Greenhouse Gas and Energy Use Inventory for Merit Network, Inc.

By Edward Carrington, Jialu Chen, Paige Greenberg, Haolin Li, and Sharmane Tan

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Project Advisor:

Geoffrey Lewis, Ph.D., *Research Area Specialist Lead, University of Michigan*

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Abstract

This project, conducted on behalf of Merit Network in collaboration with the University of Michigan's School for Environment and Sustainability, aimed to address the challenges of digital equity and environmental sustainability in broadband internet infrastructure provision in Michigan. Merit Network operates as an Internet Service Provider (ISP) for educational and research institutions in Michigan. As a team, we evaluated the environmental impact of Merit's internet infrastructure and operations and provided recommendations for enhancing sustainability. Our research approach used two primary methods: life cycle assessment (LCA) and energy use analysis. We conducted a comprehensive evaluation of the environmental impacts associated with Merit Network's data centers and fiber network infrastructure using LCA. This entailed a systematic review of the entire lifecycle of their infrastructure, from construction and installation to operation and end-of-life disposal. By quantifying inputs and outputs at each stage, we provided strategies for Merit to reduce its environmental footprint. In parallel with our LCA, we examined Merit Network's energy use through utility bill analysis. This method provided valuable insights into energy use patterns, such as seasonal variations and peak use periods across different data centers and network components. By analyzing these patterns, we identified outliers, inefficiencies, and opportunities for energy-saving measures. Our findings offered a new understanding of the environmental ramifications of Merit Network's operations and provide a baseline for measuring future improvements.

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Abbreviations and Acronyms

ABC	Activity-Based Costing
BOM	Bill of Materials
BSL	Broadband Serviceable Location
BTS	Bureau of Transportation Statistics
Btu	British Thermal Unit
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide equivalent
CPP	Clean Power Plan
CSV	Comma-Separated Values
DEI	Diversity, Equity, and Inclusion
DSL	Digital Subscriber Line
E-Waste	Electronic Waste
EEE	Electronic and Electrical Equipment
eGRID	Emissions & Generation Resource Integrated Database
EIA	Energy Information Administration
EKEY	Equipment Key
EOL	End-of-Life
EPA	Environmental Protection Agency
ESG	Environmental, Social, and Governance
FBSL	Fixed Broadband Serviceable Location
FCC	Federal Communications Commission
FY	Fiscal Year
GHG	Greenhouse Gas
GIS	Geographic Information System
GREET	Greenhouse Gases, Regulated Emissions, and Energy use in Technologies Model
GWP	Global Warming Potential
HDPE	High-Density Polyethylene
ICT	Internet and Communication Technology
ID	Identification
IoT	Internet of Things
IP Address	Internet Protocol Address

IPCC	Intergovernmental Panel on Climate Change
IRS	Internal Revenue Service
ISO	International Organization for Standardization
ISP	Internet Service Provider
kWh	Kilowatt hours
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LEED	Leadership in Energy and Environmental Design
MAC Address	Media Access Control Address
MACC	Michigan Academic Computing Center
Mbps	megabits per second
MCVD	Modified Chemical Vapor Deposition
MJ	Megajoules
MOON-Light	Michigan Open Optical Network
MPG	Miles per Gallon
NTIA	National Telecommunication and Information Administration
OEM	Original Equipment Manufacturer
OSP	Outside Plant
OSS	Open-Source Software
PADD	Petroleum Administration for Defense District
PPA	Power Purchase Agreements
PDF	Portable Document Format
PoP	Point of Presence
RANCID	Really Awesome New Cisco ConfIg Differ
RECs	Renewable Energy Credits
RT	Request Tracker
SASB	Sustainable Accounting Standards
SDR	Standard Dimension Ratio
SKEY	Site Key
SNMP	Simple Network Management Protocol
SOP	Standard Operation Procedure
SQL	Structured Query Language
SUB	Service Unit Billing
TCFD	Task Force on Climate-related Financial Disclosures

U-M	University of Michigan
UN	United Nations
UNITAR	United Nationals Institute for Training and Research
UNU	United Nations University
USD	the United States Dollar
VLAN	Virtual Local Area Network

Introduction

Background

Access to high-speed broadband internet serves both educational opportunities and economic development. According to Michigan High-Speed Internet Office, over 212,000 households in Michigan lack high-speed broadband internet, with an additional 865,000 facing barriers like affordability or digital literacy [1]. Closing the digital gap between the well-connected urban areas and remote, unconnected areas is vital to ensure all citizens can participate fully in the digital society and benefit from advancements in technology.

While the adoption of broadband internet is a priority to achieve socio-economic objectives, there are environmental trade-offs to consider. The deployment of broadband infrastructure often involves substantial energy use, electronic waste, and disruption of natural habitats. In 2007, the greenhouse gas (GHG) emissions from the Information and Communication Technology (ICT) sector were between 1% and 1.6% of global emissions [2]. By 2020, this contribution nearly doubled to 3% to 3.6%. If the current annual growth rate continues, the ICT sector's contribution to global GHG emissions could surpass 14% of 2016 global levels by 2040 [2].

To address these challenges, innovative solutions are needed that balance technological advancement with sustainable practices. Employing renewable energy sources, recycling electronic components, and designing less intrusive infrastructure can help minimize the ecological impact of broadband expansion. Sustainable broadband infrastructure is crucial to reducing the environmental footprint of our digital world.

Merit Network is a non-profit that acts as a service provider of over 4,000 miles of fiber-optic middle-mile infrastructure throughout Michigan's upper and lower peninsulas [3]. Merit also serves as a research and education network that values innovative problem solving, fostering a unique opportunity for interdisciplinary research that addresses the complexities in environmental reduction. This holistic approach demonstrates Merit's commitment to advance digital equity while prioritizing environmental goals.

As the push for sustainable business practices gains momentum—driven by customer preferences, regulatory demands, and environmental responsibilities—companies that prioritize sustainability early can gain competitive advantages including cost savings and enhanced brand reputation. This creates opportunities for businesses to innovate and align with global sustainability trends. A comprehensive evaluation of the value proposition for sustainability practices as it relates to Merit Networks is provided in Appendix 1.

The growing intersection of socio-economic and environmental goals presents a significant opportunity for interdisciplinary research to explore these trade-offs. While current federal funding supports broadband expansion and digital equity initiatives, climate policies often overlook subsidies or grants to promote sustainable broadband infrastructure. Aligning these policies could create a synergy that fosters an inclusive and environmentally sustainable digital landscape in Michigan (Appendix 5).

How Internet Works: Physical Infrastructure

Broadband internet, as currently defined by the Federal Communications Commission (FCC), refers to high-speed internet access with a minimum download speed of 100 Mbps and an upload speed of 20 Mbps [4]. Unlike dial-up internet, which requires manual dialing and provides slower speeds, broadband allows for the transmission of multiple signals simultaneously and offers an "always-on" connection [5]. Broadband internet service can be delivered by the following technologies: fiber optic, fixed wireless, DSL, cable, and satellite [6]. Fiber optic technology is the technology that serves as the physical backbone of Merit Network.

The following illustration explains how fiber interconnectivity operates, as it is most applicable to Merit's Network. Fiber optic internet transmits data as light pulses through optical fibers, involving three key stages: signal generation, transmission, and reception. In the signal generation stage, electronic data are converted into modulated light pulses; computers transform binary data into electrical signals, which are then encoded as light pulses by an optical transceiver [7]. During signal transmission, these modulated light pulses travel through optical fibers, where they are periodically amplified using optical amplifiers and regenerators to mitigate signal loss from attenuation and dispersion [7]. At the reception stage, incoming light pulses are detected by a photodetector, which then converts the light back into electrical signals [7]. These signals are then amplified and demodulated to retrieve the original binary data.

Broadband Network and GHG Emissions

Broadband networks, especially those relying on fiber-optic infrastructure like Merit's, have the potential to significantly reduce GHG emissions. Fiber-optic networks are more energy-efficient compared to older copper-based systems [8]. The transmission of data via light pulses in fiber-optic cables requires far less electricity, which reduces the overall carbon footprint of internet service providers (ISPs) that use fiber [8]. Fiber-optic networks also support more data transmission at higher speeds with lower latency, resulting in less lag and making them ideal for remote work, teleconferencing, and cloud computing. By enabling more efficient remote work and reducing the need for physical travel, fiber optic broadband networks indirectly contribute to lower emissions from transportation [9].

The expansion and operation of broadband networks does contribute to GHG emissions through energy use, particularly in data center operations and network equipment. Data centers, which house servers that store and transmit internet data, are one of the largest users of electricity in the Information and Communication Technology (ICT) sector [10]. The energy required to power these facilities often comes from non-renewable sources, contributing to carbon emissions.

Procurement of renewable energy to operate network infrastructure, as well as implementing energy-efficient data center designs reduce broadband network emissions. Initiatives such as adopting distributed energy generation to power data centers or switching to more efficient cooling systems can have a significant reduction in GHG emissions [11].

Internet Equity: The Digital Divide (Project MOON-Light)

Broadband connectivity expands opportunities in education, employment, healthcare, and access to critical services. The COVID-19 pandemic further highlighted the digital divide, revealing how families without reliable internet at home were left at a disadvantage, unable to engage in remote learning, telehealth, and other necessary services. The National Telecommunication and Information Administration's (NTIA) Broadband Infrastructure Program awarded Merit Network funding to support the Project Michigan Open Optical Network (MOON-Light) initiative, which aims to expand broadband access in unserved and underserved areas. This public-private partnership to strengthen community networks across Michigan, the project delivered affordable, reliable high-speed internet to 17,000 unserved households in 74 counties [12]. Unlike private infrastructure, which offers services from a single provider to residents, the MOON-Light network delivers regional connectivity through an open-access platform, allowing multiple providers to use the infrastructure to offer high-capacity broadband services to residents and businesses. It also addressed the academic disparities linked to unequal broadband access. Merit's expansive fiber-optic network facilitates energy-saving digital services for Michigan's communities, supporting telemedicine, remote education, and smart grid technologies that contribute to overall GHG reduction [13]. The project modernized 2,200 miles of Merit's existing fiber network by expanding its optical capabilities, upgrading aging infrastructure (multi-slot terminal) with modern data center interconnect technologies, and establishing 103 access points to serve nearly 70,000 census blocks [14]. MOON-Light extended broadband access to 16,499 unserved households, including 2,305 rural locations [14]. This transformative project addressed critical connectivity gaps by enhancing Merit's network capacity.

Project MOON-light marked a significant departure from standard operations, with activities deviating from typical yearly patterns. To address this anomaly, operations were annualized over the network's lifespan to account for the unusual circumstances during the study year. Operations were annualized to ensure that the data reflect a more accurate and consistent measure of typical performance and resource use over time. This approach helps normalize any atypical variations and provides a stable reference point for future analysis and planning. Future studies should use the annualized baseline for establishing energy efficiency and emissions reduction targets.

Project Objectives

The primary deliverable of this project is to establish an energy use baseline for Merit Network's data center and fiber optic network operations during the fiscal year 2023-2024. This baseline will serve as a foundation for identifying strategies and measuring future progress in reducing the environmental impact of Merit's operations. The assessment will guide the development of a sustainability strategy that supports both existing operations and potential expansions aimed at bridging the digital divide. Merit's sustainability program will focus on addressing broadband infrastructure challenges by exploring solutions to minimize its environmental footprint.

Within this project, we will conduct a comprehensive audit of both direct and indirect greenhouse gas emissions associated with Merit Network's data centers and fiber optic networks for the fiscal year 2023-2024. Our research will focus on identifying and quantifying emissions from data center operations, such as those from servers and cooling systems, and network activities like fiber production and maintenance.

Key questions we aim to address include: What is the current baseline of energy use and emissions for this infrastructure, and how can these emissions be mitigated?

The insights obtained will aid in the development of a sustainability strategy aimed at optimizing operations and reducing the environmental footprint, supporting both current infrastructure and future expansion efforts. Explicit project goals included:

- Establish an energy use baseline for the operation of Merit Network's data center and fiber optic network based on the fiscal year 2023-2024.
- Data Centers Direct Emission Audit: Identify and quantify energy use emissions from servers, cooling systems, backup power systems, and other data center components.
- Network Direct Emission Audit: Identify and quantify energy use emissions from fiber production, procurement, transportation, supply chain, maintenance, hubs, and end-of-life disposal.
- Indirect Emission Audit: Assess emissions from procurement and waste disposal.

Methods and Calculations

This section outlines the method, scope, objectives, and specific emissions sources for Merit's comprehensive GHG audit.

Scope of the Study/Reporting Framework

Our GHG audit is modeled after the *ICT Sector Guidance built on the GHG Protocol Product Life Cycle Accounting and Reporting* [15]. The ICT Sector Guidance builds on the GHG Protocol Product Accounting and Reporting Standard and International Organization for Standardization (ISO) Life Cycle Assessment (LCA) standards 14040:2006 and 14044:2006 [16], [17]. It provides additional technical guidance for GHG assessments of ICT products and services and ensures that the assessment leverages best practices in GHG accounting and reporting. This framework informed the definition and implementation of:

- Boundary Setting
- Data Collection and Data Quality
- Allocation
- Assessing Uncertainty
- Calculating Inventory Results

Limitations in data collection, allocation, and uncertainty assessment are affected by a lack of external verification. This constrains comprehensiveness and absolute conformance with the GHG Protocol standards and ICT Sector Guidance.

Accounting Methods
The accounting method employed is Activity-Based Costing (ABC), which allocates GHG emissions by directly associating emissions with specific activities and processes at both conventional and process levels. This method provides detailed insight into how various activities and processes contribute to total GHG emissions, enabling accurate environmental management recommendations.

Data Collection

Data Request and Reception Workflow
Following Merit Network's project plan approval in March 2024, data requests were distributed to relevant departments. Under the accepted non-disclosure agreement, the received data were stored in a secured shared Google Drive. The raw data are preserved in their original format and were added to Google Sheets as needed. To ensure the preservation of critical data, all calculations were performed in separate documents, and relevant email communications were maintained as plain text.

Data collection occurred through two main channels: direct interviews and file requests. Internal sources included accounting records, such as utilities and fuel expenses from NetSuite, along with technical documentation covering vehicle fleets, fiber infrastructure, equipment housing, and Geographic Information Systems (GIS) data. The complete dataset is maintained in the project's shared drive, with key supporting documentation provided in this document's appendix.

The utility bill data was initially received in an unstructured Google spreadsheet. The dataset contained inconsistencies such as duplicates and unordered entries. The data was cleaned to remove duplicates, reorder entries, and fill in missing information. Once normalized into a structured format, it was exported as a CSV file for analysis.

The GIS data were originally received as a snapshot of Merit's ArcGIS database consisting of two main layers: a point layer (for example, data collocations, connecting points, data centers) and a polyline layer (which maps the fiber network). All GIS layers are associated with attribute tables that describe the non-spatial part of the data. Table 1 is a list of the main data fields that were used in our analysis.

Table 1. Main Fields in the GIS Attributes Table

Field (Column) Name	**Type (Point/Polyline)**	**Description**	**Note**
Object ID	Point	Unique id	-
Station ID	Point	Point name	Not valid for some connecting points
Address	Point	Point street address	Missing for some records
Site Key	Point	Site key of the data centers/collocations	Valid only for data centers/collocations
Last Updated	Point/Polyline	Last updated time of the record	-
Status	Point/Polyline	Operating status of the point/line	Usually operating (= 101)
Calculated Length	Polyline	Calculated length (in meters) of the fiber segment	-
Measured Length	Polyline	Measured length (in meters) of the fiber segment	-

Additional documentation was sourced through external partnerships with the University of Michigan Fleet Services, University of Michigan Property Disposition, Thermobond, and Juniper Networks. Pertinent reference materials and supporting evidence are provided in the appendices of this document as well as the shared drive.

Data Collection and Quality
Data for this assessment were sourced from:

- *Internal records* provided detailed information on materials and components used in data centers and network infrastructure.
- *Historical utility bills* offered insights into energy use patterns across different locations.
- *Supplier information* was utilized to obtain data on material acquisition and manufacturing processes.
- *Interviews with Merit Network staff* were conducted to validate the data collected and to provide context for operational practice.

Emissions and LCA Scope

Emission Unit (Impact Category)
The impact category is defined in terms of kilograms of carbon dioxide equivalents (kg CO_2e). This unit provides a standardized measure of greenhouse gas emissions, allowing for the aggregation and comparison of emissions across different sources and activities within operations.

Emission Sources
The assessment will consider emissions from five primary sources:

1. Fiber Network – includes fiber optic cable and network devices
2. Utility Huts
3. Energy Demand
4. Transportation
5. End-of-life Disposal

Each source encompasses distinct activities and processes that contribute to the overall GHG footprint, presenting a holistic lifecycle view of the Merit network's environmental impact.

Aggregated Functional Unit
The sum of GHG emissions (kg CO_2e) from network operations and data center operations. This aggregate measure provides an overarching view of the combined impact of these critical components of Merit's infrastructure, facilitating targeted analysis and mitigation efforts.

Unique Functional Units

- kg CO_2e from driving 1 km in a personal vehicle for business travel: IRS Rate
- kg CO_2e from driving 1 km in a personal vehicle for business travel: Dollar Amount
- kg CO_2e from driving 1 km in a U-M leased vehicles for business travel: Dollar Amount
- kg CO_2e from the production and end of life disposal of 1 km of ¼" Steel Guide Wire Cable
- kg CO_2e from the production and end of life disposal of 1 km of ¼" Outdoor Protective Conduit
- kg CO_2e from the production of one 10' x 20' ThermoBond Building maintenance cabinet

Scope and Boundaries
The scope of this assessment is cradle-to-grave, encompassing all stages from raw material extraction, manufacturing, transportation, and use, to end-of-life disposal.

Reporting Interval
The reporting interval for this assessment is the fiscal year from July 2023 to June 2024.

Project Scope
The project scope involves conducting a Life Cycle Impact Assessment (LCIA) of Merit's Data Center and Fiber Network. This will include systematically evaluating the environmental impacts associated with operations such as energy, GHGs, transportation, fiber network, and waste, translating raw inventory data into impact metrics to inform decision-making and improvement strategies.

Merit's Fiber Cable Network Infrastructure

Merit Network operates over 4,000 miles of fiber-optic infrastructure, connecting communities statewide. Figure 1 below is a map showing the backbone fiber network, data centers, and POP (point of presence) sites owned by Merit. A POP site is a physical location where a communications provider enables other carriers to connect to its network.

Merit provided the length of installed fiber optic cable and supporting structures for three calendar year periods [18]:

- Round 1: Year 2012 – 2013
- Round 2: Year 2013 - 2014
- Legacy: Year 2000 - Present

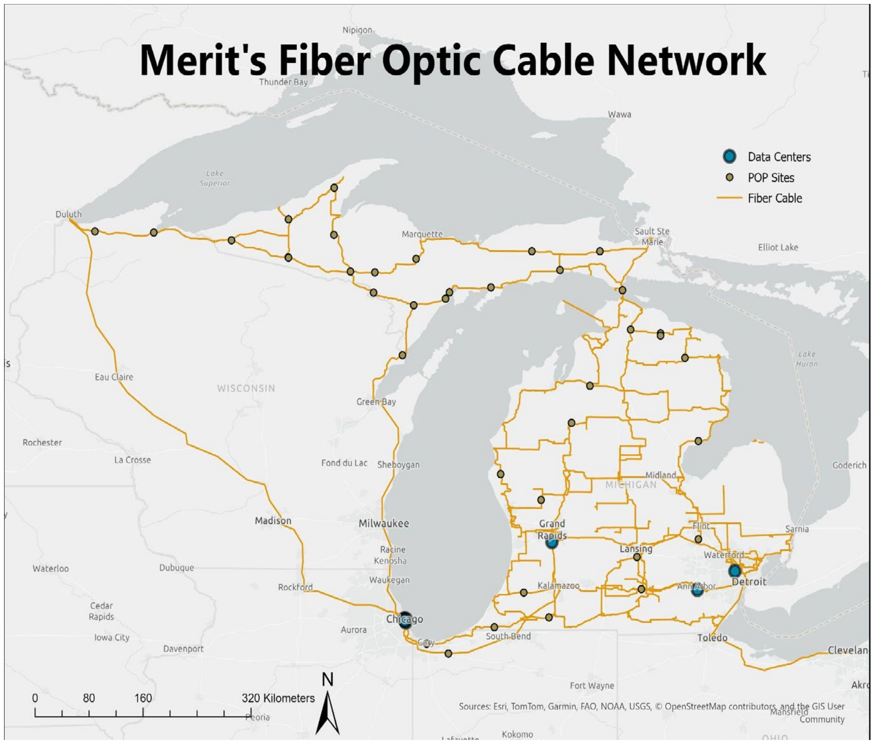

Figure 1. Merit's Fiber Optic Cable Network

¼" Steel Guide Wire Cable

Aboveground fiber optic cable is supported by ¼" steel messenger wire. The fiber optic cable and messenger wire maintain a one-to-one distance ratio throughout the network. One ft of ¼" steel wire cable weighs 180.07 kg/km [19]. The embodied GHGs per 1 kg of steel wire are 2.27 kg CO_2e. [20] The total weight of steel wire in the network was then multiplied by its emissions factor (408.8 kg CO_2e/km) to calculate embodied emissions of 243,065.8 kg CO_2e [20].

Indoor Protective Conduit

The weight for the interior 1.25" High-Density Polyethene (HDP) Standard Dimension Ratio (SDR) 11 pipe is 0.18 lbs per foot, resulting in a total weight of 267.86 kg per kilometer [21]. The SDR (Standard Dimension Ratio) is the nominal outside diameter divided by the minimum wall thickness, indicating the thickness of a pipe's wall [22]. Applying an emission factor of 2.6 kg CO_2e per kilogram of HDPE [23], the embodied GHGs for the conduit are 696.46 kg CO_2e per km.

Outdoor Protective Conduit

The weight for 1.25" HDPE SDR 11 pipe is 0.31 lbs per foot, resulting in a total weight of 1017.06 lbs per km [24]. Converting this to kg gives 461.33 kg per km. With an emission factor of 2.6 kg CO_2e per kg of HDPE [23], the embodied carbon for the conduit is calculated to be 1199.46 kg CO2e per km. As a check on this estimate, the volume of HDPE per km was estimated based on the conduit's dimensions, including outside diameter, wall thickness, and inside diameter, assuming a one-to-one ratio of fiber optic cable to conduit. Dimensions were derived from a spec sheet that detailed the dimensions of a 1.25" HDPE SDR 11 pipe [24]. With an HDPE density of 970 kg/m³, the calculated mass per kilometer is 447.98 kg. Using the HDPE emission factor, the total embodied GHGs for the conduit are 1164.74 kg CO_2e per km [23]. The average of the two values was used to calculate the embodied emissions of HDPE conduit.

Optical Fiber Cable Emissions Factor Selection

To determine the appropriate emissions factor for optical fiber cable production, we conducted a comparative analysis of academic papers, focusing on their calculation methods. The emissions factor for production of optical fiber cable was selected based on the functional unit of the study, the study's scope, and whether the study met criteria of being peer-reviewed, using established protocols, and for temporal scope. We did not believe geographic scope would have a large impact on the emissions factor.

The baseline selection criteria were:

- **Cradle-to-gate analysis:** Raw material extraction to finished product
- **Peer-reviewed sources:** Studies with academic merit and adherence to scientific standards
- **Established protocols:** Use and disclosure of recognized methods and ISO standards
- **Temporal scope:** Current methods and environmental impacts of fiber optic cable production

Based on the above criteria, our search resulted in three papers that executed the cradle-to-gate life cycle [25] [26] [27].

Unger and Gough [25] calculated the emissions of the service of providing internet access to all units in an accommodation complex in Ireland to be 129.28 kg CO_2e per km of optic fiber cable. This study covers the entire life cycle from cradle-to-grave and we can use their results as long as they are able to be segregated into life cycle stages. They published a peer-reviewed journal but do not list established ISO protocols. The study was published in 2008, which is less recent than the other two studies that we assessed. Based on their methods, the emissions factor of 129.28 kg CO_2e per km of optical fiber also includes the production of copper cable and converters, since these items are incorporated into the system providing internet access. Figure 6 in the paper, shown below as Figure 2, is a bar graph of the global warming potential for the production, use, end-of-life, and credits for the copper cable, converters, and optical fiber cable.

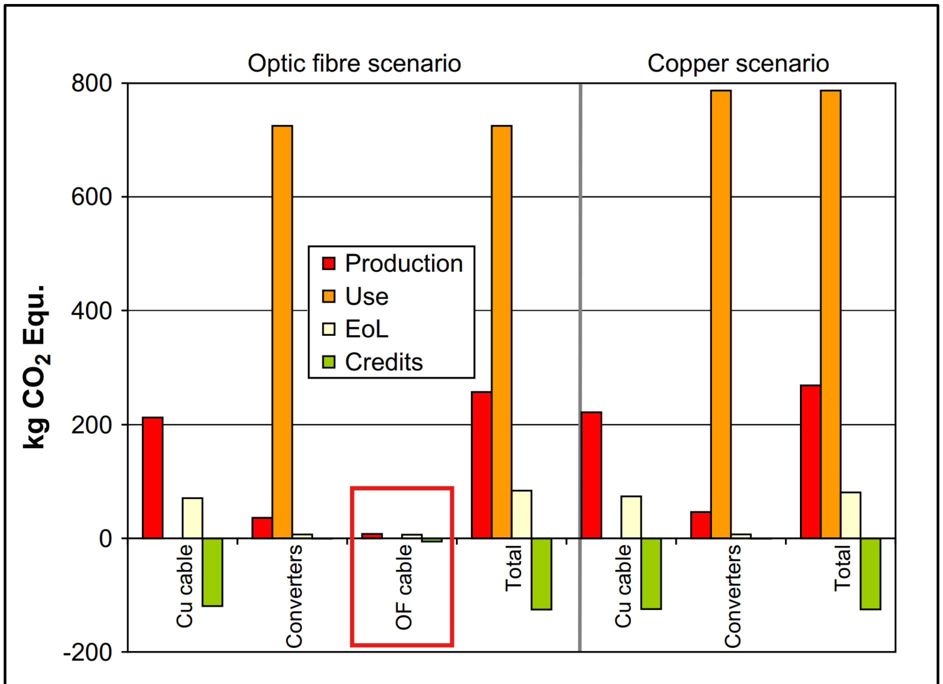

Fig. 6. Global Warming Potential in kg CO_2 equivalents for different life stages of the optic fibre and copper scenario.

