ORGANIZATIONAL RESOURCE MANAGEMENT AND ENVIRONMENTAL SUSTAINABILITY. A TIME-SERIES ANALYSIS OF ICT SECTOR GREENHOUSE GAS EMISSIONS IN ROMANIA (2013-2022)

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The impact of the Information and Communication Technology (ICT) sector has a complex nature. While on one hand it boosts the digital transformation of organizations and countries' economic growth, on the other hand it has negative environmental impact as a result of its overall contribution to global greenhouse gas emission. The goal of this paper is to provide insights on how to better reconfigure organizational resource management by marrying environmental sustainability goals with the enhanced usage of information technology and information systems in streamlining and optimizing organizational processes. To this end, it provides a comprehensive literature review that approaches ICT as an organizational resource, as well as a time series analysis of Romania's ICT sector's greenhouse gas emission from 2013 to 2022. Its recommendations underline the ongoing need for Romanian organizations deploying ICT for digital transformation to observe climate objectives concurrently and hence, better integrate ICT as an organizational resource and capability.

Key words: Information and Communication Technology, ICT environmental impact, greenhouse gas emissions, sustainable ICT, organizational resources, total cost of ownership.

1. INTRODUCTION

Greenhouse gas emissions and air pollutants resulting from production processes – including those within the Information and Communication Technology (ICT) sector – contribute to climate change, pose risks to human health, and negatively affect the environment and biodiversity. Therefore, it is essential to create synergies between the digital and green transitions: promoting the

widespread adoption of low-carbon digital solutions across all sectors while simultaneously working to minimize the environmental footprint of the ICT sector itself.

Understanding the ICT sector's contribution to air emissions is a crucial first step in assessing the broader environmental impacts of digitalization.

According to the OECD definition (OECD, 2025:12), the Information and Communication Technology (ICT) sector comprises manufacturing, trade and services industries. In terms of manufacturing, the ICT sector includes the production of components, computers, communication equipment, consumer electronics, and magnetic and optical media, while the trade component focuses on the wholesale of those products. Concerning the services part, ICT includes software publishing, computer programming, consultancy, facilities management, data processing, hosting services, web portals, and repair services for computers and communication equipment. An important component of those is represented by telecommunications activities which include wired, wireless, satellite, and other telecommunication operations.

The ICT sector plays a major role in digital transformation and economic development in countries like Taiwan, Malaysia or India. Additionally, the ICT sector is an important innovation driver for emerging technologies like artificial intelligence and 5G and renewable energy technologies. All of the above considered, the environmental impact of ICT has become one of the major concerns nowadays. According to World Bank and International Telecommunication Union estimates, the ICT sector contribution to global GHG emissions is between 1.5% and 4% - (World Bank & International Telecommunication Union, 2025), on par with the aviation industry. The increased focus on this issue is justified by the steep rise in digital infrastructure represented by data centers, telecom networks and connected devices as a result of implementation or adoption of IoT, 5G, and edge computing (Grand View Research, 2024; Precedence Research, 2025; IoT Analytics, 2024). Additionally, ICT lifecycle leaves significant environmental footprints (UK Government, 2025; Balde et al., 2023). Nonetheless, ICT plays a dual role and its positive impact is visible in its contribution to energy efficiency and digital innovation (International Telecommunication Union, 2024; The Shift Project & GreenIT, 2019).

All of the above considered, the focus of this study is to analyze the impact of air emissions from the ICT sector in Romania for the 2013-2022 time period. The research question is how ICT environmental

impact can be strategically managed. The objectives are therefore two-fold. The literature review aims at providing a comprehensive outlook on how to balance ICT as a critical resource in organizations from the perspective of its positive and negative impact on environment, the direct, indirect and environmental costs associated with ICT sector's energy consumption, regulatory compliance and reputational risks, structured approaches to establishing cross-functional capabilities and leadership commitment to ensure the success of Green IT and Green IS initiatives in the context of optimized organizational capabilities. The second objective of the study is to analyze the environmental impact of greenhouse gas emissions of the ICT sector in Romania between 2013 and 2022 by using average time series indicators such as mean emissions per capita, absolute changes, dynamic indices, and growth rhythms in order to substantiate future implementation of recommendations on how sustainable ICT practices can mitigate the sector's expanding carbon footprint while supporting the country's digital transformation objectives.

2. LITERATURE REVIEW

In order to understand the environmental impact of ICT sector greenhouse gas emissions on organizational resources and underpinning management practices, we will focus on four inter-related research strands, namely resource-based view (RBV) and its extension – the natural resource-based view (NRBV), total cost of ownership (TCO), green IT and green IS, and organizational capability development. All of them allow for approaching ICT infrastructure from a strategic perspective that requires complex management strategies. Thus, the RBV and NRBV frameworks allow us to analyze ICT infrastructure as a critical organizational resource that entails both a strategic approach to its management along with the inclusion of environmental sustainability considerations (Barney, 1991; Hart, 1995; Wade & Hulland, 2004). Such a perspective allows for further consideration of how digital resources can be managed not only as productivity boosters, but also as assets whose environmental footprint can impact an organization's long term competitive advantage (Hart & Dowell, 2011). Additionally, we resort to the TCO conceptual framework in order to expand the traditional life cycle approach that focuses on acquisitions and operational costs by showing how greenhouse gas emissions contribute to direct and indirect organizational costs generated by

