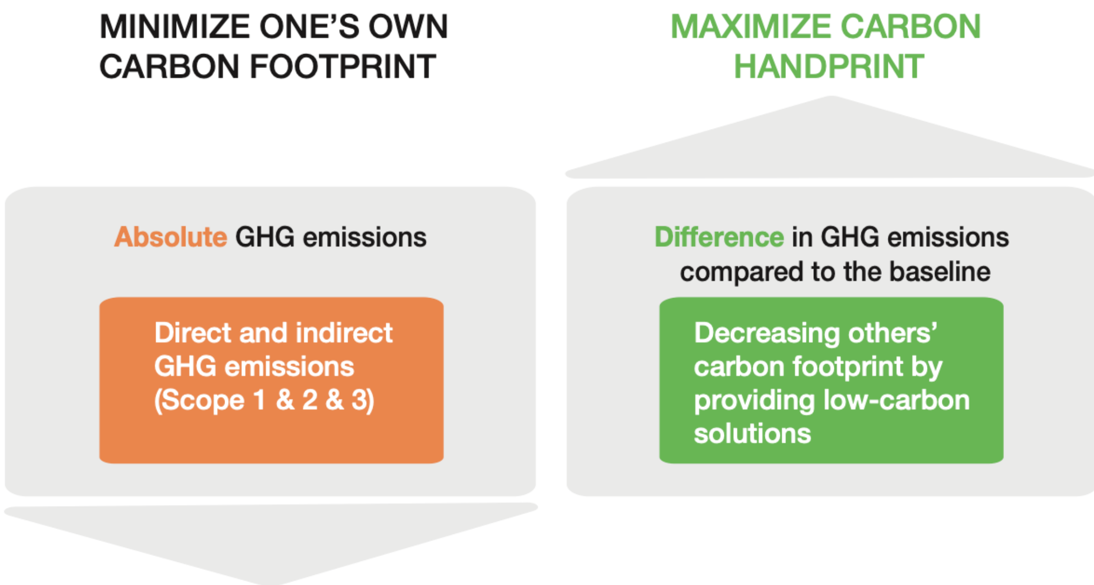

Figure ES-1. Finnish approach to footprint and handprint management with a goal of minimizing the footprint and maximizing the beneficial handprint. Source: Pajula et al. 2021.

Methods for handprint estimation calculate the beneficial environmental and climate impacts of products and services over their life cycles by taking into consideration material use, energy use, lifetime and performance, waste, and carbon capture and storage based on international protocols. Calculation results indicate the size of the *handprint* created by a company's product, with a bigger beneficial *handprint* being better. A carbon handprint may be created either by offering a new solution with a lower carbon footprint compared to the baseline solution, or by helping a customer to reduce the footprint of their existing processes relative to business as usual. An example could be a food packaging solution that, when compared to the baseline packaging, is produced with lower emissions and additionally helps to extend the food's shelf life, preventing food waste. The main steps for *handprint* estimation generally involve

1) identifying the operating environment (customers of the product, potential contributors to the handprint, baseline footprint)

2) defining life cycle analysis (LCA) requirements (functional unit, system boundaries, data, and sources)

3) estimating the handprint (calculating the new footprint and subtracting it from the baseline footprint)

4) critically reviewing the handprint and communicating the findings

We have identified two approaches for implementing handprint estimation in a GHG reporting and disclosure context. *Sharing responsibility and sharing credit* involves separately estimating the footprint and handprint and allowing companies to take concrete steps to minimize footprint emissions and maximize handprint savings in parallel. *Attribution of savings* involves quantifying all aspects of the full life cycle emissions of a good or service and allocating the emissions to each market player based on their contributions or responsibility.

In this white paper, we consider two applications of ICT-enabled solutions for electric energy management, one front-of-meter on the utility side and one behind-the-meter on the end-use customer side, to assess how ICT solutions could contribute to lowering GHG emissions in such applications and how emissions credits might be allocated in these scenarios.

Both solutions represent market-ready grid management approaches that offer end users, and companies throughout the supply chain, the opportunity to significantly reduce costs, energy use, and resulting GHG emissions. These solutions enable handprint savings among value chain partners, promote further data collection and analysis, and integrate renewable resources into the grid. Both ICT-powered solutions employ virtualization (which means moving a service such as substation control from a local server to the cloud) and emphasize systems optimization through automation, machine learning, and predicted maintenance to reduce risks and costs. Such virtualization benefits are consistent between both solutions, including enhanced reliability, life cycle management, integration of distributed energy resources, and greater utilization of existing assets.

These solutions depend on significant analytics and compiled data. They also require methodologies to quantify impacts from each ICT-enabled measure and acceptable approaches for attributing the handprint savings to different actors in the supply chain.

The solutions differ with respect to analytical needs, audiences, and data availability. For example, ICT solutions such as the Spirae Platform offer monitoring of indicators of GHG emissions reductions and can provide detailed information on correlations with central processing unit (CPU) cycles, CO_2 offsets, and the contributions of renewables to potential savings for customers. ICT solutions deployed by utilities may be hampered by being implemented in regulated environments with privacy restrictions that inherently limit data collection.

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Our research finds that while many companies in the sustainability community aspire to net-zero life cycle GHG targets, current knowledge and practices make this approach challenging to implement. Thus, ACEEE suggests that companies strive to minimize the full life cycle GHG impacts of their operations and products in use, not merely focus on getting some subset of their emissions to zero.

Current data and analytic capacity enable companies to make reasonable estimates and take concrete steps to reduce the GHG footprint of their own operations (i.e., scope 1 and 2 emissions). This capability is enabled by data collection and analysis of companies' own operations and their energy providers (i.e., electric utilities and power producers). We see the path also emerging to make defensible estimates of upstream scope 3 emissions through ICT-enabled supply chain tracking and tracing, and perhaps extending the accounting to end-user sites. The steps that a company needs to take to minimize its footprint are clear, as are the responsible entities.

The estimates for downstream scope 3 life cycle GHG emissions have fundamentally different characteristics from upstream emissions, with inherently greater uncertainty due to the complexity and variations in how end users will use the goods and services they procure. In addition, multiple entities will, in most cases, enable or contribute to the GHG emissions that result from the use and end-of-life stages of the product life cycle. From a policy perspective, a single responsible entity is unclear. Rather, we see multiple entities contributing to GHG emissions. ACEEE suggests that it may be appropriate to treat these two phases of product life cycles as separate but complementary. A company should strive to minimize its own footprint and maximize handprint savings (decrease the footprint of others) by providing low-carbon solutions (see figure ES-1). The implementation of this vision is still in its emerging stages.

The conclusions from our research indicate that:

- The shared responsibility and shared credit approach appears promising in cases where downstream scope 3 emissions cannot be clearly identified and separated between value chain partners.

- The impact-attribution approach is promising in cases where ICT enables the collection of detailed energy use and emissions data for component elements from different value chain partners.

