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Small business, big footprint: the digital carbon footprint dilemma in small and medium-sized enterprises

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Abstract:
A major contributor to climate change is the emissions from Information and Communication Technology (ICT) devices and digitalisation. Energy use, heat production, and the operation of assets all contribute to the production of harmful emissions. However, indirect emissions, such as production and disposal, also play a role. We rely mainly on the output of small and medium-sized enterprises (SMEs). This paper focuses on the emissions of SMEs. Is it certain that cloud services (remote data storage and management) leave a much smaller carbon footprint than ICT devices for own use? These two solutions lead to a paradox: using more modern devices to produce less emissions requires more energy and generates more heat. This article analyses how to resolve this paradox for SMEs.

Keywords:
carbon footprint; SMEs; digitalization; digital emission; ICT emission; emission paradox.

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1. Introduction

Climate change is currently one of the biggest problems for the sustainability of life on Earth. It is now clear that the current pattern of economic growth has environmental impacts that threaten the survival of life on Earth. According to the Intergovernmental Panel on Climate Change (IPCC) report 2022, greenhouse gas (GHG) emissions will continue to rise. This was also the case in the decade between 2010 and 2019, when the average annual increase was at its highest, but the rate of increase has now slowed compared to the previous decade [1].

However, Information and Communication Technologies (ICT) now present a fairly positive picture from a sustainability perspective, as they have substantially transformed the way we communicate and work, revealing opportunities to reduce the impact on human nature. For example, e-commerce, teleworking, videoconferencing and Covid-19 have reduced the global movement of people and goods, thereby reducing oil consumption and greenhouse gas emissions [2]. Does the spread of different digital technologies/techniques and innovations really reduce the environmental impact of economic activities?

To ensure sustainable digital transformation, efforts are needed to green digital infrastructure, manage climate risks, and reduce environmental footprints. In the era of digitalisation, data infrastructure such as data centres and cloud solutions are crucial in supporting public management and delivering services efficiently. However, these key elements of contemporary societies come with challenges. They require significant energy, utilize important resources, and add to greenhouse gas emissions. For a sustainable digital transition, it is necessary to focus on making digital infrastructure more eco-friendly, handling climate-related risks, and minimizing environmental impacts [3].

To address these issues, the International Telecommunication Union and the World Bank in partnership with the Federal Ministry for Economic Cooperation and Development (BMZ) and the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) have developed a practitioner's guide to 'Green data centres: towards a sustainable digital transformation' [3]. The guide covers six critical dimensions that practitioners can consider to green data centres:

- climate-resilient data centres;
- sustainable design and buildings;
- sustainable Information and Communication Technology;
- sustainable energy;
- sustainable cooling;
- e-waste management.

These factors should also be included in public procurement strategies and criteria, as well as in broader policies and regulations, to promote investment in environmentally friendly data centres and enhance the resilience and efficiency of existing data centre infrastructure [3].

Hence, the theme of this study is to analyse the paradox that the more advanced (mainly digital) tools are used to reduce emissions (hereafter used interchangeably with emission equivalents), the more energy is needed and the more heat is generated as a result of exploiting the potential of these tools. In other words, as an unintended side effect, mitigation efforts themselves are likely to increase emissions. The related research gap: what are the environmental impacts of the digitalisation of small and medium-sized enterprises (SMEs)?

The aim of the study is to answer the question: can the paradox be resolved, and if so, how and in what direction? On the other hand, it aims to define a framework that can be used to resolve this paradox, based on the results of the available literature, and which is capable of reconciling the current carbon footprint of SMEs with their environmentally sustainable operations.

The focus of the study is on the SME sector and related digitalisation. This is primarily due to the low digital maturity of SMEs and the lack of change in their digital competitiveness [4]. As a consequence, it is crucial that companies adopt the right technology/techniques in their digital transformation with the least possible environmental impact.

SMEs are a special case in terms of emissions, because most of them are not able to adapt modern low-emission technologies and other solutions, which are mainly linked to digitalisation and digital technologies. On the one hand, they do not have sufficient resources to purchase them, and on the other hand, their operation and use do not offer significant economic benefits. By contrast, medium-sized and large companies can afford, and are expected, to include in their strategic objectives the optimisation of emissions, in addition to minimising their carbon footprint. These require very costly up-front solutions and investments, the return on which these types of businesses can incorporate into their long-term economic objectives. A further aim is to enable a wider range of SMEs, accounting for half of EU GDP, to start measuring their digital emissions by resolving this paradox. The importance and timeliness of the issue is underlined by the fact that SMEs account for 63% of total CO_2 emissions in the EU [5].

Energy efficient cloud computing has become a priority for the EU. Data centres need to become more energy efficient, reuse waste energy such as heat and use more renewable energy sources in order to become carbon neutral by 2030 [6]. The progression of digital technology in Europe clearly indicates a shift towards edge computing. This practical approach underlines the importance of processing data near its origin, focusing on efficiency and independence [7].

SMEs need an optimisation model that allows them to operate optimally with the lowest possible emissions. The model should be a multi-component and multi-faceted tool, including the functions of the possible and optimal IT/digitalisation tools in terms of emissions and costs, trained on a quantitative scale of values. The set of link functions describing the interaction of these elements is expected to be vector-vector functions. The latter is important because the interactions of some elements can worsen or can improve the individual emission values. In this paper, we do not provide such a model, but rely on the literature to demonstrate that such a model has a justification. Such an analysis is not to be found in the currently available literature, and this gap filling is a scientifically novel element of the paper.