energy consumption, carbon pricing mechanisms, regulatory compliance, and reputational risks (Ellram, 1995; Curry & Donnellan, 2012). Also, the Green IT and Green IS frameworks contribute to this literature review through the structured approaches by which they enable organizations to decrease their IT and IS related environmental footprint and employ digital technologies for sustainability purposes (Watson et al., 2010; Melville, 2010; Seidel et al., 2013). Last but not the least, the concepts that fall under the umbrella of organizational capability development contribute to identifying the main actions that can be undertaken by organizations to develop and use capabilities that secure environmental sustainability (Teece, 2007; Chen et al., 2015; Nishant et al., 2016). The above proposed theoretical frameworks are aimed at approaching ICT sector emissions as a critical organizational resource that requires a strategic focus, along with comprehensive cost estimates, structured approaches to implementation and a sustainable approach to capability development. They also contribute to contextualizing our findings related to Romania's ICT sector emissions within the debates on sustainable digital transformation and the related environmental responsibility of organizations.

2.1. Resource Based View (RBV) & Natural Resource Based View (NRBV)

According to the Resource-Based View (RBV) perspective, an organization's critical resources and capabilities underpin its competitive advantage as long as the management strategies deployed focus on treating them as valuable, rare, inimitable, and non-substitutable (VRIN) (Barney, 1991). In this context, as literature in the field shows, ICT represents a critical organizational resource (Barney, 1991; Wade & Hulland, 2004) whose major role in achieving competitive advantage is particularly underlined by contemporary concerns regarding the necessity to balance digital transformation objectives with environmental sustainability goals (Dao et al., 2011; Melville, 2010). Nonetheless, ICT represented by its various platforms – hardware (computers, servers, network devices), software (enterprise applications, operating systems), network and telecommunications (internet, WAN, LAN), as well as by data storage systems, cloud services, security infrastructure (firewall, Encryption, antivirus) cannot be treated as a critical organizational resource in the absence of solid management frameworks. What is more, the effective development and consolidation of the latter is very much dependent on contemporary

concerns over environmental sustainability. Henceforth, the conceptual delineations provided by the Natural Resource-Based View (NRBV) approach contribute to refining the management practices aimed at integrating such approaches into competitive advantage focused strategies for managing organizational resources (Hart, 1995; Hart & Dowell, 2011). In this context, the NRBV highlights the ways in which organizations can reduce their carbon footprint by strategically managing their digital resources through the adoption of low-carbon technologies and green innovation.

ICT faces a two-fold imperative: to remain a strategic organizational asset considering the latest developments in IT infrastructure (i.e. data centers, communication networks, computing devices, software systems), while not becoming a liability (Malmodin & Lundén, 2018) as a result of its huge consumption of energy and generation of substantial greenhouse gas emissions. Sustainability commitments, regulatory require-ments, environmentally-conscious markets make the NRBV salient for how organizations reconfigure their strategic approach to achieving competitive advantage by leveraging the power of ICT.

As a World Bank 2024 report shows, the ICT sector contributes at least 1.7% of global greenhouse gas (GHG) emissions, a share comparable to the aviation industry, while between 2018 and 2022, there has been an increase in ICT sector energy demand and emissions as a result of a 72% increase in data center connectivity, 14% increase in broadband subscriptions and 17% rise in the number of internet users. On the other hand, worth mentioning, as the report highlights, 60% of the renewable power purchases in 2021 were made by tech companies which represented some of the top global electricity consumers adopting renewable energy. Also, some of the European Commission's Joint Research Centre (JRC) show mixed data about the Janus like opportunities and challenges raised by ICT. For example, according to the 2021 ICT TASK FORCE STUDY, ICT infrastructure (data centers and telecommunication networks) accounted for 79% of overall ICT emissions in 2020, up from 61% in 2010. Also, the life cycle of ICT devices – from material extraction, manufacturing, use, to end-of-life – generates significant material and emission footprints. The carbon footprint for manufacturing such devices has doubled between 1995 and 2015, accounting for about 2% of global climate impacts in 2015. In relation to that, the number of connected devices is rapidly growing, with an estimated 41.6 billion connected devices worldwide

by 2025, driving increased data production, storage, and transmission. However, ICT is has been proven to play a major role in society, especially during the COVID-19 pandemic, by enabling connectivity and supporting economic and social functions. In conclusion, as this study shows ICT has a direct life cycle impact in terms of resource consumption and disposal rate, but also positive and negative effects from its use, as well as systemic socio-economic impacts – all of which underscore its dual nature. Therefore, the management of ICT as a strategic resource organization wide needs to take into consideration both its role as an enabler of future efficiency and effectiveness focused solutions, but also as a driver of environmental changes. Therefore, from such a perspective, integrated policy measures should be envisaged in order to ensure ICT sustainability as a system and across its lifecycle.

2.2. Total Cost Of Ownership (TCO)

The Total Cost of Ownership (TCO) approach represents a comprehensive framework that supports a full scale depiction of the economic implications that the use of ICT resources has across a product's lifecycle (Ellram, 1995; Ellram & Siferd, 1998). Its initial application concerned the direct and indirect financial costs associated with the acquisition, deployment, operation, maintenance and disposal of assets. Nowadays, TCO also includes environmental factors that account for cost breakdown (Ferrin & Plank, 2002; Heilala et al., 2006), such as energy costs, carbon and emissions taxes, regulatory compliance, reputational risks and uncertainty about the future of technology such as artificial intelligence (Molla, 2009; Curry et al., 2012).

