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Maintaining a Secure Foundation of Cybersecurity Awareness while Reducing eWaste and Carbon Output through Ethical User Actions and Sustainable Green Computing

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Abstract

To better understand how we can help reduce the climate crisis, this research examined user computing activities in detail to analyze and identify eWaste actions causing unknown catastrophic climate degradation. Countless individuals are oblivious to the damage and devastation being caused to the climate by even a single user. As the world becomes more technologically based than ever before, the global impact on the planet has never been greater. This study examines in great detail end-users' normal computer usage to identify where, how, and why they are generating excess eWaste. We argue that the resultant data collected will provide support for our theory, positing that increasing consumer awareness of better computational practices can lead to positive actions to reduce eWaste.

This research study utilized a multiple case study approach to achieve our stated research objectives; recognizing computer actions identified as most detrimental to the climate by level of eWaste (CO_2e output) and introducing alternative user actions that are ethical, green, and produce less eWaste. In addition to helping reduce the overall user-level carbon footprint and eWaste output, the sustainability of these alternative user actions can be maintained with zero reduction in privacy or security for end users. Results from this study contribute to the extant body of literature across multiple disciplines, including privacy, green computing, information system science and technology, cybersecurity, and sustainable computing.

Keywords: privacy, information systems, climate crisis, user behavior theory, carbon footprint, information security, green computing, electronic cookies, eWaste, case study methodology

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1. Introduction

The *Climate Crisis* can no longer be avoided. Irreparable damage is being done to our planet daily by end users and corporations, knowingly or unknowingly, through eWaste and abuse, due to a lack of knowledge and a lack of accountability.

Due to the increased contribution to the climate crisis, it is essential to adopt environmentally sustainable technology and computing actions to ensure the overall health of our planet. We investigate the problem presented in this research by examining corporate and user actions to determine their level of eWaste output. During data collection and data analysis, computational actions are categorized as either end-user or corporate based on (i) the nature of the action being executed, (ii) the relationship of the user and the action, (iii) the location of the action being taken, and (iv) the duplicability of the action.

In this study, secondary data sources were first analyzed to discover actions and behaviors causing significant climate damage by both corporations and end-users. Next, the identified set of actions and behaviors were assessed and evaluated to determine their individual climate output measured in terms of eWaste. Finally, to compare and identify green, sustainable computing actions and behaviors users can implement, an exhaustive analysis was completed to determine an alternative set of acceptable computing actions and behavior options for consumers. This list of activities was matched with the previously identified alternative user actions to ensure they are ethical, sustainable, green, and produce less eWaste while maintaining data integrity, security, and privacy.

Literature review examining the nature and impact of user actions on the climate crisis across multiple disciplines, including Privacy [1, 2], Green Computing [3], Information System Science and Technology [4, 5], Cybersecurity [6], Sustainable Computing [7–9], and various climate domains [10, 11], has exposed a gap in the research: minimal research exploration examining the negative impact individual user actions have based on carbon dioxide equivalent (CO_2e) emissions and carbon output (eWaste) [1, 2, 6, 7], and [9].

To the best of our knowledge, while prior research has explored the problem in different ways to "Go Green" [3, 7, 9, 11, 12], this research is the first of its kind to explore and evaluate individual actions and behavioral practices to determine an estimated, quantifiable emission and eWaste output associated with daily computational tasks. This project examines in detail both corporate actions and behaviors and end-user actions, behaviors, and online security habits, during normal computer usage to identify excess eWaste from wasteful carbon emissions. While reducing the overall carbon footprint and minimizing eWaste output, the sustainability of the presented alternative corporate and end-user actions and behaviors can be implemented and maintained with zero reduction in privacy or increased security concerns for users.

2. Literature review

Technology as a medium has become the lifeblood of society for both end users and corporations. Increased reliance on today's technology has dramatically increased the amount of CO_2e emissions released into the atmosphere, causing catastrophic damage on a global scale. To better understand how we can help to reduce the climate crisis, this research investigated in detail, the actions and behaviors to identify eWaste causing unknown catastrophic climate degradation. Due to the increased contribution to the climate crisis, it is essential to adopt environmentally sustainable technology and computing actions to ensure the overall health of our planet.

The climate crisis is an area of concern that has affected most academic disciplines. Many researchers have focused their efforts on how various issues are associated with a negative impact on the climate crisis with varying degrees of scope and success. Miotti *et al.* [13] quantifies the diverse level of carbon emissions that come from light-duty vehicles across the United States. They state that 13% of all greenhouse gas emissions are a result of vehicle fuel combustion from transportation around the world [13]. Jeswiet and Kara [14] approach the climate crisis from a manufacturing point of view and developed a concept known as Carbon Emissions Signature (CES™). This allows the amount of carbon emissions to be calculated during the manufacturing of a product, allowing the manufacturers to be held accountable for inefficient manufacturing tactics [14]. Approaching the problem from a food production perspective, Filho *et al.* [15] describes how the production of food negatively influences climate change. They demonstrate that crops and livestock production contain the highest contribution of excess carbon output in the food production chain [15].

