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# ASSESSMENT OF THE PRODUCT CARBON FOOTPRINT OF OFFICE EQUIPMENT ACROSS THE ENTIRE LIFE CYCLE

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ABSTRACT: Purpose: The aim of the article is to publicise the issue of carbon footprint emission from office equipment because this problem is not yet widely recognised in the ICT industry. Methodology/approach: The product carbon footprint (PCF) of various information and communication technologies (ICT) was assessed - 196 products of 12 groups representing a broad spectrum of office equipment - covering the entire life cycle (LCA) from production to disposal. Findings: The level of carbon footprint of a given office device depends on its size, including its energy demand. It should be noted that although smaller devices individually have a smaller carbon footprint, due to their common use (many pieces), they may generate emissions similar to larger ones. Originality/value: The results of the carbon footprint statistics of ICT devices included in the result section may constitute valuable input for companies to calculate the carbon footprint in offices. They can also be used as a data set for the carbon footprint calculator of ICT devices.

KEYWORDS: Product Carbon Footprint (PCF), Information and Communications Technology (ICT), Life Cycle Assessment (LCA), corporate social responsibility (CSR), office equipment

## Introduction

The integration of corporate social responsibility (CSR) into the operational fabric of businesses has become a critical focus in contemporary corporate strategy, particularly in the context of environmental sustainability. This study explores the intersection of CSR and environmental sustainability, with a specific emphasis on the product carbon footprint of office equipment. In this regard, it is crucial to consider the broader context of how environmental policies influence corporate practices, especially within the framework of the European Union's aggressive climate strategies. The article (Chovancová et al., 2020) provides essential insights into the interconnected dynamics of energy consumption, economic growth, and $CO_2$ emissions. This relationship underscores the importance of integrating environmentally sustainable practices within corporate strategies to not only comply with regulatory standards but also to contribute to the broader goal of achieving carbon neutrality. As the EU moves towards becoming the first carbon-neutral continent, understanding these dynamics becomes even more critical for businesses aiming to align their operational strategies with sustainable practices, thus reducing their environmental impact while supporting economic growth. The authors conducted a focused bibliometric analysis using the Web of Science Core Collection, employing the following search criteria: ALL=((carbon footprint OR Sustainable Development OR Environmental Management OR Workplace Ecology OR Office Energy Consumption OR Corporate Environmental Responsibility OR Green Office Technology OR CO2 Emission Reduction OR Workplace Environmental Footprint OR Eco-Efficiency OR Sustainable Office Practices) AND (office equipment OR Product Life Cycle OR Life Cycle Assessment (LCA) OR Electronics and Environment)). The results are depicted in Figure 1.

The analysis was conducted using VOSviewer, a bibliometric visualisation tool that facilitates the mapping of relationships based on data extracted from scientific publications. This method allows researchers to discern patterns and trends within specific fields of study. The authors initiated their analysis by gathering data from the Web of Science Core Collection, employing an elaborate array of search terms that bridged environmental sustainability with office equipment usage. These terms included "carbon footprint", "Sustainable Development", "Environmental Management", and "Office Energy Consumption", among others, thus ensuring a thorough exploration of the literature pertinent to corporate social responsibility (CSR) and environmental impact.

The scope of the study was confined to publications from the years 2019 to 2024 across disciplines such as green sustainable science technology, environmental sciences, and several other relevant fields, aligning the research with the contemporary discourse in CSR and sustainability. Furthermore, the inclusion criteria were refined to encompass only those studies that addressed Sustainable Development Goal 12, focusing on responsible consumption and production, thereby integrating the research within a global sustainability framework.

Employing VOSviewer, the authors performed a co-occurrence analysis to determine the frequency and patterns of terms appearing together within the literature. This process initially identified 727 keywords, but the raw data was filtered by applying a threshold of a minimum of 5 occurrences of a keyword. Subsequently, the analysis produced 179 items, organised into 13 clusters, and revealed 1085 links, indicating the interconnections among these terms. The thickness of these links is directly proportional to the frequency of term co-occurrence, thus providing a visual representation of how often specific terms are discussed together. Such visualisations reveal which concepts are most commonly associated within the field, indicating the interdependencies and commonalities in research discussions about CSR and environmental sustainability.

Through the co-occurrence analysis, key interconnections between terms such as "ICT" and "sustainability impact" or "energy performance" were identified, underscoring the interrelation of these areas in achieving environmental sustainability in office settings. The frequency of keywords and the robustness of their connections offer insights into the prevailing discussions within the field. Dominant themes identified through such links suggest focal areas in integrating CSR into business operations, particularly in relation to environmental sustainability.

The insights garnered from this bibliometric analysis using VOSviewer extend beyond mere keyword associations, providing a nuanced understanding of how CSR integration and environmental strategies are perceived and implemented within the corporate sector. This analysis illuminates the prevalent trends and potential gaps in the current research, guiding future investigations towards

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areas that might benefit from deeper exploration and development. Thus, the methodological approach not only enhances comprehension of the existing research landscape but also strategically informs future scholarly endeavours, aiming to fortify the integration of sustainable practices within corporate operational frameworks.