For example, the UK Government's "Total Cost of Ownership" guide emphasizes evaluating not just initial purchase costs of ICT solutions, but also ongoing operational, maintenance, transition, and environmental costs–including energy consumption and disposal–over the entire lifecycle to ensure value for money in public sector investments.

Also, the 2024 United States Data Center Energy Usage Report highlights that data center data center energy consumption continues to be a significant portion of operating expenses, with combined energy use of servers, storage, network equipment, and infrastructure rising steadily. In this respect, energy costs represent a substantial share of total operational costs, driven by growing demand for data services and increased compute workloads. Therefore, as per this report's findings, energy consumption patterns and projections should be

included in comprehensive TCO analyses for data center planning and management. What is more, as per the projections of the International Energy Agency (IEA), global electricity demand from data centers will more than double by 2030 due to AI and other digital services, with renewables expected to supply up to half that energy by decade's end. That is tightly related to the inclusion in the TCO of the operating expenses tied to energy consumption.

Additionally, based on the JRC ICT Task Force report for environmental and operational cost components, ICT contributes to greenhouse gas emissions as a result of its production and use. In terms of the finite resources it uses, their exploitation generates air, soil and water pollution. Its use is heavily dependent on energy consumption, while the fast update and evolution of technology makes the amount of ICT waste increase exponentially. Last but not the least, its disposal is prone to generating potentially hazardous waste since ICT recycling rates are very low globally and 80% of ICT waste worldwide remains undocumented.

Therefore, the integration of environmental costs into the ICT TCO could contribute to informed decision making concerning how to balance expenditures on energy-efficient infrastructure with environmental and energy costs.

Worth mentioning is that investment in renewable energy and technology meant to reduce emissions contribute to reductions in long-term costs (Elliot & Binney, 2008; Dedrick, 2010) and secure against the likely increase in energy prices as a result of foreseeable spikes in the demand.

In conclusion, TCO frameworks need to be updated in order to include environmental costs arising from observing compliance and security regulations on greenhouse gas emissions, sustainable approaches to ICT end of life, risk management plans on direct and ICT indirect environmental impact, direct environmental costs related to carbon pricing, emissions trading, and sustainability reporting. That welcomes an integrated approach that aligns the allocation of organizational resources to the sustainability goal. In this way, ICT can be both a key cost factor, but also an enabler of a sustainable organizational strategy.

2.3. Green IT and Green IS frameworks

The management of organizations' environmental impact as a result of their information technology and information systems is best known by the names of Green IT and Green IS. While the former is focused on practices to manage technology lifecycle, the latter emphasize the role of information systems in supporting sustainable

organizational processes and practices. Green IT models propose solutions aimed at optimizing IT infrastructure through the use of energy-efficient hardware, renewable energy deployment, managing and decreasing the amount of e-waste. From this perspective they are more concerned with technology and operations design, as well as disposal management strategies with a view to diminishing IT environmental footprint. Among the challenges of adopting green IT practices, the most prominent are change management practices and infrastructure compatibility. On the other hand, Green IS models take an organizational and societal approach by integrating behavioral, technological and environmental aspects (Wang et al. 2015; Loeser 2013)

The Green IT Readiness model by Molla et al (2009, 2011) describes an organization's readiness to integrate IT with a focus on its environmental impact across four dimensions: attitudes – the beliefs about and commitment to environment – policy expressed as governance structure and standards, practices that demonstrate the implementation of environmentally focused IT initiatives, and technology – in terms of its availability and use of energy-efficient solutions. According to this model, Green IT initiatives require a coordinated approach

spanning all four dimensions rather than piecemeal, isolated approaches (Molla & Abareshi, 2012).

The Energy Informatics Framework proposed by Watson et al highlights IT's two pronged role: as an environmental challenge – Green IT and as a solution – Green by IT. Consequently, it addresses IT both from the perspective of its impact on environment, but also as a facilitator of solutions organization wide by which organizational processes and societal systems in general can benefit from the use of IT. The framework was subsequently used for enhancing IT lifecycle and end-of-life approaches (Berthon & Donnellan, 2011; Dao et al., 2011).

A framework that links organizational transformation to organizational change theory and that highlights the need for a more comprehensive approach to transformation belongs to Seidel et al.'s (2013). Their research underlines that Green IS needs to be connected to broader organizational practices encompassing people, processes, culture besides technological infrastructure (Seidel et al., 2017). In a transformational context that includes environmental concerns, the role of IS is three fold: to facilitate organizational members' sense making of environmental issues, to ensure transparency of environmental impacts and to support new practices and business models that reduce environmental impact.

Loeser et al. (2017) capitalize on Jenkin et al.'s (2011) research agenda for Green IT and develop a framework for linking Green IT strategies to environmental sustainability strategies. They describe efficiency oriented strategies aimed at reducing resource consumption, effectiveness oriented strategies with a role in securing business models' sustainability and innovation-oriented strategies focused on the development of new green products and services for which IT is an enabler.

The goal of overviewing the key approaches in the field of Green IT and Green IS is to highlight that efficiency and effectiveness approaches need to be part of a joint effort and undertaken strategic wise. Also, Green IT and Green IS as concepts and practices require that besides technical expertise, stakeholder engagement and management commitment are secured.