The Science Direct research database was examined between 2012 and 2022 for the following search terms:

- carbon footprint + SME: 1286 results,
- carbon footprint + digitisation: 9783 results,
- digitalisation + SME: 7258 results,
- digital transformation + SME + carbon footprint: 248 results, of which 170 journal articles.

The narrowed search covers the following topics: environmental sciences, energy, engineering, decision support, management and economics, social sciences, chemistry, computer science, and psychology. Articles on computer science focus on the digital transformation of manufacturing and logistics systems. The papers published in the fields of management and economics focus on the digital transformation of financial systems, blockchain technology and the digital transformation of customer processes. This suggests that there are no studies in the current literature that specifically address the environmental impacts of the digitalisation of SMEs in relation to CO_2 emissions.

To justify the existence of a paradox, it is necessary to tackle it, which is exploratory research. This will be answered by an exploratory and deductive approach based on a review of the literature. In our opinion, the justification of the model can later be verified by empirical data.

The paper first introduces the digital carbon footprint paradox and then clarifies the concepts of carbon footprint, carbon emissions and digital emissions. Then discusses the relationship between ICT and the digital footprint, and how the paradox can be resolved for SMEs. The paper concludes with a summary and conclusions chapter.

2. Literature Background

2.1 Digitalisation and sustainability

Wireless sensors and monitoring technology have enabled the development of the concept of smart grids, smart homes and smart buildings to optimise energy management in individual rooms by monitoring parameters such as temperature, humidity or sunlight [8], [9]. This of course further complicates the paradoxical situation of emissions. Mobile apps allow customers to measure and reduce their GHG emissions. This improves customer engagement (digital business outcome) and supports sustainability goals such as achieving net zero emissions. The circular economy platform creates new revenue, which translates into business outcomes for both digital business and sustainability [10], [11].

However, the dependence on ICT devices and services is growing rapidly, so the energy needed to produce and operate ICT devices is also increasing significantly. The energy required to produce and operate the ICT devices in use contributes significantly to the formation of carbon dioxide, greenhouse gases and other global warming pollutants [8]. Empirical evidence also shows that despite the energy efficiency improvements in ICTs over the past seven decades, the carbon footprint continues to grow. Large-scale investments and rapid developments are taking place in the ICT sector, which are potentially energy-hungry areas of innovation, including IoT, data centres and cloud computing. These are fuelled by the demand for big data and are also being further boosted by the use of artificial intelligence (AI) techniques for big data analysis [12].

In fact, the domain of sustainability is difficult to define, as the concept is multi- and transdisciplinary and ICT and related innovation affect socio-economic organisations at all levels through actions, decisions and behaviours. Hence, sustainable innovation is only possible if all levels of relevant organisations are involved [13], [14].

When it comes to the sustainability of digitalisation, two different approaches are appropriate. Green by IT is about making processes more efficient and sustainable by introducing IT systems. Greening by IT aims to make IT itself more sustainable. The main building blocks of the digitalisation strategy are data centres (storage, processing) and telecommunication networks (transmission) [15].

Digital sustainability is an organisational activity that seeks to achieve sustainable development goals through the use of technologies that create, use and transmit electronic data. Some of the most commonly used technologies include blockchain, artificial intelligence, machine learning, big data analytics, mobile technology and its applications, sensors and other IoT devices, and other telemetric devices such as satellites and drones [16]. Digital sustainability is the means by which digitalisation can achieve global sustainability goals [17]. In this case, digital sustainability is able to combine the two strategic objectives of sustainability and digital transformation to bring about positive social and environmental change rather than focusing on merely reducing it [14].

According to Ardito et al. [18], there is no evidence that combining digitalisation and sustainability improves firm performance. While there is a generally optimistic view that the use of digitalisation tools is key to sustainability, it is important to be aware that digitalisation can also be a disruptive force, because unintentionally, uncontrolled or underestimated, it can negatively affect sustainability and its development. Ghobakhloo [19] makes a similar observation that in an Industry 4.0 environment, interconnected computers, smart materials and smart machines communicate with each other, interact with the environment and ultimately make decisions with minimal human involvement.

Digital business and sustainable business outcomes can feed each other. The digitalisation of manufacturing and business processes, and the use of smarter machines and tools, can bring many benefits, such as increased manufacturing productivity, more efficient use of resources and reduced waste. IoT, data and analytics can optimise wind turbines, reducing costs (digital business outcome) and greenhouse gas emissions (sustainability outcome). Nevertheless, digital connectivity, information production and sharing as the real strength of Industry 4.0, can have contradictory impacts on the three pillars (economic, environmental and social) of sustainability.

Carnerud et al. [20] concluded that there is a high degree of overlap between sustainability and sustainable development. Quality management (QM) researchers have a positive view of sustainability, as well as of digitisation, but digitisation initiatives are not at the cutting edge of the QM paradigm. This is probably a result of the recent emergence of too many new concepts and technologies in the toolbox for business process re-engineering.