Figure 2. Figure 6 from Unger and Gough, GWP of network components [25]

The emission factor of interest for the application to Merit's network is the outlined bar in the graph representing the kg CO_2e of optical fiber production, however, the exact value cannot be determined due to limitations with the scale and labels on the published graph. The authors did not respond to a request to provide the exact value.

The studies from Inakollu et al. [26] and Pinto et al. [27] have functional units that focus on cable production and meet the criteria for cradle-to-gate analysis, being published in a peer-reviewed journal, using established ISO protocols, and being recently published. Inakollu et al. state an emissions factor of 4.8 kg CO_2e per km of fiber and Pinto et al. state a business-as-usual emissions factor of 8.02 kg CO_2e per km of fiber, with other scenarios ranging from 6.36 to 8.75 kg CO_2e/km fiber. The main difference between these two studies is the inclusion of raw materials and the optical fiber production process. The values from these two studies are much less than the emissions factor of 129.28 kg CO_2e from Unger and Gough, which includes other products and processes, such as converters and copper cable. In the breakdown of Unger and Gough's value, the bar on the graph representing optical fiber production is in the same range as Inakollu and Pinto, but we were not able to determine an exact value.

Both Inakollu et al. and Pinto et al. included Scope 1 and Scope 2 emissions from optical fiber production, though the inclusion of Scope 3 emissions differed. Inakollu et al.'s Scope 3 emissions only included major purchased raw materials, whereas Pinto et al.'s emissions factor captures the production processes of all involved materials. In regards to the difference in production processing, Inakollu et al.'s calculations are based on vapor-phase axial deposition, while Pinto's calculations are based on modified chemical vapor deposition (MCVD), the most common manufacturing process to produce optical fiber [27], [28], [29].

We identified several additional studies that mention an emission factor for optical fiber cable [30], [31], [32]. Two of the papers did not calculate an emissions factor, instead referencing another paper that had performed the calculations. The emission factor used by Griffa et al. was a reference to Unger and Gough and the one used by Mehryar was a reference to Pinto. Wright et al. broke down the global warming potential for current cable designs by the individual materials in a graph, and we were not able to determine an exact emission factor.

For the study of Merit's network infrastructure, we chose the emissions factor of 8.02 kg CO_2e per km from Pinto et al. The study meets the baseline requirements, and it includes the production processes for all raw materials. Inakollu provided an emissions factor of 4.8 kg CO_2e per km and Pinto provided a range of 6.36 – 8.75 CO_2e per km. Combining these, we will perform a sensitivity analysis with a range of 4.8 - 8.75 kg CO_2e per km of fiber to determine how much the emissions factor selection impacts the results.

The emissions factors and fiber length were combined to calculate the total embodied emissions in the fiber network, as shown in Table 2. Sections of the fiber network are divided based Merit's documentation. The total amount of embodied carbon emissions in the fiber network is about 3.15 million kg CO_2e. This number includes all fiber optic cable and associated messenger strands or HDPE conduit.

Table 2. Fiber network Embodied GHG Emissions (Merit-supplied rounds of replacement)

Item	Distance (km)	Emission Factor (kg CO_2e/km)	Emissions (kg CO_2e)
Round One (2012-2013)			
Aerial Fiber	594.65	8.02	4,769.10
Associated ¼" messenger strands	594.65	408.75	243,065.82
Underground Fiber	910.40	8.02	7,301.44
Associated 1.25" HDPE Conduit	910.40	910.40	828,834.78
Indoor Fiber	0	8.02	0
Associated 1.25" HDPE Conduit	0	696.46	0
		Round One Total	**1,083,971.15**
Round Two (2013-2014)			
Aerial Fiber	189.10	8.02	1,516.56
Associated ¼" messenger strands	189.10	408.75	7,7294.27
Underground Fiber	1,686.59	8.02	13,526.44
Associated 1.25" HDPE Conduit	1,686.59	910.40	1,535,476.14
Indoor Fiber	0	8.02	0
Associated 1.25" HDPE Conduit	0	696.46	0
		Round Two Total	**1,627,813.42**
Legacy (2000-Present)			
Aerial Fiber	280.67	8.02	2250.96
Associated 1/4 messenger strands	280.67	408.75	114,724.44
Underground Fiber	349.71	8.02	2,804.67
Associated 1.25" HDPE Conduit	349.71	910.40	31,8376.88
Indoor Fiber	9.01	8.02	72.28
Associated 1.25" HDPE Conduit	9.01	696.46	6,276.71
		Round Three Total	444,505.94
		Total	**3,150,013.79**

Maintenance Activities

For Merit's data center and network operations to function reliably, consistent maintenance is needed. The raw maintenance calendar data from the request tracker (RT) ticket export was saved in Google Sheets following a CSV conversion [33]. In the new document, unique activity IDs were manually assigned to activity types based on their memo lines. After assignment, a new sheet was created using Excel's VLookup function to match all original ticket ID's corresponding activity type. The number of ticket IDs for each activity type was tabulated to display the rate/prevalence of different activity types. The rates and types of maintenance activities are displayed in Figure 3.

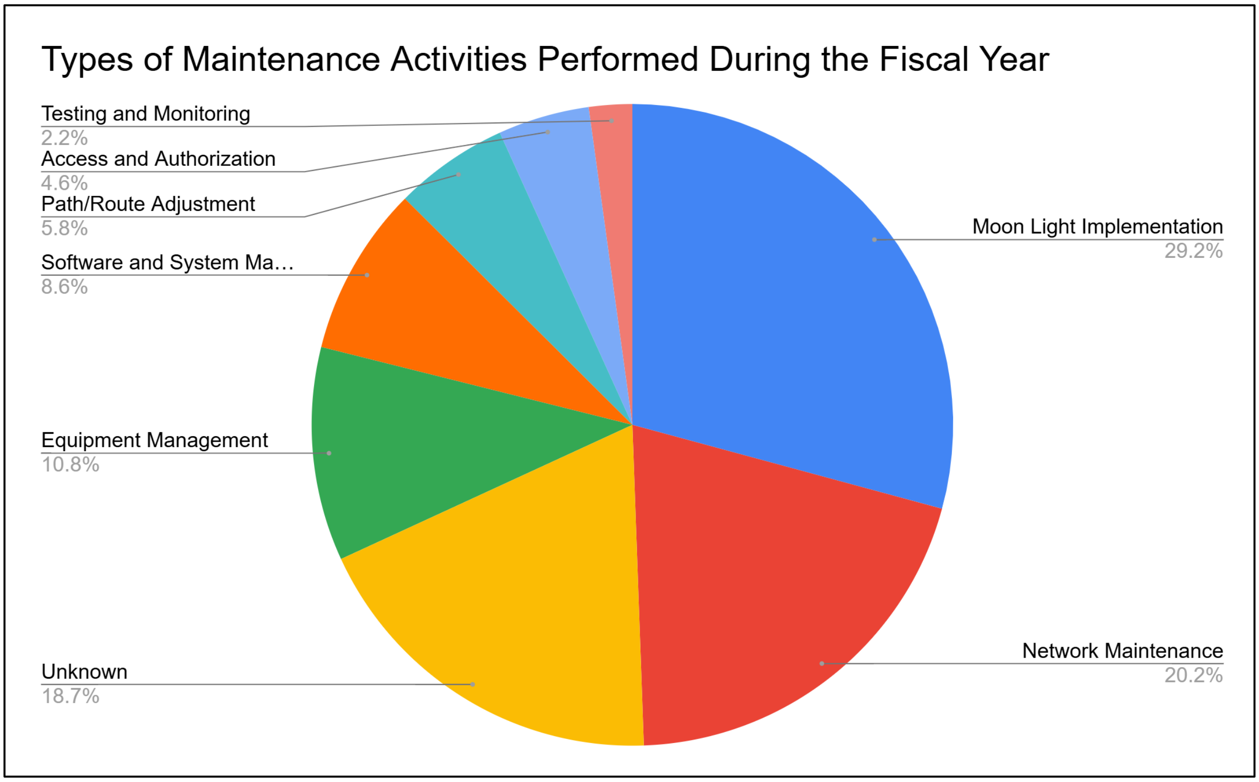

Figure 3. Types of maintenance activities performed during the fiscal year

A meeting was conducted with members of the Outside Plant (OSP) team to gather insights into maintenance trends and the prevalence of various activities. During this meeting, standard operation procedure (SOP) documentation for prevalent internal maintenance activities was requested. The OSP team referred to the Network Operations team (NetOpps) for Merit's internal maintenance procedures and documentation. NetOpps was unable to provide SOP documentation, however they were able to summarize maintenance trends [34].

OSP is responsible for coordinating third-party vendor maintenance, including work performed by Western Tel-Com, Inc.. Western Tel-Com, Inc. is a technical service provider specializing in telecommunications and fiber optic network maintenance and underground cable installation [35]. Western Tel-Com, Inc., an independent third-party contractor, services the majority of Merit's network physical infrastructure.

The following is a list of maintenance items performed by Western Tel-Com, Inc. in the past fiscal year as detailed in the Western Tel-Com, Inc. Invoices and Purchase Orders [36], [37].

- Fiber Splicing – Joining two fiber optic cables together
- Fiber Lateral Builds – Connecting fiber optic cables to a building
- Fiber Disconnects – Removing fiber optic cables
- Fiber Wreck Outs – Accidental damages or breaks
- Fiber New Builds – Installation of fiber optic cables

GHG emissions calculations from maintenance activities performed by independent contractors were omitted from this report as this audit serves to analyze emissions associated with Merit's internal operations. As per the GHG Protocol, emissions from outsourced maintenance are not attributable to Merit Network's operational footprint but contribute to Western Tel-Com's Scope 1 and Scope 2 emissions.

In-House Maintenance Calculations

The attempt to quantify GHG emissions from internal maintenance activities faced significant obstacles due to data limitations. The primary reasons for these data gaps include inconsistent documentation practices, with maintenance activities recorded at varying levels of detail and clarity. This inconsistency made it challenging to systematically categorize activities for emissions calculations. The lack of standard operating procedures (SOPs) for documenting maintenance activities resulted in variations in reporting, further complicating efforts to analyze and quantify emissions data. These challenges underscore a significant need for improved documentation and procedural clarity to enable future assessments and improve reporting accuracy. Further recommendations related to in-house maintenance calculations are documented in the recommendations section.

Utility Huts LCA

The second component of emissions is contributed by utility huts. Merit owns and operates utility huts throughout the state of Michigan. Since these utility huts have already been built and house the equipment Merit uses, the emissions from the production of the huts are part of the embodied emissions for Merit and are included in the annualized operational emissions. The energy used to power the equipment will be accounted for in Merit's operations, this LCA only covers the emission from the production of the physical building.

Life Cycle Assessment of ThermoBond Building (10' x 20') Maintenance Cabinet

The Life Cycle Assessment of the ThermoBond Building 10' x 20' maintenance cabinet estimates embodied GHG emissions per unit. The functional unit in this LCA is one ThermoBond Building 10' x 20' maintenance cabinet, with system boundaries set as cradle-to-gate (end-of-life is not included). This LCA only includes the materials used to construct the shelter and excludes any equipment that Merit stores in the hut. Data collection was based on the supplier's website and their unit-specific bill of materials (BOM), which included the quantity of parts, manufacturer's in-house part number, external vendor part number, and descriptions of each line item [38], [39]. Data from the BOM and website were aggregated into an Excel sheet. The components were separated into two categories, proprietary components specific to ThermoBond Buildings, and retail/market-available parts. The ThermoBond Buildings parts did not have individual weights listed, so these were estimated using data sheets from similar market-available parts. The weights of retail components were determined using the BOM detailed vendor and part number to source original manufacturer specification sheets. The shell of the utility hut was estimated using data from the lightweight shelters section of the ThermoBond website and ThermoBond Hut Spec Sheet, because wall and roof components were not included in the BOM. One utility hut was estimated to be 10' wide by 20' long [38], [39]. The weights of each part were entered in an LCA model of the ThermoBond building using SimaPro, an LCA software [40]. The weight of each part and the corresponding material used in SimaPro can be found in Table 24, Table 25, and Table 26 in Appendix 7. The Impact 2002+ method was used to calculate the cradle-to-gate life cycle impact of a single utility hut.

Figure 4 below shows the network diagram of the GHG emissions for the materials used in one 10' x 20' ThermoBond lightweight maintenance shelter. The materials GHG impact is around 12,500 kg CO_2e. The network diagram shows that the shelter, which includes the floor, walls, roof, and skid assembly, is responsible for the largest amount of those emissions, with a value of 4,813 kg CO_2e. The other main contributors are the two air conditioning units, a breaker, and the lights in the hut. The nodes that are visible in the network diagram in Figure 4 have the largest contribution out of the total 140 nodes that make up the system. Figure 22 in Appendix 7 shows the top 24 main contributors to the utility hut. Merit has 20 standalone utility huts, which means the total embodied emissions are 250,000 kg CO_2e.

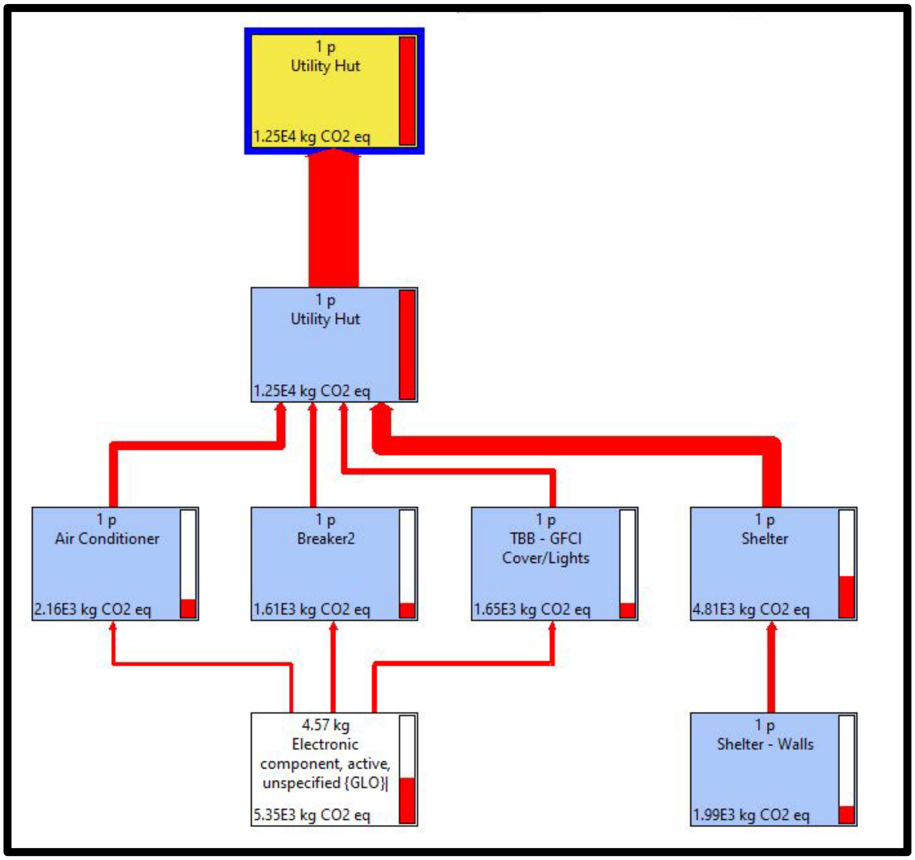

Figure 4. SimaPro utility hut LCA network diagram of largest contributors to GHG emissions

Energy Use

Utility Bill Audit: Original Proposed Workflow (From Prospectus)
Utility bill analysis was used to examine historical energy use data from utility bills. This method provides insights into energy use patterns of Merit's data centers and network infrastructure over time. By collecting and analyzing historical utility bill data, we identify trends and patterns in energy use, such as seasonal variations or peak use periods. This analysis allows us to compare energy use data across different data centers and network components, identify outliers or areas of inefficiency, and inform decision-making regarding energy management strategies and investment in energy-saving technologies.

Energy Use Analysis: Original Version (Utility Bill from Service Provider)
A crucial assumption of this method was that all locations with Merit-owned equipment would have an itemized bill from the utility service provider that would detail energy use. Based on this assumption the following process was used to determine energy use at each location.

A CSV was extracted from an SQL database, detailing all Merit payments within the Utilities & Fuel Expense Accounts from the fiscal year 2023-2024. The descriptions in this dataset included the address of the billed item. Each address was paired with corresponding Skeys (Site Keys) from an additional "Network Equipment with Site Data Sheet," linking the billing data to specific infrastructure types (data centers, network hubs, and office spaces). These SKeys were then cross-referenced with EKeys (Equipment Keys), which detail the specific equipment at each site. Using Oracle NetSuite, utility bills were filtered to isolate payments associated with data center addresses based on the SKey filter. The intention was to review these filtered billing documents to extract energy use data for each billing cycle. The goal is to establish annual kWh use and calculate corresponding kg CO_2e emissions based on the energy provider's electricity generation portfolio.

Original Version Challenges

Energy providers operate indirectly with Merit Network and are not directly responsible for billing management. Utility bills from third parties lack detailed metrics like kWh use and price per kWh, creating challenges in allocating energy demand per site. For most locations, Merit is not the direct bill payer as Merit is collocated with other ICT companies who share utility costs. Merit does not receive a detailed energy bill based on their operations at each location. The billing types and collocation contracts vary based on the location's ownership type. To overcome the data limitations associated with using utility bills as the assumed data source. To address the data limitations of relying on utility bills as the primary data source, a different approach than originally planned was employed to calculate the operational power and energy demand for Merit's network operations. This refined method, detailed in a later section, involves using OEM spec sheets and the specified power demand of each individual device to determine the total network demand.

Data Centers and Sites

Merit wholesale data centers are collocated with either the University of Michigan or 123Net, which have different billing contracts and energy use structures. Merit also hosts equipment in data centers without a sublease agreement for networking access, and billing contracts and energy use structures vary per agreement.

Wholesale Data Centers

Wholesale data centers are Merit's leased collocation space with the ability to sublease to members. Currently, Merit keeps contacts with two collocation providers for network services These included the Michigan Academic Computing Center (MACC) at University of Michigan and 123Net Network services. Due to differences in contracts and the nature of the service providers, energy use estimation for the two types of wholesale data centers should be implemented in separate ways.

Merit at the University of Michigan

Merit Network and the U-M are independent tax entities. Merit Network is a Michigan private non-profit, non-stock membership organization. It acts as an agent, providing advanced networking services to the University to support research and educational initiatives. This relationship is governed by hosting agreements and shared governance structures. These agreements outline the quality, scope, and reliability of services provided by Merit Network. Per the hosting agreement, the University provides two racks of equipment space in U-M data centers for access by Merit's member universities, free of charge. Additionally, the University offers extra rack space to Merit at cost. The terms and conditions for this additional space are outlined in a separate agreement. Merit hosts equipment at cost in the Michigan Academic

Computing Center (MACC) data center at the University of Michigan. The following paragraphs describe the calculations used to estimate Merit's emissions from billed data center use.

Purchasing Agreement
The rack rate and electricity charge are shown in Figure 5, in an excerpt from the *FY25 ITS Financial Summary* [41].

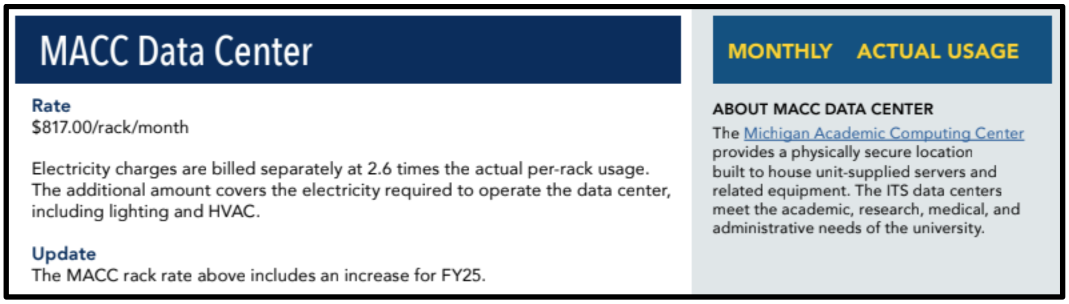

Figure 5. Example rack rate and electricity charge

Payment Method
Service Unit Billing (SUB) is the university's internal billing method used by Recharge Units to charge other units for goods or services. Costs are billed using an approved rate and recorded in a specific fund. SUBs create vouchers in the procurement system, ensuring that the billing unit is credited, and expenses are accurately reallocated to the correct departments. Per communications with the accounting team there is no additional documentation of the charges in the form of a receipt or a PDF.

Received Data
Data revived from SQL as a CSV titled FY24 Energy info v4. MACC utility bill data were removed from the original dataset and organized in an independent sheet.

Calculation Methods
Given the MACC Data Center total rack rate of $817.00 per rack per month and the monthly combined utility charges (electricity and rent), the dollar amount spent on electricity was calculated by removing the dollar amount spent on rack rental using the following formula:

*Monthly Dollar Amount Spent on Electricity Only: Total Charge - (817 * the number of racks rented per month)*

Merit at 123Net
Merit Network partners with 123Net for collocation services, utilizing 123Net's data centers in Southfield and Grand Rapids. Merit uses these facilities to host its infrastructure, offering access to its members.

Locations: Merit hosts equipment in two collocated data centers with 123Net

- Southfield Datacenter - SFDC [DC2]
- Grand Rapids Datacenter - GRDC [DC4]

Telecommunications Data Centers
Telecommunication data centers are data centers that are outside of Merit's network but with service purchased by Merit for data exchange between networks and service providers. These data centers include:

- Network DC: Big Ten Academic Alliance Data Center
- Network DC: CoreSite Chicago Data Center (CH1)
- Network DC: Equinix Chicago
- Network DC: Northwestern University Co-location facility

Due to the indirect relationship with Merit's operating network, the energy use (and thus GHG emissions) of these data centers is outside of the emissions audit scope of this report.

Network Hosting Sites (Pop Sites)
Network Hosting Sites or point-of-presence (PoP) sites are either vendor-owned infrastructure with hosting agreements or Merit-owned cabinets.

Merit installs and operates equipment at member sites, where PoPs serve as core distribution points and are crucial for network connectivity. While some members charge for collocation and utilities, others do not. For this study, emissions from members that do not charge for utilities will not be attributed to Merit. These emissions are considered the operational and financial responsibility of the vendor. Merit does not directly control or manage energy purchasing or use at PoP sites where electrical use is not charged.

A list of PoP sites with charges was merged with a separate sheet detailing the SKey for all PoP sites. These site keys were then utilized to retrieve all bills associated with those locations from the past fiscal year from accounting records and expense reports, filtered by location. This approach was largely inconclusive as financial data did not detail all expected charges for all units. The lack of itemized billing hinders the attribution of purchased energy. Future studies should focus on improving data collection as outlined in the recommendations section of this report. Enhanced data clarity is necessary to better understand financial allocations and expenditures.

The energy use and GHG emissions in hosted sites are highly dependent on the network equipment. Please see the calculation methods below for details.

Network Equipment and Operations

The annual energy use estimates for Merit Networks' internet infrastructure are based on metered performance data collected through Really Awesome New Cisco Config Differ (RANCID) and Simple Network Management Protocol (SNMP). These are network management systems that collect and organize information on network devices. The respective network management systems and their capabilities are described below.

- RANCID [42]

  Really Awesome Network Cisco Config Differ is an open-source tool that collects and archives configurations from Cisco and Juniper routers. It tracks configuration changes nightly, stores differences in a CSV repository, and provides a web interface for viewing and comparing configurations. RANCID uses SSH or Telnet to log into network devices to retrieve configuration files. It can be integrated with SNMP (Simple Network Management Protocol) for enhanced network monitoring and management.

- SNMP [43]

  Simple Network Management Protocol is a network management system used to oversee and configure devices such as routers and switches. It facilitates monitoring device status and gathering performance data.

The data collected from the management systems were delivered as CSV files, providing detailed insights into energy use across network devices.

Methods

Utility Bill Data Cleaning Process
The data cleaning process begins with raw utility data exported from an Oracle database maintained by Merit. The primary goal of this process is to systematically transform the raw utility bill data into a dataset suitable for geospatial and analytical applications. A key challenge in this process involves extracting address information (and subsequently latitude and longitude coordinates) from the raw data, which are originally stored as descriptive text specifying the address or simply the name of the location.