Within the technology domain, *Green Computing* has been identified as the practice with a potential to make the biggest positive impact. Due to a growing awareness of the negative environmental impact and cost efficiency [1], *Green Computing* has become a principal area of interest within society and is rapidly growing within the Information Technology (IT) and Information System (IS) domains. *Green Computing* refers to the study and practice of using computing devices in an eco-friendly manner [1, 2], and [3]. Through broad implementation and adaptation, the adoption of Green Computing by both individual users and corporate entities has the potential to reduce carbon emissions. As a tool for reducing carbon output, there exist four distinct paths for action within the Green Computing framework: (i) Green Use, (ii) Green Disposal, (iii) Green Design, and (iv) Green Manufacturing [4]; known colloquially as the 4G's of Green Computing [16–18].

Green use is using computing devices in a manner that reduces their energy consumption, thus being more eco-friendly by reducing carbon emissions [19]. Many devices allow the user to adjust power management [20] settings on their device. The open industry standard, *Advanced Configuration and Power Interface* (ACPI), is a setting in a computer's Basic Input/Output System (BIOS) that allows the device to automatically turn off certain components, such as monitors and hard drives, after a set period of inactivity [3].

Green disposal consists of reusing or recycling unused technology equipment and components instead of throwing them away [19]. Within the past few years, Google has begun adopting recycling programs for their customers. This program allows the customer to request a free shipping label, pack their device in a box, mail it, and let Google responsibly recycle their old mobile, technology, or computing device(s) [21].

Green design consists of the way in which computers and similar devices are designed; ensuring that they use energy efficiently and are safe for the environment [19]. As mentioned in Albertao *et al.* [8], software can be designed for efficient energy use by ensuring the program has proper reusability through software performance, dependability, usability, reliability, accessibility, and overall project footprint.

Green manufacturing is the process of manufacturing computers and similar devices in an eco-friendly manner that leaves minimal to no impact on the environment [19]. Google has also begun to use 100% recycled materials within the manufacturing of their products. This can be seen through the development of the Pixel 5, which possesses a 100% recycled aluminum enclosure [21] on the exterior of the mobile device.

Harm to our environment comes from various domains relating to both end users and corporations, including production [1], home-Use computing [2–4], cloud computing [5–7], eWaste of physical technology and computing parts and components [8, 9, 22], Computer and Software Engineering [23], Virtualization [12], IT Services [24], Computer Science [10], Green Technology [11, 25, 26] and more. While literature evidence exists to support a growing concern across research domains over the environmental damage caused by eWaste, "Technology" as a category remains one of the most damaging due to its potential for long-term catastrophic degradation to our planetary requirements needed for life [1, 2, 4, 25] and [27]. Despite this concern, and an abundance of research evidence indicating widespread damage and the potential for destruction to the environment, manifested in the current climate crisis, there has only been minimal research exploring the use of technology and devices in a sustainable and green manner [1, 3–5], and [28]. Moreover, minimal research has been committed to better understanding the role that corporations and individuals play in reducing emission waste [2, 3, 6], and carbon output [7, 9].

Within the current body of literature, evidence indicates the potential to reduce the current climate crisis by increasing end-user and organizational awareness of alternative sustainable computational practices. Moreover, despite the growing popularity, not only are green practices and sustainable actions in IT [29] slow to be introduced, but eco-friendly strategies that *have been introduced* within corporate environments are not being utilized efficiently or effectively. To help fill this research gap, this investigation examined the specific impact that behavioral change can have on reducing carbon emissions, both by corporate entities and individuals. The results from this study will contribute to the extant body of literature across multiple disciplines, including privacy, green computing, sustainable computing [20], information system science and technology, cybersecurity, and climate domains.

3. Research methodology

3.1. Multiple case study design

A multiple case study research design was utilized in this research study, allowing us to analyze multiple use cases in which the individual user or corporate entity have conducted research resulting in decreased carbon emissions in the *Information Technology* (IT) sector. The scope of this research emphasizes the need for sustainable computational practices by both end users and corporations. Sustainable practices are identified through secondary research as computational actions and behaviors detrimental to the climate through excess carbon output (eWaste causing a negative impact on the environment). In addition, we introduce a set of sustainable and green alternative actions and behaviors producing less carbon emissions and CO_2e.

All actions identified, whether alternative or detrimental, were evaluated, analyzed, and assessed. During data aggregation, data assessment was completed to identify carbon emissions, alternative actions, and poor computational actions contributing to the climate crisis. Furthermore, through our analysis, this study was able to develop and introduce a set of sustainable computational practices that minimize the overall environmental impact of carbon emissions without any compromise in user privacy and security concerns.

To properly analyze the negative impact actions and behaviors from end users and corporations are having on our environment, we must first identify specific actions and behaviors causing significant eWaste; determined by CO_2e emissions and carbon output. To effectively discern the source and nature, we separated corporate actions and behaviors from end-user actions and behaviors and evaluated their negative climate impact and eWaste separately.