Andriushchenko et al. [21] showed that digital transformation of businesses can be achieved through sustainable development. The mathematical model presented ensures that the risks associated with digitalisation can be anticipated and minimised. This allows the prediction of business activity taking into account the vector of development (digital transformation). Under uncertain conditions, the use of the model helps to ensure the quality of the digital transformation of the business, regardless of the level of development of the company.

The digital transformation brings many benefits, which also have a positive impact on combating climate change and reducing CO_2 emissions. However, ICT investment is a significant component of CO_2 emissions. It also increases the production, use and data transfer of digital devices and the energy consumption of the internet network (more data centres and servers/routers involved). For example, the energy consumption of the device during streaming results in additional CO_2 emissions.

2.2 The paradox

As demand for data centre services grows rapidly, the carbon footprint of these facilities will also grow rapidly if companies do not reduce their environmental impact by increasing energy efficiency and optimising consumption. Fig.1 shows how different ICT trends impact the growth of emissions from data centres, networks and devices, leading to exponentially increasing energy consumption. The number of connected devices is steadily increasing, expected to reach 55.7 billion by 2025, generating huge amounts of data. Data will also need to be stored, further increasing the demand for data centres [22], [23].

To retain customers, storing data in the cloud or seamless data integration forces data centres to operate uninterrupted, so data centres need to use diesel generators as a backup power source. This in turn leads to greenhouse gas emissions and has a significant impact on the climate change. These emissions can be described in terms of a digital CO_2 footprint or digital carbon footprint [24]. In addition, heat in data centres needs to be reduced. To address this thermodynamic threat, data centres rely on cooling, which accounts for more than 40 percent of electricity consumption. In addition to cooling, data centres emit acoustic waste, known as noise pollution. This can lead to increased blood pressure and cortisol levels, as well as anxiety [25].

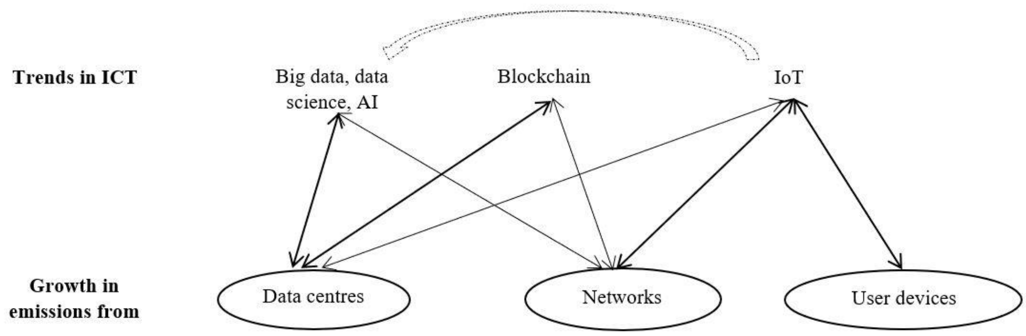

Fig.1. The impacts that trends in ICT have on growth in emissions from data centers, networks, and devices [23]

The preceding finding is reinforced by the Jevons paradox [26], according to which technological improvements that improve the efficiency with which a resource is used, rather than reducing the use of the resource, actually increase it. Economist William Stanley Jevons observed that technological improvements that enabled more efficient use of coal led to greater use of coal in many areas of industry. He says that energy conservation is hopeless because increased efficiency increases demand. Nevertheless, improved efficiency can improve quality of life.

The above shows that although energy efficiency is improving, overall energy consumption is not decreasing. This is reinforced, inter alia, by the rebound effect of working part or all of the time at home, whereby the employee spends the time saved by travelling to work. This results in additional energy use comes from. Thus, business considerations continue to dominate, i.e. firms are using digitalisation not to reduce environmental burdens but to increase sales or reduce costs [27]. Technology is both the source of the problem and the solution. Using the right technologies and techniques can help combat climate change, but this requires taking into account our digital carbon footprint.

According to Blair [12], the following competing factors will determine the future output of ICT devices (Table 1).

Table 1. Factors contributing to future ICT carbon emissions [12]

Efficiency	Innovation
Renewable energies	Moore's Law
Contact	Jevons paradox

The left-hand column shows a number of factors that can help reduce ICT emissions, starting with increasing efficiency. For example, since the advent of computing, Moore's Law has helped to improve efficiency. To complement this, many sectors of the ICT industry are increasing the percentage of energy from renewable sources. There has been significant progress in data centres, less so in the decentralised internet. There are also important arguments that ICT development is leading to lower emissions in other sectors through improved accessibility [28].

On the right-hand column, many experts argue that the period covered by Moore's Law is coming to an end. Moreover, the effect of the Jevons paradox is often ignored.

The lack of consensus on which technologies should be included in the calculation of ICT GHG emissions makes the calculation of emissions very difficult. Some preliminary estimates do not take into account the full life cycle and supply chain of ICT products and infrastructure. For example, the energy used to manufacture the products and equipment, the carbon cost associated with all their components and the operational carbon footprint of the companies behind them, the energy used to use the equipment (including its availability), and finally the energy used to dispose of it once its purpose has been fulfilled [23]. All digital activities have a carbon cost. However, many companies are not aware of this fact and the level of awareness varies across sectors. The extent is relatively higher in the banking and consumer goods manufacturing sectors and lowest in manufacturing [29].