- Given that the handprint concept is not well understood or accepted in the GHG and socially oriented investor communities, we suggest that ICT companies engage with these communities to build awareness of the concept and frame ongoing discussions within these groups and with other stakeholders by convening key stakeholders (e.g., investors, nongovernmental organizations (NGOs), shareholders, value chain partners, end-use customers) to review/discuss the approach.

- Our research suggests that these issues around handprint are not unique to ICTs, so these ICT companies may wish to engage with other industries (e.g., solar, insulation, HVAC) that are facing similar reporting and disclosure challenges related to scope 3 emissions, as well as the broader business community through trade associations.

Introduction

In the last 25 years, there has been significant progress in defining protocols for companies to track, estimate, report, and reduce the greenhouse gas (GHG) footprint of their operations (EPA 2021b, 2021c), especially for scope 1 (direct emissions from company facilities) and scope 2 (indirect emissions from fuel and energy use, especially purchased electricity). This ability to estimate emissions is enabled by data collection and analysis of companies' own operations and their energy providers (i.e., electric utilities and independent power producers). Defensible estimates of upstream scope 3 emissions (from a company's supply chain) are also becoming possible through the use of information and communication technologies (ICT) that enable supply-chain tracking and tracing. Thus, the steps a company needs to take to minimize its footprint are relatively clear, as are the responsible entities.

In contrast, there has been more limited progress on estimating and validating downstream scope 3 emissions reductions. In particular, current greenhouse gas (GHG) protocols are limited in their ability to estimate and account for downstream emissions reductions that occur from the use of products, such as energy-efficient equipment or products that reduce energy use or GHG emissions at an end-user's site. The estimates for downstream scope 3 life cycle GHG emissions have fundamentally different characteristics from upstream emissions, with inherently greater uncertainty due to the complexity and variations in how end users will use the goods and services they procure. In addition, multiple entities will, in most cases, enable or contribute to the GHG emissions that result from the use and end-of-life stages of the product life cycle.

This white paper explores how ICT companies could report the impacts of end-user customer applications of their ICT-enabled solutions in their environmental, social, and governance (ESG) and sustainability communications. This reporting is intended as a supplement to estimates of corporate footprint using the existing GHG Protocol (GHG Protocol 2022). While the primary focus of this project is on energy-related GHG emissions, this approach can be extended to other social and environmental indicators such as sustainability, equity, diversity, resilience, workforce, and public health issues.

ICT has the potential to significantly reduce the GHG emissions of end users through improved system efficiency, as has been documented over the past two decades (GeSI 2008; Elliott, Molina and Trombley 2012; Active Efficiency 2022). Examples of system-efficiency enhancing products include technologies like variable speed compressors and fans using smart controls and sensors in residential household appliances like refrigerators, interactive energy use and efficiency monitoring dashboards for buildings and manufacturing plants, and highway toll systems using priority lanes with differential pricing and dynamic messaging based on traffic volume and flows.

While many organizations are engaged in minimizing the negative environmental impacts (e.g., carbon footprint) of their activities through efficient use of resources and lowered emissions, some companies are going further in responding to the global climate change imperative by taking steps to help reduce the footprint of their customers through the products and services they provide (such as ICT technology solutions). These emission-reducing benefits are increasingly referred to as *handprint* effects. The estimation and attribution of these handprint effects is complicated by the diverse and interconnected networks of companies that create and deliver these solutions. For companies in ICT value chains, the challenges can be even greater.

Many entities in ICT value chains may be able to claim contribution to their value chain partners' and end-users' GHG emissions reductions from the application of ICT solutions. These complexities raise concerns about potentially double-counting benefits—particularly GHG emissions reductions—as well as fairly attributing all enabling entities in the value chain. As a result, protocols used to measure, report, and validate benefits must strive to accurately attribute the contributions of all market players. No single right way exists to accomplish the attribution, but it must be transparent and agreeable to all involved parties. This can be accomplished through negotiations among the parties that are memorialized in contracts; similar questions, such as assignment of tax rights, have been handled in this way. Who takes how much credit for emissions reductions will depend on these negotiations. Handprint impacts may be assigned to an individual entity in the value chain, apportioned to multiple parties, or jointly to all the companies whose goods and services enable these impacts. Allocations could be made based on where the value proposition is the greatest, that is, which entity would gain the most from being able to take the credit.

Since ICT value chains are very complex, it is important to focus on each ICT solution's biggest and most material life cycle contributions to GHG emissions. This approach can be described as "good enough"—accurate yet not burdensome. A *qualitative credit* may be applied as well so that a company could cite its total handprint value contribution to value chain partners and end users without formally being allocated emissions.

This white paper explores what data and analyses are required to validate and provide a necessary level of confidence in estimates of handprint benefits resulting from the application of ICT solutions, and how these effects should be characterized for various purposes (e.g., ESG reporting, public statements, and customer engagement) by different entities in the value chain.

Background

Investors and advocates are increasingly pushing companies to show tangible progress in addressing the climate crisis. Recognizing the environmental and financial risks of maintaining the status quo on emissions (or making only incremental progress), many companies are increasingly committing to GHG reductions targets. In many cases reporting requirements are voluntary, but some are beginning to be mandated.

In the United States, some companies (approximately 8,000 facilities including large GHG emitters, fuel and industrial gas suppliers, and CO_2 injection sites) must report their GHG emissions and related data to the Environmental Protection Agency's (EPA) GHG Reporting Program annually based on requirements outlined in the U.S. Code of Federal Regulations

(CFR Title 40 2022). These data are used by businesses and others to track and compare GHG emissions across different facilities, identify emissions reduction opportunities, and minimize wasted energy and money. (EPA 2021a) As investors increasingly recognize that investment risk and climate risk are intertwined (BlackRock 2021; SEC 2022), we see demand increasing from stakeholders including investors, financial institutions, and insurers for companies to disclose more of their environmental data. This demand for disclosure is now extending beyond the regulatory and investment communities. Purchasers of a company's products and services, as well as the company's own employees, want to support and work for mission-driven, socially and environmentally responsible organizations.

Given these pressures, the benefits to companies from disclosing GHG emissions include:

- protecting and improving a company's reputation by being transparent
- gaining a financial, performance, and/or customer marketing edge over competitors
- preparing for upcoming changes in mandatory environmental reporting rules and related new regulations
- identifying potential environmental risks and/or leveraging opportunities
- tracking and benchmarking progress against other companies in a comparable peer group
- supporting the reporting and disclosure requirements for company investors, partners, vendors, and customers (CDP 2022)

Since climate change represents one of the biggest economic risks facing companies, several initiatives over the past decade have pushed for ESG disclosures to appear in addition to sustainability reports in companies' financial filings with the Securities and Exchange Commission (SEC). Companies are also increasingly committing to and following guidelines set out by organizations like the Sustainability Accounting Standards Board (SASB) and the Task Force on Climate-Related Financial Disclosures (TCFD) framework.