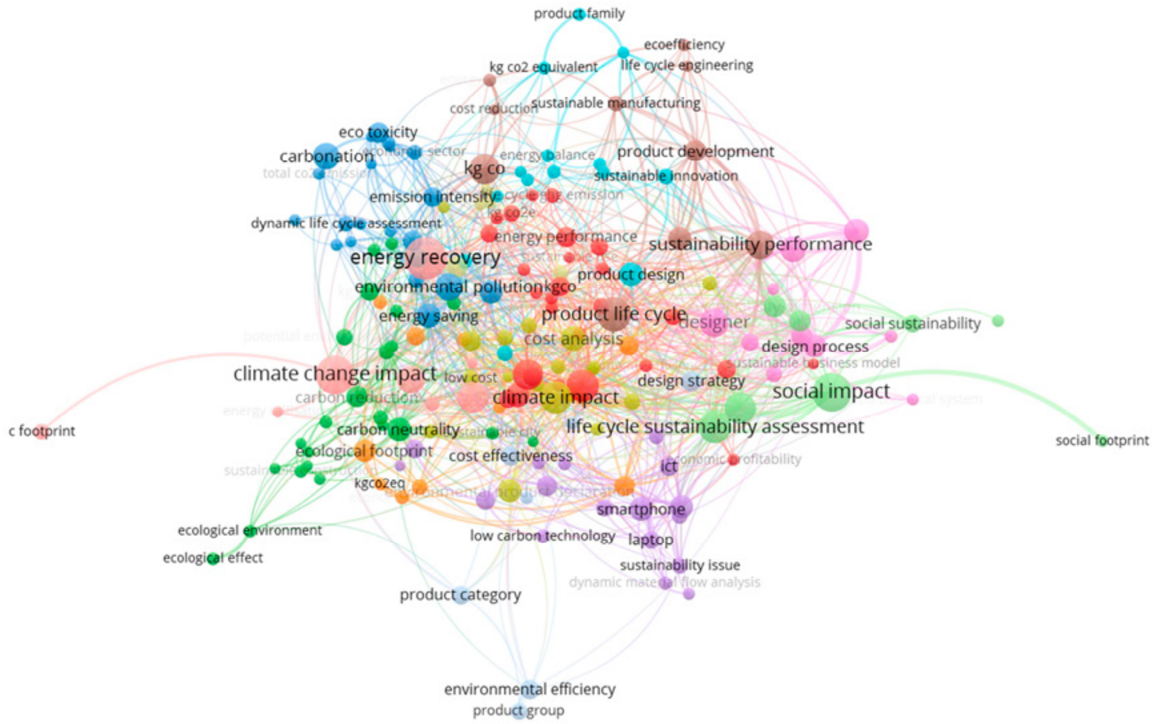


Figure 1. Research background – results from Web of Science search by VOSViewer

The authors position their work within a framework illustrated in Figure 2, exploring the interconnectedness of Information and Communications Technology, sustainability impact, energy performance, and social sustainability. ICT equipment is itemised in Annex A-6, Section II, "Capital Outlays", under "Office Equipment, Furniture and Fixtures", which details items such as desktop computers, mobile devices, tablets, printers, scanners, projectors, projector screens, and other necessary office productivity tools, including network devices like switches, routers, and power supplies.

The paper underscores the significant technological transformations affecting the carbon footprint across the lifecycle of office equipment. A compelling instance is cited from an Energy Star report on office equipment, which claims that if every home office product purchased in the U.S. this year were ENERGY STAR certified, it could prevent 1.5 billion pounds of greenhouse gas emissions – equivalent to the emissions from 158,000 vehicles – and save over $117 million in annual energy costs.

This research provides an overview, acknowledging that the application of ICT equipment varies significantly; some sectors use it minimally, while others are highly dependent. Furthermore, the usage intensity can differ greatly, ranging from occasional use to nearly continuous operation in shift-based offices. This disparity can be observed in the contrast between industries like manufacturing and service-oriented sectors. For instance, in the manufacturing sector, ICT plays a crucial role in facilitating e-logistics, optimising supply chain management, and enhancing operational efficiencies. According to the article (Tokarski & Bielecki, 2024), the implementation of ICT in manufacturing not only supports logistical operations but also drives innovation and competitive advantage. Through this analysis, the authors aim to convey a general perspective on how ICT equipment can impact environmental outcomes and how shifts towards more energy-efficient and lower-carbon footprint products could influence office environments.

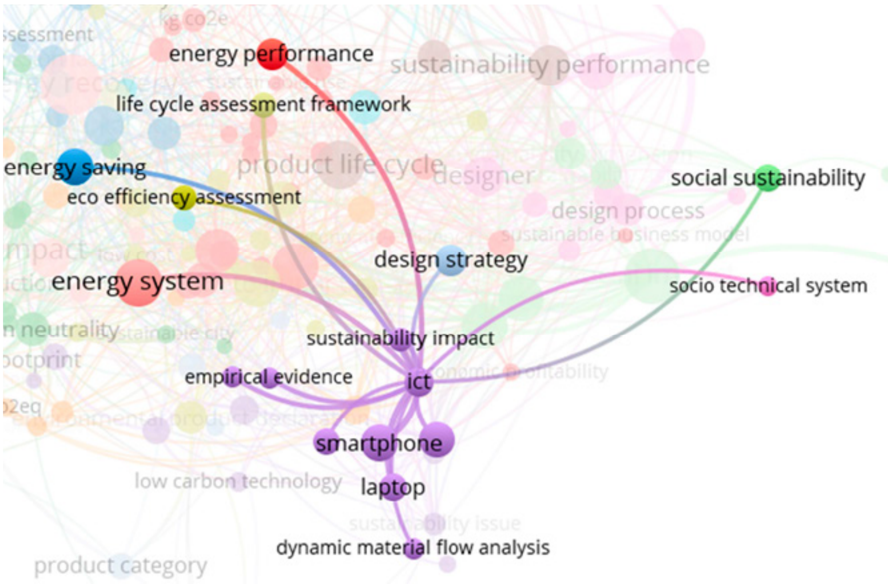


Figure 2. Interconnections between ICT and sustainability – results from Web of Science search by VOSViewer