For example, Gartner Transportation and Logistics recommends that companies try to reduce storage and processing requirements by, among other things, moving from point-to-point to hub-oriented integration patterns and adopting more modern data integration techniques, such as data virtualisation, which do not require data movement. According to Simon Mingay, Gartner's Vice President of Research, the following principles deserve wider adoption [30]:

- Avoid unnecessary duplication of data, for example by using shared repositories and data virtualisation.
- To achieve analytical goals, minimise the amount of data processed by developing standardised, automated reports based on historical data needs to serve future data needs.
- Storing data on passive media using a tiered approach.

All of the above show that digitalisation and digital developments will certainly reduce emissions and carbon footprints. However, if a Google search is associated with an average of 0.01 kilograms of carbon dioxide emissions (carbon dioxide equivalent - CO2e) and at least 4.5 billion searches are made worldwide every day, several questions arise. In addition, not only searching Google, but also using a cloud service for several hours a day (including cloud-based mail systems) can result in huge carbon emissions. In this way, the cloud is not only a material force, but also an ecological force. As it expands, so does its environmental impact [31].

It can also be observed that the more advanced an ICT system in an SME, the more services are used that would otherwise not have been used before or at a lower level of development (these tools also have energy requirements and relatively high heat emissions).While only the raw material and production are considered as a factor increasing the carbon footprint when using a paper-based spreadsheet, there are many more components to consider when using a dashboard output via a cloud service with a smartphone.

However, if an SME does not operate its own computer system (server, LAN, printers), does not use applications, data management systems, reporting tools locally, but shares them by using other people's resources, or even sharing its own resources, it can increase utilisation and reduce downtime. This will also reduce your emissions. But digitalisation only contributes to reducing the carbon footprint if it is managed wisely. The IPCC [1] report also notes that there is very little systematic analysis of the impacts that can be expected as the digital economy spreads. What kind of energy consumption will the data centres have? What will be the consumption and lifestyle impact of increasing social media usage, artificial intelligence, blockchain? How will the digital divide between social groups and regions evolve?

In our study, we investigate whether and how the digital paradox in the research question can be resolved, *"For an SME, digitalisation is an emission-reducing factor, while the consequence of digitalisation may be higher harmful emission levels."*

First, we will clarify some basic concepts. In our analysis, we narrow down the set of small and medium-sized enterprises. On the one hand, we exclude sole proprietorships and micro- enterprises (1-5 persons), as well as enterprises belonging to the top layer of the SME sector (hereafter referred to as top SMEs). The reasons for this are explained in the previous chapter. For micro enterprises, the primary operating objective function is the difference between revenue and cost. For top SMEs, the conscious choice of ICT for operations, the use of higher quality equipment, already allows to keep the carbon footprint lower. In between, most SMEs do not incorporate emissions into their operational objective function, and thus do not consider the environmental damage they cause. They do so despite the opportunity to take such considerations into account.

2.3 Digital carbon footprint

The carbon footprint shows how much greenhouse gas is emitted directly and indirectly into the air as a result of a person's lifestyle, a company or community's activities, or the life cycle of a product. The carbon footprint is the total amount of greenhouse gases directly and indirectly caused by an individual, an event, an organisation, a product, expressed in CO2e. The total footprint of an organisation covers a wide range of emission sources, from the direct use of fuels to indirect impacts such as employee travel or emissions from other organisations within the supply chain. A common classification method is to group GHG emissions according to the level of control an organisation has over them [32]. On this basis, there are three main types of GHG classification:

- Direct emissions from activities controlled by the organisation.
- Emissions from electricity use.
- Indirect emissions from products and services not directly managed by the organisation.

The digital carbon footprint is the CO_2 emissions from the production, use and transmission of digital devices and infrastructure [22]. Digital emissions are defined as all harmful emissions that can be attributed to ICT and digital development/operation/activities and that negatively affect the carbon footprint.

3. ICT and digital carbon footprint for SMEs

According to the Eurobarometer [5] report on SMEs, EU SMEs have already taken significant steps to transform their business towards environmental sustainability. They are predominantly trying to become more resource efficient by using renewable energy, recycling or minimising waste (3Rs: Reduce, Reuse, Recycle). However, compared to 2018, the pace of improvement in their sustainability is slow. Given the significant dynamics of climate change, they need to transform faster. Their combined share of total emissions is also high, accounting for 63% of total CO_2 emissions from companies. This makes it essential that the digital transformation of these companies is appropriate, i.e. it does not matter which technologies they will adopt [5]. The situation is complicated by the low awareness within companies of the carbon footprint of their own IT infrastructure, with only a few companies having a strategy to identify this [30].

The defined footprints are heavily influenced by digitalisation on the one hand and ICT tools on the other. It would therefore be useful to define precisely which factors and components have the greatest impact on these two indicators. In our case, we refer to the elements of software, hardware, orgware, peopleware that are related to digitalisation and that play a role in the digital carbon footprint of SMEs.

Perhaps the simplest approach is to start from digital maturity and digital maturity life-cycle [33]. Fig.2 shows the Digital Maturity Technical Architecture (DMTA), which illustrates a possible digitalisation component system.