2.4. Organizational capability development for gas emissions reduction

Development or consolidation of organizational capabilities can be better approached from the perspective of international standards in the field, such as the Greenhouse Gas (GHG) Protocol Corporate Accounting and Reporting Standard (GHG Protocol, 2004)

used by companies to calculate their carbon dioxide emissions, or reports of entities like The International Telecommunication Union (ITU) and the World Benchmarking Alliance (WBA) who issue reports like the Greening Digital Companies 2025: Monitoring emissions and climate commitments, or Measuring the Emissions & Energy Footprint of the ICT Sector. Implications for Climate Actions (ITU & World Bank, 2023; ITU & WBA, 2025).

Digital companies in particular use the Greenhouse Gas (GHG) Protocol Corporate Accounting and Reporting Standard to calculate their carbon dioxide emissions across Scope 1 (direct emissions), Scope 2 (indirect emissions from purchased energy), and Scope 3 (value chain emissions) categories (GHG Protocol, 2004; 2011). The latter looks at organizational capabilities in terms of designing organizational goals and inventory (Chapter 2) organizational boundaries (Chapter 3), and managing inventory quality (Chapter 7). Organizational boundaries support business and not only to identify the specific entities or operations for which an organization accounts for GHG in its inventory. In this respect, capability development concerns the capacity of an organization to report emissions accurately across equity share or control based functional structures. Establishing boundaries

heavily relies on the context in which an organization operates, its legal framework and structure, operational control, company ownership – all of which need coordination across multiple teams – accounting, legal and operational – for GHG accounting purposes (GHG Protocol, 2004, Chapter 3).

The development of a comprehensive GHG inventory for a given organization requires adequate capabilities to monitor, collect, analyze and report data for decision-making purposes. The principles emphasized by the GHG protocol related to the development and maintenance of organizational capability targeting GHG emissions are transparency, completeness, and accuracy and they can be sustained through rigorous data governance, internal controls and emissions reporting. GHG Protocol is supplemented by ISO 14064-1: Organizational-level GHG emissions quantification and reporting (ISO, 2018).

Development or consolidation of organizational capabilities for the ICT sector can be better approached through specialized frameworks that address the unique challenges of digital technologies. The GHG Protocol ICT Sector Guidance (2017) offers methodologies tailored to telecommunications networks, data centers, hardware, and software, recognizing complexities such as extensive supply chains, shared infrastructure requiring sophisticated allocation methods, and the dual nature of ICT's environmental impact – both its direct emissions and its enabling effects that can reduce emissions in other sectors. Capability development in this context requires expertise in life cycle assessment, allocation methodologies for shared resources, and measurement of both environmental footprint and handprint (GHG Protocol, 2017).

The Science Based Targets initiative (SBTi) further shapes capability requirements by establishing emission reduction targets aligned with limiting global temperature increase to 1.5°C. The SBTi ICT Sector Guidance provides decarbonization pathways specifically for network operators and data center operators, acknowledging challenges like rapid technology evolution and the critical importance of addressing Scope 3 emissions (GSMA et al., 2024). Meeting these requirements involves building capabilities in strategic planning, scenario analysis, supplier engagement, and transparent reporting.

Scope 3 emissions management presents a particularly demanding capability area given that value chain emissions typically represent 80-90% of total emissions for ICT companies. The GHG Protocol Scope 3 Standard outlines fifteen emission categories across upstream and downstream activities (GHG Protocol, 2011),

while the GSMA Scope 3 Guidance for Communication Operators offers practical methodologies for telecommunications companies (GSMA et al., 2023). Capability development here concerns establishing supplier data collection systems, developing product life cycle assessment expertise, creating customer engagement mechanisms, and building collaborative platforms.

Data management capabilities form the foundation of all emissions management activities. Organizations need systems for collecting activity data, applying emission factors, calculating emissions across all scopes, and maintaining data quality through validation processes (GHG Protocol, 2004, Chapter 7). More advanced organizations implement automated data collection, integrate emissions data with enterprise systems, and deploy AI/ML for data quality assurance. The ITU-T L.1410 standard provides specific guidance on data requirements for ICT equipment, networks, and services (ITU-T, 2014).

Beyond technical expertise, organizational capacity requires governance structures, leadership commitment, and cultural transformation. Leading organizations establish dedicated sustainability functions with board-level oversight, integrate climate targets into executive compensation, and embed environmental considerations into procurement and product development processes (Watson et al., 2010; Jenkin et al., 2011). The Green IT Readiness model emphasizes coordinated development by addressing attitudes, policies, practices, and technology at the same time (Molla et al., 2011).

3. METHOD

For the analysis of the data we used the average indicators of time series for the years 2013 to 2022 in Romania.
We calculated the mean

$$\bar{y} = \frac{\sum_{t=1}^{n} y_t}{n}$$ (1), the average of absolute change

$$\bar{\Delta} = \frac{\sum_{t=2}^{n} \Delta_{t/t-1}}{n-1} = \frac{\Delta_{n/1}}{n-1}$$ (2), the average of dynamic indices

$$\bar{i} = \sqrt[n-1]{\prod_{t=2}^{n} i_{t/t-1}} = \sqrt[n-1]{i_{n/1}}$$ (3) and the average rhythm of changing

$$\bar{r}_{\%} = \bar{i}_{\%} - 100$$ (4).