The first step in the process focuses on filtering relevant utility records and identifying or assigning addresses. Geocoding is then performed using Google Maps API to obtain latitude and longitude coordinates. The next step links addresses to corresponding SKEY, descriptions, and geospatial attributes. One thing to notice is that in many records in the utility bill, the addresses were not plainly given by the descriptive field but were rather implied by the common name of the network site. For example, the Chicago data center was marked as DSC-001 in some records. To make sure these records are also correctly geo-located, keyword-based matching was adopted to enhance the result by associating the common names (keywords) with predefined site key information based on the bill descriptions. The final cleaned dataset, containing geocoded locations and original contextual data including the power demand and other descriptive fields, was exported for further analysis, supporting utility expense tracking and spatial mapping.

Energy Use Calculation Methods
An inventory of network devices was compiled using NetDisco. NetDisco is a Perl-based network management application that scans network devices using SNMP to collect information like device models, serial numbers, interfaces, VLANs, IP addresses, and MAC addresses. Primary data generated from Netdisco scans included the following data sets: Network Equipment with site data.csv, Ciso-Device.csv and Juniper-Device.csv. All primary data sets are stored in the private shared drive including the original CSV export. These data sets detail the Serial Number, Model Number, Ekey and Skey of all branded devices on the network.

Adtran devices account for small percentage of all active devices on Merit's Network. Emissions and energy use related to Adtran devices were omitted from this analysis due to the challenges in sourcing reliable energy use data for these devices.

The Network Equipment with site data.csv file detailed the Site Address, Serial Number, EKEY and SKEY of all active Cisco and Juniper devices at the time of scanning. Juniper and Cisco devices account for the majority of Merit networks' total internet infrastructure. The Network Equipment with site data.csv file did not include the model number of active devices. The power demand of each device is based on the model number of the equipment, not the serial number.

The Ciso-Device.csv and Juniper-Device.csv files detailed the model and serial number of each device. Cross referencing this information, a model number was matched with a serial number from the Network Equipment with site data.csv. This paired inventory of serial and model number (with additional address and EKEY) formed the basis of the energy use calculations based on supplier spec sheets.

This inventory was converted into a spreadsheet, where the model and serial numbers of all active equipment were recorded. Using the model numbers, the original equipment manufacturer (OEM) specification sheets for each piece of active equipment were retrieved from the OEM resource portal. All specification PDFs are listed in Appendix 8.

The minimum, typical, and maximum power demand were sourced from these specification sheets when available. Power demand was specified in watts, based on AC (Alternating current) configuration at room temperature. Figure 6 is an example of the power demand data as presented in OEM documentation.

Table 3. Power Specifications

Description	Cisco ASR 920 Router
Power consumption	ASR-920-12CZ-A: Max 115W, Typical: 80W ASR-920-12CZ-D: Max 110W, Typical: 80W ASR-920-4SZ-A: Max 105W, Typical: 75W ASR-920-4SZ-D: Max 105W, Typical: 75W
AC input voltage and frequency	Voltage range: 85V AC to 264V AC, nominal 100V AC to 240V AC Frequency Range: 47 to 63 Hz, nominal 50 to 60 Hz
DC input voltage	Voltage range: -19.2V DC to -72V DC, nominal -24V DC to -48V DC

Figure 6. Example OEM specification sheets: power demand per device [44]

Given Merit's network uptime of 99.99%, it was assumed that all equipment operated for 99.99% of the fiscal year, resulting in a total operational time of 8759.12 hours (365 x 24 x 0.9999) [45]. Using the known power demand from the supplier spec sheet (in watts) and the calculated operational time (in hours), the cumulative energy use per device was computed in watt-hours (Wh). The equation for calculating annual energy use per device is as follows:

Equation 1

$$Device\ Uptime\ in\ Hours = Reported\ Network\ Uptime\ Percent\ x\ Total\ Hours\ Per\ Year$$

Equation 2

$$Annual\ Energy\ Use\ Per\ Device = Spec\ Sheet\ Power\ x\ Device\ Uptime\ in\ Hours$$

The energy use, originally calculated in terms of Wh, was converted to kilowatt hours (kWh). When the annual energy use per device on the network was calculated, the sum of all individual demands was summed to calculate the total energy use (kWh/year). Most specification sheets provided explicit power demand values, but not all sheets detailed the maximum, minimum or typical power demand values. The maximum power demand was the most prevalent and was therefore used to predict power demand as it was available for most devices and gave a conservative estimate. This calculation assumption was based on the guidance in Section 2.8.2 "Calculating GHG emissions for the customer domain use stage" of the GHG Protocol Product Standard [15].

In the absence of any power demand variables the maximum power supply rating was used as a proxy for maximum power demand. When only one coefficient was provided by the supplier it was assumed to be the maximum power demand variable due to industry convention. A CSV export of all devices and their respective power demand and street address (Address, EKEY and SKEY) was then used to create a figure displaying Merit's energy use per location using GIS software. The baseline results for Merit Network's power demand are detailed in the results portion of this report.

Greenhouse Gas Emissions Calculation Methods

Emissions factors (EFs) convert electricity use into GHG emissions based on the source fuels used to generate that electricity. They represent the mass of atmospheric pollutants released per unit of electricity used. Emission factors vary by region due to different mixes of energy sources used for electricity generation. Regional EFs for this calculation were sourced from the EPA's Emissions & Generation Resource Integrated Database (eGRID) [46]. A map of eGrid subregions is shown in Appendix 8. Most of Merit's network operations occur in the RFCM subregion (RFC Michigan / Eastern Power Grid – essentially Michigan's lower peninsula) so we chose to use RFCM EFs to estimate emissions from electricity use across Merit's network. Table 3 details output emission rates (lb/MWh) for the RFCM subregion as reported in eGrid 2023 [47].

Table 3. eGrid 2023 output emissions rates (lb/MWh) for the RFCM subregion

CO_2	CH_4	N_2O	SO_2	CO_2e
962.1	0.082	0.011	0.559	967.4

Equation 3 was used to estimate network emissions. After calculating the GHG per device (total electricity use and EF) a CSV export of emissions was created. Devices, and their corresponding emissions were organized by street address and used to create a map (shown in Figure 10) displaying Merit network's GHG emission per location.

Equation 3*:*

$$Annual\ Network\ GHG\ Emissions = Annual\ kWh\ of\ all\ Devices\ x\ \ Network\ EF$$

GIS Mapping and Analysis Methods

The GIS methods applied in the utility bills analysis are shown in Figure 7 and described below.

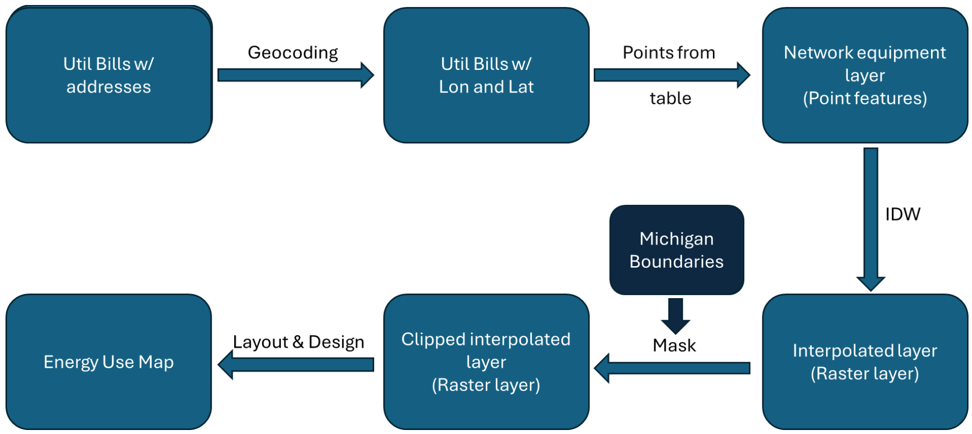

Figure 7. Diagram of the GIS process for energy use

The process begins with utility bills containing addresses, which are geocoded into latitude and longitude coordinates. These geocoded points are then converted into a point layer representing the locations of network equipment or utility service points. This point layer becomes the basis for spatial interpolation, estimating energy use across a broader region.

To refine the interpolation, the data are clipped using Michigan's geographic boundaries, ensuring that only relevant areas are considered. The interpolated layer, in raster format, represents the estimated energy use distribution across Michigan. The final step involves generating an energy use map that illustrates spatial variations in electricity use, providing insights into demand hotspots and guiding infrastructure planning or optimization efforts.

The GIS process for GHG emissions, shown in Figure 8 below, is similar. It begins by collecting utility bills containing customer addresses, which are geocoded into latitude and longitude coordinates. These geocoded locations are then converted into a point feature layer representing network equipment or key emission points. The equipment is categorized by state to ensure that state-specific boundaries and regulations are applied in the analysis. More specifically, different EFs are applied to data in different states.

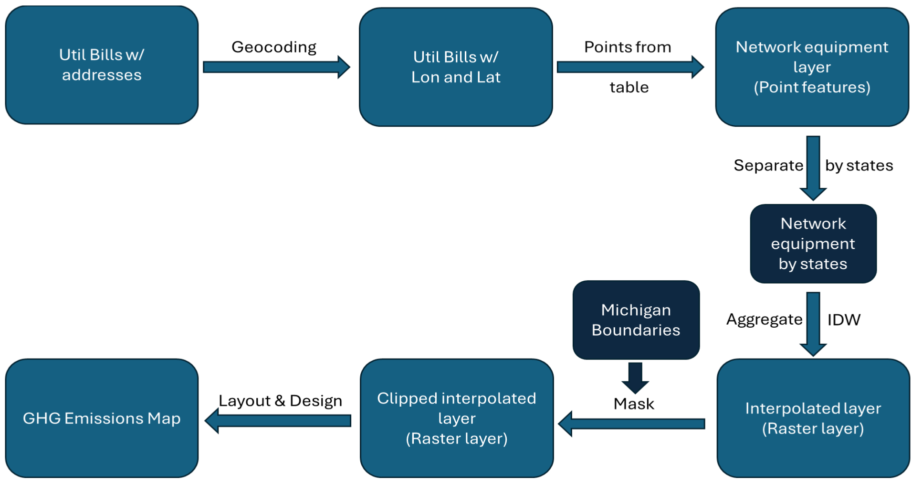

Figure 8. Diagram of the GIS process for GHG Emissions

Once the point-based data are prepared, spatial interpolation techniques are used to generate a raster layer estimating GHG emissions across different regions. This interpolated layer is clipped to fit within Michigan's geographic boundaries, ensuring the analysis is focused on the relevant area. The final output is a GHG emissions map that highlights emission patterns, helping policymakers and stakeholders identify areas with high emissions and plan targeted mitigation strategies.

Results

Combining all the above discussions and data sources, we summarize energy results in the following five sections. Energy use, estimated by detailed auditing based on equipment brands and models, is summed into a data table given in the first section. The actual energy use, sourced from Merit's utility bill and geo-located and interpolated with the above GIS process is put into an energy use map showing the spatial trends. The energy use data, further processed with emission profiles of each state given by the third section, were then converted into emission maps showing different gas emissions and the standardized GHG emission in CO_2e. Further results accounting for utility decarbonization trends in Michigan are given in the final section. Table 4 details the total FY 2023-24 annual energy use of devices on Merit's network. Table 5 contains the total FY 2023-24 emissions resulting from this energy use, based on eGrid 2023 EFs for the RFCM subregion.

Table 4. Total annual FY 2023-24 MWh of all devices at max power, by manufacturer

Juniper: Sum of all Units	619.55
Cisco: Sum of all Units	824.47
Total: Cisco and Juniper	1444.02

Table 5. Total FY 2023-24 annual CO_2e emissions from energy use

Energy Used in Fiscal Year 2023-24 (MWh)	1,444
Emission Output Rate (lb CO_2e /MWh) [47]	967
Total CO_2e Emissions from Energy Used (lb)	1,396,946
Total CO_2e Emissions from Energy Used (kg)	633,644
Total CO_2e Emissions from Energy Used (metric ton)	633

Energy Use by Location

The map in Figure 9 below illustrates the energy use of Merit's equipment network by geographic location. Each point on the map represents a piece of Merit's network equipment, identified by an installation address, which has been geolocated, and an equipment key (EKEY) linking it to a specific model and corresponding power rating. Equipment records were matched to utility bills from fiscal year (FY) 2023–24 using address-based and keyword-based methods described previously. As a result, each piece of equipment has an energy use, measured in megawatt-hours (MWh), reflecting its actual energy use during FY 2023–24. Due to limitations in available data, not all equipment could be matched directly to utility bills. For these unmatched units, energy use was estimated based on their power ratings for the study period.

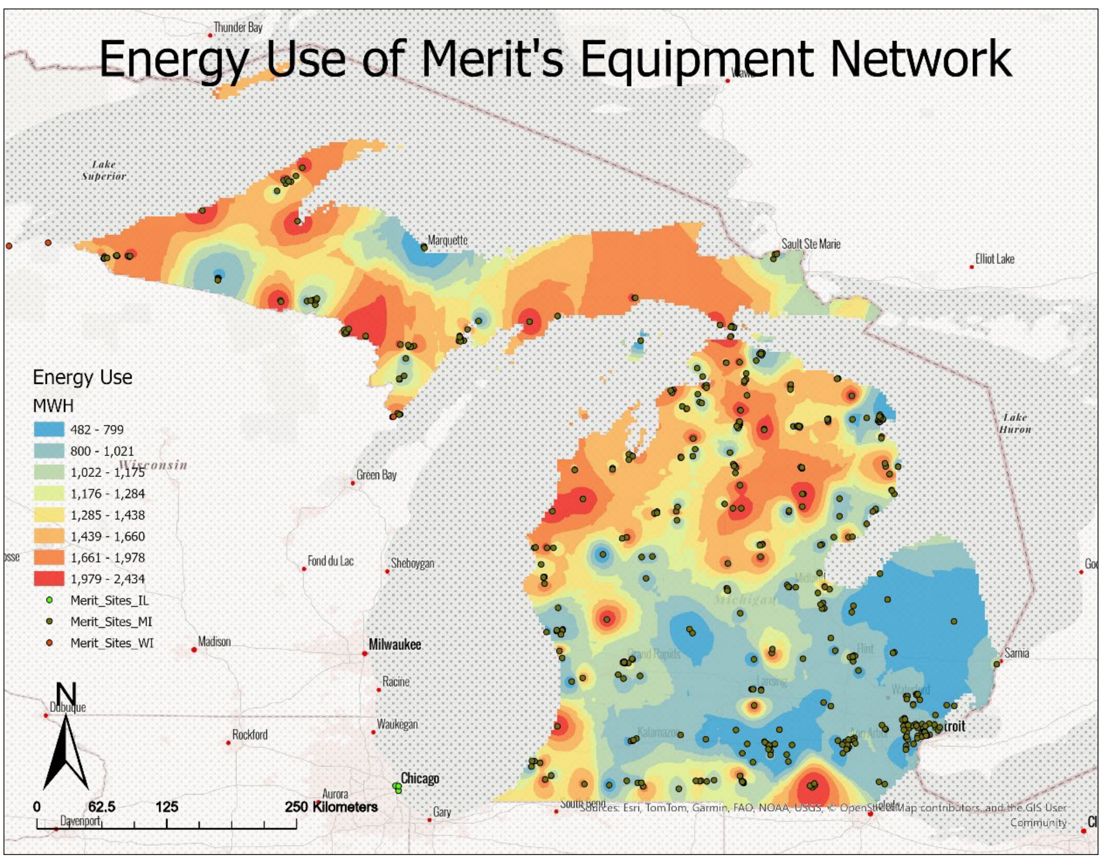

Figure 9. FY2023-24 energy use (MWh) of Merit's network by location

Emissions by Location

The map below illustrates the geographic variations of CO_2e emissions derived from energy use, given by the emission factor profiles. Results are shown as CO_2e across Merit's network infrastructure. Each point represents a specific network device installed at a designated location, with an associated wattage rating determined by its model. By combining this spatial distribution with state-specific emission factors, we visualize the localized patterns of the corresponding environmental impacts in terms of GHG emissions throughout Merit's service area.

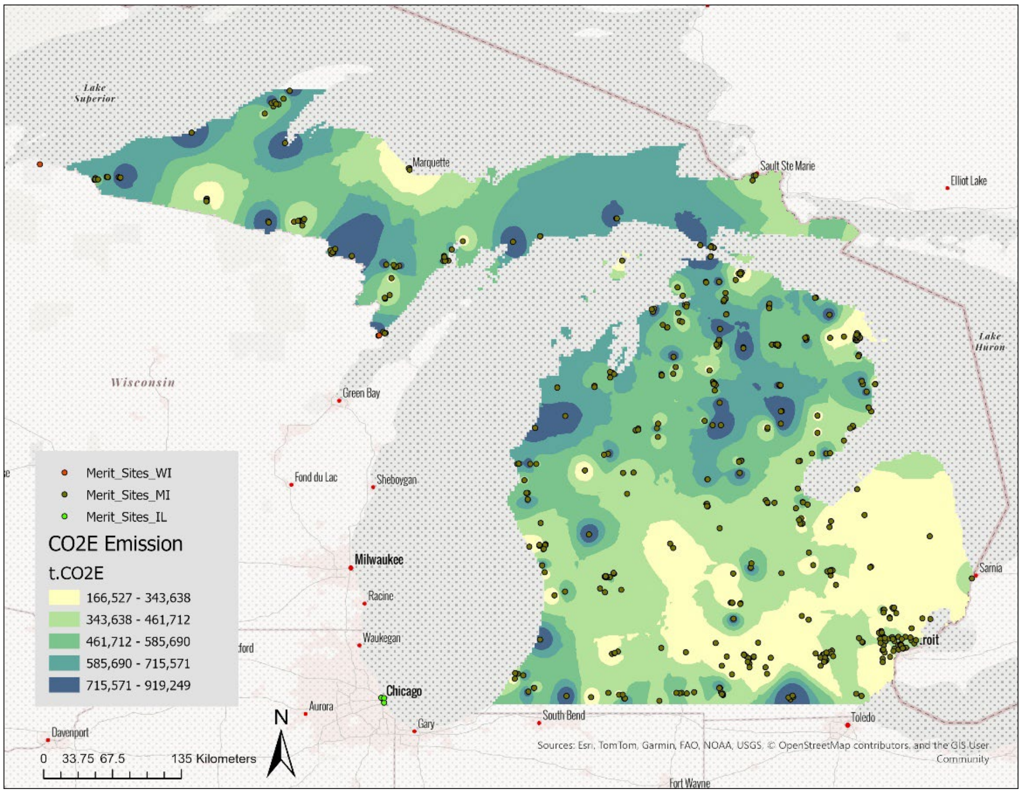

Figure 10. FY2023-24 CO_2e emissions (metric tons) of Merit's network by location (EFs from eGrid 2023)

Estimate Based on Michigan's Decarbonization Trends

The GHG emissions from Merit's internet infrastructure are directly linked to energy use and the emissions intensity of Michigan's electricity grid. Due to state-wide initiatives like Senate Bill 271 of 2023 and the MI Healthy Climate Plan, Merit's GHG emissions are expected to decrease even without additional intervention [48], [49]. Michigan is moving from a coal-heavy energy mix to increased use of natural gas, renewables, and nuclear power [50]. Based on these decarbonization scenarios, Merit can expect a significant reduction in its GHG emissions, aligning with the state's broader goals for a cleaner and more sustainable energy future. Figure 11 illustrates the anticipated emissions resulting from projected electricity decarbonization rates in Michigan. Michigan's expected decarbonization rates were used as a reference to highlight Merit's potential total operational emissions reductions, as most of Merit's infrastructure is located within the state. The total calculated network energy demand served as the baseline, with the assumption that energy use remains constant over the projected time horizon (40 Years). This figure portrays decarbonization based on kg CO_2 rather than kg CO_2e based on the reported data from the EPA's Clean Power Plan (CPP) [51]. This deviation is not considered significant, as CO_2 comprises the vast majority of total CO_2e emissions—making the observed trends in decarbonization largely consistent, even when only CO_2 data are available.

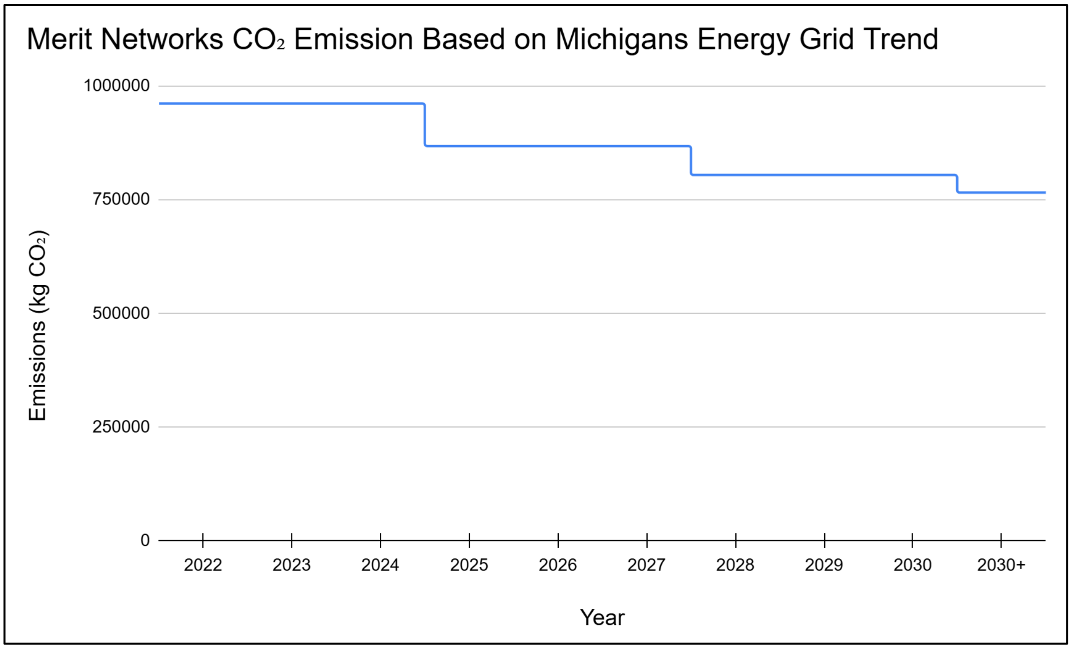

Figure 11. Merit Network's decreased CO_2 emissions based on Michigan's electricity grid decarbonization through 2030

Transportation

Transportation is the fourth primary source that contributes to Merit's operational emissions, along with the fiber network, utility huts, energy use, and waste. All types of travel would be explored in this section.

Personal Vehicles

Different functional units will be used according to the type of travel reimbursement (IRS/Dollar Amount) or transportation (Personal Vehicle or Fleet) used.

- kg CO_2e from driving 1 km in a personal vehicle for business travel: IRS RATE
- kg CO_2e from driving 1 km in a personal vehicle for business travel: Dollar Amount
- kg CO_2e from driving 1 km in a U-M leased vehicles for business travel: Dollar Amount

Personal Vehicles Miles Traveled Used for Business Expenses - IRS RATE
Vehicle miles traveled were tabulated using accounts payable information and the IRS standard mileage reimbursement rates (per year of bill) [52], [53]. Cost per line item (Amount Reimbursed) was used to calculate the distance traveled by dividing the dollar amount by the

reimbursement rate (2024: 0.670 and 2023: 0.655). The well-to-wheels energy use emission factor of 388g of CO_2 emissions per passenger mile for gasoline was sourced from GREET [54].

Personal Vehicle Emissions Used for Business Expenses - Dollar Amount
To calculate tailpipe emissions for personal vehicle miles traveled used for business expenses, where reimbursement is based on the gross amount spent at the pump rather than the IRS reimbursement rate, the following method was used. For each fuel purchase, the year, location, and price are used, with all line items assumed to involve regular gasoline. The fiscal year spans two calendar years, 2023 and 2024. Geographic regions included the Central Atlantic (PADD 1B), Midwest (PADD 2), and California. If the bill items memo line did not state, the geographic region of purchase was assumed to be the Midwest. 2023 and 2024 historical fuel price data were sourced from the US Energy Information Administration's U.S. Gasoline and Diesel Retail Prices web portal [55]. This dashboard provided the average annual price for regular gasoline specific to the geographic region. Yearly average prices of gasoline per geographic region are detailed in Table 6.

Table 6. Average yearly price of 1 gallon of regular gasoline by geographic region

Geographic Region	2023 Average Price (Retail $/gal)	2024 Average Price (Retail $\gal)
California	4.773	4.562
Central Atlantic (PADD 1B)	3.562	3.357
Midwest (PADD 2P)	3.363	3.163

By dividing the expense line item by this average rate, the volume of fuel purchased was calculated, representing the fuel used per trip. There are 8,887 grams of CO_2 emissions resulting from the combustion of 1 gallon of gasoline [56]. The calculated gallons purchased using historical gas prices is assumed to be the amount of fuel consumed per line item. The volume of fuel per line was then multiplied by 8,887 g CO_2/gal to establish the emissions footprint of each line item. Table 7 details the total emissions from Personal Vehicles Miles Traveled Used for Business Expenses using both the IRS and dollar amount per the fiscal year.