Under growing pressure from public investors, investment firms, and the government to reduce corporate carbon footprints, companies are seeking to expand disclosure and reporting of climate-related business risks as they apply to scope 1 (direct emissions from owned or controlled sources) and scope 2 (indirect emissions from the generation of purchased electricity, steam, heating and cooling consumed by the reporting company) as well as scope 3 emissions from the supply chain upstream and downstream of a company (EPA 2021b, 2021c), leading companies and customers to ask for more supplier data to account for both product and use-phase emissions. These reporting and disclosure protocols are built around a life cycle assessment (LCA) of GHG emissions as defined under the International Standards Organization's (ISO) 14000 series standards.

Given the complexity of estimating scope 3 emissions from supply chains, other methods of assessing and enabling reductions of these emissions have emerged, such as the concept of a *carbon handprint* to complement the more common *carbon footprint*.

Handprint Definition and Approaches

Most organizations are engaged in minimizing the negative environmental impacts (i.e., carbon footprint) of their activities through efficient use of resources and lowered emissions from procurement of renewable electricity and other lower-carbon energy resources. Some companies have taken the next step to help reduce the footprint of their customers by developing products and services that create positive effects (handprint). While LCA methodologies of carbon and water footprint, governed by ISO 14000 series standards, offer a standardized way to assess negative environmental impacts (footprints), they do not assess positive environmental impacts. Few well-defined, systematic methods exist to quantify handprints.

ACEEE research has identified two definitions and methods for calculating handprints that appear in the literature. Both these approaches to handprint are similar in many aspects and the discussion below attempts to capture those as well as some of the more notable differences and extensions in thought leadership that offer unique application opportunities in assessing handprints of ICT solutions.

The Finnish Approach

The VTT Technical Research Centre of Finland, Lappeenranta University of Technology, and major Finnish businesses (e.g., Nokia, Neste, and Paptic) developed an approach to quantify carbon handprints based on standardized methods. The approach was developed with the cooperation of 10 industrial partners and considers the similarities and differences in a diverse range of operating environments. This Finnish effort developed a decision pathway to define baselines and calculations in a step-by-step process and assess handprints based on LCA, footprint calculation methods, and GHG emissions. This approach offers an accessible starting point for companies to gain a conceptual understanding of handprint and provides practical application of a calculation methodology.

According to the Finnish approach, the carbon handprint equals the difference between any two options in terms of their carbon footprints, measured in mass of CO_2 equivalents. This method for handprint helps calculate the beneficial environmental and climate impacts of products and services over their life cycles by following practical guidelines and taking into consideration material use, energy use, equipment lifetime performance, waste, carbon capture and storage. Calculations indicate the size of the *handprint* caused by a company's product, with a bigger handprint considered better (figure 1). A carbon handprint can be created either by offering a new solution with a lower carbon footprint than the baseline solution—that is, business as usual (BAU) practice—or by helping the customer to reduce the footprint of their existing processes. Given a baseline stemming from current operations of an end-user company, the impact of any new ICT handprint technology's GHG emissions can be compared to business-as-usual to yield a handprint reduction estimate. For example, a new food packaging solution that is produced with low emissions and that additionally helps to extend the food's shelf life, thus preventing food waste, could be compared to the baseline packaging (Pajula et al. 2021). Handprint creation occurs in addition to footprint reduction, not instead of it. The goal is to encourage a given company to take actions that shrink its footprint while simultaneously growing its handprint.

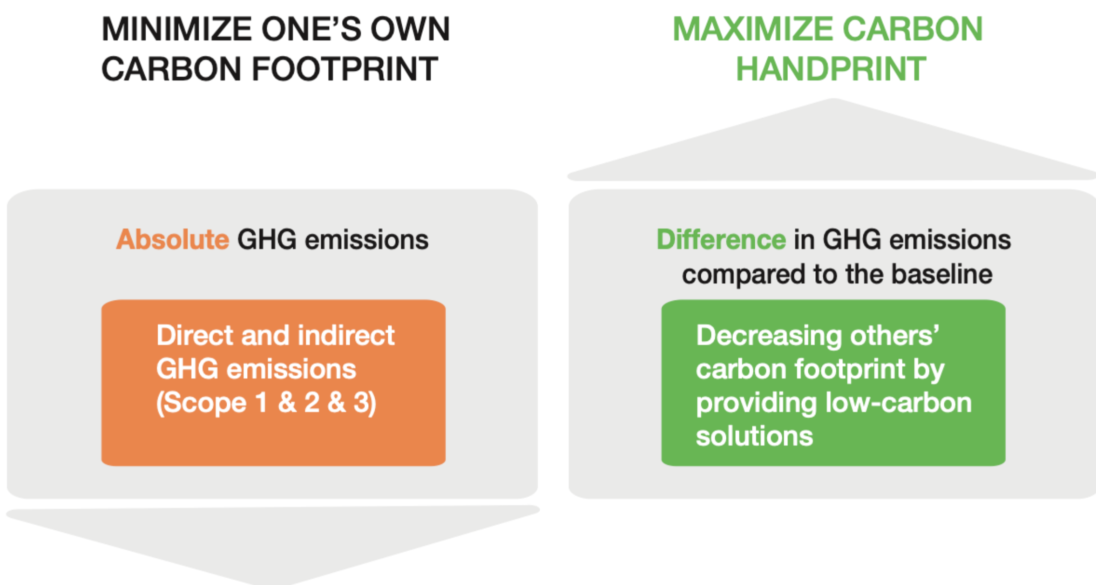

Figure 1. The Finnish approach separates footprint and handprint management with a goal of minimizing the footprint and maximizing the handprint. Source: Pajula et al. 2021.

There are four main steps in the decision pathway:

1. identifying the operating environment (customers of the product, potential contributors to the handprint, baseline definition)
2. defining LCA requirements (functional unit, system boundaries, data, and sources)
3. quantifying the handprint (calculating the new footprint and subtracting it from the baseline footprint)
4. critically reviewing the handprint and communicating the findings (Pajula et al. 2021; Business Finland 2022)

SHINE Approach

The Sustainability and Health Initiative for NetPositive Enterprise (SHINE) at the Harvard Chan School of Public Health and the Massachusetts Institute of Technology (MIT) has developed another approach to handprinting that has gained traction in some circles within the ICT community because it offers a way of addressing the complexity of scope 3 emissions (SHINE 2021a).

Like the Finnish approach (figure 1), SHINE *handprints* are changes, relative to BAU scenarios, that are measured using footprint metrics. A positive or beneficial handprint is created when an individual or company causes positive change (i.e., lowering emissions) in any area of concern—the more the better. According to SHINE, positive changes may occur anywhere on the planet and it doesn't matter whose footprint(s) the changes might reduce (SHINE 2021a). Furthermore, a handprint includes all changes caused by a company's actions that are measurable with footprint metrics, not just the GHG-reducing changes. For example, if a company promotes wasteful energy practices by end users, that shrinks a company's beneficial handprint. Defining handprints in this manner offers companies greater power and responsibility with respect to their impacts. As a result, companies have an expanded scope of influence for which they are accountable.