The field of Corporate Social Responsibility (CSR) is evolving rapidly, highlighting the need for more extensive research. Such research should not only focus on CSR strategies across enterprises as a whole but should also delve into specific elements of their operations that directly impact the environment. In the context of technology used in office settings, as noted in the article (Kozáková et al., 2024), there is an urgent need to pay greater attention to the environmental impacts of these technologies. Also, challenges posed by climate change and the need for sustainable business practices are escalating (Guziana & Dobers, 2013; Kimani et al., 2020). This relatively underexplored area in CSR strategies requires deeper understanding and analysis. Advancing this research will enable companies to implement sustainable practices more effectively and contribute to a better comprehension of how technology can support environmental goals without compromising natural resources.

## An overview of the literature

The concept of CSR has evolved significantly over the years, expanding from a focus on ethical business practices to encompassing a broader commitment to environmental sustainability (Chebaeva et al., 2021; McAloone & Pigosso, 2017). This evolving landscape necessitates a comprehensive understanding of the environmental implications of information and communication technology (ICT) in business operations, particularly in the context of office equipment (Chinn & Fairlie, 2007; Choi & Yi, 2018; Kaware & Sain, 2015; Zheng & Wang, 2021).

The concept of the carbon footprint, particularly the PCF, has emerged as a critical metric for assessing the environmental performance of products and services. This aligns with the broader shift in environmental management standards, as seen in the development of ISO 14067 and similar standards, which emphasise product-level carbon footprints (Pattara et al., 2017; Rondoni & Grasso, 2021; Wiedmann & Minx, 2007; Wright et al., 2011). Our study contributes to this discourse by focusing on the PCF of office equipment, thus providing insights into the environmental impact of these products across their lifecycle.

Furthermore, the importance of sustainable innovation in the context of Industry 4.0 is also a critical aspect of this study. The digital industrial transformation offers opportunities for addressing sustainability concerns in industrial operations (Luthra et al., 2020; Massaro et al., 2021). This research explores how the principles of Industry 4.0 can be leveraged to promote sustainable innovation in the manufacturing of office equipment, thereby contributing to the reduction of their carbon footprint (Awan et al., 2021; Cillo et al., 2019).

The study acknowledges the role of life cycle assessment (LCA) as a well-established methodology for evaluating the environmental impacts of products. The integration of IoT technologies in LCA

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offers a novel approach to assessing the PCF of office equipment, providing more accurate and real-time data (van Capelleveen et al., 2018; Fu et al., 2018; Tao et al., 2014). Life Cycle Assessment (LCA) is an advanced methodology used to evaluate the environmental impact of products or services throughout their entire life cycle. From raw material extraction, through production and distribution, to usage, and finally recycling or disposal, LCA provides a comprehensive picture of environmental impact. It consists of several key stages: defining the goal and scope, life cycle inventory (LCI), life cycle impact assessment (LCIA), and interpretation of results. LCA is particularly useful in the context of Product Carbon Footprint (PCF), which measures the amount of greenhouse gases emitted by a product throughout its life cycle, expressed in carbon dioxide equivalents (CO2e). By applying LCA to calculate PCF, a more accurate and comprehensive understanding of a product's environmental impact can be achieved. This allows for the identification of life cycle stages that contribute most significantly to greenhouse gas emissions and the development of strategies to reduce these emissions, which is crucial for achieving sustainable development goals.

In summary, this study provides a comprehensive analysis of the PCF of office equipment situated within the broader context of CSR, sustainable innovation, and environmental management. By integrating insights from various strands of literature, this research contributes to the understanding of how businesses can align their operations with sustainability goals, particularly in the context of the evolving digital and environmental landscape. The findings underscore the importance of considering the full lifecycle impact of office technologies in CSR strategies, highlighting the role of businesses in fostering sustainable development through informed decision-making. This study not only adds to the academic discourse on the environmental impact of office technologies but also offers practical insights for businesses striving to integrate sustainability into their operational practices. The comprehensive dataset of 196 office products, categorised into 12 distinct types, provides a broad overview of the PCF across different categories of office equipment, offering insights into the variations in environmental impact within this product segment. This approach is particularly relevant given the findings of (Chebaeva et al., 2021; Gaubinger & Rabl, 2013), who highlight the importance of integrating sustainability considerations into the technology development process. Our study, therefore, responds to the call for greater corporate accountability in environmental stewardship and supports businesses in making informed decisions that align with their CSR objectives and broader societal and environmental goals.