3.2. Corporate actions and behaviors

Corporations are one of the most prolific carbon abusers today [11, 30, 31]. Through the course of routine business procedures, several activities occur with high frequency within corporate environments that have a catastrophic impact on the climate crisis through eWaste and abuse. Extensive analysis of the extant body of literature highlighted this ongoing concern [32, 33] and enabled us identify to several significant problematic actions and behaviors. Current corporate activities (Table 1) being implemented associated with excess carbon output causing CO_2e eWaste include, *(i) Corporate Virtualization*, *(ii) Inefficient Software Design*, *(iii) Website Abuse*, and *(iv) Corporate Cookie Tracking*. While a variety of additional actions and behaviors cause eWaste and abuse too, these specific activities possess the ability to reverse their CO_2e output through education and training remediation.

Table 1. Corporate actions and behaviors with excessive CO_2e.

	Corporate action or behaviors
(i)	Corporate virtualization
(ii)	Inefficient software design
(iii)	Website abuse
(iv)	Cookie tracking

While corporations are some of the biggest carbon abusers on the planet [5] from their operating procedures, end users are not without fault [12]. After determining the negative climate impact of corporate actions and behavior, it was necessary to perform the same actions for end users.

3.3. End-user actions and behaviors

Analysis of the extant body of literature examining end-user actions and behaviors allowed us to identify several damaging activities end users routinely commit, based on carbon emissions [12] (Table 2). These actions and behaviors are identified as having extremely high levels of CO_2e output and are considered eWaste [9]. These activities include, *(i) Privacy*, *(ii) Power Management*, *(iii) Laptops over Desktops*, and *(iv) Harmful Websites*. It is posited in this research that an absence of individual accountability for eWaste and excessive carbon output stems from a lack of education and awareness. By identifying user actions and behaviors causing the most ecological damage [29], and associated alternative actions with reduced CO_2e output, users will possess the knowledge and ability to reduce their carbon footprint, and reverse their negative activities contributing to the current climate crisis.

These identified activities are are occurring at an alarmingly high rate by corporations and end users while unintentionally causing massive climate damage. While the associated carbon output is concerning, this research indicates that most

Table 2. End-user actions and behaviors with excessive CO_2e.

	End-user actions or behaviors
(i)	Privacy
(ii)	Power management
(iii)	Laptops over desktops
(iv)	Computer software

users are unaware of the individual level of harm they are causing from their actions and behaviors.

3.4. Data collection procedure

The focal point of our research was discovering abusive and wasteful technological activities by corporations and end users. To identify the most harmful activities, by CO_2e output, our data sample focused on corporate and end-user actions and behaviors executed during normal business and computer activities. To ensure our data sample contained only valid data, to successfully and accurately identify current actions and behaviors being implemented by corporations and end users, we developed a custom, hybrid data collection model for use during the data collection and data filtering processes.

Identifying all relevant and related actions and behaviors event data for end users and corporations began first with determining eligibility for potential inclusion in the data sample. For reproducibility, and extending this research exploration to future research projects, it was paramount to maintain a process of data duplicability relating to all data collection and data analysis procedures within this investigation. Based on previous case study research within the extant body of literature [1–3, 6, 7, 9], we created a custom hybrid model for our data collection methodology based on the most successful data collection procedures identified and implemented by preceding authors in this domain. During data identification, collection, and filtering, the custom-designed five-step hybrid process was deployed to ensure that only relevant computational actions were kept for analysis.

Listed in Table 3 are the five procedural steps taken during execution of the custom hybrid process that ensured a valid sample of corporate and end-user actions and behaviors.

Table 3. Data collection and filtering steps.

STEP 1	Data identification
STEP 2	Data collection
STEP 3	Data filtering
STEP 4	Confounding data (removal)
STEP 5	Duplicate data (removal)

Sequential progression through the individual steps allowed the systematic and methodical completion of the data collection and data filtering processes and was necessary to build a complete and total data sample set for investigation in this study. Details for each of the individual steps are provided:

STEP 1 – ***Data identification***: using academic databases to identify research on computational actions. The online data(base) repositories we designated for examination include: ProQuest (PQ), ScienceDirect, and Web of Science (WoS). Each search query used only peer-reviewed, academic, and scholarly articles that align with our research objectives for behavioral actions. The results allowed us to compare and contrast eWaste output with climate abuse/degradation.

STEP 2 – ***Data collection***: using precedent outlined in previously conducted multiple case study research, we designated a specific series of keywords to refine the focal point of our search parameters for existing research falling under one or more of the keywords used. The keywords identified for use in this research include (1) privacy, (2) information systems, (3) climate crisis, (4) user behavior theory, (5) computer security, (6) carbon footprint, (7) information security (InfoSec), (8) eWaste, (9) green computing, (10) electronic cookies, (11) sustainable computing, and related domains. We expanded domains searched by including computer science, business, and eCommerce with technology, in addition to searching all relevant case study literature. A parallel search via Google was also utilized to identify any missed corporate eWaste abusers. For ensured inclusion, we further deployed the plus (+) identifier in an appended manner to each keyword search string using both the "and"/"or" operand selector designation to identify any potentially related data.

STEP 3 – ***Data filtering***: necessary for ensuring only eligible corporate and end-user action and behavior data remained within the data set. Data identified and collected as abusive eWaste activities was further subdivided into two groups: "Corporate" and "End User."