Table 7. Tailpipe emissions from personal vehicle miles traveled for business

Accounting Method	Emissions (kg of CO_2)
IRS Rate Reimbursement	19,214
At the Pump Reimbursement	106,237
Total Emission	125,451

U-M Fleet Vehicles
Individual emissions factors were calculated for each vehicle model. Expense reports from NetSuite detailed the fuel purchases for U-M fleet vehicles, including the year of purchase and price in USD, with all vehicles assumed to use regular gasoline. Using historical data from the US Energy Information Administration, the average yearly rate of regular gasoline for Ann

Arbor, Michigan was determined using the Midwest PADD 2P region [53]. The data from 2023 and 2024 were used to calculate the volume of fuel purchased depending on the year of purchase. Fuel purchased is assumed to represent the fuel used per trip (line item). The miles per gallon (MPG) for each vehicle is contained in Table 8. Using the MPG for each vehicle and the estimated fuel volume purchased, the miles driven per transaction were calculated by multiplying the volume of fuel purchased by the vehicle's average MPG. Once miles traveled per line item were calculated, the distance was multiplied by the vehicle model-specific emission factor [55-62]. The vehicle specific tailpipe CO_2 emissions per VMT of the leased U-M vehicles are detailed in Table 9.

Table 8. MPG of Merit's U-M fleet vehicles

Car Model	Average MPG	City	Highway	Source
2023 Chrysler Pacifica	23.5	19	28	[57]
2017 Dodge Caravan	21	17	25	[58]
2019 Dodge Caravan	21	17	25	[59]
2020 Dodge Caravan	21	17	25	[60]
2019 Dodge Promaster	24.5	21	28	[61]
2023 Chevy Silverado 2500 Double Cab	18	16	20	[62]
2022 Ford F-250 Crew Cab	13.20	N/A	N/A	[63]
2018 GMC Sierra 2500 HD	14.55	N/A	N/A	[64]

Table 9. Tailpipe emission factors of Merit's U-M fleet vehicles

Vehicle ID Number	**Car Model**	**Tailpipe CO_2** (Grams Per Mile)	**Source**
271	2023 Chrysler Pacifica	401	[57]
273	2023 Chrysler Pacifica	401	[57]
28	2023 Chrysler Pacifica	401	[57]
503	2017 Dodge Caravan	445	[58]
391	2019 Dodge Caravan	445	[59]
435	2020 Dodge Caravan	445	[60]
1468	2019 Dodge Promaster	374	[61]
299	2023 Chrysler Pacifica	401	[57]
306	2019 Dodge Caravan	445	[59]
1359	2023 Chevy Silverado 2500 Double Cab	496	[62]
1259	2023 Chevy Silverado 2500 Double Cab	496	[62]
1353	2022 Ford F-250 Crew Cab	673	[63]
1169	2022 Ford F-250 Crew Cab	673	[63]
1506	2018 GMC Sierra 2500 HD	522	[65]

When available, the EPA-rated MPG was used. In the absence of EPA data for the 2022 Ford F-250 Crew Cab, an MPG was estimated from Fuelly, a user-contributed database of real-world MPG [66]. The miles traveled per line item were multiplied by the vehicle-specific emissions factor, yielding CO_2 emissions for each line item in grams. Finally, the results were summed up and converted to metric tons. Results are detailed in Table 10.

Table 10. Tailpipe emissions from Merit's U-M leased fleet vehicles

Total CO_2 Emissions of Line Item (g)	15,931,036
Total CO_2 Emissions of Line Item (tons)	17.56

Airfare

In analyzing the expense data provided by Merit Network for air travel, we encountered a significant data limitation: the only available and usable information in the dataset is the amount spent in U.S. dollars for each trip. Without details such as flight distance, route, aircraft type, or class of travel, reliably estimating GHG emissions is challenging. To proceed with the estimation, we must rely on an assumed average emissions per dollar spent. This approach is an approximation and does not capture the variability caused by differences in flight characteristics, but it allows us to provide a baseline estimate of GHG emissions. The details of our estimation methods are specified below.

Finding an Air Travel Cost - Distance Conversion Factor
The first step in estimating GHG emissions from expense data involves determining a cost-distance conversion factor (CDCF) that relates air travel costs to travel distance, expressed in dollars per mile ($/mi). Using established sources like the Sustainability Indicator Management and Analysis Platform (SIMAP), we can reference national averages for air travel costs and the typical relationship between ticket prices and distances traveled [67]. The SIMAP model integrates data from airline industry reports and national travel statistics to estimate how much of the airfare cost corresponds to a given distance. This conversion forms the basis for estimating the number of passenger miles traveled for each dollar spent, a critical input in calculating the GHG emissions for each trip.

For further calculations, we adopted the BTS (Bureau of Transportation Statistics) version of the conversion factor provided by SIMAP, which is:

$$D = C / CDCF$$

Where:

- D – airfare travel distance
- C – airfare travel cost
- CDCF – Cost-distance Conversion Factor

Finding Distance-Carbon Emission Conversion Factors
To estimate carbon emissions from air travel based on distance, we use emissions factors that quantify the amount of carbon dioxide equivalent (CO_2e) emitted per passenger mile, which is the distance-CO_2e emission conversion factor (DCCF). These factors vary depending on flight characteristics such as distance and class of service. For instance, the UK Department for Environment, Food & Rural Affairs (DEFRA) provides detailed conversion factors for greenhouse gas reporting [68]. According to DEFRA's 2023 guidelines, emissions factors for air travel are categorized by flight distance and class. For economy class, the DCCF are:

- Short-haul flights (≤ 3,700 km): 0.15 to 0.25 kg CO_2e per passenger kilometer.
- Long-haul flights (> 3,700 km): 0.08 to 0.12 kg CO_2e per passenger kilometer.

These factors account for direct CO_2e emissions and include a multiplier to reflect the increased climate impact of emissions at high altitudes, known as radiative forcing.

Thus, to calculate the carbon emissions for a trip, the formula is:

$$CE = D \times DCCF$$

Where:

- CE – CO_2e Emission
- D - Distance
- DCCF - Distance-CO_2e emission conversion factor

Airfare Results
In the fiscal year 2023–2024, Merit Network employees recorded a total of 88 airfare trips. The average cost per trip was $378, with an estimated average flight distance of 2,005 miles. Using the established conversion factors for carbon emissions, the emissions for these trips were calculated based on the distance traveled. The results are in Table 11, below.

Table 11. Sum and average of airfare travel emissions estimates (in cost, distance and CO_2e emissions)

	Amount ($)	Distance (mile)	Distance(km)	CO_2e emission (kg)	CO_2e emission (kg)	CO_2e emission (kg)
				(lower bound*)	(avg**)	(upper bound***)
Avg** **	379	2005	3227	342	442	543
Sum** **	30617	169654	273030	28443	36733	45023

*: Lower bound emission result comes from using the minimum values of DCCF (0.15 kg CO_2e per passenger kilometer for short-haul flights, 0.08 kg CO_2e per passenger kilometer for long-haul flights)
**: Avg emission result comes from using the average values of DCCF (0.20 kg CO_2e per passenger kilometer for short-haul flights, 0.10 kg CO_2e per passenger kilometer for long-haul flights)
***: Upper bound emission result comes from using the maximum values of DCCF (0.25 kg CO_2e per passenger kilometer for short-haul flights, 0.12 kg CO_2e per passenger kilometer for long-haul flights)
****: Average and sum statistics are average/sum over all 88 airfare travel records in Merit's ticketing system in fiscal year 2023-2024.

End of Life

End of Life Scope
The fifth source of emissions is contributed by End-of-Life. The End-of-Life (EOL) analysis for this baseline audit focuses on evaluating the disposal and management of assets associated with operational activities. This includes assessing how equipment, devices, and infrastructure used in daily operations are retired, recycled, or otherwise processed at the end of their useful life. This scope specifically examines equipment used directly in operational contexts, such as network devices, servers, and supporting infrastructure. However, it excludes the utility huts and office waste generated by administrative activities, such as paper, packaging, or general office supplies. Additionally, the analysis does not cover waste streams from external vendor activities. Since these processes are carried out by third-party vendors and fall outside of Merit's operational control, they are not included in Merit's direct environmental footprint.

E-Waste: Emission Factors Literature Review (Network Equipment)
Core networking devices constitute a significant portion of the total embodied emissions within the information and communications technology (ICT) sector. However, standardized emission factors for these devices are currently unavailable. This gap may stem from the highly specialized nature of core networking equipment, which is often custom-built or manufactured in limited quantities for specific applications, making it difficult to collect aggregate data or establish generalized emission factors.

To address the current lack of detailed literature on the embodied CO_2e emissions of core networking devices, we have resorted to using proxy data. This approach involves using emissions factors from similar technologies or adapting data from related sectors with comparable components and manufacturing processes. When available, data were reported in the context of CO_2e emissions. In the absence of CO_2e data, CO_2 emissions data were used instead. The use of CO_2 emissions data instead of CO2e emissions data does not compromise the reliability of this report, due to the high degree of similarity between CO_2 and CO_2e, as discussed earlier in this report.

The Dell PowerEdge R710 rack server was selected to represent core network equipment because servers and core networking devices share similar manufacturing processes, materials, and energy use profiles. Dell has produced a detailed life cycle assessment of the R710, which includes information on end-of-life treatment and recycling, which presents an end-of-life (EOL) emission impact of approximately 86 kg CO_2e per unit [69].

Calculation Methods

The CO_2 emissions from Merit's e-waste disposal were calculated using global trends from the UN Global E-Waste Monitor. Devices were first categorized by their specific type, such as shelf control units, optical amplifiers, or keyboards, and then grouped into broader categories like Network Equipment: Core, Desktop PCs, and PC Accessories, following UN e-waste conventions. Quantities of each device were recorded using Merit's Asset Disposition Forms, and emissions factors from relevant literature were applied to estimate the environmental impact for each category. The predictive models, based on waste management trends from the UN, were used to calculate the potential EOL destinations for each device category—whether they were likely to be recycled or disposed of. For instance, if 25% of a device category was expected to be recycled and 75% not recycled, the emissions for both scenarios were calculated accordingly. Each category's emissions burden was computed by multiplying the number of devices, the emissions factor specific to that device type, and the recycling or disposal probability.

Total Footprint Contribution

Merit's total e-waste footprint is determined by evaluating both recycled and non-recycled devices. Devices that are sold have zero burden with the exception of emissions from transportation to the end user. Devices that are recycled or recovered at a material recovery facility received emissions credit in return. These contributions are subtracted from the total emissions burden. In contrast, devices that enter the waste stream and are not recycled contribute to carbon emissions, as they represent an environmental cost.

Assumptions and Considerations

No Processing Emissions for Recycled Devices: The assumption that recycled devices produce no processing emissions simplifies the calculation but does not accurately represent real-world conditions. In practice, recycling processes consume energy and produce emissions, and the emissions saved by recycling are typically less than the total emissions generated from waste.

100% Material Recovery: This assumption is that all materials from e-waste are recovered.

End of Life Calculation Disclaimers

EOL emissions calculations for Merit's network equipment face limitations due to data aggregation and data traceability. Recycling rates from the UN E-Waste Monitor may not reflect the University of Michigan's practices, and emissions factors are broad averages, lacking item-specific precision. The fate of unknown items is excluded, further reducing accuracy. Additionally, assuming recycled devices produce no processing emissions oversimplifies the energy and emissions involved, though these are lower than for non-recycled waste.

Electronic Waste: Inventory and Calculations

Merits E-waste Management Procedure: University of Michigan Property Disposition
The total annual electronic waste (e-waste) generated from Merit's operations was quantified using records of e-waste submitted to the University of Michigan Property Disposition for either resale or disposal. The University of Michigan's Property Disposition department manages the disposal of surplus university property in accordance with Standard Practice Guide 520.01 [70]. Property Disposition determines the best method for handling these items (Selling / Recycling / Disposal). Each individual item processed, along with its corresponding description and quantity, was documented in Merit Asset Disposition Forms. For our calculation, all Merit Asset Disposition Forms from the relevant fiscal year were compiled into a centralized ledger. Items listed in this combined ledger were categorized by type.

Following categorization, the quantity of individual devices per category was recorded. Items were organized based on the description field of the primary waste disposal forms using key words in the description (Ex. *The HP ProBook650 Laptop)*. In cases where keywords were absent, a web search was conducted to gather the necessary information. When these searches did not yield results those items were assigned the Unknown/General E-waste tag. The total annual e-waste generated by Merit's operations, organized by type, is detailed in Table 12. A detailed count of devices by sub type can be found in Appendix 9.

Table 12. Count of Merit's annual E-waste by device type

Device type	**Count**
Network Equipment: Core	834
Unknown	277
Modem and Router: Customer Premise Equipment	72
PC Accessory	39
Laptop	32
Audio Equipment	23
Display	21
Landline	9
Desktop PC	2
Printer	2
Cables and Chargers	0
Mobile Phone	0

Disposal Scenarios
Merit does not maintain an itemized ledger of items once they have been collected by the University of Michigan, and has no knowledge whether the items were sold, recycled, or disposed of, though Merit receives 90% of the proceeds from any item that is sold. University of Michigan Property Disposition was unable to provide records detailing the type and quantity of items sold. For this study, it was assumed that no items were sold since the assets are no longer Merit's property and the disposal burden passes to the new owners. In the absence of direct device disposal data from University of Michigan Property Disposition, data from recorded e-waste disposal trends from the United Nations Institute for Training and Research were used as proxy [71].

Global E-Waste Monitor from the United Nations Institute for Training and Research (UNITAR)
North American recycling and disposal rates from the Global E-Waste Monitor were applied to estimate Merit's breakdown of device disposal outcomes. Device disposal trends were used to estimate the quantity of Merit's e-waste devices from the fiscal year of study that were either sold, recycled or disposed of. The device subtypes from Table 28 were then assigned to United Nations (UN) E-Waste Categories based on the United Nations University (UNU) key from literature [72].

UNU Keys
UNU-KEYS is a classification system used to categorize electronic and electrical equipment (EEE) for the purpose of compiling e-waste statistics. It groups approximately 900 products into 54 categories, based on comparable average weights, material compositions, end-of-life characteristics, and lifespan distributions. Merit's items were categorized by UN convention (UNU Key) as a means of later predicting recyclability rates. Table 13 assigns all Merit e-waste items to their corresponding UNU key. UNITAR was used to calculate the disposal rate of items where the UNU keys were used to codify Merit E-waste items. UNITAR recycling rates are based on UNU items.

The Global E-Waste Monitor from the United Nations provides information on the recycling rates of various device categories in North America. Table 14 illustrates these rates. Rates are used as proxy information to estimate the rate of e-waste that is recycled via University of Michigan Property disposition. Using the known number of devices per category projections were made as to how many of the devices were recycled per UN rates. These results are detailed in Table 15.

Table 13. E-Waste device type

E-Waste Categories	E-Waste Subcategories	UNU KEY
Screens, Monitors, and Equipment Containing Screens	Laptop	0303
	Display	0309
Large Equipment (excluding photovoltaic panels)	Network Equipment: Core	0307
Small Equipment	Audio Equipment	0401
Small IT and Telecommunication Equipment	Desktop PC	0302
	Mobile Phone	0306
	Printer	0304
	PC Accessory	0302
	Cables and Chargers	0301
	Modem and Router: Customer Premise Equipment	0301

Table 14. E-Waste EOL probability (UN Scenario)

E-Waste Categories	Percent Recycled (%)
Temperature Exchange Equipment	27
Screens, Monitors, and Equipment Containing Screens	25
Lamps	5
Large Equipment (excluding photovoltaic panels)	34
Photovoltaic Panels (including converters)	17
Small Equipment	12
Small IT and Telecommunication Equipment	22

Table 15. Items per EOL management based on UN projections

Device Type	Item Count	UN CATEGORY	Percent Recycled (UN)	Percent NOT Recycled (UN)	Number of Items Recycled Per UN Projections	Number of Items Not Recycled Per UN Projections
Laptop	32	Screens, Monitors, and Equipment Containing Screens	25	75	8.64	23.36
Display	21				5.25	15.75
Network Equipment: Core	834	Large Equipment (excluding photovoltaic panels)	34	66	283.56	550.44
Audio Equipment	23	Small Equipment	12	88	1.15	21.85
Desktop PC	2	Small IT and Telecommunication Equipment	22	78	0.68	1.32
Landline	9				1.53	7.47
Printer	2				0.24	1.76
PC Accessory	39				8.58	30.42
Modem and Router: Customer Premise Equipment	72				15.84	56.16

E-Waste: Emission Factors Literature Review (Excluding Network Equipment)
To assess emissions impact, emission factors for each item type were used to calculate the emission burden (or benefit) resulting from e-waste disposal. Table 16 is a review of emission factors from two sources in the literature [73], [74]. These emission factors served as the basis for calculating the overall environmental impacts concerning the total annual e-waste produced by Merit’s operations. Industry emission factors were averaged and used to estimate the CO_2 emissions associated with EOL actions.

While CO_2e is the unit used in this report, CO_2 accounts for the majority of emissions in the available data. Neither source provided disaggregated GHG emissions—only CO_2 values—resulting in a deviation from the reporting standard without significantly affecting trend interpretation. Emission factors were averaged to normalize discrepancies across the studies. Table 16 details these emission factors.

Table 16. E-Waste embodied CO_2 per device (kg/kg device)

DEVICE	SOURCE [69]	SOURCE [70]	AVERAGE
Desktop	372.8	350	361.4
Display	393.6	100	246.8
Laptop	283.4	200	241.7
Mobile Phone	50.5	50	50.25
Notebook	22.7	NA	22.7
Tablet	116.1	100	108.05
Digital Camera	25.8	NA	25.8
Printer	100.7	NA	100.7
Game Console	140.7	NA	140.7
PC Accessory	27	NA	27
Feature Phone	NA	20	20
CPE	NA	30	30

Mass Per Device Conversion

The embodied emissions coefficients for each device type are reported in terms of mass per unit. However, the source data from the property disposition form does not provide the weight of individual items, so mass-per-unit values were assigned to each device type based on industry averages. Table 17details the average weight of devices from literature.

Table 17. Typical average weight of devices

Item	Average Mass (kg)	Source
Laptop	2.5	[75]
Display	4.5	[75]
Network Equipment: Core	28.6	[76]
Audio Equipment	3.5	[75]
Desktop PC	15	[75]
Landline	1	[77]
Printer	6.5	[75]
PC Accessory	1	[75]
Customer Premise Equipment	2.5	[75]

Once the mass of the units was determined, the mass per unit was multiplied by the total count of each device type in Table 18 to calculate the total mass for all devices in that category. This total mass was then used to apply the mass-based emission factor for emissions calculation. The total mass of Merit e-waste devices is reported in Table 18.

Table 18. Total mass of Merit's E-waste devices by type

Device Type	Mass of Items Recycled Per UN Projections (kg)	Mass of Items Not Recycled Per UN Projections (kg)
Laptop	21.6	58.4
Display	23.625	70.875
Network Equipment: Core	8109.816	15742.584
Audio Equipment	4.025	76.475
Desktop PC	10.2	19.8
Landline	1.53	7.47
Printer	1.56	11.44
PC Accessory	8.58	30.42
Modem and Router: Customer Premise Equipment	39.6	140.4

EOL Results

Table 19 presents the total emissions generated and offsets achieved during the end-of-life processing of Merit's network e-waste. Emissions from recycled items are treated as deductions, as the recycled materials are used to replace primary materials in new products. This idealized substitution avoids the GHG emissions associated with the primary production of those materials. The results are calculated by taking the device count from the property disposition form, multiplying it by the recycling likelihood based on UN rates, and then applying the emission factor to determine the total emissions per device type. Devices that could not be categorized were omitted from this calculation.

The results are tabulated from the device count of the property disposition form, multiplied by the likelihood of recycling from UN rates and the emission factor to find the total emissions per device type. All device types are later summed to calculate the total emissions associated with EOL.

Table 19. Total emissions of E-waste by device type

Device Type	CO_2 Per kg	Total Emission from RECYCLED	Total Emission from NOT RECYCLED
Laptop	241.7	5,220.7	14,115.3
Display	246.8	5,830.7	17,492.0
Network Equipment: Core	86.0	697,444.2	1,353,862.2
Audio Equipment	27.0	108.7	2,064.8
Desktop PC	361.4	3,686.3	7,155.7
Landline	20.0	30.6	149.4
Printer	100.7	157.1	1,152.0
PC Accessory	27.0	231.7	821.3
Modem and Router: Customer Premise Equipment	30.0	1,188.0	4,212.0

The total contribution from end-of-life (EOL) processing is calculated by subtracting the emissions associated with recycled material from the total emissions generated during EOL. This provides the net emissions impact for Merit Networks e-waste. These results are detailed in Table 20. These results are larger than anticipated due to abnormal infrastructure changes associated with Project MOON-Light, compared to the year-on-year average baseline.

Table 20. Net emissions for Merit Networks E-waste (kg)

Emission Results	
Sum of Emissions, Recycled material	712,502
Sum of Emissions, Not Recycled material	1,402,420
Net emissions impact for Merit Networks E Waste	689,918

Results

Combining the results from the fiber network, utility huts, energy use, transportation, and end-of-life leads to an emissions total of 4,739,507 kg CO_2e for fiscal year 2024. Figure 12 shows the breakdown of the total emissions by category. The fiber network contributes 66% of the total emissions. The energy use and end-of-life categories contribute around 13% and 15%, respectively. Since the fiber network and the utility huts are embodied emissions, the areas to target for improvements are power demand, transportation, and end-of-life.

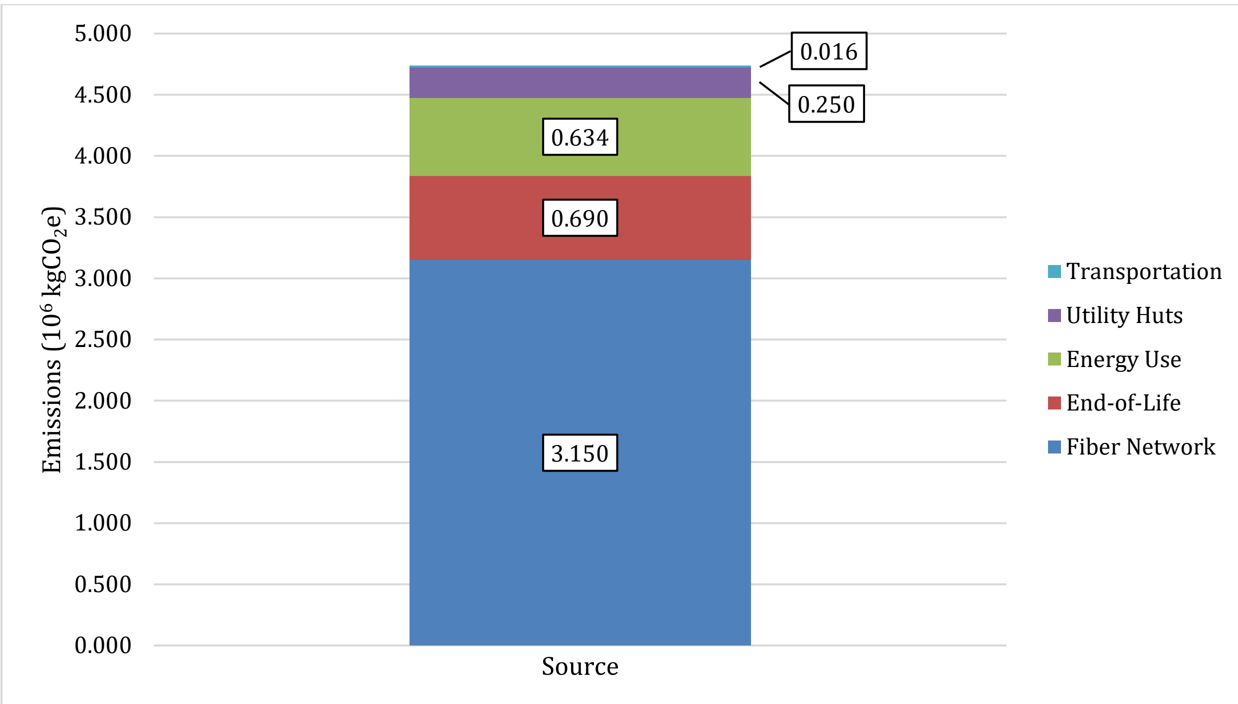

Figure 12. GHG emissions for Merit to build and operate their network in FY2024 (10^6 kg CO_2e)

If we assume that the embodied emissions from the fiber network and the utility huts are split evenly over their life span, the results show that the energy use and end-of-life categories contribute the most to GHG emissions. Figure 13 shows a single year of emissions for Merit, which totals to 1,443,244 kg CO_2e. The contribution from the fiber network shrinks to about 5% and the share for end-of-life and energy use grows to 48% and 44% respectively. The large contribution of end-of-life is due to Project MOON-light.