Faced with global challenges in sustainable development, our research focuses on understanding how sustainability management, corporate social responsibility, sustainable production and logistics practices, as well as Industry 4.0 technologies, can contribute to achieving a balance between economic growth, environmental safety, and social equity. Our goal is to ensure that current developmental activities do not limit the ability of future generations to meet their needs while simultaneously promoting progress in achieving the United Nations Sustainable Development Goals.

## Research methods

In the quest to foster sustainable business practices and reduce the environmental footprint of office equipment, a systematic approach to assessing the lifecycle environmental impacts of these products is crucial. This study employs the lifecycle environmental impact assessment research algorithm for office equipment (Figure 3), a robust methodology that integrates data collection from multiple reliable sources, including direct data from product manufacturers, third-party environmental databases, and extensive literature reviews. The comprehensive data gathered covers detailed specifications, energy efficiency, and emissions across the production, operation, and disposal phases of 196 products in 12 distinct categories.

The main objective of this research is to utilise the algorithm to calculate the Product Carbon Footprint (PCF) in terms of kilograms of $CO_2$ equivalent (kg $CO_2$e) for each product. This involves a detailed analysis that not only establishes average, minimum, and maximum PCF values for each category but also explores the variability among products within the same category. By employing a lifecycle assessment approach, the algorithm meticulously evaluates the environmental impacts from the production to the disposal stages of office equipment.

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The findings from this research, derived from the application of the lifecycle environmental impact assessment algorithm (Figure 3), are intended to inform and influence the procurement strategies and product designs of businesses and manufacturers, guiding them towards more environmentally responsible decisions. This introduction sets the stage for a deep dive into the workings of the algorithm, interpreting the results, and discussing the broader implications for sustainability in the industry.

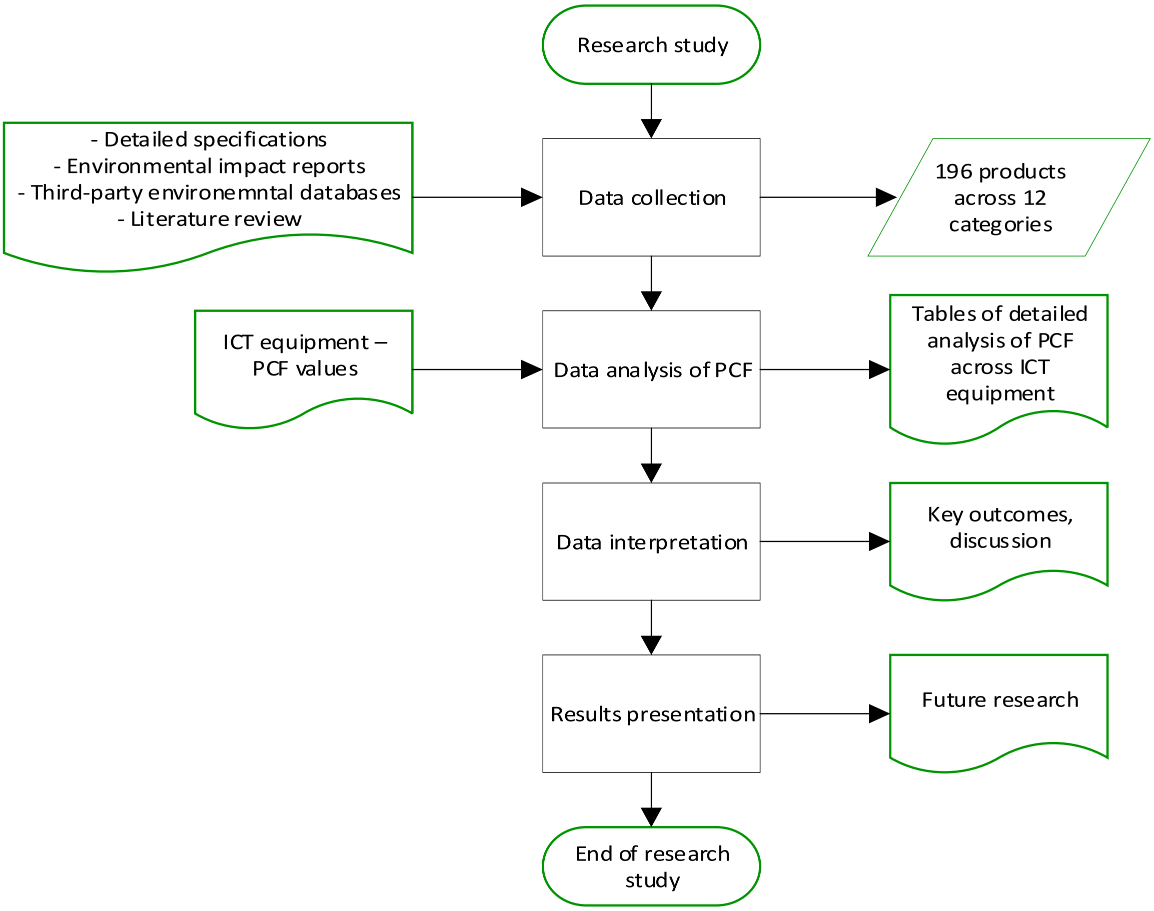


**Figure 3.** Lifecycle environmental impact assessment research algorithm for office equipment

## Data Collection and Analysis: Comprehensive and Expanded Overview

The primary objective of this study was to conduct a thorough assessment of the Product Carbon Footprint (PCF) of various office equipment, a crucial factor in understanding their environmental impact. This assessment is particularly vital in the context of corporate social responsibility (CSR) and sustainable business practices, offering insights into both the direct and indirect environmental implications of these devices, which are ubiquitous in modern office settings. To achieve this comprehensive assessment, the data collection methodology was expanded to include several key components:

Product Manufacturer Information: Detailed specifications and environmental impact reports were sourced directly from product manufacturers. This step involved gathering data on materials used, energy efficiency, and emissions during the production and operation phases, providing a foundational understanding of each product's environmental impact.