STEP 4 – ***Confounding data***: removal of all confounding data. Confounding data is "*similar actions causing eWaste output*" that occur during, or around, the same time as the eWaste action or behavior being investigated insomuch that the confounding action or behavior may be misassigned as the action/behavior of interest instead of the isolated action/behavior being investigated. In addition, offending eWaste actions and behaviors related to the *Green Computing 4G's* are excluded. These specified actions and behaviors fall outside of the Information Technology (IT) sector and are not applicable for study inclusion within this research.

Confounding events were accounted for by implementing a dedicated time buffer; a period of time −1-Day *before* the identified action/behavior event of interest ($t = -1$), and 1-Day *after* the identified action/behavior event of interest ($t = 1$) (see figure 1). Eliminating research containing confounding actions and behaviors similar in nature, as well as actions and behaviors related to the *Green Computing 4G's*, is necessary as they present difficulty in identifying the true (relevant) source of carbon emissions and could undermine results of the study.

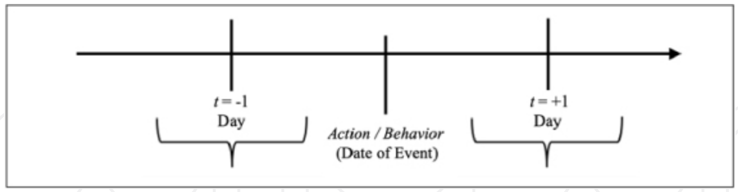

Figure 1. Controlling for confounding data.

STEP 5 – ***Duplicate data***: removal of all duplicate action and behavior event data while still maintaining the oldest data source for research examination. Using the custom hybrid model during the data collection and data filtering processes allowed us to identify and collect a complete, uncontaminated data set of all related and relevant action and behavior event data while maintaining data integrity.

To enable the successful completion of our study, data identification, collection, and filtering were completed in multiple stages. Using a framework based on a *Multiple Case Study* design, we created a new data artifact specifically for this research study that was necessary for ensuring all relevant data was collected. Furthermore, using our custom-designed hybrid process model enabled a complete sample dataset free from data corruption and errors.

3.5. Identification of data sample – actions and behavior(s)

In our research, we focused our literature review across the Technology domain as a whole, with in-depth analysis across multiple disciplines, including privacy, green computing, information system science and technology, cybersecurity, sustainable computing, and various climate domains to ensure an exhaustive sample that included all related and relevant data.

To achieve our objectives, we investigated actions and behaviors contributing the most to the climate crisis through eWaste and excessive emissions. To determine which actions and behaviors are associated with producing the most eWaste, determined by excessive carbon output, we needed to calculate (numerically) the CO_2e output for actions and behaviors.

Computation and extrapolation of all identified (and projected) CO_2e output and emission levels (eWaste) for identified actions and behaviors associated with a corporate or end-user event in this investigation were completed using calculation and formula information presented by Cucchietti *et al.* [5], and from the International Energy Agency using the following calculation (formula) [34]:

$$475 \text{ grams of } CO_2 * (\text{Number of kWh}) = \text{Total } CO_2e \text{ Output.} \quad (1)$$

Abusive corporate actions and behaviors (by CO_2e waste)

(1) ***Corporate virtualization*** – Virtualization allows a corporation to run more than one instance of an Operating System (OS) on a single piece of hardware, maximizing efficiency [26]. Corporations not utilizing this technology are wasting energy by requiring multiple computers to run duplicate instances of the same OS and applications. An estimated 5.56 Wh (0.005 kWh) is consumed by a single data center server that is utilizing a power saver algorithm without server virtualization [26]. This equates to 2.64 grams of CO_2e output per server every 30 minutes [26]. Therefore, a single server within a data center emits 126.72 grams of CO_2e every 24-h [26]. This calculation does not include energy required to cool and maintain a single server, nor does it include the overall number of servers within a single data center [26].

(2) ***Inefficient software design*** – was discovered to cause excess carbon output due to increased energy consumption [2, 8]. Numerous corporate entities utilize software development teams to maintain and produce their products. On average, a single faculty member on a software development team consumes roughly 2.5 kWh, which can be translated into 1,187.5 g of CO_2e per hour [35]. This is significant due to the overall carbon footprint that developing a single software project produces [8]. Elements such as employee commute, project efficiency (i.e. meeting deadlines), available resources, and performance all contribute negatively to carbon emissions.

(3) ***Website abuse*** – is the process of corporations contributing excess eWaste through ineffective, old, and incompatible code requiring excessive overhead to run and manage [28]. Using the Green Web Foundation's Ecograder, we were able to calculate a website's overall carbon footprint. Taking from the top websites as stated by SimilarWeb, an online website analysis tool, and inserting their base Uniform Resource Locators (URLs) into Ecograder to evaluate their average total carbon output per month [36]. After inputting Google.com, Youtube.com, Facebook.com, Twitter.com, Instagram.com, Baidu.com, Wikipedia.com, Yandex.com, Yahoo.com, and Amazon.com, we calculated the average monthly CO_2e for these 10 sites [36]. We found that on average, these top sites output 5.81 metric tons of CO_2e at 1 million + page visits per month. Note that this calculation underestimates the total CO_2e, as these sites attain over 1 million page visits per month [37].