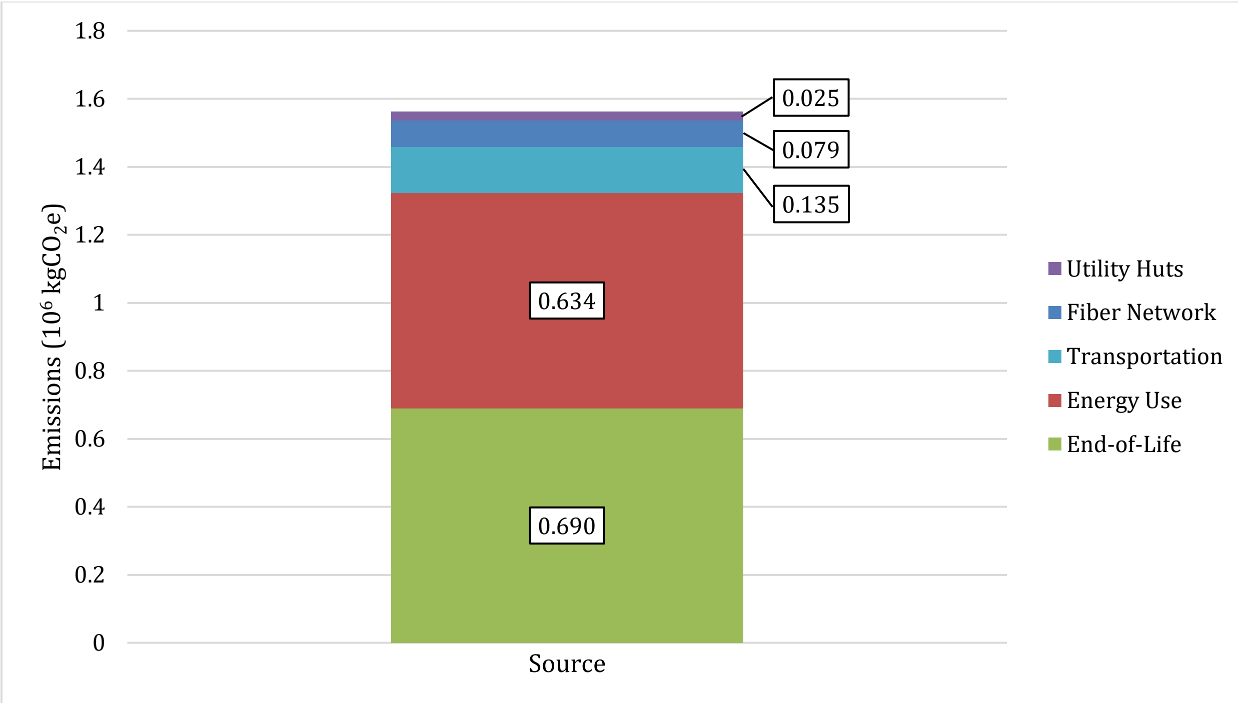

Figure 13. FY 2024 40-year annualized emissions by category assuming a 40-year lifespan for fiber and 20-year lifespan for utility huts (10^6 kg CO_2e)

Sensitivity Analysis

A sensitivity analysis identifies key factors that significantly influence outcomes and explores alternative scenarios. This process is crucial for understanding how changes in these factors affect overall results, sensitivity analysis provides insight into the robustness of results to potential uncertainty or errors in input variables. It involves systematically adjusting input parameters and evaluating the effect on results, which helps prioritize the high-leverage variables that may require more accurate data or further investigation. Additionally, this analysis highlights areas of uncertainty, allowing decision-makers to understand potential risks and develop strategies that accommodate these uncertainties.

For most calculations in this report published emissions factors translate units of activity data (like kilometers of cable laid or kilowatt-hours used) into carbon dioxide equivalents (CO_2e). Where published emissions factors are not available, estimated factors are used, though they might not fully capture the complexities of real-world scenarios. Because estimated factors simplify complex interactions into a single value that may not apply in all contexts, a sensitivity analysis can assess the robustness of emissions estimates against varying assumptions. By systematically varying these emission factors within a plausible range, the analysis helps identify which assumptions and uncertainties significantly impact the overall results.

The following section analyzes these assumptions and emission factors, presenting a series of sensitivity calculations for the emission categories evaluated in this report

Optical Fiber Cable Emissions

One of the crucial emissions factors in our study is for optical fiber cables. We used an emissions factor of 8.02 kg CO_2e per km based on Pinto et al.'s study [27]. However, differing assessments were available, ranging from 4.8 to 8.75 kg CO_2e per km from other reports [25], [26]. To perform the sensitivity analysis, we considered this range of values to assess the impact on the total emissions from Merit Network's fiber optic infrastructure.

Low-End Emission Factor: The low-end emission factor (4.8) is 40.15% lower than the originally selected emission factor (8.02). By applying this lower emission factor, the emissions associated with the fiber optic cables would be 19,297 kg CO_2e instead of 32,241. Under this scenario, total emissions would be 4,858,497.0kg CO_2e rather than 4,858,497.0, a change of -0.003%.

High-End Emission Factor: The high-end emission factor (8.75) is 9.10% higher than the selected emission factor (8.02). Using this higher emission factor, emissions associated with fiber optic cables would be 35,176 instead of 32,241. Under this scenario, total emissions would be 14,298,780 rather than 14,295,846, a shift of 0.0002%. This analysis demonstrates that the overall results are relatively insensitive to variations within the range of emission factors examined for optical fiber cables.

Energy Use

The energy used by networking devices and data centers is another critical area of impact. Network devices have detailed spec sheets specifying their minimum, typical, and maximum power demands. Using maximum values can lead to a conservative, possibly exaggerated, estimate of emissions, while typical values might underestimate them. To address these uncertainties, future analyses should incorporate real-time energy monitoring systems. This approach will provide more accurate data for simulations and help align sustainability goals more closely with actual performance. Suggestions for real-time data monitoring is detailed in the recommendations section of this report.

Industry standards show data centers rarely operate at maximum power; networks typically run at nominal power, and communication servers use 70% of their rated power under nominal conditions [78]. If this is the case for the Merit network, our calculation, assuming continuous maximum power, overestimates by approximately 30%.

Our calculation results in annual energy use of 1,444,021 kWh. A 30% reduction in power demand would result in a decrease in annual energy use of 433,206 kWh. This would lead to a total emissions reduction of 190,093 kg CO_2e, indicating that under the nominal scenario, the total GHG emissions of Merit Network devices would decrease to 443,550 kg CO_2e. Under a nominal scenario, total emissions would be 4,668,403 kg rather than original 4,858,497 kg CO_2e, indicating an overall change of approximately - 3.91%.

E-Waste Management

The management of electronic waste (e-waste) at the end of its life cycle is a critical component in the environmental footprint of Merit Network's operations. Our analysis relies on recycling rates provided by the United Nations Global E-Waste Monitor. These rates represent an average across North America and inherently assume a level of homogeneity that may not exist. Variability in local recycling practices and market conditions can significantly influence the proportion of materials successfully reclaimed, thus affecting emissions results.

In a scenario where recycling rates are lower than the UN average, fewer materials would be reclaimed, leading to higher emissions from disposal. This would result in a significant rise in emissions attributed to landfill and incineration processes. An increase in recycling rates would enhance materials recovery, leading to a reduction in overall emissions attributed to landfill and incineration processes. The following section details the changes to total emissions results given changes to recycling parameters. The first scenario assumes that the rate of recycling is 5% higher than the UN rate whereas the second scenario assumes that the rate of recycling is 5% less than the published rate.

Scenario 1: Increased Recycling by 5%
Sum of Emissions Abated (Recycled): 818,248 kg CO_2e
Sum of Emissions Generated (Not Recycled): 1,296,674.3 kg CO_2e
Net Emissions Impact: 478,426.0 kg CO_2e

This scenario shows a net decrease in e-waste emissions by 30.65%, leading to a total emissions output of 4,647,004.7 kg CO_2e, a change of -4.35% from the original total emissions of 4,858,497 kg CO2e.

Scenario 2: Decreased Recycling by 5%
Sum of Emissions Abated (Recycled): 606,756.0 kg CO_2e
Sum of Emissions Generated (Not Recycled): 1,508,166.6 kg CO_2e
Net Emissions Impact: 901,410.6 kg CO_2e

This scenario results in a net increase in e-waste emissions by 30.65%, raising the total emissions to 5,069,989.3kg CO_2e, in a change of 4.35% from the original total emissions.

The difference between a 5% change in recycling rates and the 4.35% % change in total emissions is due to the varying amounts of embodied carbon in different devices and the initial inefficiencies of recycling processes. Devices with higher embedded carbon—often those with more metal or plastic—tend to have a larger impact on emissions when they are recycled or disposed of. This means that changes in recycling efficiency affect emissions unevenly, with high-carbon devices causing more significant shifts in emission calculations even with similar recycling rate changes.

The sensitivity analysis examined key variables affecting emissions in Merit Network's operations: emissions factors for fiber cables, energy use in networking devices, and e-waste recycling rates. Changes in these variables over a moderate range did not significantly influence emissions results. This tolerance indicates that the study results are robust to our assumptions in these areas.

Data Coverage

Fixed Broadband Availability in Michigan

With the growing demand for internet access, broadband availability has become increasingly critical, and its performance is receiving greater attention from users. Under the Biden-Harris administration's "Internet for All", a total of $1.5 billion was awarded to Michigan under the Broadband Equity, Access and Deployment (BEAD) program. Michigan received one of the largest allotments. The federal funding encourages projects using fiber optic networks and aiming to serve the underserved locations in Michigan. While there is funding available to build necessary infrastructure to serve these communities, it may not necessarily incentivize providers. The quality of fixed broadband service depends on the necessary infrastructure and is influenced by regional geographical characteristics, resulting in significant spatial disparities. We aim to examine regional disparities in fixed broadband availability across Michigan and provide insights into addressing digital inequity.

The Fixed Broadband Availability Data from the Federal Communications Commission (FCC) for the state of Michigan was used for this analysis. This dataset includes records of fixed broadband technology types across all Broadband Serviceable Locations (BSLs) in Michigan, containing information on broadband providers, technology types, advertised download speeds, and census block GEOID. Our analysis includes approximately 3.99 million BSLs, comprising over 14.4 million broadband service records, covering the six major fixed broadband technologies: cable, copper, fiber, licensed-by-rule fixed wireless, licensed fixed wireless, and unlicensed fixed wireless.

Each Fixed Broadband Service Location (FBSL) represents a specific building or address where fixed broadband service can be installed [79]. Since multiple broadband providers may offer different technologies at a single FBSL, one location may have multiple broadband service records. To standardize our analysis, we retained only the broadband record with the highest advertised download speed for each FBSL. Advertised download speed refers to the maximum speed promoted by internet service providers (ISPs), representing the theoretical peak speed under optimal conditions. We then calculated the percentage of FBSLs within each census tract that offer broadband speeds of at least 200 Mbps. The 200 Mbps threshold was chosen as it is a high-performance standard for modern fixed broadband services. According to industry definitions [80], broadband speeds above this threshold can support high-bandwidth applications such as 4K video streaming, online gaming, remote work, and cloud computing. Identifying areas that meet this threshold helps highlight regions capable of supporting future connectivity demands. Then, we visualized the findings using ArcGIS Pro to produce a Fixed Broadband Availability Map, shown in Figure 14 below.

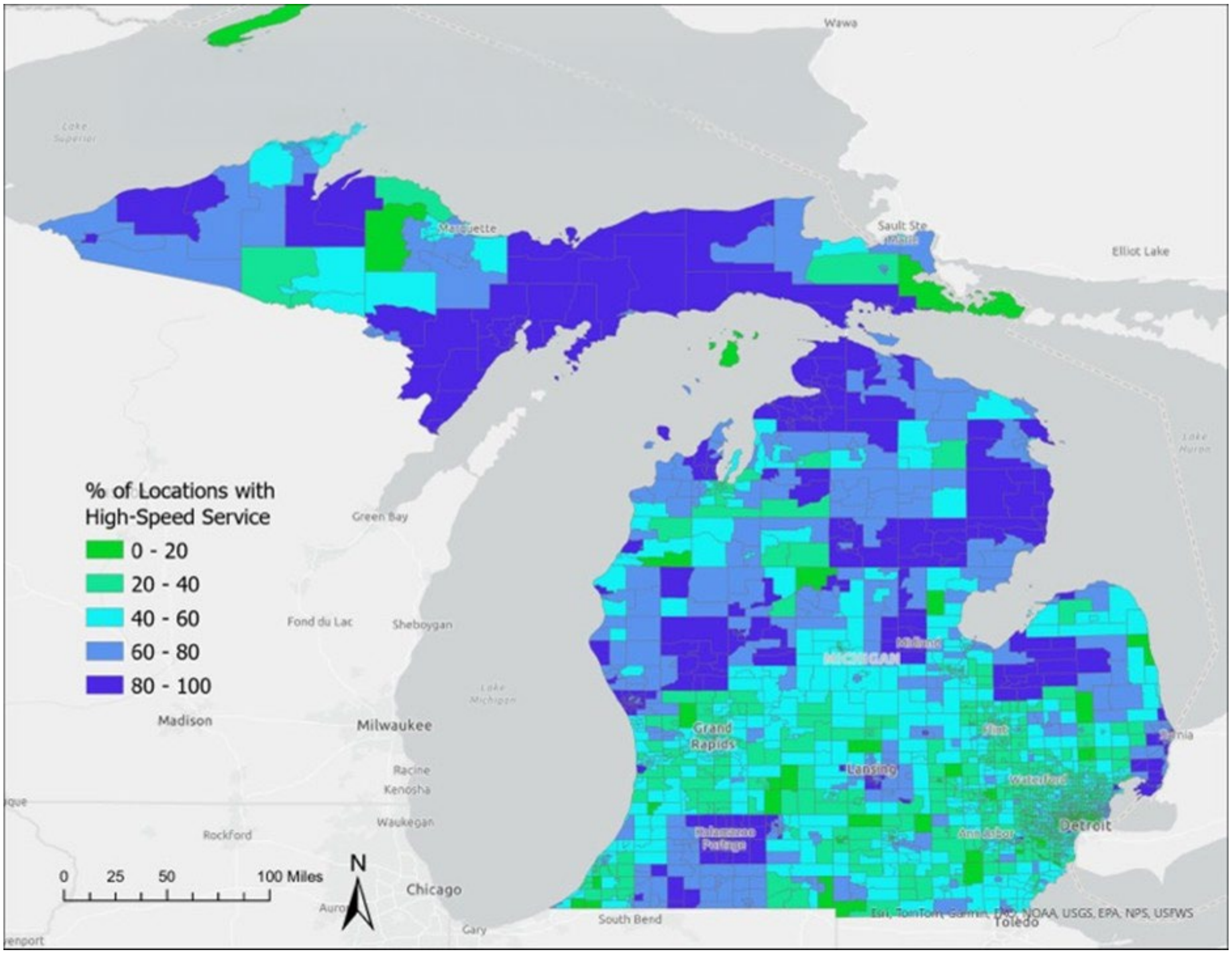

Figure 14. Percentage of locations with broadband connection in Michigan by census tract

The above map shows how the percentage of locations with broadband service varies across census tracts of Michigan. This percentage map reveals the underlying trend of high-speed broadband availability in Michigan. Broadband availability in Wayne County is significantly lower than expected. More than half of the census tracts in Wayne County have less than 20% coverage for high-speed fixed broadband (≥200 Mbps), highlighting a substantial regional disparity in broadband access.

To further investigate the distribution of high-speed broadband service across Michigan, a histogram was created to show the percentage of FBSLs that provide broadband speeds exceeding 200 Mbps within each census tract. As shown in Figure 15, the distribution is right-skewed, with most census tracts having between 20% and 60% of FBSLs offering high-speed service. The peak occurs around 40%, indicating that many areas have limited access to high-speed connections. This pattern is consistent with the observations from the spatial map analysis, illustrating how high-speed broadband access remains unevenly distributed and highlighting the need for targeted infrastructure investments to bridge the digital divide across the state.

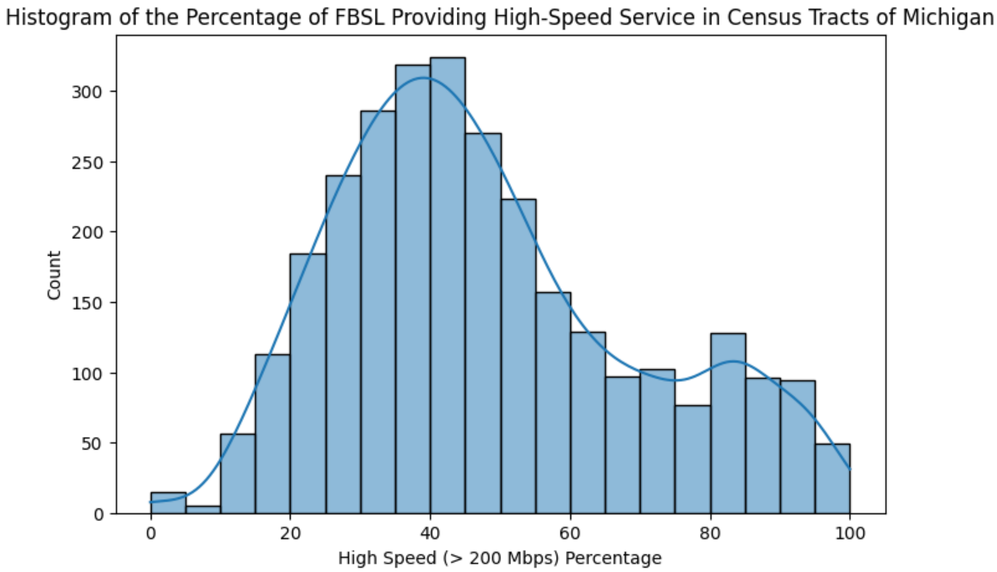

Figure 15. Histogram of the percentage of FBSL Providing High-Speed Service in Michigan

High Costs and Low Provider Incentives

Low-density areas raise technology deployment costs and discourage providers from offering fixed broadband services [83]. While funding reduces the cost of infrastructure deployment, the payback period is long and not profitable for providers due to high cost in maintenance and low-user base to breakeven. In a study in Eaton County, the cost for internet service averages $71.96 per month [84]. In a study by EveryOn, 40% of many low and lower-middle income households cannot afford to pay for a home high-speed internet subscription. The entry level subscription plans range from $55-$70, which is still higher than people are willing or able to pay [85]. This results in lower adoption rates in low-density populated areas since it is expensive, and potential customers lack the willingness to pay for it. When providers undertake a financial analysis to evaluate potential market size and projected user base that they can serve, low-density populated areas are not a consideration since it is costly to build and maintain infrastructure to dispersed users.

Population data for census tracts with high-speed broadband coverage below 20% is visualized in Figure 16, below. The results indicate that Detroit is not only densely populated but also has extremely poor high-speed broadband coverage. As shown in the population histogram in Figure 17, the majority of these underserved census tracts each have a population exceeding 1,000. The presence of substantial populations in these areas indicates that limited high-speed broadband coverage is not confined to remote or sparsely inhabited locations. Furthermore, statistical analysis reveals that approximately 450,000 people live in census tracts where high-speed broadband coverage is below 20 percent, underscoring the scale and urgency of the issue.

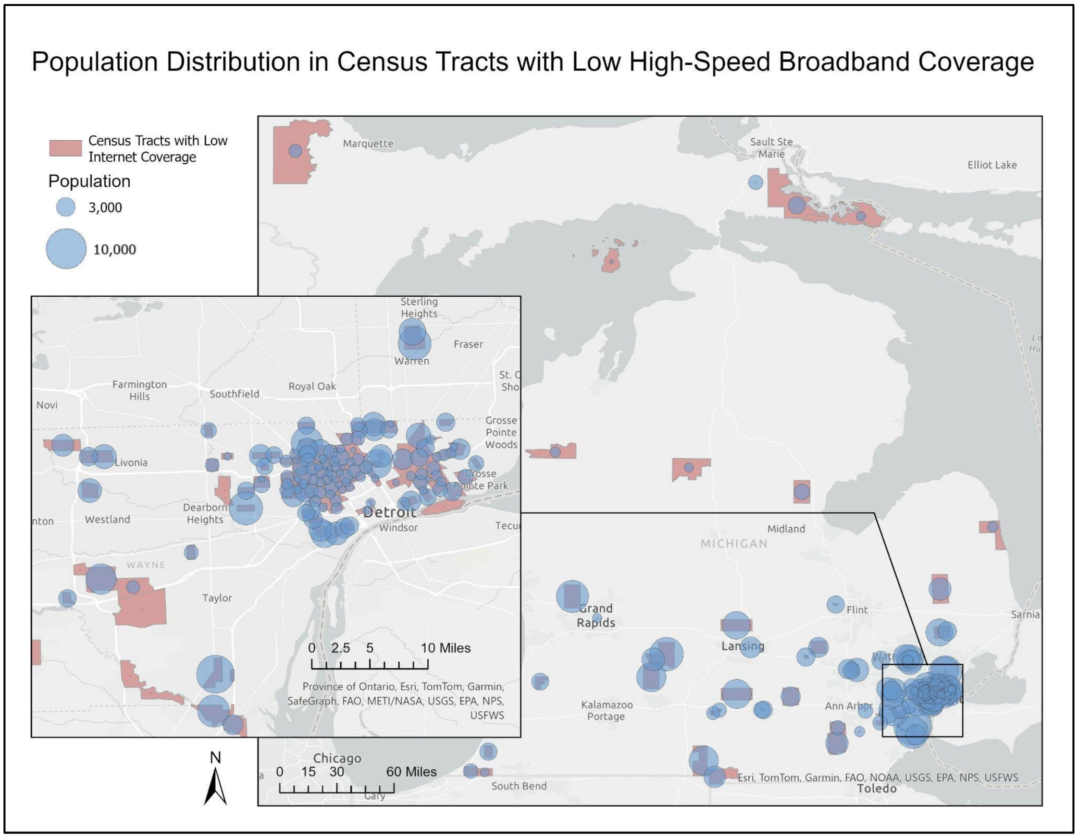

Figure 16. Population Distribution in Census Tracts with Low High-Speed Broadband Coverage

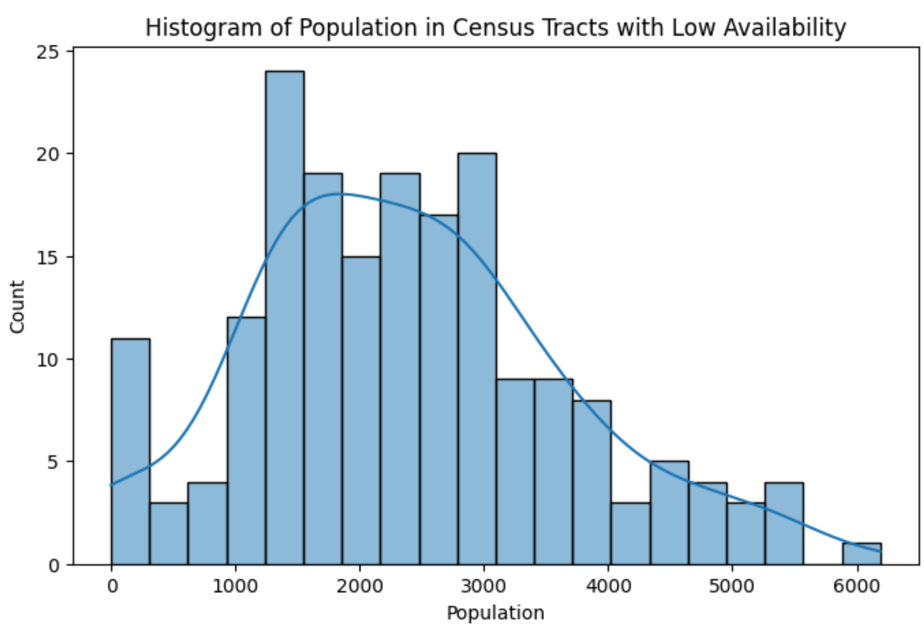

Figure 17. Histogram of Population in Census Tracts with Low Availability

Case Study in Wayne County: Identifying Gaps via Provider-Based Analysis

This case study seeks to address the uneven distribution of high-speed broadband coverage by exploring the problem from the perspective of service providers. Specifically, it aims to understand how provider presence, technology type, and service quality contribute to digital inequality. By analyzing fixed broadband data in underserved areas, we hope to develop a replicable framework that can be applied in other regions facing similar challenges.

We focused our analysis on Wayne County, a typical area with low broadband coverage and high population density, and we identified census tracts where high-speed broadband coverage is below 20%. Using FCC Broadband data, we examined all providers operating in these underserved areas and categorized them by technology type. We then evaluated the distribution of these technologies by provider and conducted a statistical analysis of their reported download speeds. This approach allowed us to assess both the infrastructure deployed and the quality of service delivered.

Our analysis revealed that 11 providers operate in these underserved regions, with the major providers being AT&T, T-Mobile, Xfinity, Metro Wireless, and Verizon.

- AT&T predominantly offers copper-based broadband in these areas, which suffers from low speeds and severe signal attenuation.
- Metro Wireless relies exclusively on Unlicensed Fixed Wireless technology, which is susceptible to interference, poses security concerns, and experiences speed limitations during peak hours.
- T-Mobile and Verizon provide Licensed Fixed Wireless, which offers higher speeds and broader coverage but comes with higher deployment costs.
- Xfinity delivers broadband via cable, which can provide fast connections with speeds of up to 1000 Mbps.