Examples of used product manufacturer information:

- https://www.asus.com/content/product-design-manufacturing/
- https://support.hp.com/us-en/products
- https://www.lg.com/global/greener-products-application

Third-Party Environmental Databases: The study utilised recognised databases that track product lifecycle impacts. These databases provided standardised and peer-reviewed data, ensuring consistency in the measurement of PCFs across different products and adding a layer of verification to the manufacturer-provided information.

Examples of used third-party environmental databases:

- https://epeat.net/
- https://www.environdec.com/
- https://www.energystar.gov/

Literature Review: A thorough review of academic and industry publications was conducted to supplement and cross-verify the data obtained. This review was particularly focused on establishing the PCFs related to the disposal and recycling phases of the products, areas often underreported in manufacturer data.

Examples of used literature:

- https://greenly.earth/en-gb/ressources/barometer-carbon-footprint-2022
- https://greenly.earth/en-gb/ressources/life-cycle-assessment-infographic
- https://link.springer.com/article/10.1007/s00170-021-07980-w

### Data Analysis and Interpretation

Data were meticulously collected for 196 products across 12 distinct groups, representing a broad spectrum of office equipment. Each product's PCF was calculated in kilograms of $CO_2$ equivalent (kg $CO_2$e), covering the entire lifecycle from production to disposal. This lifecycle assessment approach ensured a comprehensive evaluation of environmental impact, avoiding a narrow focus on just one phase of the product's life.

The data were then analysed to determine the average, minimum, and maximum PCF for each category. This detailed analysis was instrumental in identifying not just the typical environmental impact of each category but also the range of impact. It highlighted the diversity in design, manufacturing processes, and energy efficiency among different models and brands within each category. Such detailed analysis is crucial for pinpointing specific areas where improvements can be made to reduce the carbon footprint.

The results of this analysis are presented in a tabular format, providing a clear and concise overview of the findings. This format effectively conveys complex data in an accessible manner, allowing for easy comparison and interpretation. The table details the average, minimum, and maximum PCF values for each category, along with the number of products analysed. This presentation not only highlights the overall trends in PCF across different types of office equipment but also draws attention to the variability within each category.

By providing a comprehensive view of the PCF associated with a wide range of office equipment, this study offers valuable insights for businesses and organisations. It guides them in making more environmentally responsible choices in their office technology procurement strategies. The findings can inform decisions towards products with lower carbon footprints and can also be used to identify priority areas for innovation and improvement in product design and manufacturing processes. Ultimately, this research contributes to the broader goal of reducing the environmental impact of office operations, aligning with the principles of CSR and sustainable development.

## Research Implications and Future Directions

The study's findings have significant implications for businesses seeking to enhance their environmental sustainability. By identifying the products with the highest and lowest PCFs, companies can prioritise their efforts to replace or upgrade the most impactful equipment, thereby making a more substantial contribution to reducing their overall carbon footprint. Additionally, the insights gained from this research can be instrumental for manufacturers in the office equipment industry, highlighting the areas where sustainable design and production can be improved.

Furthermore, the study opens avenues for future research, particularly in exploring the effectiveness of various strategies to reduce the PCF of office equipment. This could include investigating the

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lifecycle impacts of emerging technologies, assessing the benefits of recycling and refurbishment programs, and exploring consumer behaviour's role in the equipment's environmental impact.

In conclusion, this comprehensive and expanded analysis of the PCF of office equipment provides a valuable resource for understanding the environmental impact of these essential devices. It offers a foundation for both businesses and manufacturers to make informed decisions that contribute to a more sustainable future, aligning with CSR objectives and broader global sustainability goals.

## Results of the research

The data presented here indicate significant differences in the carbon footprint (PCF) of various types of office equipment. Copiers exhibit the highest average carbon footprint, which could be attributed to their size, complexity, and intensive use in office environments. On the other hand, smaller devices like USB drives/DVDs, computer mice, and webcams have a considerably lower average carbon footprint, reflecting their smaller sizes, simpler construction, and potentially less intensive usage.

This table (Table 1) presents a comprehensive analysis of the Product Carbon Footprint (PCF) for various categories of office equipment. It details the average, minimum, and maximum PCF values in kilograms of $CO_2$ equivalent (kg $CO_2e$) for each category, alongside the number of products analysed. This data provides a nuanced view of the environmental impact of each type of office equipment, from the most commonly used devices like copiers and printers to less considered items like webcams and USB drives. The inclusion of a range of PCF values (minimum to maximum) for each category offers a deeper understanding of the variability in environmental impact within each type of equipment.