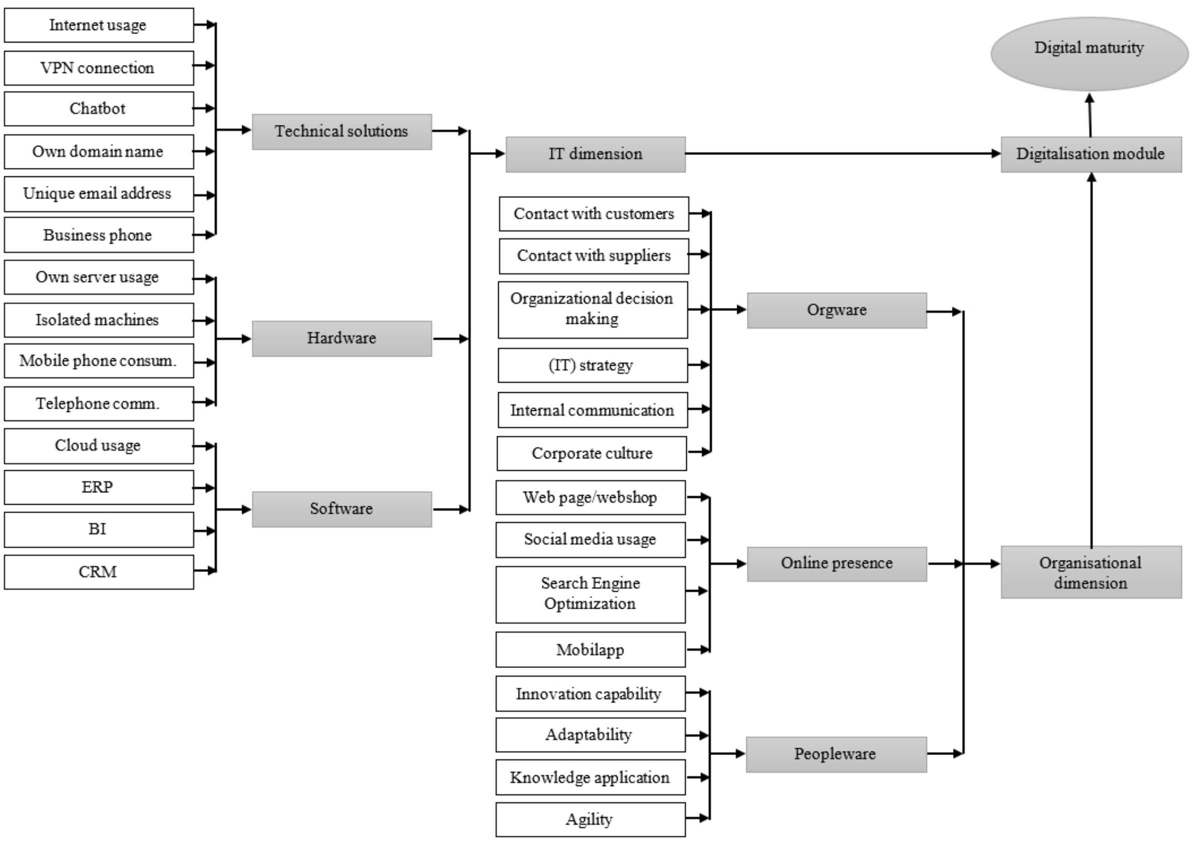

Fig. 2. Framework of Digital Maturity Technical Architecture [34]

In our case, we need to consider which components have a significant digital footprint. It is clear that all components of the technical solutions are important, and it is also clear that they need to be extended. All components of hardware necessary and expansion should be carried out. The software components also need to be extended and restructured. So, the IT dimension plays a significant role. The ICT organisation can be abandoned, its emissions are not significant for digitalisation. The online presence is very important, it does not need to be restructured. Human ICT, like the ICT organisation, is negligible for the purposes of our present analysis. Let us then examine the reconstructed components.

The first component to be recreated concerns technical solutions.

- It is clear that the digital emission of technical components will be indirect. This is important because in such a case the digital emissions are shared among several users and the utilisation of the hardware behind such components is much higher and implies lower emissions per unit of time than using this type of own hardware resource (e.g. no unnecessary energy consumption for stand-by, no amortisation during stand-by, etc.).
- Digital devices are constantly transmitting data over the internet. The relationship between the level of energy consumption of data networks and the amount of data transmitted is very complex. This is due to the constant fluctuations in the amount of data and the which should take into account the peak times with maximum data volumes. However, this relationship can be estimated as follows:

  Energy consumption = transmission duration * time factor + amount of data transmitted * volume factor.

From this estimate, assuming different transmission speeds and data volumes, the greenhouse gas emissions of the data network for the following activities can be estimated as follows [35], [36]:

- Greenhouse gas emissions from data networks,
- 4 hours of video streaming per day: 62 kg CO2e per year,
- Backing up 1 gigabyte per day: 11 kg CO2e per year,
- Internet activity emissions: 1 hour of standard video discussion 270 MB data, 0.008 kWh/GB internet electricity consumption, 321g CO2/kWh emissions.