(4) ***Cookie tracking*** – stems from the use of corporate "Web Cookies" (cookies); invented in 1994 and designed to allow for the storage of user data between a web server and a client. More concerning, however, is the realization that cookies are inherently designed to TRACK and SPY ON end-users' computing habits, online activity, and internet preferences under the guise of convenience [7, 30]. Cookies consist of strings comprised of semi-colon-separated key-value pairs and have two general types: 1st party cookies and 3rd party cookies. 1st party cookies are stored by the domain that is currently displayed in the user's address bar and are often used by eCommerce applications to store items in a 'cart' between site visits. On the other hand, 3rd party cookies are cookies placed by a domain not currently displayed within the address bar. These cookies are utilized by data brokerage firms, online advertisers, and tracking applications [25].

Many sites use these cookies to track user data (i.e. shopping cart, preferences, etc.). Companies such as Google Analytics utilize 3rd party cookies to provide users with personalized ads relevant to topics they might be interested in [5]. Google Analytics currently has cookies present on over 550,000 unique websites [5]. In total, online advertising outputs 11 to 159 million tons of CO_2e [5]. As seen in Table 3, cookie tracking can contribute to 428.6 metric tons of CO_2e per month from cookie traffic within a single site (Netflix.com) [5].

A fascinating example demonstrating the negative impact that *Cookie Tracking* is having in real time is the "Carbolytics Project" by Moll *et al.* [5] (see figure 2). "Carbolytics is an interactive web-based installation that shows the average global cookie traffic in real time, or in other words, displays how cookies are parasitizing user devices to extract personal data and feed it into a massive yet obfuscated network of organisms" [5].

Figure 2. Carbolytics project.

Table 4 represents a categorical breakdown of corporate actions and associated eWaste CO_2e output emissions:

Table 4. Corporate actions and associated eWaste (CO_2e output and emissions).

	Actions	eWaste (CO_2e output emissions)
(i)	Corporate virtualization	~126.72 g/day
(ii)	Inefficient software design	~1,187 g/h
(iii)	Website abuse	~5.81 metric tons/month
(iv)	Cookie tracking	~428.6 metric tons/month

Abusive end-user actions and behaviors (by CO_2e waste)

(1) ***Privacy (cookies)*** – for end users, in terms of CO_2e output and eWaste, is associated with cookies (ad tracking) [7, 12]. As mentioned, end users are subject to being tracked by cookies on nearly every site they visit. This impacts not only users' privacy but also their carbon emissions. On average, when evaluating over 1200 different companies and their tracking cookies, there is an average traffic of 197 trillion cookies per month [5]. This equates to 11,442 monthly metric tons of CO_2e emissions, as seen in Table 3 [5].

(2) ***Power management*** – the lack of power management features was discovered to unnecessarily cause excess eWaste by end users [6, 11, 28, 35]. By becoming more aware of specific actions and behaviors possessing the potential for eWaste abuse, end users are able to take personal accountability for their carbon output and reduce their wasteful activities. Power Management is a category where end users can make positive changes in reducing their carbon footprint through a slight change in how they currently use their computing technology [6]. A standard desktop left idle with the monitor on, and power management features disabled, will consume an estimated 0.214 kWh [35]. This equates to 101.65 g CO_2e when utilizing formula (1).

(3) ***Laptops over desktops*** – is an area of contention in which users choosing desktop computers over laptops are doing so to the detriment of the environment via excess eWaste [25]. Computer manufacturers are dedicating corporate resources to making portable computers with more power, increased battery, and larger display sizes while reducing CO_2e eWaste [11, 25] by making varying sizes of laptop computers that are more acceptable to larger swaths of consumers. Laptop computers are also designed by corporations to omit less eWaste than their desktop counterparts. Laptops are also becoming more powerful, easier to shut down and reboot when not in use and offer reduced power-saving technologies that minimize carbon output (footprint) and monetary cost-of-use.

When comparing the electricity consumption of idle and busy laptops versus desktops, data show that overall, laptops produce less carbon emissions [35]. A desktop with monitor consumes an estimated 0.181 kWh [35] when used. Utilizing our formula and multiplying the estimated kWh by the 475 g of CO_2e results in 85.975 total CO_2e output. Meanwhile, a laptop being used consumes an estimated 0.049 kWh. Utilizing our formula translated the estimated kWh into 23.275 CO_2e output [35].

(4) ***Harmful websites*** – using websites that are not eco-friendly due to inefficient design and development. Through the use of "cookies," some browsers produce more eWaste while simultaneously violating end-user privacy [2]. In addition, frequenting websites that consume high levels of energy per page visit, due to inefficient development [28, 36, 37].

This inefficient development coincides with the previously mentioned ***Website Abuse*** under ***Corporate Actions***. These aspects draw excess energy usage that passes down to the end user and ultimately affecting their carbon footprint. Taken from the top websites, as stated by Similar Web and Ecograder, YouTube, Twitter, and Instagram lead to high levels of CO_2e per page visit [36, 37]. For example, if a user visits Youtube.com, they are accepting 1.169 g of CO_2e per page visit [37]. This does not include the time spent streaming videos from the platform, solely the loading of an individual page. Table 5 represents the categorical breakdown of end-user actions and associated eWaste CO_2e output emissions:

Table 5. End-user actions and associated eWaste (CO_2e output and emissions).