**Table 1.** Detailed Analysis of Carbon Footprint Across Office Equipment Categories: Average, Minimum, and Maximum PCF Values

| Category of Device | Average Carbon Footprint (PCF, kg $CO_2e$) | Minimum Carbon Footprint (PCF, kg $CO_2e$) | Maximum Carbon Footprint (PCF, kg $CO_2e$) |
|---|---|---|---|
| Copier | 3246.53 | 1200.00 | 16100.00 |
| Printer | 1886.82 | 231.40 | 3236.35 |
| Desktop Computer | 1076.02 | 140.10 | 3248.00 |
| Laptop | 359.44 | 131.82 | 1600.00 |
| Monitor | 179.43 | 66.19 | 460.00 |
| Multimedia Projector | 113.69 | 83.18 | 182.93 |
| Mobile Phone | 36.33 | 7.00 | 79.90 |
| Keyboard | 14.49 | 4.02 | 31.60 |
| Headset | 5.77 | 1.62 | 7.14 |
| Computer Mouse | 5.51 | 1.45 | 22.00 |
| Webcam | 5.43 | 1.28 | 7.00 |
| USB Drive/DVD | 1.77 | 1.28 | 2.29 |

It is noteworthy that the largest discrepancies between the minimum and maximum carbon footprints are observed in the categories of copiers and desktop computers. This may suggest a wide variety of models and technologies used in these devices, leading to differences in their environmental impact. For instance, more modern copiers and desktop computers might be more energy-efficient and produce less $CO_2$ emissions throughout the product's life cycle.

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**Table 2.** Detailed Analysis of Carbon Footprint Across Office Equipment Categories: Average, Relative and Ratio PCF Values

| Product Category | Average Carbon Footprint (PCF, kg $CO_2$e) | Relative Carbon Footprint (% of Copier) | Equipment Ratio to Copier Quantity |
|---|---|---|---|
| Copier | 3246.53 | 100.0000% | 1.00 |
| Printer | 1886.82 | 58.1181% | 1.72 |
| Desktop Computer | 1076.02 | 33.1437% | 3.02 |
| Laptop | 359.44 | 11.0715% | 9.03 |
| Monitor | 179.43 | 5.5268% | 18.09 |
| Multimedia Projector | 113.69 | 3.5019% | 28.56 |
| Mobile Phone | 36.33 | 1.1190% | 89.36 |
| Keyboard | 14.50 | 0.4466% | 223.90 |
| Headset | 5.77 | 0.1777% | 562.66 |
| Computer Mouse | 5.51 | 0.1697% | 589.21 |
| Webcam | 5.43 | 0.1673% | 597.89 |
| USB Drive/DVD | 1.77 | 0.0545% | 1834.20 |

Analysing the data from Table 2, we can derive several interesting points regarding the carbon footprint and equipment distribution in a modern enterprise:

- Copiers: With the average PCF of 3246.53 kg $CO_2$e, copiers stand as the reference point, representing the most significant single-device impact on carbon emissions within office technology. Their ICT equivalence ratio is 1, signifying that all other equipment's carbon footprint and ICT value are compared against this central unit.
- Printers: With a PCF at 58.1181% of the copier's emissions, printers have an ICT equivalence ratio of 1.72. This indicates that in terms of carbon footprint, one copier is equivalent to about 1.72 printers. While this reflects a significant environmental impact, it also underscores the necessity of printing technology in business operations, balancing ecological considerations with operational needs.
- Desktop Computers: Desktops have a PCF of 33.1437% compared to the copier, with an ICT equivalence ratio of 3.02. The ratio suggests that three desktop computers have a combined carbon footprint similar to that of a single copier. This highlights the relative efficiency of desktops and their importance in the workplace, especially considering their robustness for a variety of tasks.
- Laptops: Laptops stand out for their low PCF, which is just 11.0715% of the copier's footprint, and a high ICT equivalence ratio of 9.03. This means the carbon footprint of nine laptops is comparable to one copier, illustrating the shift towards more energy-efficient, portable computing solutions in modern work environments.
- Monitors: Monitors have a PCF of 5.5268% relative to copiers and an ICT equivalence ratio of 18.09. The high ratio here indicates that you could have over 18 monitors for the carbon footprint of one copier. This could reflect the trend towards multi-monitor setups that enhance productivity without significantly increasing the carbon footprint.
- Multimedia Projectors: With a PCF of 3.5019%, projectors have an ICT equivalence ratio of 28.56, which is quite high. This suggests that despite their importance in presentation settings, projectors are relatively carbon-efficient, allowing for a high number of devices with minimal impact compared to a single copier.
- Mobile Phones: Exhibiting a minimal PCF of 1.1190% and an ICT equivalence ratio of 89.36, mobile phones represent an extremely carbon-efficient communication tool. The high ratio illustrates how mobile technology has become pervasive in the business sector, allowing for extensive deployment with relatively low environmental costs.

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- Keyboards, Headsets, Computer Mice, and Webcams: These peripherals have the lowest carbon footprints on the list, with ICT equivalence ratios ranging from 223.90 to 597.89. The extremely high ratios indicate that a vast number of these devices collectively match the carbon footprint of a single copier. This suggests that while essential for day-to-day operations, their individual environmental impacts are minimal, highlighting the potential for widespread use with a small carbon footprint.
- USB Drive/DVD: Standing at an ICT equivalence ratio of 1834.20 and a PCF of only 0.0545%, this category represents the most carbon-efficient group. The data shows that a very high number of these storage devices can be used with a negligible increase in carbon footprint, emphasising their role as sustainable tools for data storage and transfer.