4. RESULTS AND DISCUSSION

Air emissions from the ICT sector are divided into five distinct categories, which we will analyze one by one.

4.1. Greenhouse gases (CO_2, N_2O in CO_2 equivalent, CH_4 in CO_2 equivalent, HFC in CO_2 equivalent, PFC in CO_2 equivalent, SF_6 in CO_2 equivalent, NF_3 in CO_2 equivalent) in kilograms per capita

The mean signifies that the average greenhouse gas emissions per capita in the ICT sector is 24.3 kg CO2 equivalent. This serves as a reference average value for the country analyzed.

Table 1 The average indicators of time series for greenhouse gases

the mean	24.300
the average of absolute change	0.656
the average of dynamic indices	1.028
the average rhythm of changing	2.777

The average of absolute change (0.656) represents the average absolute change in emissions between periods (likely between years). A small value suggests that annual variations in ICT sector emissions are relatively steady and not very large.

The average of dynamic indices (1.028) – a dynamic index above 1 indicates a slight average increase in emissions. Essentially, emissions in the ICT sector are growing on average by about 2.8% annually – idea confirmed also by the average rhythm of changing (2.777%).

We also did a graphic analysis of the evolution of the greenhouse gases air emissions from the ICT sector in Romania. The emissions increased from 21.1 kg in 2013 to 27.0 kg in 2022.
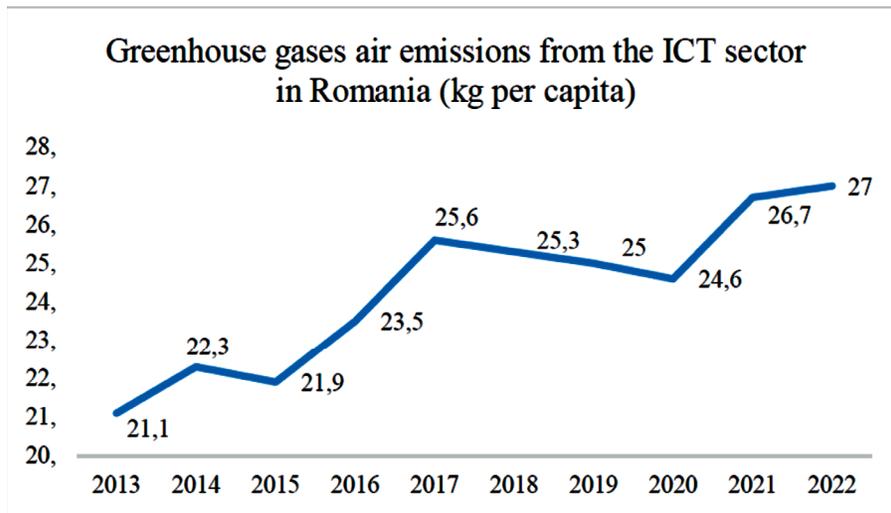

Fig. 1 Greenhouse gases air emissions

There is a slight but consistent upward trend in these emissions. Annual fluctuations are moderate, indicating a stable increase rather than sharp swings. This may signal growing use or impact of the ICT sector on the environment, posing challenges for sustainability.

In the COVID period (2020) we can observe a slight decrease — possibly reflecting reduced activity in offices or shifts to more energy-efficient remote work setups.

The ICT sector in Romania has seen steady growth in GHG emissions per capita over the past decade — likely due to: growth in digital infrastructure (data centers, mobile networks); increased internet and device usage; more energy demand from ICT services and devices.

Despite minor fluctuations, the trend is consistently upward, emphasizing the need for greener ICT practices (e.g., renewable-powered data centers, energy-efficient hardware).

4.2. Carbon dioxide

The average carbon dioxide emissions per capita in the ICT sector is 22.05 kg, which is slightly lower than the previous mean of 24.3 kg. This might suggest some improvement or differences in the dataset or time period.

Table 2 The average indicators of time series for carbon dioxide

the mean	22.050
the average of absolute change	0.522
the average of dynamic indices	1.024
the average rhythm of changing	2.428

The average yearly absolute change in emissions is 0.522 kg CO_2 equivalent per capita, a bit smaller than the previous 0.656, indicating somewhat more stable emissions over time.

The average of dynamic indices: 1.024 indicates an average growth rate of about 2.4% annually (slightly lower than before), showing that emissions are still increasing but at a slightly slower pace.

The average rhythm of changing: 2.428 – this rate shows the overall average change rhythm and confirms the steady but moderated growth in emissions from the ICT sector.

Emissions per capita from the ICT sector are still growing but at a slightly slower and more stable rate compared to the previous dataset. This could reflect progress in sustainability efforts, adoption of greener technologies, or data reflecting a different region or timeframe.
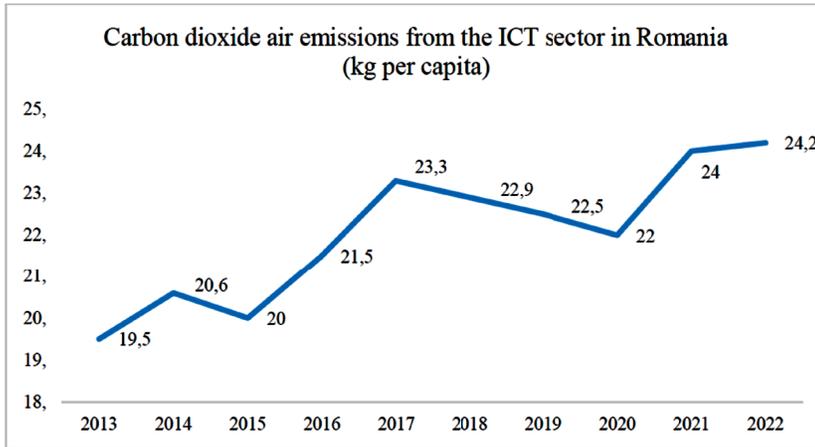
Fig. 2 Carbon dioxide air emissions