	Actions	**eWaste (CO_2 output emissions)**
(i)	Privacy (Cookies)	~11,442 metric tons/month (1200 Company sample)
(ii)	Power management disabled	~101.65 g/h
(iii)	Laptops over desktop	Laptop: ~23.275 g/h Desktop: ~85.975 g/h
(iv)	Harmful websites	YouTube: ~1.169 g/page visit

3.6. Data analysis

The main objective of a case study approach is to examine and analyze the nature of a specific item of research interest and its impact in a real-world setting. Moreover, the overreaching objective of a *Multiple Case Study* approach requires specific analysis of event data across a spectrum of domains. This methodology permits the collection of a vast amount of data points for independent analysis to determine their relevance to the research problem being investigated. Based on the successful use of a multiple case study methodology by previous researchers in the extant body of literature, a multiple case study was the most effective solution available to best achieve the objectives(s) of this research.

It is argued in this study that corporations and end-users' perceived lack of accountability, responsibility, and awareness of detrimental actions contributing negatively towards the climate crisis is the leading factor impeding positive change. On this basis, we posit that once these alternative sustainable actions are presented, corporations and end users will act ethically to help reduce their role in the current climate crisis. There were two objectives in this research examination: (1) identifying, discovering, and evaluating the carbon output of computational actions and behaviors from corporate entities and end users (2) introducing an alternative set of green, sustainable actions, and behaviors emitting less carbon output and reducing eWaste. To accomplish our research goals, data analysis was performed in multiple stages.

To enable the successful completion of our study, data identification, collection, filtering, and analysis were completed in multiple stages. Using a framework based on a *Multiple Case Study* design, we created a new data artifact specifically for this research study. Our custom hybrid design process required the completion of the following stages: (1) defining the problem, (2) identifying the data set for analyses and assessment, (3) discovering potential data sources to be used for data collection, (4) describing inclusion (filtering) parameters for identified data, (5) data collection (actions and behaviors for corporations and end-users), (6) CO_2e output and carbon assessment, and (7) presenting alternative actions and behaviors.

There were two goals for this research investigation; to examine in detail the environmental impact, eWaste output, and contributions that corporate and end-user actions and behaviors have on the ongoing climate crisis and to identify and present an alternative set of actions and behaviors for corporations and end users to implement that are sustainable and green, reduce eWaste output, and minimize their carbon footprint.

To accomplish the stated research objectives, exhaustive data analysis was conducted across multiple stages. First, secondary corporate data sources were analyzed to recognize computer actions that are most detrimental to the climate by the level of eWaste (CO_2e and carbon emissions output). Second, an alternative set of user actions was identified and evaluated to determine their individual climate output measured in terms of eWaste to compare and identify acceptable green computing actions. An exhaustive analysis was then completed to determine an acceptable level of safe computer usage action options for consumers matched against the previously identified alternative user actions. This competitive analysis ensured the newly identified actions and behaviors are ethical, sustainable, and green, while producing less overall eWaste. While reducing the overall user-level carbon footprint and eWaste output, the sustainability of these alternative user behaviors will be maintained with zero reduction in privacy or security concerns for end-users.

(1) ***Alternative corporate actions and behaviors***

(a) ***Corporate virtualization***

Allows a corporation to run more than one system at a time but causes massive eWaste. To minimize energy consumption within data centers, corporate entities can adopt server virtualization. Thus, leading to a decrease of 17.153 g of CO_2e emissions annually [26]. To put in perspective the overall impact this small change can have on reducing the current climate crisis, a large organization that is not utilizing cloud virtualization can save at least 40%–60% of CO_2e by switching solely to a cloud infrastructure [11].

(b) ***Inefficient software design***

Discovered to cause excess carbon output due to increased energy consumption [2, 8]. Minimizing onsite developers can reduce transportation carbon emissions. Ensuring project deadlines are being met will help minimize wasted labor hours, thus limiting carbon output per faculty. Lastly, requiring developers to ensure the software is performing as efficiently as possible will allow for decreased energy usage, thus reducing carbon emissions for both users and corporations [8].

(c) ***Website abuse***

Corporations contribute excess eWaste through ineffective, old, and incompatible code requiring excessive overhead to run and manage [28]. Improvements to website efficiency can decrease their overall carbon footprint. Such improvements can be done to the websites speed in which pages render, caching of static assets, setting explicit width and height of image elements, removal of unnecessary code, and hosting on a webserver using renewable energy sources [37].