SHINE handprints are comprehensive and expand on the definition and use of the concept. They capture all the changes caused by a company, both internal and external to its own footprint. This means that reductions to a company's footprint may be a subset of its handprint. *Internal handprints* are reductions to the ICT producing company's own footprint. For example, if a company produced an ICT technology (not a grid management ICT solution), which could be applied to its own chip production or server operations to reduce GHG emissions, then that would be considered an internal handprint. Conversely, *external handprints* (referred to simply as *handprints* in this paper) are positive changes that occur outside the organization's footprint. These handprints may be reductions to some other company's footprint, or they may be positive changes that are not reductions to any specific company's footprint. Internal and external handprints are equally valuable at enabling companies to become NetPositive or net beneficial (SHINE 2021b). This differs from the VTT approach to handprint approach, which is built on the principle that handprint savings are not achieved by reducing one's own footprint but rather by improving the performance of others—by reducing their footprint (Pajula et al. 2021).

Given this definition of handprints, SHINE proposes the mechanism of shared or collective responsibility for emission generation/impacts and shared credits for emission reductions. In the footprint framework, all the actors in the chain share responsibility for the impacts they co-cause, whether directly or indirectly, and no matter how many other actors also share responsibility for these same impacts. Any company that is part of an action chain shares responsibility for its impacts. When data are available to quantify the fraction of the impact caused by a specific player in the action chain, then the proportional impact of that actor in the supply chain may be estimated for the footprint (SHINE 2021b).

When estimating the *total handprint of a group of actors*, SHINE proposes counting the jointly caused or overlapping handprints only once. This approach applies the same logic that is used to avoid double counting when estimating the collective footprint of a group of companies in an industry. If one or more companies supply goods or services to others in the group, then they will have overlapping footprints. When calculating their joint footprint, the impacts in these overlaps are counted only once to avoid double counting (SHINE 2021b).

Life Cycle Assessment and Handprint

Life cycle analysis approaches are useful in evaluating the handprint of a company's goods and services. LCAs consider all inputs and outputs (positive and negative) related to that product in all phases of its life cycle, from raw material extraction through use to end of life. ICT offers opportunities to expand a company and its value chain partners' handprints while reducing the footprint of partners further down the value chain and end users; these positive inputs and reductions in emissions can be captured in the LCA of ICT-enabled goods and services.

Sustainable operations mean serving a broad range of stakeholders, such as a diverse workforce, health and wellness advocates, local communities, and consumers. A *social LCA* (SLCA) applies the LCA methodology to identify and assess all the potential social and socioeconomic implications and impacts throughout a product or organization's life cycle, from extraction of raw materials to final disposal (cradle to grave) and may also be useful to consider in handprint assessment methodologies (UN Environment Programme 2022).

To address scope 1, 2, and 3 GHG emissions, a holistic approach is necessary to develop a meaningful view of impacts throughout the life cycle of goods and services. For example, a product life cycle includes all the environmental, social, and economic impacts associated with the production and use of a particular product, from cradle to grave, including emissions from raw materials, manufacture, transport, storage, sale, use, and disposal. Along that product value chain, energy and other natural, social, and economic resources are used; waste is generated; and the related impacts, both positive and negative, are distributed across societies to varying degrees around the globe. The goal of a life cycle approach is to reduce negative impacts from all points and sources of emissions (UN Environment Programme 2017). Figure 2 below illustrates the life cycle stages of an ICT solution in terms of environmental emissions.

<table>
<tr><th colspan="7">ICT Product Life Cycle Stages</th></tr>
<tr><td rowspan="3">Product</td><td>A1</td><td>Raw material extraction</td><td rowspan="3">Cradle to gate</td><td rowspan="5">Cradle to end-user site</td><td rowspan="16">Cradle to grave</td><td rowspan="17">Cradle to cradle</td></tr>
<tr><td>A2</td><td>Transport</td></tr>
<tr><td>A3</td><td>Manufacturing</td></tr>
<tr><td rowspan="2">Implementation</td><td>A4</td><td>Transport</td><td></td></tr>
<tr><td>A5</td><td>Installation</td><td></td></tr>
<tr><td rowspan="7">Use</td><td>B1</td><td>Use</td><td></td><td></td></tr>
<tr><td>B2</td><td>Maintenance</td><td></td><td></td></tr>
<tr><td>B3</td><td>Repair</td><td></td><td></td></tr>
<tr><td>B4</td><td>Replacement</td><td></td><td></td></tr>
<tr><td>B5</td><td>Refurbishment</td><td></td><td></td></tr>
<tr><td>B6</td><td>Operational energy use</td><td></td><td></td></tr>
<tr><td>B7</td><td>Operational water use</td><td></td><td></td></tr>
<tr><td rowspan="4">End of Life</td><td>C1</td><td>Deconstruction</td><td></td><td></td></tr>
<tr><td>C2</td><td>Transport</td><td></td><td></td></tr>
<tr><td>C3</td><td>Waste processing</td><td></td><td></td></tr>
<tr><td>C4</td><td>Disposal</td><td></td><td></td></tr>
<tr><td>Beyond Life</td><td>D</td><td>Reuse/Recovery/Recycling</td><td></td><td></td><td></td></tr>
</table>

Figure 2. Life cycle stages for ICT products. Source: Adapted from Esram and Hu 2021.

Many of the uncertainties that LCA modelers face in building a life cycle inventory for the analysis of ICT solutions also hamper the identification and reporting of scope 3 emissions. Some of these uncertainties are discussed in the next few sections.

HANDPRINT IN CURRENT GHG PROTOCOL

Although the current GHG Protocol does not use the term *handprint*, Category 11 of the Corporate Accounting and Reporting Standard includes emissions from the use of goods and services sold by the reporting company. The category specifies that a reporting company's scope 3 emissions from the use of products they sell include the scope 1 and 2 emissions of end users, and the total expected lifetime emissions from all relevant products (GHG Protocol 2011).

Challenges in Applying GHG Protocol to ICT Solutions Enabled By Value Chains

Several challenges exist in applying scope 3 emissions identification and reporting frameworks to the value chains associated with ICT solutions. In particular, attributing scope 3 emissions to individual value chain players under existing GHG reporting protocols is complicated because multiple companies are involved in implementing ICT solutions. These challenges include

- *Understanding handprint*. We have limited understanding of the difference between emissions contributions from supply chains (footprint) and those resulting from the use of emissions-lowering goods and services (handprint).

- *Multiple players*. ICT solution implementations involve numerous major and sometimes also minor component manufacturers, service providers, vendors, and end users.

- *Defining boundaries*. It is not easy to identify the boundaries of scopes 1, 2, and 3 of each of these players, which necessarily overlap, and thus avoid double counting emissions and credits.