The data illustrates a significant variance in the carbon footprint across different types of office equipment. It reveals a clear trend towards higher quantities of low-carbon-footprint devices, which aligns with a growing environmental consciousness in business practices. Copiers and printers, while essential, represent a major part of the carbon footprint and are less numerous. In contrast, items like mobile phones, peripherals, and storage devices, despite their high numbers, contribute much less to the overall carbon footprint. This suggests that strategies to reduce the carbon footprint in office environments could focus on optimising the use and efficiency of high-impact devices like copiers and printers while also taking advantage of the relative carbon efficiency of smaller, more numerous devices.

In this study, we present a column diagram (Figure 4) that visually represents the distribution of environmental impacts, as measured by the Product Carbon Footprint (PCF), across various categories of office equipment. The diagram is based on the percentage contribution of each category to the total PCF, offering a clear and concise visualisation of how different types of office equipment contribute to environmental concerns. This approach allows for an immediate grasp of the relative significance of each category in terms of its environmental footprint, providing a straightforward yet powerful tool for understanding the data.

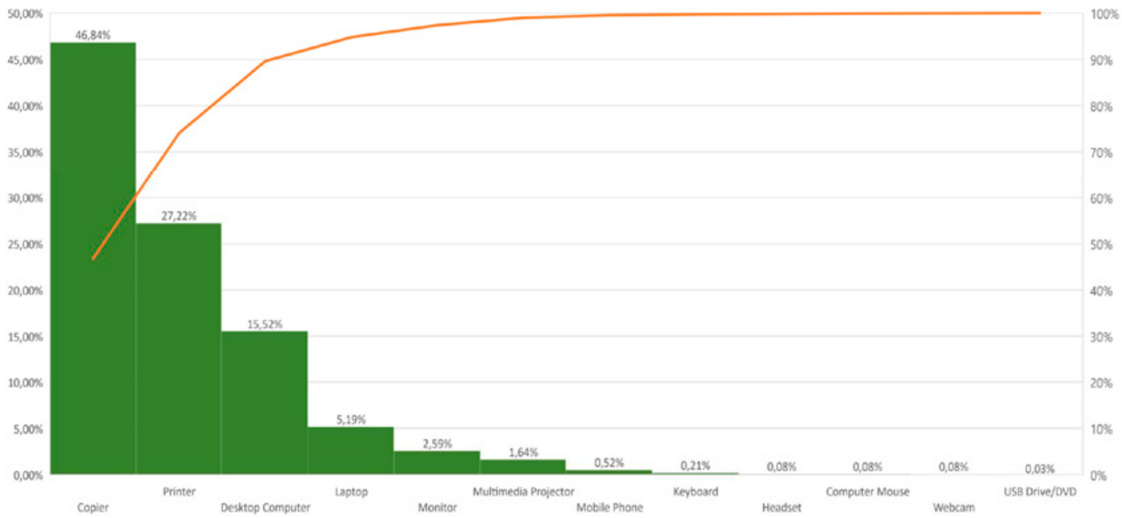


**Figure 4.** Comparative environmental impact of office equipment: a percentage distribution of product carbon footprint

The column diagram reveals some insightful trends:

- Dominance of Copiers and Printers: The most striking observation is the dominant environmental impact of copiers and printers, which together account for over 70% of the total PCF. Copiers alone constitute nearly half of the environmental impact (46.84%), while printers contribute an additional 27.22%. This significant share underscores the substantial role these devices play in office-related environmental footprints, likely due to their high energy consumption, complex manufacturing processes, and intensive use in office settings.

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- Comparatively Lower Impact of Computing Devices: Desktop computers and lap-tops, while essential in modern offices, have a comparatively lower environmental im-pact, contributing 15.52% and 5.19% respectively. This could be attributed to advancements in energy efficiency and a growing emphasis on sustainable design in the computing industry.
- Minimal Impact of Smaller Accessories: Interestingly, smaller office accessories like keyboards, headsets, computer mice, webcams, and USB drives/DVDs collectively contribute less than 1% to the total PCF. This minimal impact highlights the relative environmental friendliness of these smaller devices, possibly due to their smaller size, lower energy requirements, and simpler manufacturing processes.
- Role of Multimedia Projectors and Monitors: Multimedia projectors and monitors, contributing 1.64% and 2.59%, respectively, have a moderate impact. This could be related to their energy usage patterns and the materials used in their production.
- Implications for Sustainable Office Practices: The data presented in the column diagram have significant implications for sustainable office practices. Prioritising the reduction of environmental impacts from copiers and printers could be a strategic focus for businesses aiming to lower their overall carbon footprint. Additionally, the findings suggest that while focusing on larger equipment is crucial, attention should also be given to the cumulative impact of smaller devices over time.

In conclusion, the column diagram effectively highlights the varying degrees of environmental impact across different office equipment categories, providing valuable insights for businesses, manufacturers, and policymakers aiming to enhance sustainability in office environments.