We have a noticeable growth between 2015–2017 (+3.3 kg); small plateau from 2018–2020, possibly due to energy efficiency or reduced office activity during the pandemic; second climb from 2020–2022, reaching a new high.

The CO_2 is the dominant greenhouse gas from the ICT sector. The steady increase aligns with: expanded access to internet and digital services; growth of data traffic and cloud computing; larger numbers of personal and business devices. However, Romania's CO_2 emissions per capita in ICT are still moderate by EU standards.

Continued growth without mitigation could push emissions higher — but renewable energy adoption and energy-efficient digital infrastructure could help flatten the curve.

4.3. Methane

The average value here is much lower than the previous ones (around 3.39 kg CO_2 per capita), which suggests this is likely a different indicator or a subset of emissions – maybe a specific gas or a smaller sector within ICT.

Table 3 The average indicators of time series for methane

the mean	3.390
the average of absolute change	0.144
the average of dynamic indices	1.051
the average rhythm of changing	5.104

The yearly absolute change is smaller (0.144), meaning fluctuations are quite modest.

The average of dynamic indices (1.051) indicates a growth rate of about 5.1% annually, which is a faster increase compared to previous data sets. The change rhythm confirms this faster growth trend – over 5% annual increase.

This indicator is growing faster but starts from a smaller base. It could be measuring a more specific emission type or sub-sector within ICT, showing a sharp rise but still at lower absolute emission levels. The faster growth might indicate emerging challenges or expanding activities in that part of the sector.

~25× higher than CO_2 per gram. Likely sources of CH_4 in ICT are natural gas use for powering on-site systems or backup generators and fugitive emissions in energy supply (e.g., gas infrastructure leaks). Also, CH_4 trends often mirror natural gas use and energy grid changes.

4.4. Methane (CO_2 equivalent)

The mean (94.990) – This is a much higher average value, suggesting this dataset measures a much larger quantity, likely total emissions or a broader category within the ICT sector.
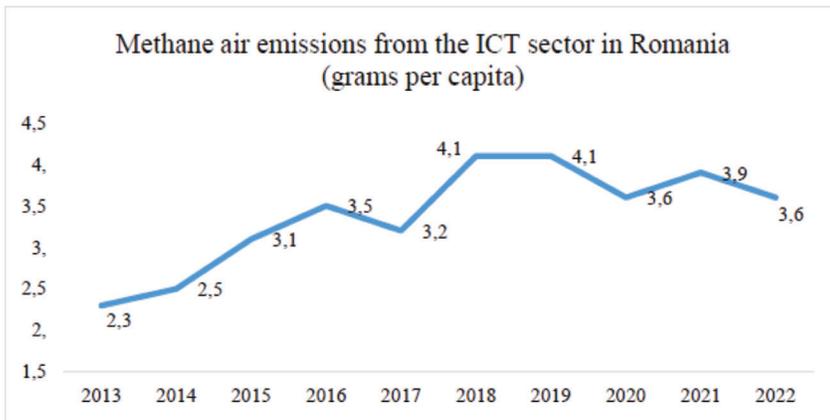

Fig. 3 Methane air emissions

Emissions rose steadily between 2013 and 2016. We have a dip in 2017, followed by a peak in 2018–2019 (4.1 g/capita). Slight decline post-2019, possibly tied to reduced on-site energy use or cleaner fuels during the pandemic years.

Methane is a minor component of total GHG emissions in ICT (in grams), but it has a warming potential

Table 4 The average indicators of time series for methane (CO_2 equivalent)

the mean	94.990
the average of absolute change	4.167
the average of dynamic indices	1.052
the average rhythm of changing	5.211

A relatively large average absolute yearly change (4.167), meaning the emissions vary significantly from year to year.

The average of dynamic indices (1.052) indicates an average growth rate of about 5.2% per year, which is consistent with a steady increase and the average rhythm of changing (5.211) confirms a dynamic growth trend of over 5% annually.

methane's warming impact vs. CO_2. Even though methane is emitted in grams, its CO_2-equivalent impact is substantial.