- *Variability*. Continuous changes in the supply chain make it difficult to characterize and account for emissions from the manufacture, use, and disposal phases of ICT products (see Guldbrandsson and Bergmark 2012). (1) Raw material acquisition depends on long supply chains that are highly influenced by market variability. (2) In the production stage, the component supplier base changes continuously over the lifetime of different product systems depending on price and availability. So, it is challenging to collect comprehensive product-specific data for the entire upstream supply chain when only representative data for components, materials, and processes may be found. (3) The use stage of ICT equipment may be influenced by user behavior, which leads to inherent uncertainties about how and when physical components will wear out from use and require changing. The impact of the source of electricity that powers the equipment adds additional uncertainty. (4) For the end-of-life stage, there are limited data on suppliers and recyclers and many geographic variations.

- *Good enough*. Data and accounting need to be *good enough*—accurate and sufficiently detailed but not unduly burdensome to collect and assess.

AWARENESS/ACCEPTANCE OF HANDPRINT IN THE ENVIRONMENTAL COMMUNITY

Based on an informal survey of environmental groups involved in GHG reporting and those involved in environmentally, sustainably, and socially responsible investing, the term "handprint" does not appear to be used in describing activities covered under the scope 3 emissions category.

While the Securities and Exchange Commission (SEC) does not seem to be explicitly using *handprint* in developing their climate and ESG disclosure rules, the concept may be worth considering in light of their recently proposed rulemaking. In March 2022 the SEC issued a draft rule that would require companies to include certain climate-related disclosures in their registration statements and periodic reports, including information about climate-related risks that are reasonably likely to have a material impact on their businesses, results of operations, or financial conditions, and certain climate-related financial statement metrics in a note to their audited financial statements. The required information about climate-related risks also would include disclosure of a registrant's GHG emissions, to assess a registrant's exposure to such risks. Thus, the SEC is requiring the adoption of standards (e.g., SASB, TCFD) by which companies disclose material ESG risks; these standards include topics like labor practices and business ethics among the disclosure elements, which typically reflect scope 3 and handprint concerns (SEC 2022).

The ICT Advantage

Using the carbon handprint concept allows a company to improve its sustainable product portfolio; the handprint may be seen as a competitive advantage and a valuable part of a carbon-neutral business toolkit. The growing prevalence of ICT has raised concerns about increasing emissions footprints—but these increases have been largely constrained by dramatic improvements in technology and operations (Masanet et al. 2020). In fact, ICT enables the transition in energy efficiency from static component efficiency to optimization of efficiencies across systems, expanding the potential for handprint savings through energy and GHG emissions reductions (Elliott, Molina, and Trombley 2012).

Handprint opportunities from optimization of systems, especially energy-related ones, are intertwined throughout the economy, which makes it challenging to allocate scope 3 emissions between different companies who join together to implement ICT solutions. As a result, the handprint concept has evolved to accommodate alternate ways of looking at scope 3 emissions.

APPLICATION OF HANDPRINT ASSESSMENT APPROACHES TO ICT SOLUTIONS

Essential applications of handprint assessments for ICT solutions in transportation, utilities, industry, buildings, and other sectors include smart logistics, smart grid management, smart manufacturing, advanced building management systems, and cloud computing. There is growing demand for solutions powered by intelligent efficiency due to the considerable potential for energy and GHG reductions.

Over the past two decades ICTs have enabled a transition of energy efficiency from a static, device-focused practice to one with a broader, systems-optimization focus that is now on the front lines of responding to climate change. ACEEE research has shown that if homeowners and businesses were to take advantage of available ICT that promotes system efficiency, the United States could reduce energy use by about 12–22% while the annual energy cost savings of ICT in the commercial and manufacturing sectors could exceed $50 billion (Rogers et al. 2013). As more parts of the economy become interconnected, often through ICT, opportunities for reducing emissions through applications of ICT will increase even further.

Past ACEEE research (Elliott, Molina, and Trombley 2012) about opportunities enabled by proliferation of ICT in buildings and manufacturing found that many applications and sectors are linked by prominent, common ICT uses. Savings opportunities included data centers, cloud-based storage, and grid modernization and resiliency. Such improvements were enabled by ICT solutions. They also included automation, the Internet of things (IoT), advanced data collection and sharing, and other digital infrastructure advances.

Illustrative Applications of ICT-Enabled Solutions

We consider applications of two sample ICT-enabled solutions. The Dell Technologies Grid Management Platform is a front-of-meter (FTM), outside the customer meter solution deployed by utilities. The Intel and Spirae Cloud-Managed DERMS and Emulator is a behind-the-meter (BTM) solution inside the customer meter focused on managing energy use on the end-use customer site. We assess how ICT contributes to lowering GHG emissions through these applications and how emissions credits might be allocated. We explore differences between the two applications, how they may be complementary, and how they fit into an evolving energy system with increasing demands for low-GHG electricity and grid resilience as more electricity customers take control of their own energy production and usage. Figure 3 illustrates the two ends of the spectrum.

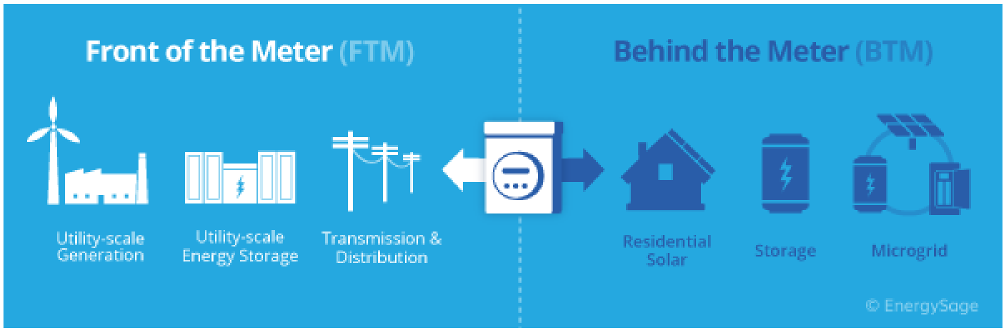

Figure 3. FTM and BTM energy systems. Source: EnergySage 2022.

Dell Technologies Grid Management Platform

The Dell Technologies/VMware/Intel Grid Management Platform (Dell 2020) is a front-of-meter (FTM) (outside the customer meter) utility-side grid management solution. The target end-use customer markets for this solution include both utility substations and load-control centers. The solution updates grid management systems through the use of virtual infrastructure that includes virtualization of grid distribution and transmission in the control center, as well as virtualization in the distribution and transmission substations. Virtualization refers to the use of technology to simulate and create virtual twin images of utility substations, distribution grids, transmission lines, and other components internal and external to the grid to give operators a better real-time electronic view of the grid without the need to travel for physical inspection. The solution is intended to accommodate the peak demand and reliability requirements associated with the transition of the utility grid from a rigid energy flow model to a data-driven model that supports renewable resource integration and flexible customer loads. This transition requires advanced analytical capabilities and modern distributed infrastructure to deliver real-time information and insights to meet changing customer and system demands.

Virtualization within the utility grid occurs at both the control center and the substation. Virtualization of the control center involves virtualizing grid management systems in the data center. This enables control capabilities such as management of feeder automation, Internet of things analytics, improved efficiency, storage optimization, and distributed energy resources.