(d) ***Cookie tracking***

Cookies are inherently designed to TRACK and SPY ON end-users' computing habits, online activity, and internet preferences under the guise of convenience [7, 30]. Alternatives to cookie tracking are currently lacking on a large scale, however Google has recently announced their intention to create what they call the "The Privacy Sandbox" [38], an in-development industry-wide initiative that will improve user privacy across the web and

Android Platform. This solution will limit the intrusive tracking of users and provide safe alternatives to existing technology by removing 3rd party cookies from Chrome browser in 2023 [38]. This initiative will not only increase user privacy but will also decrease the overall energy consumption and CO_2e emissions of current cookie tracking [5] and [38]. Although it is unclear the impact "The Privacy Sandbox" will have on the environment, it can be assumed that a decrease in third-party cookies will lead to a decrease in energy consumption caused by said cookies; leading to a reduction in atmospheric CO_2e output [5] and [38].

(2) ***Alternative end-user actions and behaviors***

(a) ***Privacy (cookies)***

The concern for end users, in terms of CO_2e output and eWaste emissions, is associated with cookies and ad tracking [7, 12]. Alternative actions users can take to lessen their cookie carbon footprint would be to reject all non-essential cookies when browsing websites. Oftentimes, there will be a box that appears on screen, asking the user to accept the site's cookies, and usually designed in a way where it appears that the "Accept All Cookies" button is the only option. However, there is usually an additional button present that allows you to reject all non-essential/non-functional cookies as well.

(b) ***Power management***

Bad practices cause unnecessary emission of excess eWaste by end users, associated with normal computing tasks when interacting with technology devices [6, 11, 35]. One alternative solution would be to enable the power management features within the desktop device. Standard power management features may trigger the monitor to enter low-power sleep mode after about 15 min of inactivity, and the computer to enter sleep or hibernate mode after about 30 min of inactivity. Enacting these features will result in an estimated 1,554.30 kWh saved annually, the equivalent to reducing 738,292.50 g of CO_2e emissions annually [39]. Additional examples of *Power Management* alternatives include: (1) turning off the computer, monitor, and printers when not in use, (2) turning off external peripherals when not used, and (3) powering off mobile devices when not in use or no longer being used (i.e., tablets, Nintendo Switch, etc.) [6].

(c) ***Laptops over desktops***

An area of contention where users are choosing desktop computers over laptops, to the detriment of the environment via excess eWaste [25]. Alternative options exist for end users, including utilizing a less power-hungry laptop over a desktop whenever possible. In order to be as green as possible, it would also be beneficial for an end user to use a laptop certified by Energy Star; usually denoted by their *Star* insignia [3]. Energy Star is designed to promote and recognize energy efficiency within technology and climate control equipment [3].

(d) ***Harmful websites***

Alternative actions to avoid excessive carbon output include limiting time spent on harmful websites, limiting visits to said websites, and advocating for more eco-friendly websites.

4. Findings

The final sample contained a series of actions and behaviors of corporations and end users discovered to be causing the most damage to the climate crisis. Identification of activities expelling the most carbon eWaste was essential in achieving our research objectives, presenting an alternative set of actions and behaviors that can be implemented by corporations and end-users to reduce their overall carbon footprint (eWaste) while maintaining data integrity and privacy.

4.1. Alternative actions and behaviors

Harmful user actions and behaviors were identified for corporations and end users, based on level of carbon output (eWaste) [8, 10]. We then investigated the data to determine a series of alternative, green, and sustainable actions and behaviors to reduce carbon output, minimize eWaste, and maintain privacy.

(1) ***Alternative actions and behaviors for corporations***

Organizations have a moral obligation to account for their direct impact on the climate crisis. This equates to accepting responsibility for excess carbon output (eWaste) they produce while simultaneously making plans for becoming *"carbon neutral"* (eliminate eWaste output). In this study, we identified a list of actions and behaviors associated with excess corporate eWaste; based on CO_2e emissions (Table 3). In furtherance of our research objectives, we then present a list of alternative user actions and behaviors below that: (1) produce less eWaste, (2) are sustainable and green [19], and (3) reduce their carbon footprint.

Table 6 represents the breakdown of corporate actions and behaviors with identified alternative green and sustainable actions or behaviors to reduce eWaste CO_2e output:

Table 6. Corporate actions and behaviors with alternative green and sustainable actions or behaviors.

	Actions and behaviors	Alternative actions or behavior (green and sustainable)
(i)	Corporate virtualization	– Switching to fully virtualized cloud computing servers
(ii)	Inefficient software design	– Minimize on-site developers – Minimize wasted labor by sticking to project deadlines – Ensure software energy efficiency
(iii)	Website abuse	– Improve page rendering speed – Cache static assets – Explicitly set the width and height of images – Remove unnecessary code – Host web server using renewable energy
(iv)	Cookie tracking	– Use cookie alternatives such as Google's "The Privacy Sandbox"

(2) ***Alternative actions and behaviors for end users***

End users produce an excessive amount of carbon output and contribute greatly to the climate crisis [10]. It is posited that users unwittingly contribute excess eWaste due to a lack of awareness and education of the actual amount of carbon dioxide equivalent (CO_2e) they are producing during their daily computer use. By providing end users with facts, figures, and knowledge regarding their contribution to climate degradation, we believe individuals will choose to make positive changes. Through our study, we first identified actions and behaviors users currently engage in causing high carbon output (eWaste).