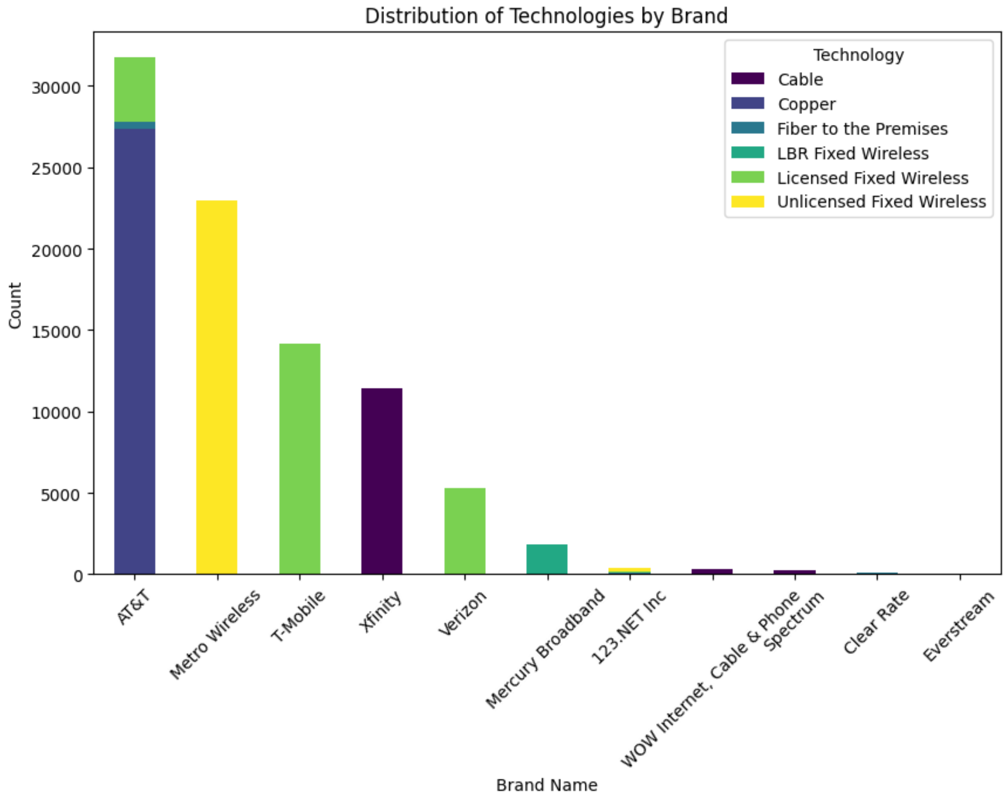

Figure 18. Distribution of Technologies by Brand

An examination of broadband speeds, as illustrated in Table 21, shows that among the five major service providers, Xfinity is the only provider with an average speed exceeding 1000 Mbps, while the other four providers have average speeds below 200 Mbps. This may indicate that providers in these areas need to upgrade their broadband infrastructure and also reflect disparities in digital infrastructure investment.

Table 21. Statistical summary of download speeds (Mbps) by brand in Wayne County

Brand	Min	Max	Mean	Median	Mode
WOW Internet, Cable & Phone	1200	1200	1200	1200	1200
Xfinity	100	1200	1199.77	1200	1200
123.NET Inc	1000	1000	1000	1000	1000
Everstream	1000	1000	1000	1000	1000
Spectrum	1000	1000	1000	1000	1000
Mercury Broadband	150	150	150	150	150
Verizon	10	1000	106.93	50	50
T-Mobile	25	100	64.67	100	100
AT&T	10	1000	63.05	50	10
Clear Rate	30	45	30.36	30	30

These findings have significant implications for addressing the digital divide. The concentration of outdated or suboptimal technology in underserved areas suggests that merely increasing provider presence is insufficient. Instead, targeted investment in modern infrastructure, particularly cable or fiber, may be necessary to close the broadband gap. Expanding Xfinity's cable service or encouraging T-Mobile and Verizon to increase deployment of licensed wireless technology, could be effective solutions. Moreover, the absence of fiber underscores systemic disparities in digital infrastructure planning and investment. The analysis implies that broadband inequality is not just about geographic coverage but also about the types of technology deployed and the performance they deliver. Provider-based analysis helps identify which companies are best positioned to make meaningful improvements and which technologies should be prioritized in low-access areas.

The provider-based analytical approach used in this case study appears to be a promising method for understanding broadband infrastructure disparities, though its applicability may vary depending on data availability and local conditions. The steps, including identifying underserved tracts, mapping providers and technology types, and evaluating download speeds, can be adapted to other geographic regions using FCC data. This method offers valuable insights for planners, policymakers, and infrastructure investors seeking to prioritize broadband expansion in underserved communities.

However, the analysis has several limitations. It focuses solely on fixed broadband services, excluding mobile connectivity, which may be crucial in some rural or low-income contexts. Additionally, important aspects of service quality such as latency and user experience were not assessed due to data constraints. Reported speeds may not reflect the actual performance experienced by users, and the data may not fully capture recent changes in provider infrastructure. To enhance reliability, this framework should ideally be complemented with ground-level surveys or community input where feasible.

Potential Solutions for Merit Network Expansion

Since Merit serves libraries and K12 schools, Merit can consider expanding Project MOON-Light, improving its service by offering faster speed limits by modernizing its existing infrastructure. Merit could also consider partnering with providers within a five-to-ten-mile buffer in the area of households who get served. Instead of the deployment of new infrastructure, it could work with partners to improve its existing infrastructure. This would also result in lower emissions.

Recommendations

Based on our review of Merit's operations and emissions, data revealed difficulties in aggregating information, largely due to disorganized or incomplete entries. The lack of a centralized system and standardized coding practices made reporting inefficient, time-consuming, and less accurate. To address these challenges, we present the following recommendations to enhance data management and reporting. In addition, based on our baseline emissions calculations to highlight key opportunities for emissions reduction and outline strategies to support these improvements.

Data Management

Official Classification Site Type
Create a standardized field that allows categorization of sites. Current site data (SKEY) lack the type of site at a location (Hut, PoP, Datacenter). Standardizing this classification ensures consistency across the system, enabling quicker, more complete searches and improved reporting accuracy. By codifying locations by type, queries can be pulled to analyze all locations of a certain type.

Join Maintenance Records with Finance
Integrate maintenance records with financial data to calculate profit and loss per site. This process involves linking maintenance logs to the relevant cost centers or revenue streams for each location. This allows the assessment of the financial health of each site by comparing maintenance expenses with income or operational savings. This integration will also help identify sites requiring disproportionate attention and prioritize those needing improvement first.

Financial, Maintenance, and Network Integration
Integrating financial, maintenance, and network data provides a comprehensive view that enhances operational efficiency [81]. The combined data supports informed decision-making, better resource allocation, and improved financial health for each site.

Use Lat and Long instead of Address
Employing latitude and longitude coordinates instead of traditional addresses ensures more accurate location data. Address discrepancies between billing, street, meter, and physical locations can lead to inefficiencies. Geospatial coordinates improve asset tracking, synchronize billing with actual locations, and enhance integration with GIS platforms for advanced spatial analysis.

Sustainability Data Management Software
Utilizing a sustainability data management software can streamline the process of tracking, analyzing, and reporting environmental metrics [82], [83]. This software can handle diverse data streams, such as energy use, waste generation, and water use. Future reports can be generated automatically using relevant emission factors and reporting protocols. Model products and platforms included Oracle Cloud EPM for Sustainability and Workivas Carbon Management Software. Refer to Appendix 6 for potential risks when adopting a centralized database.

Developing Emission Factors for Core Networking Devices
It is recommended that efforts be made to develop standardized emission factors for core networking devices, which currently represent a major gap in embodied emissions accounting within the ICT sector. Given the specialized and often custom-built nature of this equipment, establishing generalized emission factors will require collaboration across manufacturers, as well as the adoption of approaches such as those used by Meta—combining cost-based estimates, product-specific LCAs, and advanced data modeling—to improve accuracy and comparability [84].

Data Generation

Label Maintenance Tickets by Activity Type in RT
To streamline the handling of maintenance tickets and future analysis add a dropdown field in the RT system that categorizes each maintenance ticket by its activity type. The categories could include Equipment Install and Software Update, which would allow for more efficient tracking of specific tasks. This systematization ensures that reporting and performance analysis can easily distinguish between different types of work. An annual ledger could be generated detailing common maintenance practices.

Standardize Maintenance Documentation
Develop and implement clear standard operating procedures (SOPs) for all maintenance activities to ensure consistency and transparency in reporting practices. By adopting these improvements, Merit Network can gain a more accurate and comprehensive understanding of the GHG emissions associated with its maintenance activities, thereby supporting broader sustainability objectives.

Standardize Personal Vehicle Travel Reimbursement
When reimbursing personal vehicle travel, standardize the reimbursement options: pump rate or the IRS rate. Choosing a consistent reimbursement option will simplify the accounting process. The IRS model is preferred because it relies on miles traveled to calculate reimbursements, and VMT can be estimated afterward. VMT data collected through the reimbursement process can then be used to calculate annual business travel emissions. If the pump rate is used, include the price of gas and the model of car so that MPG can be sourced and VMT calculated.

Power Monitoring per Location and Network
Integrate power and energy monitoring tools into existing asset management systems. Tracking key metrics such as energy use and efficiency in real-time will allow you to address any inefficiencies quickly.

Fiber Cable Monitoring
To manage the specifications and brand of fiber cables at installation, create a record entry process. This process will log the relevant information about each cable when it is installed, providing traceability and ensuring the proper upkeep of infrastructure. There is currently no ledger of the cable brand or type in the ground.

Personal Airfare Travel
To track personal airfare travel, particularly airport codes, add fields in your travel expense reporting system that capture the origin and destination airport codes. This will provide more detailed reporting that is useful for analyzing emissions but also travel patterns and costs related to specific locations or routes.

Green Operations

Renewable Energy Adoption
Transitioning to renewable energy sources such as solar, wind, or geothermal significantly cuts down on greenhouse gas emissions and reduces dependence on fossil fuels. This can be implemented through on-site renewable energy installations, purchasing green power from energy suppliers or renewable energy credits.

On-Site Renewable Energy Installations
Explore the feasibility of on-site renewable energy solutions, such as solar panels, wind turbines, or geothermal systems, as well as short-term energy storage systems. Refer to Appendix 4.

Power Purchase Agreements (PPA)
Power Purchase Agreement (PPA) is a long-term contract between two parties, one that generates electricity and one looking to purchase from. The price of the electrical output is at an agreed price and usually lower than what the buyer would pay for their utility. PPAs help to save on energy costs while meeting renewable energy commitments. It provides immediate savings and access to clean energy without high upfront costs. It keeps energy prices stable and lower rates compared to traditional utility bills [85]. PPAs offer a pathway for Merit Networks to secure long-term, fixed electricity supplies directly from renewable energy plants.

Renewable Energy Credits (RE Credits)
Renewable Energy Credits (RECs) represent proof that energy has been generated from renewable sources and fed into the electricity grid. Purchasing RECs allows organizations to support the renewable energy market, offset their electricity use with green power, and demonstrate their commitment to sustainability [86].

The current climate funding and incentives available in Michigan are highly focused on increasing the capacity of clean energy projects and prioritizing the acceleration of energy decarbonization [49]. Since Merit does not have on-site renewables, it does not qualify for most of the existing funding available. Merit can consider enrolling into green credit programs or purchasing RECs to offset its operational electricity use.

Build a Sustainability Initiative: Add to Value Statement
Incorporating a sustainability initiative into your organization's value statement underscores a commitment to environmental responsibility. This could include specific sustainability goals, integrating eco-friendly practices into daily operations, and engaging stakeholders in

sustainability efforts. Emphasizing sustainability in your core values demonstrates leadership and dedication to positive environmental and social impacts. Refer to Appendix 2.

Developing a Comprehensive Sustainability Plan
Merit Network should establish clear targets, timelines, and actionable strategies to reduce GHG emissions, enhance energy efficiency, and adopt renewable energy sources. Robust monitoring and reporting will ensure accountability and progress. The value proposition of having a sustainability strategy is discussed Appendix 1.

Climate Risk Management Strategy
Implementing a comprehensive climate risk management strategy assessing vulnerabilities and planning for resilience to ensure organizational preparedness for weather extremes and long-term climate changes. By adopting a proactive approach, an organization can safeguard its operations, minimize disruptions, and enhance overall resilience to climate-related risks. Refer to Appendix 3 for details.

Climate Insurance
Michigan experiences frequent severe storms where each event exceeds $1B loss [87]. The frequency of these climate events has been increasing over the years. Merit could consider secure climate insurance to protect against financial losses from extreme climate-related events. This coverage provides a crucial safety net and enables quicker recovery, ensuring business continuity in the face of environmental risks [88]. Competitors' climate action plans and Task Force on Climate-related Financial Disclosures (TCFD) reports quantify the material risks posed by climate change, as detailed in Appendix 2. This material risk assessment underscores the fiduciary responsibility to address climate exposure and highlights the strategic value of climate insurance as risk management too.

Potential Solutions for Merit Network Expansion
Since Merit serves libraries and K12 schools, Merit can consider expanding Project MOON-Light, improving its service by offering faster speed limits by modernizing its existing infrastructure. Merit could also consider partnering with providers within a five-to-ten-mile buffer in households who get served. Instead of the deployment of new infrastructure, it could work with partners to improve its existing infrastructure. This would also result in lower emissions.

Transportation

Merit could consider leasing hybrid vehicles to reduce fuel use and lower greenhouse gas emissions. Additionally, the company could optimize its maintenance travel schedule by consolidating trips, minimizing the number of separate journeys made, cutting down on unnecessary travel and associated environmental impact [89].

End-of-Life

As the highest emission contribution is end-of-life disposal, Merit could identify circular pathways to ensure devices are disposed of at recycling centers instead of being passed on informally, where proper disposal may not be guaranteed. Merit could take an active role in this process by collecting used equipment from its operations, coordinating transportation to approved recyclers. There are many designated recyclers in Michigan and Merit could set up a recycling strategy to ensure its devices get their material recovered [90]. This would close the loop on product lifecycles but also reduce Merit's end-of-life emissions.

Recommendations for Future Studies

Region-specific electricity emissions factors
Use geospatial analysis to associate Merit facilities and devices with the eGrid subregion where each of them is located. Use eGrid EFs for these subregions when calculating emissions associated with individual facilities and devices instead of applying the RFCM EFs to the entire Merit network. Note that this complicates comparison with results presented in this report.

Expand EOL to Included Office Waste
Non-operational waste was not included in this audit. Future studies should include office waste streams to identify opportunities for minimizing environmental impacts associated with everyday office activities.

Office Space Utilization
Future studies should investigate the current utilization of office space to identify inefficiencies and opportunities for optimization. By potentially reducing the need for permanent office setups, organizations can significantly decrease their carbon footprint. Given that office spaces are currently underutilized, an analysis of rightsizing office space to match actual space needs.

LEED Certification [91]
Explore the potential benefits of pursuing Leadership in Energy and Environmental Design (LEED) certification for networking facilities and data centers. LEED certification provides a framework for implementing measurable and sustainable green building design, construction, operations, and maintenance solutions. LEED certification framework helps an organization to reduce its utility costs and less waste overall.

Conclusion

This study examined the environmental impact of Merit Network's broadband infrastructure and operations, focusing on greenhouse gas (GHG) emissions associated with data centers and fiber optic networks. This research provides valuable insights into energy use patterns and the emissions footprint of Merit Network's activities. It serves as a baseline to guide and assess future sustainability efforts.

Our findings highlight the dual role of broadband infrastructure in both enhancing wireless internet speeds and introducing significant environmental challenges. The expansion of fiber-optic networks contributes to reduced emissions, yet the energy demands of data centers and operational equipment pose substantial environmental burdens. e-waste management, considering the complexities associated with recycling practices, is another source of impact.

To mitigate these impacts and shrink Merit' GHG emissions, we recommend transitioning to renewable energy sources, enhancing energy efficiency through advanced technologies, and procuring clean energy. As Merit Network seeks to expand its infrastructure to close the digital divide in Michigan, a sustainability-driven approach will not only support environmental goals but also enhance its marketability and community relations. By promoting sustainable practices internally and among its partners, Merit Network can lead the way in achieving digital equity while minimizing its GHG footprint.

This research provides a starting point and framework for Merit to identify existing gaps in data tracking and management to improve its data traceability. It helps Merit to understand the breakdown of its GHG emissions from its operations and identify reduction pathways. The recommendations provided here would enable Merit to immediately reduce emissions in specific areas of its operations and accurately project its future emissions.

Author Contributions

Edward Carrington

- Appendix (60%)
- Background (50%)
- Conclusion (80%)
- Data Collection (80%)
- Data Management (70%)
- End of Life (100%)
- Energy and Power Demand (100%)
- Fiber Cable Network Infrastructure (50%)
- Maintenance (100%)
- Recommendation (70%)
- Sensitivity Report (100%)
- System Scope and Project Objectives (50%)`
- Vehicle Transportation (100%)

Jialu Chen

- Data Coverage (100%)

Paige Greenberg

- Acknowledgements (100%)
- Table and Figure Labeling and Formatting (100%)
- Abbreviations and Acronyms (100%)
- Project Objectives (30%)
- Fiber Cable Network Infrastructure (50%)
- Fiber Optic Cable Emission Factor Selection (100%)
- Utility Huts LCA (100%)
- Compiled Results (100%)
- Appendix (30%)

Haolin Li

- System
  - Data Reception (50%)
  - Fiber Cable Network Infrastructure (50%)
  - Energy Use (100%)
- Transportation
  - Airfare (100%)

Sharmane Tan Kim See

- Introduction (100%)
- Project Objectives (70%)
- Recommendations (60%)
- Conclusion (100%)

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Appendix 1: Sustainability Value Proposition

From Member Values to Financial Value:

Quantifying the prevalence and depth of sustainability initiatives within our member portfolio.

Opportunity to Leverage Merit's Sustainability Results
Embedding sustainability into Merit's operations can contribute to retaining existing members and gaining new members by appealing to member sustainability initiatives. Additionally, in reviewing potential competitors it becomes clear that the larger ISPs often have sustainability reporting requirements that have led to efficiency programs while our smaller, more local competition both does not have these requirements and largely does not have sustainability goals. This leaves a gap Merit can uniquely fill, defining the shortcomings of the required reporting programs of larger ISPs while creating a differentiator amongst our competitors that specifically addresses an issue important to a large portion of our membership: environmental and social responsibility.

Review of Member Sustainability Commitments
Using a list of Merit's current members, a keywords search was performed to locate publicly available sustainability goals. Member organizations were not contacted and only public initiatives were considered per the scope of this study. Results were tabulated and organized based on the following scale indicating the scale of members' sustainability initiatives.

1. *No Public Mention of Sustainability Goals*
2. *Sustainability Goals only detail Fiscal Sustainability*
3. *Sustainability Goals only detail Sustainable Agriculture and Conservation*
4. *Sustainable messaging was presented but goals were not explicitly stated*
5. *Sustainable Goals detailed explicit intentions or action items*

After all queries were codified the results were tabulated to convey generalized trends among the following market sectors: Commercial Businesses, Community College, Government, Healthcare, K12, Library, Other Non-Profit, Private 4-Year Higher-Ed and Public 4-Year Higher-Ed.

Sustainability Trends Across Sectors Highlight Varying Opportunities
Public 4-Year Higher Education institutions demonstrate the highest commitment, with 88.89% of members having either explicit sustainability goals or sustainable messaging. In contrast, sectors such as Libraries and K12 Education show minimal engagement, with 89.29% and 88.99% respectively having no clear climate action plan and focusing primarily on fiscal goals or lacking sustainability goals altogether. However, the nature of these organizations still promote and benefit from sustainability practices (re-use of materials through libraries, or re-using and fixing devices needed for K12 curriculum), highlighting an example of where Merit may create

an innovative program that intertwines environmental and social equity goals. While Community Colleges, Private 4-Year Higher Education institutions, and Other Non-profits exhibit relatively lower rates of explicit sustainability goals, they have substantial sustainable messaging, indicating their interest in visible support of sustainable practices.

Industry Demand for Sustainability Presents Merit with a Distinct Leadership Advantage
The following section reviews the current sustainability commitments of major industry players in the ICT market (AT&T, Charter, Comcast, and Verizon) as of Spring 2024. Notable trends include commitments to carbon neutrality by 2035, extensive use of renewable energy, and energy efficiency projects. Each public company has established official emission reduction goals; however, these plans exhibit various vulnerabilities and limitations. Additionally, Merit's more local competition largely does not engage in sustainability planning. This analysis underscores the industry's call for Merit to pioneer sustainability initiatives.

Merit is uniquely positioned to create an innovative sustainability plan that integrates both environmental and social dimensions. As a nonprofit research & education network Merit can provide community-centric solutions. Merit's distinct positioning allows for leveraging advanced research expertise, promoting sustainability education. By combining sustainability initiatives with Merit's existing DEI goals, we can create a comprehensive framework that addresses both environmental concerns and social equity.

Sustainability Practices Promote Profitability and Community Relations
Incorporating sustainability values into Merit's operations can drive profit generation by enhancing our brand image, differentiating us in the market, and tapping into the growing demand for eco-friendly and equitable practices. Merit's community-oriented approach enables localized sustainability, allowing us to implement and promote eco-conscious initiatives that resonate deeply with our members. For individual members, Merit's commitment to sustainability translates into tangible benefits. By adopting energy-efficient technologies and sustainable procurement practices, Merit could potentially offer competitive pricing and enhanced services, directly improving member satisfaction and loyalty. This support helps members achieve their sustainability goals, enhances their own brand reputations, and contributes to a larger network of eco-conscious practices. Healthcare, Government, and Commercial sectors rank somewhere in the middle, suggesting some interest and further opportunity for Merit to uniquely define a program that resonates with these sectors.

Confronting Skepticism: Sustainability's Business Case
Sustainability isn't driven by societal trends; it's a critical strategic imperative for effectively managing material risks and guaranteeing long-term financial success. Environmental risks directly impact operations, supply chains, and asset health. Failure to address these risks can result in disruptions, increased costs, and reputational damage. Sustainable systems leverage advanced technologies and approaches to enhance resilience, minimizing susceptibility to external disruptions. Through the integration of energy-efficient technologies, organizations can optimize resource utilization, reduce dependency on finite resources, and mitigate the impact of energy price volatility.

Conclusion
The internal study revealed varying levels of commitment across sectors, presenting opportunities for Merit to support green transitions and strengthen member relationships. Competitor ISP sustainability goals underscore the importance of proactive measures in achieving carbon neutrality, addressing emissions, and including social metrics. By scrutinizing competitors' sustainability frameworks, Merit can pinpoint industry standards and opportunities for innovation. Synthesizing these insights and embedding sustainability values into Merit's operations not only meets member expectations but also promotes profitability and fosters collaboration with partners, ultimately positioning Merit as a leader in sustainable business practices.

Suggested Next Steps
Develop Sustainability Plan: Create a comprehensive sustainability plan for Merit, aligning with operational goals and member needs. Detail targets, timelines, and actionable strategies to embed sustainability across operations.