The measurable benefits include:

- reduced costs and net energy savings from systems optimization
- greater utilization of existing assets
- deferring the need for distribution investments to maintain capacity margins while avoiding rate increases to recover investment costs and save energy.

The unmeasurable benefits of the Dell Technologies solution for grid management include

- improved grid reliability and resiliency from virtualization, or the decoupling of physical hardware from operating systems enabling agility in IT response and management
- enhanced data security, protection, and recovery
- streamlined operations for the customer utility
- rapid life cycle and overall systems management

Utilities can also optimize overall use of non-distributed, renewable grid assets through dynamic load management. The solution's efficiency improvements in substation function save energy and reduce GHG emissions, enable technology interfacing with customers to optimize energy use, and allow for greater integration of renewables into the grid while displacing GHG intensive non-renewables.

These opportunities all factor into the total possible energy and GHG savings in the handprint of the Dell solution. However, while at least some of these benefits afforded by the Dell platform are likely measurable, the schedule for the current research effort did not allow sufficient time to interact with Dell to gather additional data.

Companies involved with this technology could leverage these handprint assessments to communicate the value of the potential GHG, energy, and cost savings enabled by this solution through product marketing, ESG communications, and reporting. Opportunities to increase handprints might also be used as offsets in public commitments to GHG reductions throughout the supply chain. Additionally, the data collection and data assembly needed to support handprint assessments could be employed to identify scope 3 emissions sources and further savings opportunities.

Further analysis would be needed, including advanced data on which parts of the solution enable the most energy, cost, and GHG savings. To make appreciable progress on allocating handprint effects to Dell and its supply chain partners, it would be necessary to determine scope 3 benefits to the value chain, devise a methodology that quantifies impacts from individual GHG mitigation measures, and establish a baseline of emissions and energy use associated with current Dell Technologies/VMware/Intel-enabled physical hardware in substations as well as the savings already enabled through existing ICT approaches (including automation, IoT analytics, resource optimization, etc.).

Intel and Spirae Cloud-Managed DERMS and Emulator

The Intel-Spirae cloud-managed distributed energy resource management system (DERMS) and Emulator platform (St. John 2014; Spirae 2022) is a behind-the-meter (BTM) management solution inside the customer site. The Spirae solution may be implemented by both microgrid developer and utility customers.

The Spirae BTM solution, known as the Wave Platform, offers a dynamically scalable architecture for integrating and managing high levels of renewable and distributed energy resources (DERs) at the edge of the grid. Spirae's Wave distributed energy resource management system (DERMS) includes peak shaving, energy shifting, virtual power plant, facility management, and real-time microgrid features such as import-export, transition to island, spinning reserve management, and resynchronization features. While at least some of these benefits afforded by the Spirae Wave Platform are likely measurable and displayed through the Spirae dashboard, the schedule for the current research effort did not allow sufficient time to interact with Spirae to gather additional data. The Wave Platform may be implemented as on-premises (based on Edge Server) or cloud-based models (at the edge of DERs). It seeks to seamlessly integrate DERs from many manufacturers and enables service providers to remotely activate and manage energy services for their customers. Instead of treating distributed assets as individual devices, the Wave Platform functions as an operating system for distributed energy and virtualizes such assets. The platform includes user interfaces to allow everyone from repair technicians to distribution grid operators to organize and manage multiple assets and merges the software layer that manages all the DERs, so no upstream element needs to communicate with battery inverters or generators of the distributed energy asset. Spirae also offers grid simulation services, so clients can model, test, and validate new technologies prior to field deployment.

Through its platform, Spirae offers non-utility actors like big corporate or government clients microgrids-as-a-service or energy-as-a-service. In general, offerings by grid management solution providers that help reduce GHG emissions may also be marketed as sustainability-as-a-service solutions that enable more companies to report their scope 3 emissions and help with corporate social responsibility efforts (Spirae 2016).

Spirae is a key market partner for Intel's grid management solutions for microgrids. The target end-use customer markets for the Spirae solution include (1) electric utilities, (2) energy service companies (ESCOs), (3) large emitters like cloud service providers (CSPs) (e.g., data centers), (4) distribution network operators, (5) energy service providers (ESPs), and (6) commercial and industrial sector companies. Value chain partners include a range of technology, industry, training, and simulation partners (Survalent 2017; Spirae 2016). Market stakeholders include utilities, microgrid operators, technology partners (e.g., Intel, Amazon Web Services, companies such as Survalent, Cisco, Arvensys), and investors who have financed Spirae's development and growth as a business. Other energy management markets outside the utility industry that use DERMS include automotive (i.e., electric vehicles), industrial equipment, and electrical equipment.

Applying the Spirae Wave Platform may result in a wide range of ESG benefits, such as the ability to monitor

- GHG emissions reductions and correlate that with CPU cycles
- CO_2 offsets
- contributions of renewables to potential savings

Use of the platform also is associated with a variety of end-use customer benefits such as the ability to

- integrate numerous microgrids and/or DERs into the main grid for regulated utilities
- improve efficiency and reliability of grid operations
- synergistically maintain power flow balance and grid stability in concert with existing back-end control systems (such as supervisory control and data acquisition (SCADA), distribution management system (DMS), outage management system (OMS), customer information systems (CIS), and advanced metering infrastructure (AMI)) and transform potentially disruptive new distributed resources such as electric vehicles and renewable energy into supportive assets
- use data to make capital investment decisions
- build more consumer-centric energy systems
- allow more refined market participation by utilities
- access simulation laboratories where the integrated solution may be modeled and refined prior to implementation by the utility or microgrid operator

The results from a handprint assessment could be used by Spirae and its partners in product marketing, ESG communications and reporting, and employee engagement. Key information and data needs of end users and value chain partners include questions about the impact of the Spirae Wave Platform on partners, utilities, other end-use customers, and value chain partners. Handprint assessment may be used by stakeholders of the Spirae Wave Platform to identify GHG scope 3 emission sources in granular detail and potentially help in allocation of carbon credits among value chain partners. Results from the handprint assessment might be used to identify additional opportunities for GHG reductions.

Similarities and Differences Between the Two Case Studies

Similarities

Both the Dell Technologies and Spirae solutions represent market-ready grid management approaches that offer end users and companies throughout the supply chain the opportunity to significantly reduce costs, energy use, and resulting GHG emissions. These solutions enable handprint impacts among value chain partners, promote further data collection and analysis, and help integrate renewable resources into the grid. Both ICT-powered solutions also center around virtualization and emphasize systems optimization through automation, machine learning, and predicted maintenance to reduce risks and costs. Virtualization offers benefits that are consistent across both solutions, including enhanced reliability and resiliency, life cycle management, integration of distributed energy resources, and greater utilization of existing assets.

The solutions also face similar application challenges in meaningfully reducing emissions for supply chain partners. Both depend upon significant analytics and compiled data. They also require methodologies that quantify impacts from each ICT-enabled measure, and acceptable approaches for attributing the handprint effects to different actors in the supply chain.