Examination of the technical components shows that their use is not always environmentally friendly. 24-hour internet can result in an SME using the network even when it is not needed but when availability makes it reasonable (as we have seen, a Google search is equivalent to 0.01 kg of CO_2 emissions). While Google previously estimated an average online search to consume 0.3 watt-hours of electricity, roughly equal to driving 0.0003 miles in a car, this figure is probably much higher now due to Google incorporating generative artificial intelligence (AI) models into its search algorithms [37]. Conversely, a device's stand-by mode also uses unnecessary energy, both for standby and for rapid response. It also consumes energy for applications that are not needed. So, on the one hand, a good internal policy can help a lot to plan resources in a way that they can be optimally used, also with respect to extreme loads. If such events occur infrequently and predictably, then it is always advisable to hire and share resources.

The other big problem with technical components is redundancy. As the current data storage policy tends towards virtual data erasure, i.e., data is not physically erased but only logically, a lot of redundant data storage is needed. For example, the ultimate goal is for all of Google's data centres and offices to become carbon neutral by 2030 at the latest [38]. A well-designed cloud application should use only the necessary resources. This is important because when fewer resources are used, it implies that fewer virtual machines operate in a data centre, leading to lower energy consumption and reduced carbon dioxide emissions. Therefore, the initial step in minimizing the digital carbon footprint linked to cloud computing is to structure applications efficiently.

Every time we use AI to generate an image, write an email, or ask a question to a chatbot, it comes at a cost to our planet. The CO_2 emissions of digital or AI-based services are less obvious and harder to measure. Indeed, a new study by researchers from the AI startup Hugging Face and Carnegie Mellon University has revealed that creating an image using a potent AI model consumes as much energy as it takes to charge a smartphone fully. Nonetheless, the study also discovered that the energy required for generating text using an AI model is considerably lower. Luccioni and her team investigated the emissions associated with AI tasks available on the Hugging Face platform. Generating images stood out as the most energy- and carbon-demanding task among AI-based activities. On the other hand, the text generation model with the lowest carbon intensity they evaluated produced an amount of CO_2 equivalent to driving a similar vehicle for 0.0006 miles [37]. Generative AI models consume a lot more energy because they perform multiple tasks simultaneously like generating, classifying, and summarizing text, rather than focusing on a single task like classification. The latest generation of AI systems consumes significantly more carbon than the ones we used just two or five years ago. For a comparative perspective, it is estimated that during their training, OpenAI's GPT-3 and Meta's OPT released over 500 and 75 metric tons of CO_2, respectively. The substantial carbon footprint of GPT-3 can be attributed in part to its training on older hardware, which was less energy-efficient [39]. The most important suggestion is to train the machines in a place where the energy needs can be largely provided by renewable energy sources.

The technology infrastructure supporting net-zero energy data centres will become increasingly modular and demand-driven. For example, cloud and edge computing systems allow data processing and storage to span multiple devices, systems and even multiple locations. For example, a shift to edge computing can reduce energy consumption by processing data closer to the source. This reduces the need to transmit data to a data centre hundreds of miles away.

Yet, there is a method that not only improves online experiences but also supports environmental sustainability - the use of Content Delivery Networks (CDNs). CDN is all about optimising the access time and loading speed of the website, even if you want to access it from a physically remote machine. Computer networks sometimes have to serve huge distances. Usually, we do not think about the exact path that data takes when we type a website address into a browser. CDNs consist of a network of servers, distributed across multiple geographic locations, positioned in a strategic manner. CDNs improve the ability to scale, reduce server loads, and help build a more stable and responsive streaming setup. The careful location of CDN servers cuts down the distance for data travel, leading to swifter delivery of content, less buffering, and better video clarity. Regarding the carbon footprint of video streaming, while it is a matter of concern, it remains comparatively low due to swift advancements in energy efficiency within data centres, networks, and devices. As technology continues to progress, the energy used for streaming video is anticipated to reduce, further emphasizing the significance of CDNs in advocating for digital sustainability [40].

A similar problem exists with electronic mail. A group message with an attachment is always stored in at least one copy in the sender's account (mail server), but also available in at least one copy in each recipient's account, not to mention the private copies downloaded to desktop, phone. This is incredible high energy and resource wastage. With a smart resource solution, a single instance would be sufficient and with shared access - with appropriate security solutions of course - data storage energy and resource requirements can be saved. These are of course only partially passed on to SMEs, but are included in the overall footprint as an indirect footprint.

The use of chatbots is perhaps the clearest benefit from an account manager's ICT perspective. This should include the emissions generated during the commute to and from the workplace, the use of desktops and other ICT devices during working hours, and on-call time. Based on Reyes-garcía et al. [35], the annual commuting per person in the UK is 750 kg CO_2 equivalent and in the Netherlands 410-630 kg CO_2 equivalent. Conversely, when using chatbots, only the application's standby and operational ICT emissions need to be accounted for, which are much lower emissions than the human solution (here, network and individual connectivity energies and emissions need not be considered, as they are the same in both cases).

5G as a technical component poses an interesting problem. It provides higher quality communication, for SMEs using IoT, it provides much faster and more accurate communication. As it is an important factor of their objective function, its use is essential. As its presence is independent of the SMEs, its use is appropriate, although it will always increase indirect output and be a burden on the SMEs, regardless of their intentions.