Update Value Statement: Incorporate explicit sustainability commitments into Merit's value statement, affirming our dedication to community-focused sustainability and member-centric environmental stewardship

Table 22. Percent of Members Organized by Sustainability Status per Industry

		No Clear Climate Action Plan			Climate Action Plan		Climate Conscience Member
	Pending Status	No Goals	Fiscal Goals	Agriculture Goals	Sustainable Messaging	Explicit Goals	Sustainable Messaging or Explicit Goal
Commercial	0.00%	71.43%	14.29%	0.00%	0.00%	14.29%	14.29%
Community College	0.00%	24.00%	28.00%	0.00%	28.00%	20.00%	48.00%
Government	3.45%	41.38%	5.75%	11.49%	5.75%	32.18%	37.93%
Healthcare	0.00%	70.59%	0.00%	0.00%	5.88%	23.53%	29.41%
K12	0.00%	88.99%	2.75%	0.00%	1.83%	6.42%	8.26%
Library	0.00%	89.29%	0.00%	0.00%	10.71%	0.00%	10.71%
Other Non-Profit	0.00%	72.13%	6.56%	1.64%	11.48%	8.20%	19.67%
Private 4-Year Higher-Ed	4.55%	54.55%	0.00%	0.00%	22.73%	18.18%	40.91%
Public 4-Year Higher-Ed	0.00%	5.56%	5.56%	0.00%	11.11%	77.78%	88.89%

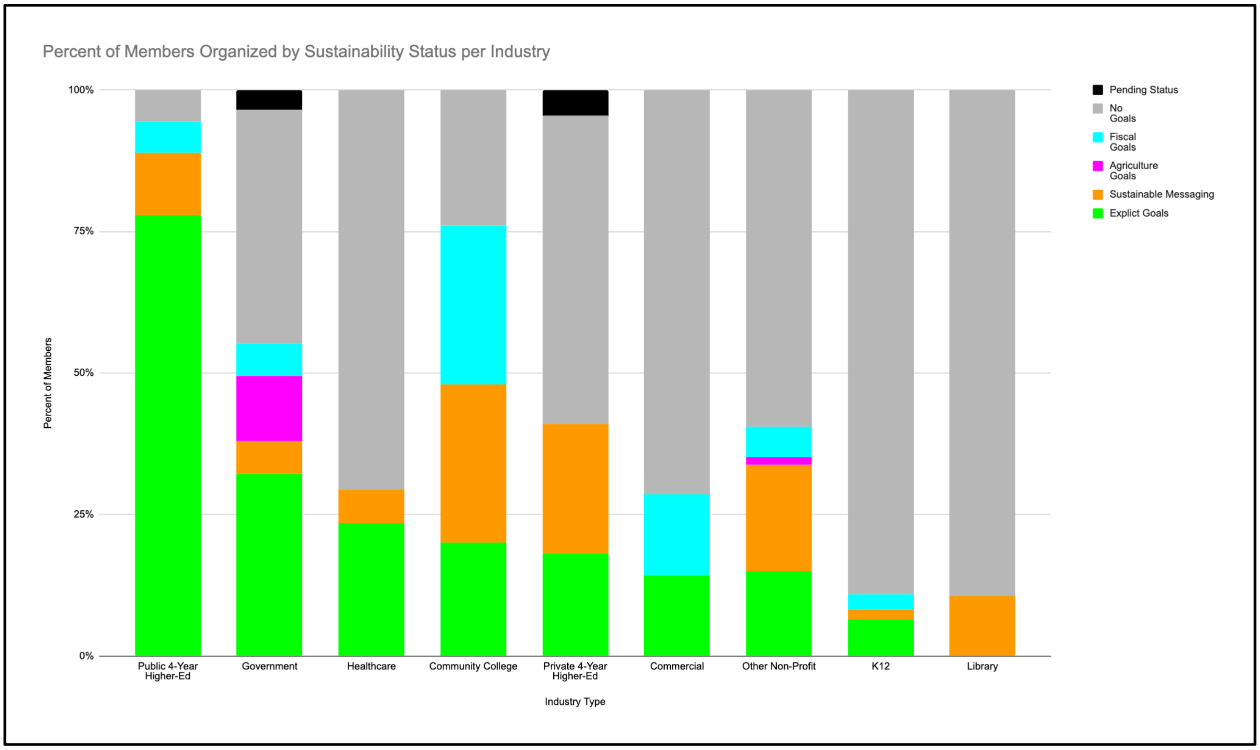


Figure 19. Percent of Members Organized by Sustainability Status per Industry

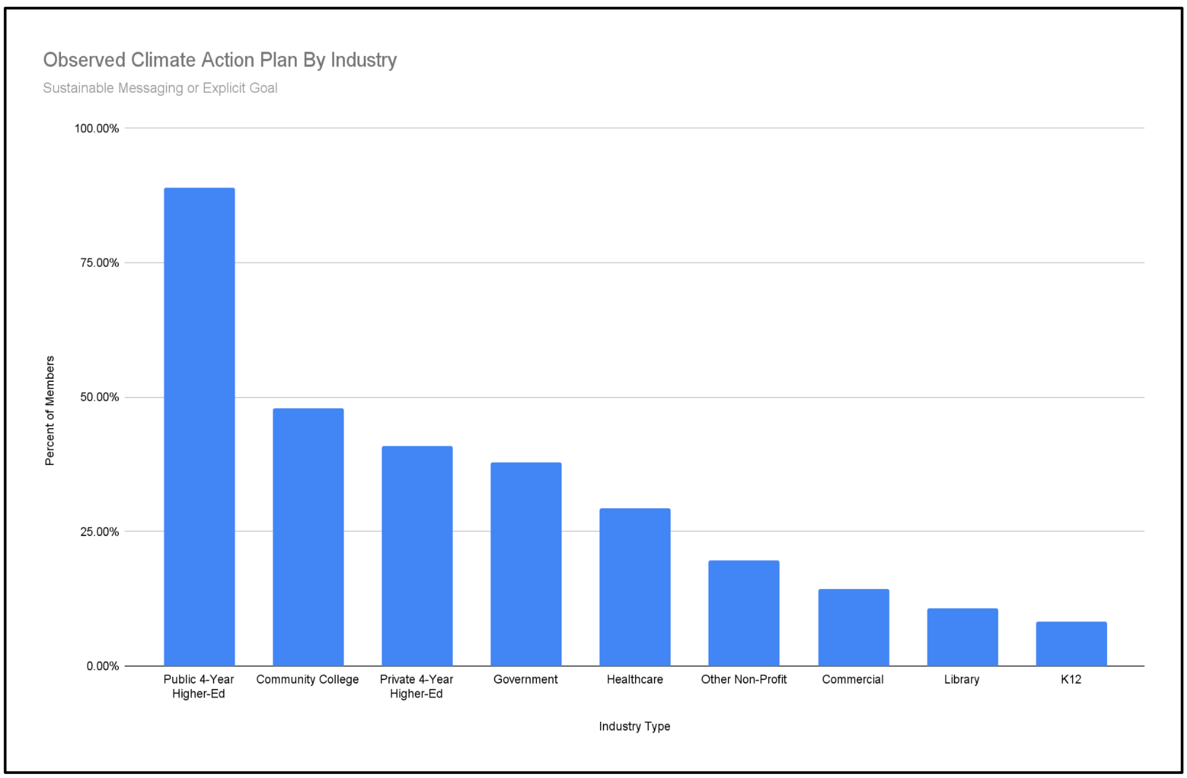


Figure 20. Percent of Members with a Climate Action Plan per Industry

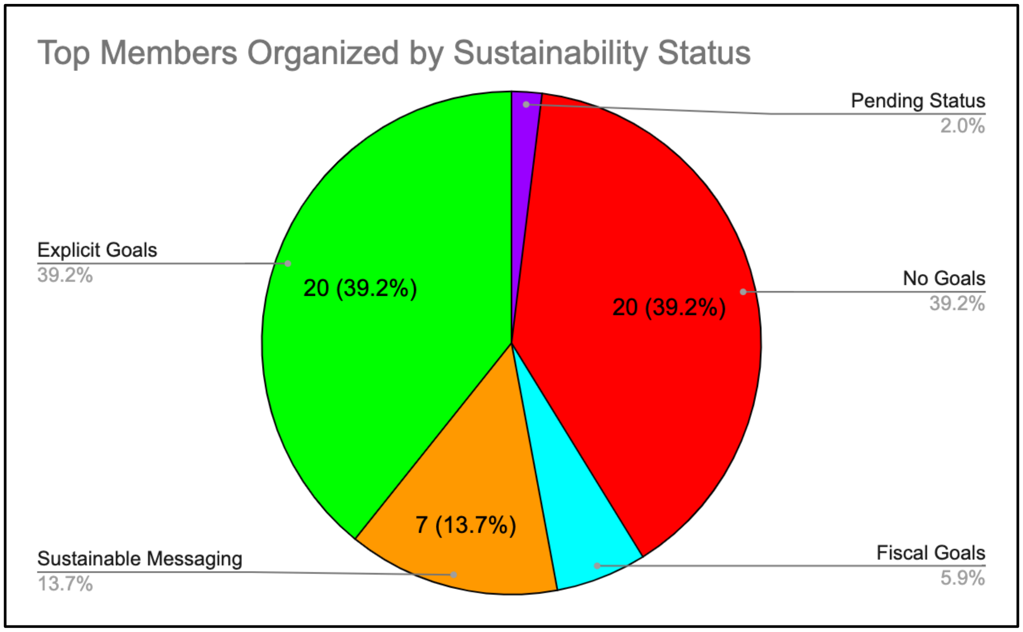


Figure 21. Top Members Organized by Sustainability Status

Appendix 2: Review of Competitor Climate Action Plan

AT&T's: Synopsis of Climate Action Plan [92]
AT&T's Climate Action Plan aims for carbon neutrality by 2035, Key strategies include renewable energy power purchase agreements, high-quality carbon offsets, and extensive energy efficiency projects. Their Climate Action plan is approved by the Science Based Targets initiative.

AT&T's: Climate Action Plan Vulnerabilities
AT&T's Climate Action Plan relies on carbon offsets, customer cooperation, and faces challenges from the purchasing of new vehicles. The plan includes initiatives like the Gigaton Goal, which aims to help customers collectively reduce a gigaton of GHG emissions. This goal depends on customers using AT&T's smart climate solutions to manage and reduce their individual emissions. Additionally, the reliance on Carbon credits to reduce GHG is highly scrutinized and unregulated.

Charter: Synopsis of Climate Action Plan
Charter Communications aims to achieve carbon neutrality by 2035 through energy efficiency, renewable energy use, and a cleaner vehicle fleet. The company established a Buildings Energy Efficiency Community of Practice, conducted energy audits, and optimized network energy use. The company is a founding signatory of the Small Network Equipment (SNE) and Set-Top Box (STB) Energy Efficiency Initiatives. Audited verticals are conducted in compliance with the Sustainable Accounting Standards Board (SASB) and Task Force on Climate-related Financial Disclosures (TCFD) framework.

Charter: Climate Action Plan Vulnerabilities
Charter lacks an explicit environmental report or GHG inventory reports. The company's environmental, social, and governance (ESG) focus is skewed towards social initiatives that promote immediate financial benefits. Despite the implementation of various energy efficiency measures, the environmental impact is insignificant in the context of overall energy use. Operations GHG have increased annually, indicating a potential conflict between business expansion and emissions reduction goals. While Charter has made strides in energy efficiency and sustainability, the incremental gains are insufficient for substantial emissions reduction. To meet the 2035 carbon neutrality goal, Charter must adopt more aggressive measures across all scopes of emissions. The sustainability report details ambitious goals without actionable evidence towards achieving their sustainability goals. The report details the company's existing footprint without any promising initiatives to reduce it.

Comcast: Synopsis of Climate Action Plan
Comcast aims to be carbon neutral by 2035 for Scope 1 and 2 emissions. They've reduced these emissions by 38% since 2019, largely through increased use of clean energy, grid improvements, and operational efficiency. Their efforts include renewable energy agreements and transitioning to a green fleet. Comcast is a member of the Science Based Targets initiative. Comcast has

issued a $1 billion green bond to fund clean energy, energy efficiency, and sustainable infrastructure projects,

Comcast: Climate Action Plan Vulnerabilities
There are no immediate vulnerabilities or poor practices detailed in their sustainability reports. The report's largest weakness is a lack of certifications. Comcast is a sustainability leader in the ICT sector.

Verizon: Synopsis of Climate Action Plan
Verizon aims to achieve net-zero operational emissions by 2035, with an interim target of a 53% reduction by 2030, in alignment with the UN Climate accord. Verizon's emission reduction strategy targets operational emissions by phasing out fossil fuels, improving energy efficiency, and shifting to renewables. Verizon's scope 2 reduction initiatives focus on energy efficiency measures across networks, data centers, and buildings. Strategies include network modernization, decommissioning legacy equipment, optimizing cooling processes, deploying AI solutions, and sourcing renewable energy. Scope 3 emissions are addressed through supplier engagement and product lifecycle management. Verizon's emission reduction strategies are validated by credible organizations like the Carbon Disclosure Project, EcoVadis, and the EPA. Sustainability audits are TFCD, SASB and ISO compliant.

Verizon: Climate Action Plan Vulnerabilities
Verizon's sustainability initiatives exceed industry standards, yet regulatory complexities and limited renewable energy access present hurdles. Supply chain sustainability and technological innovation pose challenges for Verizon's emission reduction strategy, especially concerning Scope 3 emissions. Achieving significant reductions in Scope 3 emissions requires collaboration with suppliers and partners across the value chain, as well as innovative approaches to product lifecycle management.

123 Net: Climate Action Plan
123Net explicitly highlights Environmental and Social Responsibility in their company vision. The mission statement subpoint lacks explicit goals but details the pursuit of Energy-efficient data centers and strategies to reduce CO_2 emissions. 123 Net’s climate action plan is minimal and lacks validity.

Truestream: Climate Action Plan
Truestream and its parent Great Lake energy do not have any explicit publicly available sustainability goals or commitments. Great Lake energy offers Renewable Energy services but still lacks corporate sustainability initiatives and targets.

PFN: Climate Action Plan
PFN does not have any explicit publicly available sustainability goals or commitments.

Highline: Climate Action Plan
Highline does not have any explicit publicly available sustainability goals or commitments.

Surf Internet: Climate Action Plan
Highline does not have any explicit publicly available sustainability goals or commitments.

Baraga Telephone: Climate Action Plan
Baraga Telephone does not have any explicit publicly available sustainability goals or commitments.

Merit Network: Climate Action Plan
Merit Network does not have any explicit publicly available sustainability goals or commitments.

Sources		
1	**AT&T**	[92], [93], [94]
2	**Charter**	[95]
3	**Comcast**	[96]
4	**Verizon**	[97]
5	**123 Net**	[98]

Table 23. ISP Sustainability Initiatives

Company	Classification	Reporting Obligation	Carbon Neutrality Target Year (Scope 1/2)	Key Strategies for Climate Action	SBTI
AT&T	Public (NYSE)	YES	2035 (1)	Energy Efficiency, PPA, Carbon Offset, Green Fleet (1)	YES (1)
Charter	Public (NASDAQ)	YES	2035 (4)	Energy Efficiency, PPA, Green Fleet (4)	NO (4)
Comcast	Public (NASDAQ)	YES	2035 (5)	Energy Efficiency, PPA, Green Fleet (5)	YES (5)
Verizon	Public (NYSE)	YES	2035 (6)	Energy Efficiency, PPA, Green Fleet (6)	YES (6)
Merit	Private Nonprofit Education Network	NO	NONE	NA	NA
123Net	Private For Profit	NO	NONE	Energy Efficiency (7)	NO (7)
PFN	Private For Profit	NO	NONE	NA	NA
Highline	Private For Profit	NO	NONE	NA	NA
Truestream	Private For Profit	NO	NONE	NA	NA
Surf Internet	Private For Profit	NO	NONE	NA	NA
Baraga Telephone	Private For Profit	NO	NONE	NA	NA

Appendix 3: Climate Risk Management Strategy: Competitor TCFD Summary

Climate Change: An Immediate Threat to Network Operations
Extreme weather events driven by climate change are increasingly disrupting critical internet and data service infrastructure [99]. Record-breaking heat waves forced Google and Oracle to shut down data centers to prevent overheating, demonstrating the vulnerability of existing systems [100], [101]. Similarly, extreme heat caused a failure at a Twitter data center [102]. Current cooling infrastructure is insufficient for rising global temperatures. According to the Uptime Institute, nearly half of global data centers have reported disruptions due to extreme weather [103]. These events expose significant vulnerabilities and highlight the need for a climate resilient infrastructure and a corporate climate risk management strategy.

Consequences of Chronic Climate Risk: Expected Future Costs due to Rising Temperature
The rising global temperature poses chronic climate risks, significantly impacting data center operations and associated costs [104], [105]. Rising global temperatures have prolonged intensive cooling seasons [106]. Cooling demands are increasing year over year, contributing to higher energy use, driving up operational expenses [107], [108]. Insurance premiums for data centers are likely to surge due to heightened risk profiles, and the potential for downtime during extreme weather events threatens substantial business losses [109].

Climate Risk Disclosure and Response
Publicly traded telecommunications companies have explicitly identified climate change as a significant risk to business in their 10-K filings and TCFD reports. These documents underscore the critical need for investments in climate-resilient infrastructure and the establishment of robust management frameworks. The following is a series of quotes from industry leaders detailing the material risks of extreme heat and climate change and their respective abatement strategies.

Verizon: Physical Risk Statement [110]
Chronic physical risks included long-term changes in climate and weather patterns, including changing levels of precipitation, mean temperatures, and sea level rise. According to the IPCC, in a 4°C world where carbon policy fails to mitigate global average temperature increases, the severity of changes in overarching climate patterns will be much more intense than today, including an average rise in sea level of 11.81 inches by 2030 and a reduction in worldwide productivity and gross domestic product growth. In a 2°C world, we expect the increase in chronic impacts to occur over a much longer timescale and to be more limited.

Verizon: Impact to Business [110]
Our operational costs may increase as a result of shifts in climate patterns, and the threat of these issues may impact current and future business decisions related to our data centers, facilities, and networks. It could also impact our operational costs through increased energy use and spend and costs to repair facilities. These impacts could also result in drops in productivity or increased operational costs for our suppliers that would be passed on to Verizon.

Verizon: Management Approach [110]
Rising and extreme temperatures could cause our cooling infrastructure to run more frequently and, in turn, present an additional burden to local power and water resources. Efforts to reduce the energy required to run these units and boost efficiencies include programs to optimize energy use by upgrading to more efficient units, increasing temperature set points, leveraging green energy (including wind and solar), and using artificial intelligence in managing our cooling systems. In addition, our pursuit of ENERGY STAR and LEED certification has helped to reduce energy use.

AT&T: Physical Risk Statement [92]
Physical risks of climate change — such as intense storms, droughts and wildfires — threaten infrastructure, supply chains and communities. Transition risks — such as policy changes, regulatory and legal shifts, and market expectations — can add business costs and uncertainty.

AT&T: Impact to Business [111]
Extreme weather events precipitated by long-term climate change have the potential to directly damage network facilities or disrupt our ability to build and maintain portions of our network and could potentially disrupt suppliers' ability to provide products and services required to provide reliable network coverage. Extreme weather events such as the highly active tropical storm season along the Gulf and Atlantic coasts and, and the increasing frequency and severity of wildfires across the Western U.S., have the potential to directly damage our network facilities or disrupt our ability to maintain portions of our network.

AT&T: Management Approach [111]
Our network team builds all cell sites to meet or exceed state structural standards— including those in disaster prone areas. We conduct regular analysis to ensure cell sites can withstand wind, ice & other environmental factors. We also deploy high-capacity battery backup to these sites.

Climate change poses quantifiable material risks to network operations for telecommunications companies. Verizon and AT&T highlight these in their TCFD reports. Verizon identifies chronic physical risks such as long-term changes in climate and weather patterns, including increased temperatures and sea level rise. These changes can lead to higher operational costs, facility repairs, and reduced productivity. AT&T points to extreme weather events like storms and wildfires that threaten infrastructure, supply chains, and network reliability. Both companies underscore the severe impact of climate change on their operations, necessitating significant investments in climate-resilient infrastructure.

To mitigate the adverse effects of climate change, telecommunications companies are implementing robust climate risk management strategies. By focusing on climate-resilient infrastructure, energy-efficient technologies, improved cooling systems, and onsite renewable energy sources, they aim to enhance operational resilience and sustainability. These strategies address immediate risks and align with long-term corporate sustainability goals.

Appendix 4: Climate Resilient Cyber Infrastructure

Energy-efficient Hardware and Software

Optimizing energy efficiency in data centers reduces costs and enhances sustainability. Implementing advanced control systems and energy-efficient components, along with software optimization, significantly decreases energy use and costs [112].

Improved Cooling Systems

Energy-efficient cooling systems, such as liquid cooling and advanced air conditioning, greatly reduce data center energy use [112], [113].

Onsite Renewable Energy Sources

Investing in renewable energy infrastructure, like solar panels and wind turbines, enables data centers to produce clean energy onsite [114]. Onsite generation and storage systems, such as microgrids, enhance grid resilience by reducing reliance on external power sources [115]. Investing in battery and energy storage ensures reliable power supply despite weather conditions.

Climate Resilient Cyber Infrastructure Implementation

Telecommunications companies like Verizon and Comcast are actively investing in climate-resilient infrastructure [116], [117]. They are implementing energy-efficient technologies across operations to lower energy use and carbon emissions. Additionally, they are constructing and retrofitting buildings to meet high environmental standards, ensuring better resource efficiency. These companies are also committing to large-scale renewable energy projects to reduce dependence on fossil fuels. Climate change presents both immediate and chronic risks to cyberinfrastructure. Companies such as Verizon and AT&T underscore the critical importance of adopting climate-resilient strategies to mitigate the impact of extreme weather events and escalating temperatures. Implementing energy-efficient technologies, improving cooling systems, and investing in renewable energy are pivotal measures to bolster resilience. In light of the global climate crisis a Climate Risk Management Strategies is highly recommended. By implementing these strategies, Merit can better safeguard against disruptions, minimize environmental impact, and ensure long-term financial sustainability

Appendix 5: Sustainability and DEI

Merit's Sustainability Plans Promote its Existing DEI Commitment
Sustainability initiatives promote DEI goals by addressing environmental justice and reducing social inequities. Climate change disproportionately impacts marginalized communities, making the pursuit of sustainability integral to achieving a diverse, equitable, and inclusive society. Merit's existing DEI framework supports the implementation of sustainable initiatives; a culture that actively pursues the dismantling of interpersonal barriers promotes innovation and collaboration, essential for effective and enduring sustainability practices. By integrating DEI and sustainability, Merit ensures that its environmental efforts are equitable, inclusive, and innovative, benefiting all stakeholders and fostering long-term success.

Merit is expanding DEI efforts and actively considering a workforce development program. This program would promote DEI by offering underrepresented groups access to tech training and career advancement. Prioritizing diversity and inclusion in this program creates a more equitable workforce, in turn fostering innovation and sustainability.

The following is a list of ISP providers and their respective workforce development programs.

AT&T: AT&T's development programs, including the IT Apprenticeship Program launched with NOVA, focus on creating opportunities for underrepresented groups in the tech industry [118]. Their workforce development initiatives emphasize technical skills training, mentorship, and career advancement, supporting both DEI and sustainability [119], [120].

Charter Communications: Charter's workforce development programs aim to diversify the tech workforce by providing education and training opportunities to individuals from diverse backgrounds.

Comcast: Comcast's approach to workforce development includes targeted recruitment and training programs for minorities and women. Their sustainability initiatives address environmental justice through community-based projects that improve access to technology and internet services in underserved areas.

Verizon: Verizon's sustainability and DEI efforts are interlinked through initiatives like their Digital Inclusion Program, which aims to bridge the digital divide for underrepresented communities. Their workforce development programs emphasize equity and inclusion.

There is a strong market trend of ISPs providing workforce development programs to accelerate DEI initiatives. Merit should build out a workforce development curriculum that pursues DEI goals through environmental justice.

Appendix 6: Security Considerations for ICT Sustainability

Sustainability Audit: Vulnerability Analysis

Sustainability audits have a material impact on improving operations and resilience to disruptions by identifying inefficiencies, lowering operational costs, and understanding vulnerabilities in the supply chain [121]. This pursuit of continuous operations ensures businesses can mitigate risks, enhance resource management, and maintain stability amid environmental and regulatory changes [122].

Sustainability Audit and Cyber Securities Synergies

A sustainability audit adds value to cybersecurity and operational security by expanding risk assessment criteria to include environmental factors [123]. By evaluating how sustainability practices intersect with cybersecurity and operational security, organizations gain a deeper understanding of potential risks and vulnerabilities. A sustainability audit enhances environmental resource management by providing insights into non-financial risks and aligning risk management strategies with broader sustainability objectives.

Sustainability: Increased Exposure and Vulnerabilities

Sustainability audits in ISPs can heighten cybersecurity risks. Sustainable initiatives often involve software-optimized systems and the internet of things (IoT) deployments, both prone to vulnerabilities [124]. In database management, reliance on centralized control systems may expose databases to manipulation by malicious actors [125]. Additionally, IoT devices within ISP infrastructures commonly lack fundamental cybersecurity measures, potentially compromising sensitive data stored in databases [126]. Furthermore, the adoption of open-source software (OSS) in database management exacerbates vulnerabilities [127]. Balancing sustainability objectives with robust cybersecurity measures is crucial to safeguarding sensitive data and ensuring ISP resilience.