Differences

The two solutions represent two sides of the grid management spectrum, with the Dell solution being front-of-meter and the Spirae solution behind-the-meter, each with different requirements and limitations. These ICT solutions differ with respect to analytical needs and audiences. The Dell platform would usually be implemented within regulated entities (utility substations and control centers), and any analytical needs must conform to regulatory requirements. The primary audience for utilities consists of public utility commissions (PUCs) and the Federal Energy Regulatory Commission (FERC). The Spirae solution functions on the utility feeder level and is useful for reporting data that may be used to make capital investment decisions. Utilities might use the Spirae Wave Platform to determine the optimal combination of DERs at dispersed grid locations, while utilities can use the Dell solution to accommodate peak demand and reliability changes associated with the transition to a data-driven, virtualized grid focused on renewable resource integration and flexible customer loads.

Data availability

As regulated entities, utilities have inherent limitations on the kinds of data that their systems may be able to collect for privacy reasons. Distributed energy resources (DERs) and microgrids, on the other hand, are largely unregulated (although there may be some overlap with a regulated utility when DERMS are integrated into the utility grid) and have greater freedom to collect data from the grid management system. Thus, the two case studies demonstrate differing levels of data availability, with the Spirae solution collecting more data that may be used for impact attribution compared to the Dell solution.

Impact of handprint analysis on value chain and customer partners

Calculating the handprint of the Spirae solution will show it reduces the footprint of value chain and end-user, customer partners by decreasing their emissions through improved efficiency and reliability and virtualization of DERs. The Spirae solution also offers detailed monitoring of GHG emissions reductions and can provide granular information such as correlations with CPU cycles, CO_2 offsets, and the contributions of renewables to potential savings for customers, which can help in assessment and reporting of scope 1, 2, and 3 emissions for value chain and customer partners.

Assessing the handprint of the Dell platform would also demonstrate a reduction in the emissions and footprint of value chain and customer partners through improved efficiency and reliability of the utility substation and control center and virtualization of original equipment manufacturers. Although detailed data may not be collected due to privacy requirements in the regulated utility space, the potential for energy savings could be used in product marketing and ESG communications.

Suggested Handprint Analysis, Estimation, and Attribution Approaches

The purpose of handprint evaluation and communication is to share information on potential footprint reductions for value chain partners and end-use customers so scope 3 emissions may be better estimated, reported, and perhaps reduced.

However, challenges remain with handprint reporting. It has yet to be fully embraced by organizations such as socially oriented investment firms, SASB, TCFD, the SEC, and the GHG community (e.g., Ceres, CDP (formerly the Carbon Disclosure Project)). Furthermore, in some cases detailed impact attribution may not be feasible, and it may not be possible to estimate and report scope 3 emissions.

The two case studies demonstrate the potential for differing levels of data available from the implementation of ICT for grid management solutions, depending on the type of solution, the use case, the target end market, and the inherent privacy requirements associated with behind-the-meter versus front-of-meter solutions. Also, the audiences and analytical needs of both solution implementations differ, given their relationship with regulatory authorities. As a result, the feasibility of using a handprint approach may vary depending on the type of ICT solution

We have identified several approaches to implementing handprint in a GHG reporting and disclosure context. The two primary ones we describe are *sharing responsibility and sharing credit* and *attribution of savings*. The former benefits from the expanded definition of handprint as espoused by SHINE, while the latter requires detailed data such as that collected by the Spirae platform or building energy management systems (BEMS). In addition, we have identified two other approaches: *carbon leader approach* and the *Shapley value allocation*.

SHARING RESPONSIBILITY AND SHARING CREDIT

The SHINE approach evaluates handprints using a life cycle methodology that focuses on a cradle-to-gate scope (which corresponds to the raw materials acquisition and product manufacturing stages as shown previously in figure 2) in calculating footprints. The gate-to-grave scope (which corresponds to implementation of the product, use, disposal, and end-of-life stages) frequently differs depending on the use case of ICT solutions. Thus, consistently focusing on a cradle-to-gate scope for all footprints impacting handprints reduces or eliminates potential differences between use cases and ensures comparability across handprints.

The socially oriented investment community may be open to this idea of sharing responsibility and sharing credit, given their known concerns over identifying and allocating scope 3 emissions. Since this is a current focus of discussion, it may be timely to engage with them to incorporate this concept into the commitments they seek from companies—if it is clear to them that this expands, not limits, the potential for GHG reductions. Similarly, the investment community is likely to seek definitions of the kinds of scenarios, use cases, and industries that would most benefit from such an approach and how complementary actions would affect the relative risks to the companies.

Changes in GHG protocols would also be required to implement this approach:

- GHG Protocols: It will be necessary to identify the elements in the protocol tied to scope 3 emissions and determine how to integrate the SHINE handprint concept.
- SASB, TCFD, SEC: Given that the SEC intends to adopt standards (SASB, TCFD) to govern the reporting of ESG risks by companies in their filings, we can identify which SASB climate-risk elements are directly connected with scope 3 reporting and disclosure and determine how to integrate the SHINE handprint concept in those elements of the standard(s).

The shared responsibility and credit approach may work best in ICT applications where value chain partner contributions cannot be easily demarcated, or the data cannot be collected for privacy reasons. Hence, it would be useful to identify use-case scenarios where this approach is most valuable and build legitimacy by developing a consistent framework for applying this approach.

In a collective responsibility and shared credit model, all the companies involved in the implementation of the ICT solution are equally empowered to make positive changes and reduce footprints. They would be collectively working to expand handprint opportunities for the ICT market and for industry. They also have the possibility to influence footprints outside their value chain. In the end, such an approach could lead to overall reductions in GHG emissions and expansion of handprints through beneficial actions that offset the energy use and emissions from the application of ICTs and other handprint-enabling technologies.

This approach is likely to be well received by certain segments of the ICT market and some companies such as Dell because they are already grappling with the challenges of delineating their scope 3 emissions from supply chains; the shared model offers a way forward, in addition to potential use in product marketing and ESG reporting efforts. However, if scope 3 emissions data reporting continues to be required as currently characterized in the GHG Protocol, this approach may not address the challenges of attributing emissions to specific sources within a group of value chain players involved in implementing an ICT solution.

ATTRIBUTION OF SAVINGS

Methods already exist for attribution of energy or cost savings. These applications build on extensive, well-defined protocols employed by federal agencies, groups of industrials, and others to evaluate and certify energy savings from efficiency measures. Examples include methods used by utility energy efficiency programs and labeling efforts such as EnergyStar and the National Electrical Manufacturers Association (NEMA) Premium. The NEMA Premium energy efficiency motors program was created to promote the choice of energy-efficient motors that satisfy the needs and applications of users. The program includes voluntary performance labels indicating products that meet the standards. Other examples include the U.S. Department of Energy (DOE) Uniform Methods Project, which has developed protocols to determine energy savings from energy efficiency measures for commercial and residential buildings included in ratepayer-funded energy efficiency programs (DOE 2022b). To be certified and recognized by DOE's Superior Energy Performance in the industrial sector, facilities must implement an energy management system that meets the International Organization for Standardization (ISO) 50001 standard for demonstrated improved energy performance, which is measured by achievement audit (DOE 2022a). Protocols such as these may be adaptable to evaluating GHG emissions and handprint, but not without adjustments, including additional data collection and analysis. These methods may need to be combined to evaluate various metrics of interest. In other cases, new indicators will need to be defined to determine values for ever-changing metrics. Adapting and creating new protocols and evaluation, measurement, and verification (EM&V) measures to verify new savings metrics will require a robust stakeholder convening process, which itself will rely on investing in coordination and facilitation.