So far, there has been no mention of electromagnetic pollution. The non-wired communication devices used (routers, switches, telephones, Bluetooth devices, sensors, etc.) cause permanent electromagnetic pollution. The main problem is that only a very small fraction of the electromagnetic waves propagating in all directions is used. There is more scope for reducing pollution here: the energy from such emissions could be used to charge and power devices, thus reducing the electromagnetic pollution of companies without compromising the quality and speed of data transmission, and reducing the level of CO_2 equivalent pollution. The other components are not discussed in detail in this study.

The second and most important emission component is hardware. The problem with hardware components is the high energy demand and the relatively high heat generation, high recycling and high energy and cost requirements and a lot of waste. Therefore, the use of a large number of these components in SMEs requires a high degree of caution. It is advisable to use as few tools as possible, focusing only on those that are essential to the operation. The energy they use will be direct energy for SMEs and the emissions will be direct. Which ICT hardware components are absolutely essential? Generally, one consumerised mobile communication device per person, although if the SME's data security policy allows, these can also be the users' private devices, reducing the number of devices and in this case the utilisation is much higher. This is much more efficient in terms of digital emissions. These devices can replace much more energy intensive desktops, notebooks, etc.

Although it is inconceivable for an SME not to have at least one desktop-like tool, if for no other reason than to perform accounting, bookkeeping and process management tasks. These will not be addressed in the present study, but will be a necessary and important element for the subsequent model.

Many other hardware items, such as servers, printers, specific hardware items, can be used in a shared way in many cases, thus reducing their number. Shared use, in turn, implies greater use of technical components. All digital devices emit CO_2 during their use phase, whether at home or in the office, through their consumption of electricity. This energy consumption is highly dependent on the specific user behaviour. A notebook is used for an average of four hours a day, consuming 32 watts of electricity, which results in a carbon footprint of 25 kg of CO_2 per year. It is assumed that a smartphone is usually plugged into a charger for four hours a day, consuming five watts during this time [36].

Of course, the production of digital devices such as smartphones, notebooks and televisions are also a major greenhouse gas emitter. These emissions are mainly caused by the process chemicals used in the extraction and processing of raw materials and the energy required for semiconductor production. For example, the production of a large flat-screen TV (over 50") emits 1000 kilograms of CO_2. For a laptop, 250 kilograms of CO_2 are emitted during production. It is estimated that a smartphone or a digital voice assistant (e.g. Alexa) emits about 100 kilograms of CO_2 during production [36].

4. Case studies

The SMEs we studied show a very different picture at the digital lifecycle level and at the level of digital maturity. As this article is not a case study, we present two extreme examples from Hungary, which differ greatly in both maturity and digital mindset.

The first example shows an insecticide and sanitary disinfection company from a digitalisation perspective. The company is located in an in-demand sector, but also has - apparently - not very high digital needs. In the first two initial years, it only used the legally required digitisation functions and the communication with its employees was done through digital consumerisation, using the employees' own smart devices. The mandatory functions are electronic invoicing, bookkeeping and tax reporting. Due to the nature of the sector, all of these were solved through cloud services. Their carbon footprint, which is not very high due to data traffic, can be considered negligible compared to similar SMEs in other sectors. As the company was targeting a larger market segment for development, digital development was necessary. The development required a "call centre" centre built on its own hardware assets. It also needed a dynamic web system through which information and orders could be managed. All of the latter were accessed via a cloud service, so electronic pollution was greatly increased. One positive consequence of this is that telephone communication has been greatly reduced - thus reducing the resulting electrical energy consumption and electromagnetic pollution. The possibility of operating the purchased hardware from its own device was also considered, but the cost of this was not covered by the SME (peopleware problem). Furthermore, a small business ERP on own hardware was implemented to manage stocks and orders. This had a relatively low power requirement to run - and seemed ideal from a cost perspective. The result of the company's improvements in this direction was an increase in turnover of about 10 times, an increase in energy consumption of only three times, and an overall increase in estimated emissions (CO_2 equivalent) of about four times. All this with the right choice of digitalisation.

The other company we studied is in the manufacturing sector, producing and selling oils. The company has ramped up its online activities during the Coronavirus, with a dramatic surge in orders in the recent period. The website was developed by an external company even before the outbreak, in this case directly. Their website is responsive, i.e. optimised for different devices. Since January 2020, the use of social media has become even more conscious and intensive. A lot of effort is put into search engine optimisation. Around 60% of online purchases come from Google. Regarding the use of the cloud, everything is stored on servers, but advertising material is stored in the cloud. They use an administration system running on their own server to support their accounting, but they do not have the right software for production planning, so they can only do by own development. To eliminate this problem, the company is considering implementing a cloud-based ERP system, which is more advantageous from a budget and human resources point of view. It can be a crucial step in the life of the company as to which provider to purchase the system from. Because the company operates on a zero-waste approach, it is looking for a solution where the server park behind the cloud service is powered by renewable energy. Here again, the paradoxical idea of which solution has less impact on the environment comes into play. It should be stressed that, despite this, there is integration in the company, although it is not complete, but it is high for a company of this size. In terms of consumerisation of mobile telephony (a significant factor for SMEs), the performance is outstanding, as messaging applications are used extensively in everyday communication. This is a great solution in terms of process integration, as they are used to share up-to-date information on the different company activities. However, it also works on a cloud basis. This is counterbalanced by the fact that the company is powered by renewable energy, so the power supply for the company's own server and ICT devices can compensate for the use of the cloud.