Appendix 7: Utility Hut Data Tables and SimaPro Results

Table 24. Outsourced Parts and Materials for Utility Hut Construction

Part #	Generic Category	Quantity	Individual Product Weight (lbs)	Total Weight (lbs)	Part Weight (lbs)	SimaPro Material
QO140M200 [128]	Breaker	1.00	20.5994	20.5994	1.3595604	Polyphenylene sulfide {GLO}| market for | APOS, S
					0.0205994	Polyethylene terephthalate, granulate, amorphous {GLO}| market for | APOS, S
					0.0205994	Epoxy resin, liquid {RER}| market for epoxy resin, liquid | APOS, S
					0.102997	Kraft paper, bleached, at plant/RER S
					0.1647952	Corrugated board box {RER}| market for corrugated board box | APOS, S
					0.617982	Copper, anode {GLO}| market for copper, anode | APOS, S
					4.1610788	Aluminium, primary, cast alloy slab from continuous casting {GLO}| market for | APOS, S

					14.1311884	Steel, low-alloyed {GLO}| market for | APOS, S
MC4002-A [129]	Electronic Control Board	1	9.97	9.97	4.985	Aluminium, primary, cast alloy slab from continuous casting {GLO}| market for | APOS, S
					3	Electronic component, passive, unspecified {GLO}| market for | APOS, S
					1.985	Electronic component, active, unspecified {GLO}| market for | APOS, S
W24AB-A05ZPXXXJ [130]	Air Conditioner	2	400	800	250	Aluminium, primary, cast alloy slab from continuous casting {GLO}| market for | APOS, S
					50	Copper tube, technology mix, market mix, at plant, diameter 15 mm, 1 mm thickness EU-15 S
					200	Steel, low-alloyed {GLO}| market for | APOS, S
					50	Steel, chromium steel 18/8 {GLO}| market for | APOS, S
					150	Cast iron {GLO}| market for | APOS, S

					48	Polyethylene terephthalate, granulate, amorphous {RoW}| production | APOS, S
					45	Refrigerant R134a {GLO}| market for | APPS, S
					2	Electronic component, active, unspecified {GLO}| market for | APOS, S
					5	Electronic component, passive, unspecified {GLO}| market for | APPS, S
GB114420TBI [131]	Ground Bar	1	9	9	9	Copper, cathode {GLO}| market for | APPS, S
B1448 [132]	Aluminum Cover	2	1.9	3.8	3.8	Aluminium, primary, cast alloy slab from continuous casting {GLO}| market for | APPS, S
CLR-12-2 [133]	Ladder	4	27	108	108	Steel, low-alloyed {GLO}| market for | APPS, S
CP9000-08 [134]	Plastic Case	1	2	2	2	Polyethylene terephthalate, granulate, amorphous {GLO}| market for | APPS, S
7215 [135]	Breaker	1	48	48	38.4	Aluminium, primary, cast alloy slab from continuous casting {GLO}| market for |

						APPS, S
					7	Electronic component, passive, unspecified {GLO}| market for | APPS, S
					2.6	Electronic component, active, unspecified {GLO}| market for | APPS, S
AJA20034-200RS [136]	Power Receptacle	1.00	18	18	18	Aluminium, primary, ingot {IAI Area, North America}| market for aluminium, primary, ingot | APOS, S
Q22200NS [137]	Breaker	1	12.04	12.04	0.01204	Steel, chromium steel 18/8 {GLO}| market for | APPS, S
					0.01204	Aluminium, primary, cast alloy slab from continuous casting {GLO}| market for | APPS, S
					0.5418	Corrugated board box {RER}| market for corrugated board box | APOS, S
					0.0602	Polyethylene terephthalate, granulate, amorphous {GLO}| market for | APPS, S
					11.40188	Steel, low-alloyed {GLO}| market for | APPS, S

					0.01204	Electronic component, active, unspecified {GLO}| market for | APPS, S
PCS [138]	Bracket	10	0.85	8.5	8.5	Steel electrogalvanized/GLO
FGS-MDSP-A [139]	Plastic Bracket	2	1.874	3.748	3.748	Polycarbonate {GLO}| market for | APPS, S
FGS-MTRM-A [140]	Plastic Bracket	2	0.611	1.222	1.222	Polycarbonate {GLO}| market for | APPS, S
UNISTRUT. 15/8 X. 16* [141]	Metal Bar	3	11	33	33	Reinforcing steel {GLO}| market for | APPS, S

Table 25. Thermo Bond Building Parts and Materials for Utility Hut Construction

Part Number	Generic Category	Quantity	Individual Product Weight (lbs)	Total Weight (lbs)	Part Weight (lbs)	SimaPro Material
099-0834 [142]	Steel Door and Frame	1	75	75	75	Steel, low-alloyed {GLO}| market for | APPS, S
	Hinges	1	1.5	1.5	1.5	Steel, low-alloyed {GLO}| market for | APPS, S
	Pins	1	0.5	0.5	0.5	Steel, low-alloyed {GLO}| market for | APPS, S
	Lever Passage and Deadbolt	1	2.5	2.5	2.5	Steel, low-alloyed {GLO}| market for | APPS, S
099-0861 [143]	Hydraulic Closer	1	4	4	4	Steel, low-alloyed {GLO}| market for | APPS, S
099-0892 [143]	Hydraulic Closer Hold Open	1	2	2	2	Steel, low-alloyed {GLO}| market for | APPS, S
100-001 [144]	Door Alarm	1	0.5	0.5	0.25	Polycarbonate {GLO}| market for | APPS, S
					0.25	Electronic component, active, unspecified {GLO}| market for | APPS, S
800-1001 [145]	GFCI Cover	1	0.1	0.1	0.1	Polycarbonate {GLO}| market for | APPS, S
500-103	Light Switch	1	0.3	0.3	0.3	Polycarbonate {GLO}| market for | APPS, S

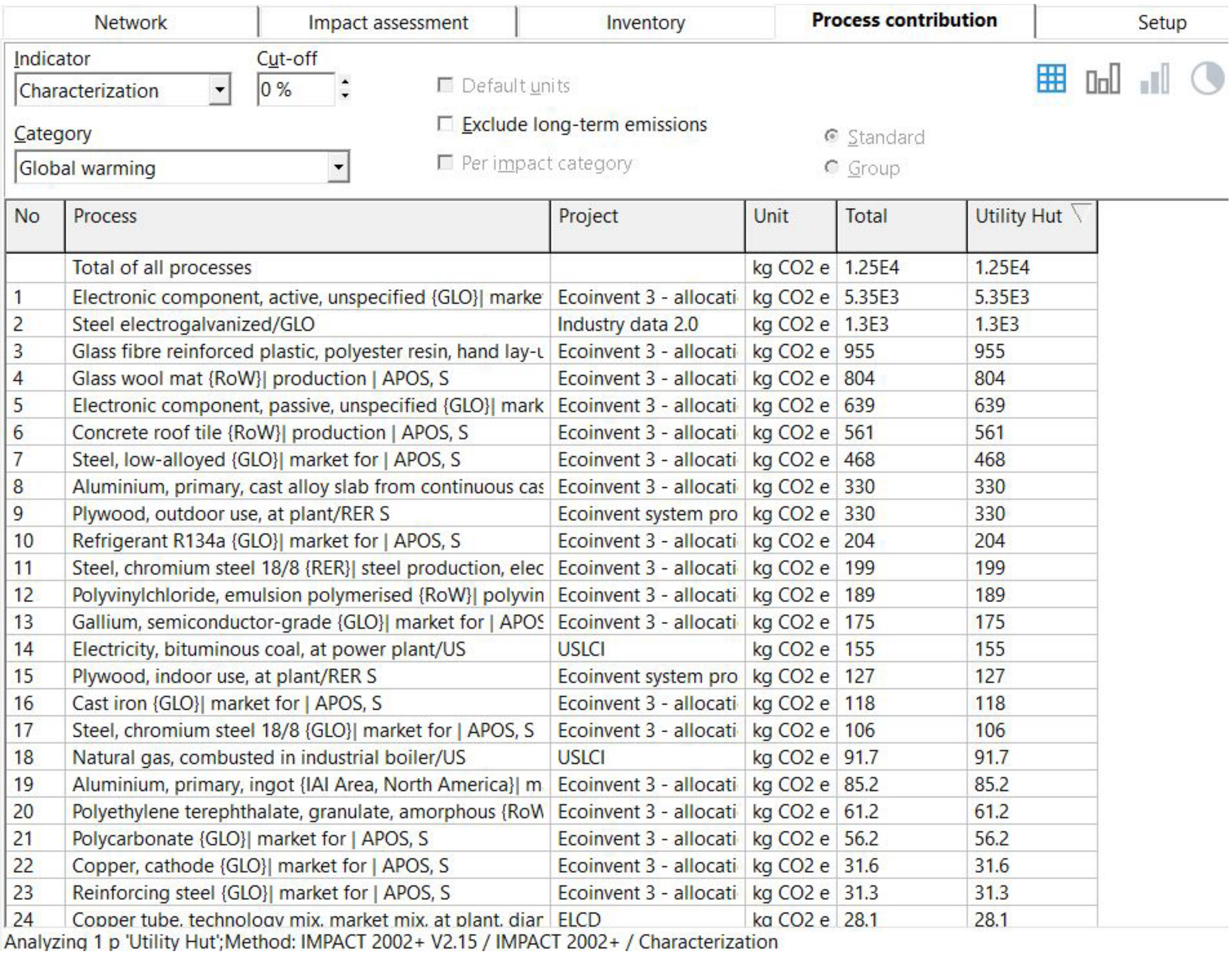
[146]						
500-0576 [147]	LED Light	4	5	20	9	Polycarbonate {GLO}| market for | APPS, S
					2	Gallium, semiconductor-grade {GLO}| market for | APPS, S
					9	Electronic component, passive, unspecified {GLO}| market for | APPS, S
500-085 [148]	Exterior LED Light	1	5	5	2.25	Polycarbonate {GLO}| market for | APPS, S
					0.5	Gallium, semiconductor-grade {GLO}| market for | APPS, S
					2.25	Electronic component, active, unspecified {GLO}| market for | APPS, S
800-101 [149]	Duplex Receptacle	8	0.2	1.6	0.96	Polycarbonate {GLO}| market for | APPS, S
					0.32	Steel, low-alloyed {GLO}| market for | APPS, S
					0.32	Electronic component, active, unspecified {GLO}| market for | APPS, S
000-015 [150]	PVC	1	1.25	1.25	1.25	Polyvinyl Chloride, bulk polymerised {GLO}| market for | APPS, S
300-023 [151]	Alarm Cabinet	1	13	13	13	Steel, low-alloyed {GLO}| market for | APPS, S

100-011 [152]	Power Fail	1	0.4	0.4	0.4	Electronic component, active, unspecified {GLO}| market for | APPS, S
100-014 [153]	Smoke Detector	1	0.5	0.5	0.25	Polycarbonate {GLO}| market for | APPS, S
					0.25	Electronic component, active, unspecified {GLO}| market for | APPS, S
850-007 [154]	Relay Rack	2	50	100	100	Steel, low-alloyed {GLO}| market for | APPS, S

Table 26. Thermo Bond Building Parts and Materials for Lightweight Shelter

System	Generic Category	Quantity	lbs / sq ft	Total Weight (lbs)	Materials	Part Weight (lbs)	SimaPro Material
Floor	Floor exterior [155]	1	2	400	3/4" CDX Plywood	400	Plywood, outdoor use, at plant/RER S
	Floor interior [156]	1	2	400	3/4" tongue and groove plywood	400	Plywood, indoor use, at plant/RER S
	Wire rodent mesh [157]	1	0.5	100	Stainless steel	100	Steel, chromium steel 18/8 {RER}| steel production, electric, chromium steel 18/8 | APPS, S
	Floor core [158]	1	0.6	120	R-11 fiberglass batt insulation	120	Glass wool mat {RoW}| production | APOS, S
	Floor interior surface [159]	1	0.75	150	vinyl tile	150	Polyvinyl Chloride, emulsion polymerised {RoW}| polyvinyl chloride production, emulsion polymerisation | APOS, S
Roof	Roof exterior [155], [160]	1	2	400	3/4" CDX Plywood	400	Plywood, outdoor use, at plant/RER S
		1	2	400	5/8″ layer of oriented strand board	400	Oriented strand board product, US SE/kg/US
	Roof interior	1	1	200	.030 fiberglass reinforced	200	Glass fibre reinforced plastic, polyester resin, hand lay-up {RoW}|

	[161], [162]				plastic		production | APOS, S
		1	0.6	120	R-19 fiberglass batt insulation	120	Glass wool mat {RoW}| production | APOS, S
Wall	Wall interior [158], [160], [161]	4	2	1038	5/8″ layer of oriented strand board	1038	Oriented strand board product, US SE/kg/US
		4	1	519	.030 fiberglass reinforced plastic	519	Glass fibre reinforced plastic, polyester resin, hand lay-up {RoW}| production | APOS, S
		4	0.6	311.4	R-11 fiberglass batt insulation	311.4	Glass wool mat {RoW}| production | APOS, S
	Wall exterior [163]	4	10	5190	aggregate (concrete/stone)	5190	Concrete roof tile {RoW}| production | APOS, S
Skid Assembly	Steel beams [164], [165]	1	18 lb / ft	954	Galvanized steel	954	Steel electrogalvanized/GLO



No	Process	Project	Unit	Total	Utility Hut
	Total of all processes		kg CO2 e	1.25E4	1.25E4
1	Electronic component, active, unspecified {GLO}| marke	Ecoinvent 3 - allocati	kg CO2 e	5.35E3	5.35E3
2	Steel electrogalvanized/GLO	Industry data 2.0	kg CO2 e	1.3E3	1.3E3
3	Glass fibre reinforced plastic, polyester resin, hand lay-u	Ecoinvent 3 - allocati	kg CO2 e	955	955
4	Glass wool mat {RoW}| production | APOS, S	Ecoinvent 3 - allocati	kg CO2 e	804	804
5	Electronic component, passive, unspecified {GLO}| mark	Ecoinvent 3 - allocati	kg CO2 e	639	639
6	Concrete roof tile {RoW}| production | APOS, S	Ecoinvent 3 - allocati	kg CO2 e	561	561
7	Steel, low-alloyed {GLO}| market for | APOS, S	Ecoinvent 3 - allocati	kg CO2 e	468	468
8	Aluminium, primary, cast alloy slab from continuous cas	Ecoinvent 3 - allocati	kg CO2 e	330	330
9	Plywood, outdoor use, at plant/RER S	Ecoinvent system pro	kg CO2 e	330	330
10	Refrigerant R134a {GLO}| market for | APOS, S	Ecoinvent 3 - allocati	kg CO2 e	204	204
11	Steel, chromium steel 18/8 {RER}| steel production, elec	Ecoinvent 3 - allocati	kg CO2 e	199	199
12	Polyvinylchloride, emulsion polymerised {RoW}| polyvin	Ecoinvent 3 - allocati	kg CO2 e	189	189
13	Gallium, semiconductor-grade {GLO}| market for | APOS	Ecoinvent 3 - allocati	kg CO2 e	175	175
14	Electricity, bituminous coal, at power plant/US	USLCI	kg CO2 e	155	155
15	Plywood, indoor use, at plant/RER S	Ecoinvent system pro	kg CO2 e	127	127
16	Cast iron {GLO}| market for | APOS, S	Ecoinvent 3 - allocati	kg CO2 e	118	118
17	Steel, chromium steel 18/8 {GLO}| market for | APOS, S	Ecoinvent 3 - allocati	kg CO2 e	106	106
18	Natural gas, combusted in industrial boiler/US	USLCI	kg CO2 e	91.7	91.7
19	Aluminium, primary, ingot {IAI Area, North America}| m	Ecoinvent 3 - allocati	kg CO2 e	85.2	85.2
20	Polyethylene terephthalate, granulate, amorphous {RoW	Ecoinvent 3 - allocati	kg CO2 e	61.2	61.2
21	Polycarbonate {GLO}| market for | APOS, S	Ecoinvent 3 - allocati	kg CO2 e	56.2	56.2
22	Copper, cathode {GLO}| market for | APOS, S	Ecoinvent 3 - allocati	kg CO2 e	31.6	31.6
23	Reinforcing steel {GLO}| market for | APOS, S	Ecoinvent 3 - allocati	kg CO2 e	31.3	31.3
24	Copper tube, technology mix, market mix, at plant, diar	ELCD	kg CO2 e	28.1	28.1

Analyzing 1 p 'Utility Hut';Method: IMPACT 2002+ V2.15 / IMPACT 2002+ / Characterization

Figure 22. Process Contribution for Top 24 Processes in kgCO2e for Single Utility Hut

Se	Impact category	Unit	Total	Utility Hut
☑	Carcinogens	kg C2H3Cl eq	519	519
☑	Non-carcinogens	kg C2H3Cl eq	1.42E3	1.42E3
☑	Respiratory inorganics	kg PM2.5 eq	18.9	18.9
☑	Ionizing radiation	Bq C-14 eq	1.34E5	1.34E5
☑	Ozone layer depletion	kg CFC-11 eq	0.0212	0.0212
☑	Respiratory organics	kg C2H4 eq	7.97	7.97
☑	Aquatic ecotoxicity	kg TEG water	4.01E6	4.01E6
☑	Terrestrial ecotoxicity	kg TEG soil	8.34E5	8.34E5
☑	Terrestrial acid/nutri	kg SO2 eq	263	263
☑	Land occupation	m2org.arable	1.16E3	1.16E3
☑	Aquatic acidification	kg SO2 eq	75.3	75.3
☑	Aquatic eutrophication	kg PO4 P-lim	5.57	5.57
☑	Global warming	kg CO2 eq	1.25E4	1.25E4
☑	Non-renewable energy	MJ primary	1.83E5	1.83E5
☑	Mineral extraction	MJ surplus	1.99E3	1.99E3

Figure 23. Impact Assessment Characterization for Single Utility Hut

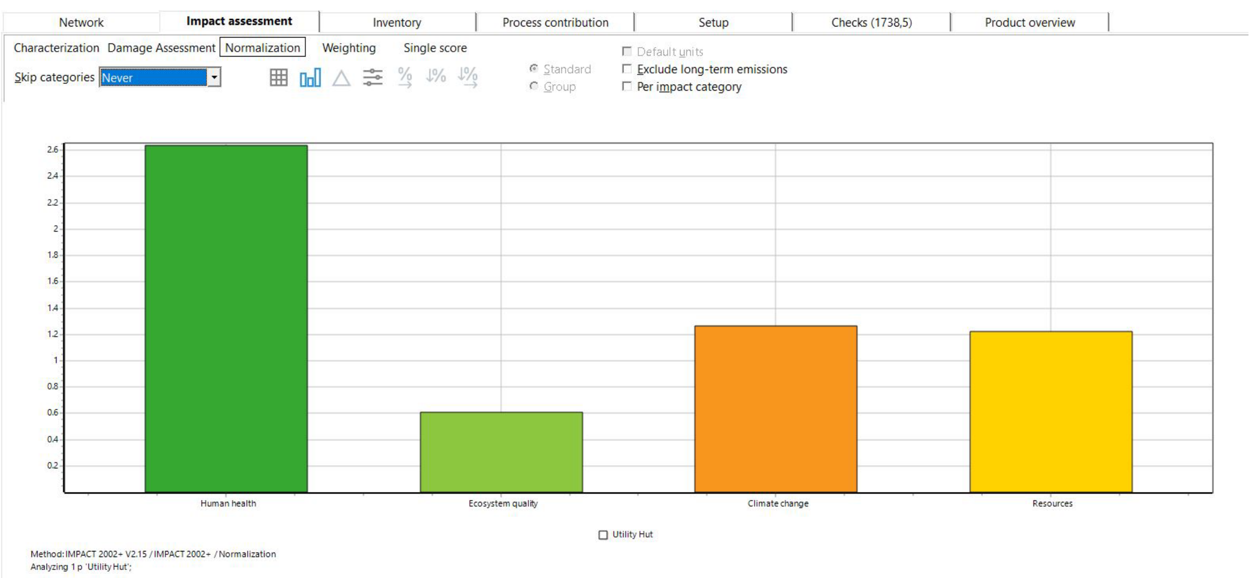


Figure 24. Impact Assessment Normalization Graph for Single Utility Hut

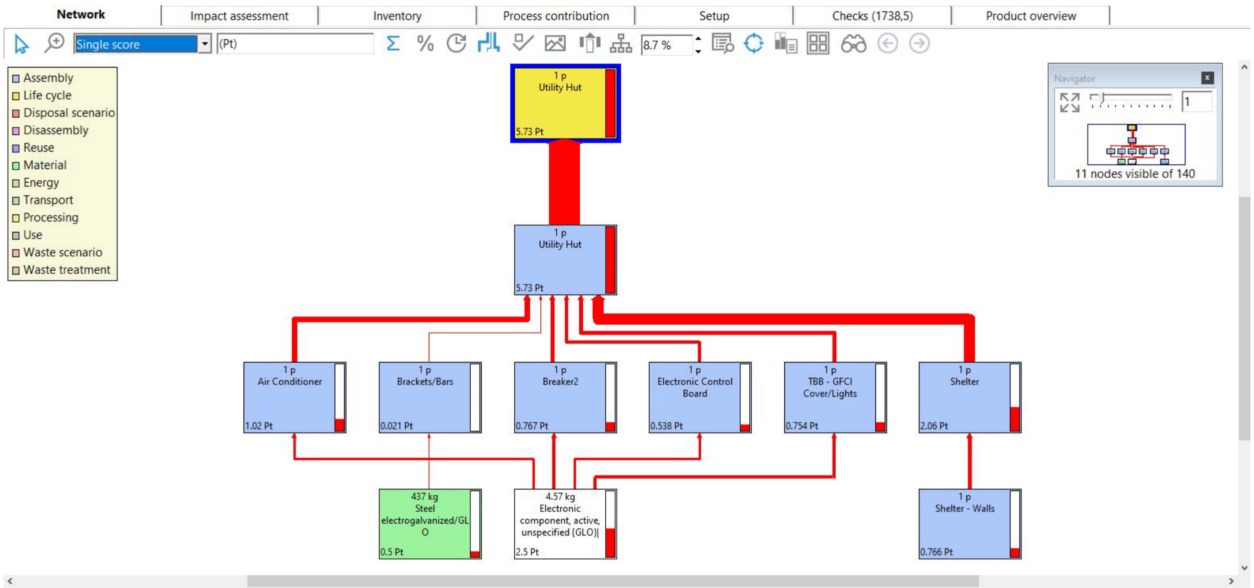


Figure 25. Expanded Network Single Score Diagram for Single Utility Hut

Appendix 8: Supplementary Energy Use Data

Table 27. Supplier Datasheets for Power Demand Calculation

JUNIPER	
Unique Value Only (Model)	Datasheet Source
EX4650-48Y-8C	[166]
EX4600-40F	[167]
MX480	[168]
JNP204	[168]
QFX5100-24Q-2P	[169]
EX4300-48T	[170]
EX2300-24T-DC	[171]
EX2300-C-12T	[171]
MX104	[172]
EX4200-24F	[173]
MX80	[174]
MX240	[168]
EX4200-48T	[173]
ACX7100-48L	[175]
JNP10003	[176]
ACX7100-32C	[177]
EX4500-40F	[178]
EX2300-24T	[171]
ACX7024	[179]
EX4300-32F	[170]
MX960	[168]
EX4200-24T	[173]
QFX5100-96S-8Q	[169]
EX4550-32F	[180]
EX3300-24T	[181]

CISCO	
Unique Value Only (Model)	Datasheet Source
ASR92016SZIM	[44]
ASR92012CZA	[44]
N5204GAZA	[182]
ASR92024SZM	[44]
ASR9204SZA	[44]
1941	[183]
2901	[184]
2911	[184]
1921k9	[185]
1841	[186]
3945SPE250	[187]
3825	[188]
Me3600x24fsM	[189]
ciscoMe3400g2csA	[190]
ciscoMe3400eg2csA	[190]
3750Ge12Sfp	[191]
ciscoMe3400g12CsA	[190]
Cat9300FixedSwitchStack	[192]
NCS540L28Z4SysA	[193]
NCS55A2MODS	[194]
ASR9204SZD	[44]
375024TS	[191]
3750Ge12SfpDc	[191]
Cat9200FixedSwitchStack	[195]
29xxStack	[196]

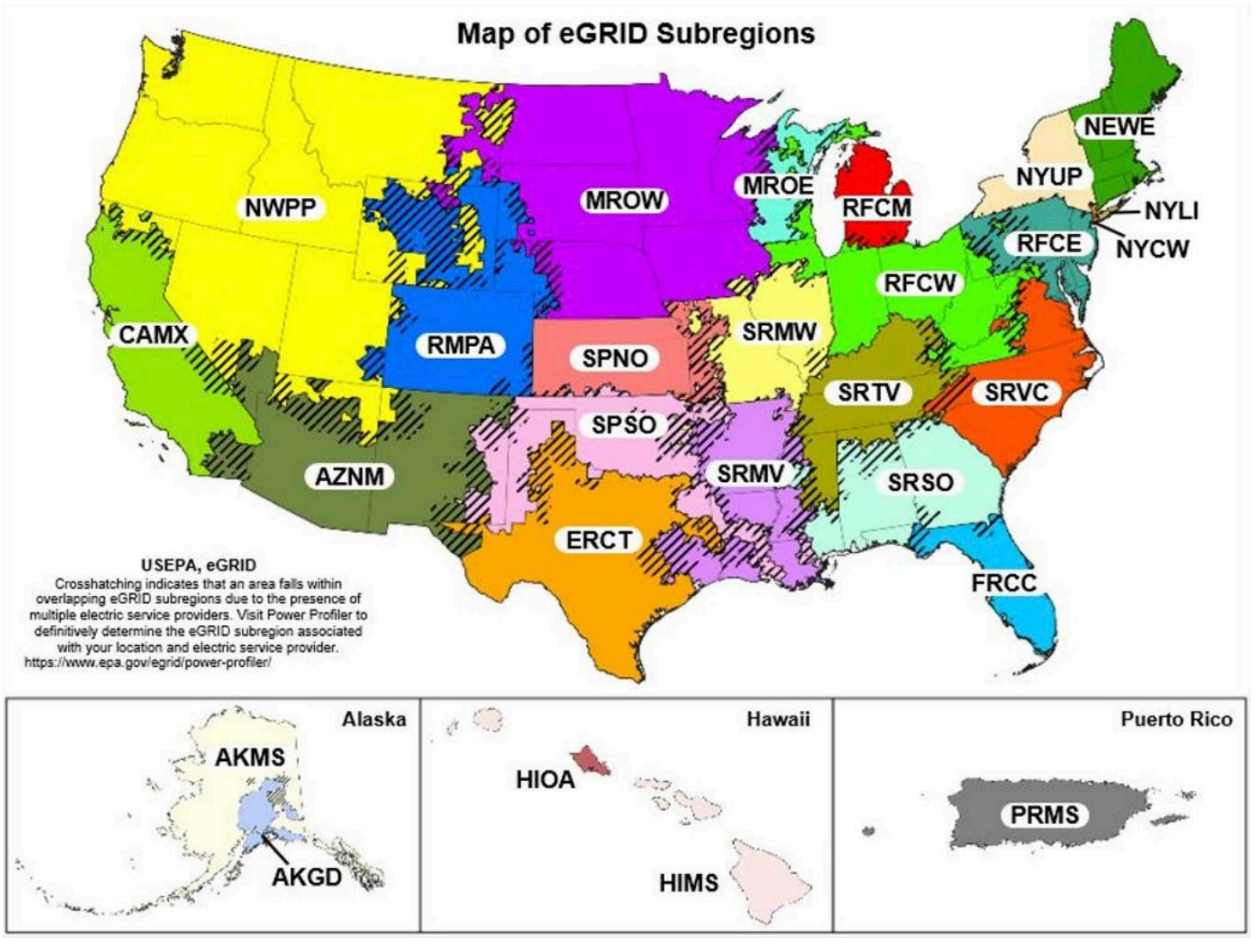


Figure 26. Map of eGrid Subregions [46]

Appendix 9: Supplementary E-Waste Data

Table 28. All E-waste Items Organized by Subtype

Device Type	Device Sub Type	Count
Network Equipment: Core	OPTICAL AMPLIFIER	201
	POWER SUPPLY	177
	SWITCH	80
	OPTICAL SHELF	68
	OPTICAL DCF	52
	OPTICAL OTHER	48
	OPTICAL CARD	34
	OPTICAL CHANNLE	28
	FAN TRAY	24
	CHASSIS	24
	DOCK	22
	SHELF CONTROL UNIT	18
	TRANSCEIVER	17
	PORT	16
	SERVER	15
	SHELF	4
	OPTICAL	4
Modem and Router: Customer Premise Equipment	ROADM	43
	MODEM	24
	ROUTER	5
PC Accessory	CABLES	35
	KEYBOARD	3
	DRIVE	1
Laptop	LAPTOP	32
Audio Equipment	AUDIO	23
Display	MONITOR STAND	12
	MONITOR	9
Landline	PHONE	9
Desktop PC	PC	2
Printer	PRINTER	2