Romania's methane emissions from ICT (in CO_2-eq) have risen steadily – peaking in 2018–2019, dipping in 2020, and slightly decreasing since. CH_4 contributes more than 100 g CO_2-eq per person annually, making it a non-trivial
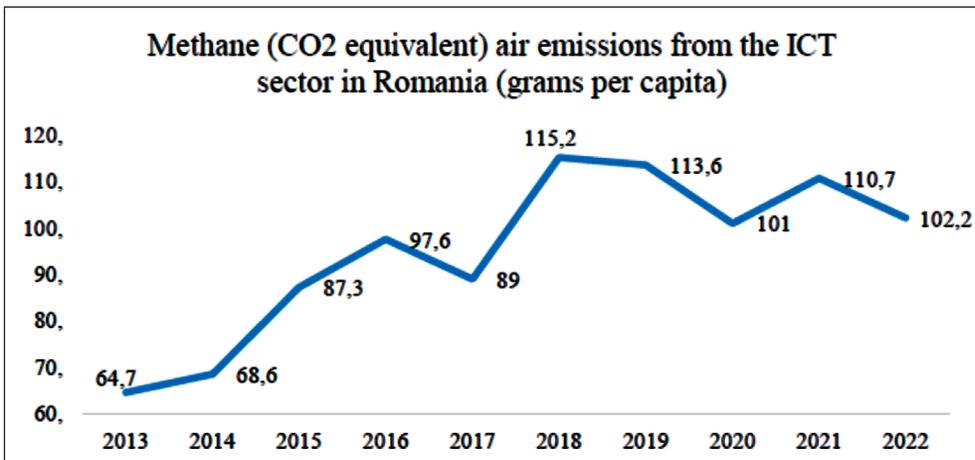

Fig. 4 Methane (CO_2 equivalent) air emissions

This dataset likely reflects a high-volume emission category or total sector emissions per capita. Emissions are growing steadily and significantly each year. The combination of high mean and growth rate points to a sector with considerable environmental impact and increasing pressures over time.

The CO_2-eq Matters because methane (CH_4) is 25× more powerful than CO_2 over 100 years. These values give a true comparison of

part of the ICT sector's climate footprint. Mitigating methane leaks and reducing fossil energy use in ICT infrastructure could meaningfully reduce this figure.

4.5. Nitrous oxide

A quite low average value (around 0.53 kg CO_2 equivalent per capita), which suggests this dataset is focused on a very specific or minor emission source within the ICT sector.

Table 5 The average indicators of time series for nitrous oxide

the mean	0.530
the average of absolute change	0.022
the average of dynamic indices	1.046
the average rhythm of changing	4.608

The average of absolute change (0.022) indicates very small absolute yearly changes, showing quite stable emissions at this scale.

but rapidly growing emission source or subcategory within ICT emissions. The absolute emissions are small, but the growth rate is notable, suggesting increasing attention might be needed here to manage future impact.

Nitrous oxide is a minor but potent greenhouse gas, with ~265× the warming potential of CO_2 per gram. Main sources in ICT likely include semiconductor manufacturing (small-scale in Romania) and electricity production (especially from fossil fuels with N_2O
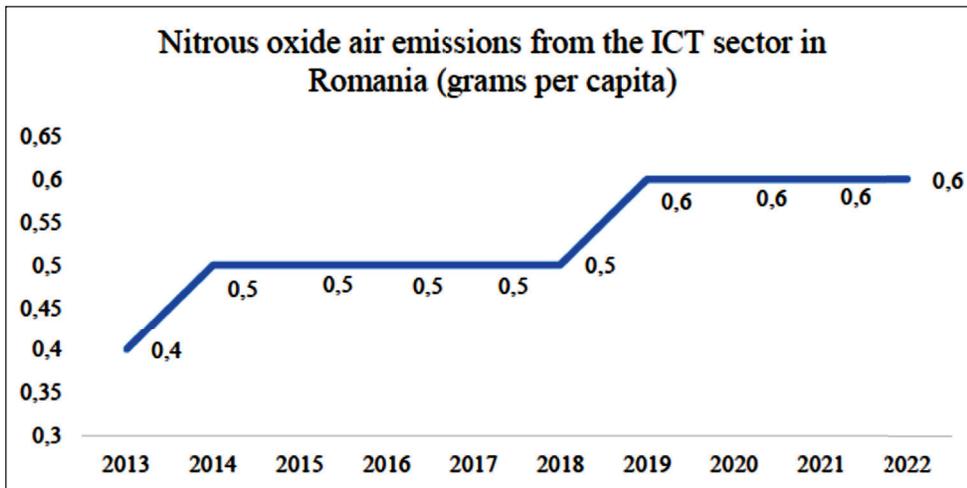

Fig. 5 Nitrous oxide air emissions

The average of dynamic indices (1.046) indicates a growth rate of roughly 4.6% per year, so even though the values are small, they are increasing relatively quickly and the average rhythm of changing (4.608%) confirms this moderate-to-high growth trend annually.

This likely represents a minor

byproducts). Romania's consistent levels suggest steady infrastructure and energy mix with minimal growth in N_2O-intensive activities.

N_2O emissions from ICT in Romania have been stable and low, averaging around 0.5–0.6 grams per capita. Despite its small share by weight, its warming potential

makes it worth tracking. Further reductions would likely depend on cleaner electricity sources rather than changes in ICT infrastructure.

5. CONCLUSIONS AND RECOMMENDATIONS

The analysis of air emissions from the ICT sector in Romania reveals a steadily increasing environmental footprint, particularly in terms of greenhouse gas emissions. While the absolute values remain moderate by international standards, the consistent upward trends in CO_2, methane (CH_4), and nitrous oxide (N_2O) emissions indicate growing environmental pressures as digital infrastructure and service usage expand.

Despite some temporary reductions during the COVID-19 pandemic, likely due to decreased in-office activity and increased remote work, emissions have generally rebounded and continued to rise. This highlights the dual nature of digitalization: while it offers opportunities for efficiency and decarbonization, it also contributes to increasing energy demand and emissions if not properly managed.