Based on these results, it can be concluded that for the second company, there is no need for cloud asset optimisation, as sustainability considerations were already taken into account in the initial development. Although the introduction of hybrid solutions could be explored for growth and on-the-fly development, they would not really represent a reduction. It can be concluded that in the current situation, this business is operating in a near-optimal way from a digital perspective - in terms of emissions.

5. Solving and resolving the paradox

Digital sustainability requirements are the means by which digitalisation can achieve global sustainability goals [17]. However, it is not certain that the combination of digitalisation and sustainability will improve the performance of SMEs. There is a general view that the use of digitalisation as a toolbox will promote sustainability. However, it cannot be ignored that digitalisation can also be a disruptive force that, unintentionally, uncontrolled or underestimated, can negatively affect sustainability and its development.

Conversely, digital transformation of businesses can be achieved through sustainable development [21], in which case it is necessary to anticipate and minimise the risks and CO_2 emissions associated with digitalisation. Digital transformation brings a number of benefits, which also have a positive impact on combating climate change and reducing CO_2 emissions. However, ICT investment is an important component of CO_2 emissions. Indeed, the production, use and transfer of digital devices generate additional CO_2 emissions. This raises the question of whether the operation of a digitally mature SME will result in fewer CO_2 emissions.

It is very difficult to say whether, in the case of SMEs, increasing digital maturity and using better quality ICT tools will reduce or increase the emissions of the business, i.e., whether improving digital maturity (quality ICT use) to reduce emissions will increase the carbon footprint of the business. This paradox can be resolved for SMEs. Of course, it is important to look at the SME environment. The first important consideration is the economic sector or industry in which the SME operates. It makes a difference whether we are looking at a logistics transport company or an accountancy firm. Both have different ICT needs. For the former, accurate, real-time communication is very important and requires the use of state-of- the-art ICT tools. The first conclusion is that, depending on the sector, in each case an ICT environment should be provided that meets the needs but does not go beyond what is necessary and seeks to make targeted use of the tools. The number of redundant or redundant devices should be kept to a minimum, taking into account security concerns. ICT developments and tools should not be used as an end in themselves, unless the sector requires it, but only as a service. This will ensure that the project and the ICT environment do not lose out in terms of carbon footprint increase.

The conclusion is that the paradox can be resolved, and this can be considered a thesis. To resolve it, a component model must be constructed such that its constituent elements are as disjoint (independent in the case of a precise formulation) or as unconnected as possible in terms of carbon footprint. The components, i.e., to determine a uniform measure, shall be normalised and transformed to a uniform measurement scale. The relationships between the components must be defined so that no subcomponent is present in a larger proportion than is perceived in reality. After the relationships have been defined, a mapping must be defined that maps these relationships and transformed quantified values to a single standard carbon or eco- emission. With this, SMEs can now determine how their ICT development, their current level of ICT maturity, is having a detrimental impact on our environment and the future of our environment. They are thus able to determine an optimal level of emissions, which of course may be the opposite of the cost-oriented target function.

6. Conclusion

In our study, we have shown the impact that the conscious use of ICT can have on an SME, and how unjustified ICT development, the operation of unjustified high quality ICT devices with a lot of knowledge, can be detrimental to the carbon footprint. Despite their aim to reduce the carbon footprint, they have the opposite effect. To resolve this paradox, a model is needed that accurately shows SMEs their current emissions. As a result of digital development, the difference between the emissions of a new operation and the status quo can be modelled, allowing them to make sensible and smart decisions when making improvements.

Digital transformation brings many benefits that have a positive impact on the fight against climate change and the reduction of emissions. ICT investment is a major contributor to CO_2 emissions. The production, use, data transmission of digital devices, the power consumption of the internet network, the multiple data centres and servers/routers involved, the power consumption of the device during streaming all contribute to additional CO_2 emissions. In our study, we have shown the impact that ICT development in an SME can have on emissions and how unjustified ICT development, the acquisition and use of ICT devices with a lot of knowledge and of unjustified high quality, can be detrimental to the carbon footprint.

Having resolved the paradox, our primary objective will be to build the model, i.e., to create an objective function from the combination of cost and output. Once this has been done create, we will develop a tool that will use the model to map the exact ICT carbon footprint of the SME, helping it to make a digitisation decision. Then we want to get an empirical picture of the current CO_2 emissions of SMEs.

The digital paradox for SMEs states that, for an SME, digitalisation is an emission-reducing factor, while the consequence of digitisation can be higher harmful emissions. One of the new scientific results of this study is a detailed analysis of the paradox and the justification of the need for a model to resolve it, as there are currently no results in the literature. Mainstream research currently focuses on the carbon footprint, digitalisation and some of the links between SMEs, while studies published in the field of management and economics focus on digital development of financial systems, blockchain technology and digital development of customer-related processes. The other novel scientific result is the development of the basis for an optimisation model that, when adapted, will allow an SME to operate optimally economically while producing the least harmful emissions. In the present paper, we do not provide this model; we have only demonstrated that the development of such a model has an exact form and justification.

The main limitation is that the paper focused on literature research. On the other hand, currently it is difficult to measure the CO_2 emissions of ICT devices, that is why the paper does not include empirical tests.

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