This analysis emphasises the importance of CSR and sustainable development in the context of technological choices in offices. Companies aiming to reduce their carbon footprint and achieve sustainable development goals can use this data to inform their purchasing and investment decisions. By selecting equipment with a lower carbon footprint, businesses can contribute to the reduction of greenhouse gas emissions and promote more sustainable business practices.

Furthermore, in the context of the product life cycle, this data underscores the need to consider the total environmental impact of office equipment, from production to disposal. This approach aligns with the principles of Life Cycle Assessment (LCA), which allow for a more comprehensive understanding of the environmental impact of products. Companies can use this information to optimise their procurement strategies, choosing devices that are not only energy-efficient in use but also sustainably produced and easily recyclable at the end of their life.

In conclusion, this data provides valuable insights for companies striving to integrate sustainable development into their business operations, highlighting the role of responsible technological choices in achieving CSR and sustainable development goals.

## Conclusions and future research

This research evaluates the Product Carbon Footprint (PCF) of various office equipment and offers important insights into their environmental effects. The analysis shows a wide range of PCFs among different types of equipment, with larger items like copiers and desktop computers having higher PCFs compared to smaller items such as keyboards and USB drives. This variation supports prior findings that the environmental impact of office equipment is complex and influenced by size, energy use, and manufacturing methods. The diversity in PCFs highlights the variety in design and technology, underscoring the importance of sustainable design and production to mitigate environmental impacts.

The study underscores the need for a detailed approach to minimise the environmental effects of office activities. It suggests that businesses should integrate PCF considerations into their purchasing decisions and calls on manufacturers to focus on sustainable innovation in design and production. Our research sheds light on key aspects of sustainable development, offering practical guidance and new perspectives in the fields of sustainability management, corporate social responsibility, sustainable production and logistics, and the application of Industry 4.0 technologies. These findings represent a step forward towards building a more sustainable future, where economic growth coexists harmoniously with environmental protection and social well-being, in line with the spirit of the United Nations Sustainable Development Goals.

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Over time, the role of the office has evolved, undergoing dynamic changes. Currently, there are sectors where offices must be present. However, there are also sectors where offices are not utilised. Regardless of often economic decisions on whether to own an office or outsource it, office services still take place. Consequently, the actual location of the office service provision does not impact the extent of ICT equipment usage – it is used in both scenarios – hence, it is not a differentiating factor. A distinguishing factor that affects the level of carbon footprint emissions is the size of the specific office device, including its associated energy demand. Generally, the rule is as follows: larger ICT devices generate a larger carbon footprint. This is related to a greater demand for resources for their production (number and type of raw materials, longer production process), higher operational demands (energy consumption), and greater recycling costs (variety of waste). Therefore, smaller ICT devices generate a smaller carbon footprint. This is true individually. However, due to their widespread use (often several, a dozen, or even dozens of units), it should be noted that the carbon footprint they generate can be comparable to that of large ICT devices, and perhaps even paradoxically higher? Abstracting from the characteristics inherent to a specific office device, the level of carbon footprint generated is also directly dependent on the frequency of its use. Hence, office equipment should be used in a rational – ecologically economical manner.

Future research could focus on evaluating the effectiveness of various strategies to reduce the PCF of office equipment. This could include exploring the lifecycle impacts of emerging technologies, the benefits of recycling and refurbishment programs, and the role of consumer behaviour in influencing the equipment's environmental impact. Additionally, longitudinal studies could assess how advancements in technology and changes in manufacturing practices impact the PCF of office equipment over time.

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## The contribution of the authors

Conceptualisation, H.W. and R.D.; literature review, H.W. and R.D.; methodology, H.W. and R.D.; formal analysis, H.W. and R.D.; writing, H.W. and R.D.; conclusions and discussion, H.W. and R.D.

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# OCENA ŚLADU WĘGLOWEGO PRODUKTU SPRZĘTU BIUROWEGO W CAŁYM CYKLU ŻYCIA

STRESZCZENIE: Cel: Celem artykułu jest nagłośnienie zagadnienia emisji śladu węglowego ze sprzętu biurowego, gdyż problem ten nie jest jeszcze powszechnie rozpoznany w branży ICT. Metodologia/podejście: Oceniono ślad węglowy produktu (PCF) różnych urządzeń informacyjno-komunikacyjnych (ICT) – 196 produktów z 12 grup reprezentujących szerokie spektrum sprzętu biurowego – obejmujący cały cykl życia (LCA) od produkcji do utylizacji. Wyniki: Poziom śladu węglowego danego urządzenia biurowego zależy od jego wielkości, w tym od zapotrzebowania na energię. Należy zaznaczyć, że choć mniejsze urządzenia indywidualnie mają mniejszy ślad węglowy, to ze względu na ich powszechne użytkowanie (wiele sztuk) mogą generować emisję podobną do większych. Oryginalność/wartość: Wyniki statystyk śladu węglowego urządzeń ICT zawarte w sekcji wyników mogą stanowić cenny wkład dla firm do obliczenia śladu węglowego w biurach. Można je również wykorzystać jako zbiór danych, do kalkulatora śladu węglowego urządzeń ICT.

SŁOWA KLUCZOWE: ślad węglowy produktu (PCF), technologie informacyjno-komunikacyjne (ICT), ocena cyklu życia (LCA), społeczna odpowiedzialność biznesu (CSR), sprzęt biurowy

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