Similar to corporations, end users have a moral obligation to account for their direct role in the climate crisis and making an active effort to become *"carbon neutral"* in their computing activities (reduction in eWaste output). After introducing the most abusive eWaste actions and behaviors, based on excess CO_2e emissions (Table 5), we present an alternative list of actions and behaviors individual end-users can take that will: (1) reduce eWaste output, (2) be more climate friendly as sustainable and green, and (3) minimize their carbon footprint.

Table 5 represents identified end-user actions and their associated eWaste CO_2e output emissions. In support of our research objectives, Table 7 represents end-user actions and behaviors with identified alternative green and sustainable actions or behaviors to reduce eWaste CO_2e output:

Table 7. End-user actions and behaviors with alternative green and sustainable actions or behaviors.

	Actions and behaviors	Alternative actions or behavior (green and sustainable)
(i)	Privacy (cookies)	– Reject all non-essential cookies – Occasionally clear browser cookies.
(ii)	Power management	– Enable power management features
(iii)	Laptops over desktop	– Using laptops when possible – Looking for Energy Star certified devices
(iv)	Harmful Websites	– Limit visits to harmful sites – Advocate for websites to become more eco-friendly

5. Conclusions

The main objective of this study was to analyze eWaste output for corporate behavior and individual actions. A secondary objective was to introduce alternative sustainable computational practices that can be adopted by both corporate entities and individual users without a loss of data integrity or privacy. The resultant research presented within this manuscript helps advance the fight against the climate crisis. By successfully identifying actions and behaviors causing the most damage to the environment, and simultaneously introducing a series of alternative ethical actions and behaviors that are sustainable and green, we offer a solution capable of reducing the negative impact on the environment through technology abuse without a loss of data integrity or privacy.

It is argued in this study that end users' perceived lack of responsibility and awareness of detrimental actions that contribute negatively towards the climate crisis is the leading factor impeding positive change. Once these alternative sustainable actions are presented, end users will be able to act and help reduce the current climate crisis.

This research was able to (1) identify abusive actions and behaviors by corporations and end-users, (2) quantitatively determine the magnitude and negative impact that specified corporate and end-user actions have on contributing to the raging climate crisis (based on CO_2e output and emissions), and (3) present a set of alternative, safe actions and behaviors that are both green and sustainable, that provide an opportunity to reduce their impact on the climate crisis.

5.1. Implications

As a contributing source of research reference, this multiple case study investigation adds to the extant body of literature across multiple disciplines. The resultant analysis serves as a basis for continued research exploration into how we can collectively work together to reduce our direct impact on the climate. In addition, this research also serves as a scientific reference resource for academics and researchers interested in better understanding how individual actions within the technology domain can have a devastating effect on the global fight against climate degradation. Future research opportunities exist to extend this research investigation to make further contributions in this domain, specifically founded in observing computing actions and behaviors for eWaste output.

5.2. Research limitations

This research adds to the body of literature across multiple disciplines and helps to bridge an identified research gap; identifying user actions and behaviors causing the most climate damage by carbon output (eWaste) and presenting an alternative set of green and sustainable actions. During the study, however, there were several limitations that present an opportunity for future research consideration: (1) Identifying additional sources for data aggregation will allow more refined accuracy levels when validating results, (2) developing more accurate models to calculate CO_2e output levels for actions and behaviors, and (3) creating a more robust methodology to determine user actions causing excess eWaste, will facilitate future green computing research with actionable results.

5.3. Research recommendations

Extending from the presented research limitations, it is recommended to continue this research stream exploring *Green Computing* and *Carbon Neutrality*. Research is needed to continue searching for more efficient and sustainable actions and behaviors to reduce the negative impact on the environment through education, awareness, and positive behavioral change.

5.4. Research summary

To better understand how we can help to reduce the climate crisis, this research investigation will examine user computing behaviors in detail to analyze and identify eWaste causing unknown catastrophic climate degradation. Countless individuals are oblivious to the damage and devastation being caused to the climate by even a single user. As the world we live in becomes more technologically based than ever before, the global impact on the planet has never been greater. This project will examine in great detail an end-user's normal computer usage and online security habits to identify where, how, and why they are generating excess eWaste. It is hypothesized that the resultant data collected will showcase support for our theory, positing that increasing consumer awareness of better computational practices can lead to positive actions to reduce the current climate crisis.

This research study utilized a multiple case study approach to satisfy the research objectives. First, secondary data sources were identified and analyzed to recognize actions and behaviors identified as most detrimental to the climate by the level of eWaste (CO_2e and carbon emission output). Second, additional user actions and behaviors were identified, evaluated, and quantitatively measured to determine their individual CO_2e output. Once assessed, we collectively identified an acceptable set of safe, alternative actions and behaviors that were ethical, sustainable, and green, to achieve the stated research object in this study. While simultaneously producing less eWaste and reducing the overall user-level carbon footprint and eWaste output, the new set of alternative actions and behaviors can be implemented and maintained with zero reduction in privacy or security concerns for users. Results from this study contribute to the extant body of literature across multiple disciplines, including privacy, green computing, information system science and technology, cybersecurity, and climate control.

Conflict of interest

The authors declare no conflict of interest.

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