Methane and nitrous oxide, although emitted in smaller quantities compared to CO_2, carry significantly higher global warming potential, making their growth rates especially concerning. These findings underscore the importance of integrating environmental considerations into ICT development–particularly through the adoption of renewable energy, energy-efficient technologies, and sustainable digital practices.

Ultimately, for digital transformation to truly support climate goals, it must be aligned with environmental sustainability efforts. Romania, like other EU countries, faces the challenge of balancing digital growth with emission reduction, and the findings of this study reinforce the need for targeted policies that promote green ICT innovation while mitigating its environmental impact.

Digitalization is transforming not only people's lives but also the environment. The European Union's digital strategy seeks to ensure that this transformation benefits both individuals and businesses, while also supporting the overarching goal of achieving a climate-neutral Europe by 2050. The use of digital technologies across society and the economy can play a positive role in accelerating the shift towards a climate-neutral economy.

In Romania's ICT sector context, the emission trends documented in this study highlight the need for systematic approaches to emissions measurement, target-setting, and reduction. Romanian ICT based organizations can leverage these international standards to assess

current capability maturity, identify gaps, and develop roadmaps for achieving science-based targets. National policy frameworks can support capability development through mandatory reporting requirements, technical assistance programs, and platforms for knowledge sharing across the sector.

Based on the research conducted in this study a number of recommendations can be identified.

First, sustainable ICT practices across an organization requires a comprehensive approach that moves beyond energy efficiency and encompasses environmental, economic, and social dimensions of a given organization.

Second, alignment to international standards like GHG Protocol and Science Based Targets initiative (SBTi), is mandatory and requires the development of comprehensive measurement and reporting mechanisms.

Third, recognition of the evidence that value chain emissions represent the greatest amount of ICT carbon footprint leads to the necessity to develop capabilities focused on data collection, life-cycle approaches, supplier and customer engagement for Scope 3 emissions reduction.

Also, the digital infrastructure – including data centers and networks – should focus more on renewable and low-carbon energy sources.

A sustainability culture can be developed or sustained via well designed governance structures and accountability frameworks that support the integration of environmental targets related to ICT use into organizational objectives and performance indicators.

At the moment, in Romania there is already a clear move towards aligning organizations and practices in the ICT sector with the EU Digital Decade (European Commission, 2024; Romanian National Action Plan, 2024), as well as green economy strategies (Digital Skills and Jobs Platform, 2024). Also, the the Romanian government relies on European Union funds to support digitalization projects and capacity building (European Commission, 2025; Romania Insider, 2025; AGERPRES, 2025). That is clear evidence as to how policy and funding can act as enablers for cross-functional coordination and capability building or enhancement.

In Romania the private sector has already adopted green IT practices and demonstrated corporate sustainability commitment (EBRD, 2025; TechTalent, 2025; Startarium & Impact Hub Bucharest, 2025; GreenPoint Management, 2025). That can be further leveraged for sustaining future efforts towards employing ICT as an organizational strategic resource for sustainability purposes and cultural transformation.

The sustainment of the aforementioned efforts requires actions like:

- the ongoing integration of renewable energy into ICT infrastructure with a view to directly lowering Scope 1 and 2 emissions. That requires relying on the maturity level of technology, as well as on policy incentives. Also, resource wise, it necessitates agreements with energy providers and investments in the necessary infrastructure.
- establishing or upgrading the necessary capacity to measure greenhouse gas emissions and reporting in alignment with international standards. It requires training, data systems development and ongoing coordination across various functions which inherently translates into multi-year resource allocation and ongoing commitment requirements.

ENDNOTES

The source of data was EUROSTAT. All these statistics are available by type of air pollutants and greenhouse gases (AIRPOL):

- Carbon dioxide without emissions from biomass (CO_2) [CO2],
- Carbon dioxide from biomass (Biomass CO_2)* [CO2_BIO],

- Nitroux oxide (N_2O) [N2O],
- Methane (CH_4) [CH4],
- Perfluorocarbons (PFCs),
- Hydrofluorocarbons (HFCs),
- Sulphur hexafluoride (SF_6) including nitrogen trifluoride (NF_3),
- Nitrogen oxides (NOx) [NOX],
- Non-methane volatile organic compounds [NMVOC],
- Carbon monoxide (CO) [CO],
- Particulate matter < 10μm [PM10],
- Particulate matter < 2,5μm [PM2_5],
- Sulphur dioxide (SO_2) expressed in SO_2 equivalent,
- Ammonia (NH_3) [NH3],
- and various air pollutants expressed in equivalents of another air pollutant:
- CH_4 in CO_2 equivalents [CH4_CO2E]
- N_2O in CO_2 equivalents [N2O_CO2E]
- HFC in CO_2 equivalents [HFC_CO2E]
- PFC in CO_2 equivalents [PFC_CO2E]
- SF_6 and NF_3 in CO_2 equivalents [NF3_SF6_CO2E]
- NH_3 in SO_2 equivalents [NH3_SO2E]
- SOx in SO_2 equivalents [SOX_SO2E]
- NOx in SO_2 equivalents [NOX_SO2E]
- CO in NMVOC equivalents

[CO_NMVOCE]

- CH_4 in NMVOC equivalents [CH4_NMVOCE]
- NOx in NMVOC equivalents [NOX_NMVOCE]

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