ICT solution providers like Intel-Spirae offer diverse, detailed, and granular data that are easily accessible by end users through dashboards. For example, the Spirae ICT solution enables monitoring parameters that are indicators of GHG emissions reductions, such as CPU cycles, electricity embodied carbon, CO_2 offsets, and contributions of renewables to potential savings. Such detailed data delineated by components within an ICT grid management solution will help clarify attribution among value chain partners responsible for different components and services.

Substantial changes may not be required in the GHG Protocol since the impact attribution method will likely help facilitate the reporting and disclosure of scope 3 emissions data as is currently required. It may even be possible to add some additional details in the GHG Protocol elements corresponding to scope 3 emissions, based on the availability of actual data that can serve as indicators of emissions.

The impact attribution approach may work best in ICT applications where the value chain partner contributions are either physically well delineated or where data can be readily and easily collected for entities that are not regulated, for example, DERs or microgrids. Hence, it would be useful to further characterize use case scenarios, such as DERs and microgrids, where this approach is most applicable, and build legitimacy by developing a consistent analytic framework for data collection, savings calculations, and attribution.

In attributing handprint impacts, all companies involved in the implementation of the ICT solution would be assigned emissions based on available data collected for their specific components in the overall grid management solution. They could use that information to identify opportunities for emissions reductions and even refine existing technologies or develop new products that offer better reductions.

This approach is likely to be well received by certain segments of the ICT market and organizations such as microgrid operators and DERs, because the availability of detailed emissions reduction data that allows specific attributions will facilitate scope 3 emissions reporting (e.g., for Intel, Dell, Spirae), support their expansion and integration into the grid, and help in product marketing and ESG reporting efforts. However, managing the vast quantities of data and using the data constructively are likely to require additional resources and effort.

Other Potential Approaches

There are other potential approaches to attributing supply chain emissions to various actors while still avoiding double counting. These approaches can also operate as benchmarks for investigating equitable distribution of savings attribution, as they enable comparisons between different and often disparate parts of the supply chain, and between different emissions reduction methods. These approaches have not been fully implemented in practice; they present avenues for future research.

- The **carbon leader approach** involves a market leader, typically the highest emitter or highest value adder in the supply chain, taking responsibility for all supply chain emissions, committing to reduction targets, and assigning emissions and/or energy use reduction targets to other actors in the supply chain. The next step is for the carbon leader to enter contracts with all other supply chain actors by paying them to achieve the established emissions reduction targets at a set internal carbon price (which would be less than the socially optimum price and should be ratcheted up over time) (Shrimali 2021).

- **Shapley value allocation** is intended to distribute both gains and costs to several actors working in coalition. This method distributes responsibility for all emissions throughout the supply chain, where no actor is allocated emissions that are larger than they directly or indirectly caused. Each actor is individually incentivized to reduce its own emissions as well as supply chain emissions. However, the Shapley value allocation relies on the existence of an internal or external carbon price, and knowledge of the emissions associated with all processes of a supply chain with certainty (Shrimali 2021).

Discussion, Summary, Conclusions, and Recommended Next Steps

Current data and analytic capacity have enabled companies to make reasonable estimates and take concrete steps to reduce the GHG footprint of their own operations (i.e., scope 1 and 2 emissions); this capability is enabled by data collection and analysis of companies' own operations and their energy providers' (i.e., electric utilities and power producers). We also see the path emerging to make defensible estimates of upstream scope 3 emissions through ICT-enabled supply chain tracking and tracing, and perhaps extending the accounting to direct customer sites. The steps that a company needs to take to minimize its footprint are clear, as are the responsible entities across the supply chain.

The estimates for downstream life cycle GHG emissions beyond the direct customers of the reporting firm have fundamentally different characteristics from the upstream emissions, with inherently greater uncertainty due to the complexity and variations in how end users will use the goods and services they procure. In addition, multiple entities will in most cases enable or contribute to the GHG emissions that result from the use and end-of-life stages of the product life cycle (see figure 2). From a policy perspective, it is nearly impossible to identify a single responsible entity. Rather, we see multiple entities contributing to GHG emissions.

ACEEE research has found that current GHG protocols are limited in their ability to address and account for scope 3 emissions, particularly downstream emissions (including carbon footprint and handprint). We also found that the guidelines for the treatment of these corporate emissions are in flux as companies and stakeholders seek to implement them to assess companies' exposure and contribution to climate risk and environmental and social responsibility, which is often challenging to track and quantify.

While many groups in the sustainability community aspire to net-zero life cycle GHG targets, current knowledge and practices make this approach challenging to implement. As Chouinard and Stanley note in their 2013 book, they chose to use the word "sustainable" as little as possible since "no human activity is yet sustainable." Rather the goal of a company should be "to make economic life more socially just and environmentally sustainable." (Chouinard and Stanley 2013) Thus, ACEEE suggests companies strive to minimize the full life cycle GHG impacts of their operations and products in use, not merely focus on getting some subset of emissions to zero.

As a result, ACEEE suggests treating the upstream and downstream phases of product life cycles as separate but complementary. A company should strive to minimize its own footprint and decrease the footprint of others by providing and demanding low-carbon solutions, as has been suggested by VTT Technical Research Centre (see figure 1). The implementation of this vision is still in its emerging stages, as discussed in a recent article in *Fortune* (Goodkind 2021) and confirmed by our research.

We found significant recent progress in attempts to propose approaches for assessing scope 3 emissions—both for estimating downstream emissions and for contextualizing their relationship to environmental and social responsibility. Our research identified three existing approaches: handprinting of downstream emissions, the use of a carbon leader, and Shapley value allocation of downstream emissions. We find that the concept of handprinting offers a potential avenue to account for scope 3 emissions, especially with respect to ICT solutions where value chains consist of numerous partner companies with overlapping boundaries.

At least two main approaches to handprint assessment appear in the literature. While they appear to correspond in terms of overall definition and general use of life cycle assessment techniques, there are some differences in how they are applied and which possible use-case scenarios they may be best suited to address.

Our research indicates that

- The shared responsibility and shared credit approach appears promising in cases where downstream scope 3 emissions cannot be clearly identified and separated between value chain partners due to the lack of data because of collection challenges, or privacy and legal reasons. If more data become more available, some use cases under the first approach may be shifted to the second approach below.
- The impact-attribution approach is promising in cases where ICT enables the collection of detailed energy use and emissions data for component elements from different value chain partners.

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