ENVIRONMENTAL IMPACT OF DIGITALIZATION ACROSS EUROPEAN COUNTRIES: A COMPARATIVE STATISTICAL ANALYSIS

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This paper examines greenhouse gas emissions from the ICT sector across the 27 European Union countries, analyzing both manufacturing and services components. Using EUROSTAT data, the analysis reveals fundamental asymmetries: ICT manufacturing emissions concentrate in lower ranges across most countries, while ICT services emissions distribute more widely with substantial high-emission clusters. Carbon dioxide dominates emissions, though methane and nitrous oxide contribute significantly when measured in CO_2 equivalents. Emission profiles reflect national ICT sector structures, energy mixes, and specializations.

Key words: *gas emissions, ICT manufacturing, ICT services*

INTRODUCTION

The digital transformation of contemporary society represents one of the most profound technological and socio-economic shifts of the twenty-first century. As European nations accelerate their digitalization efforts, the Information and Communication Technology (ICT) sector has emerged as a critical driver of economic growth, innovation, and societal change. However, this digital revolution occurs against the backdrop of an equally urgent imperative: the transition toward climate neutrality and environmental sustainability.

The European Union's ambitious target to achieve climate neutrality by 2050, enshrined in the European Green Deal, necessitates a comprehensive understanding of emissions across all economic sectors, including those traditionally perceived as "clean" or "dematerialized" such as the ICT sector. While digital technologies offer substantial potential for reducing emissions in other sectors through optimization, efficiency gains, and dematerialization of processes, the ICT sector itself generates significant environmental impacts through its production activities, energy consumption, and infrastructure operations.

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Understanding the environmental footprint of the ICT sector requires distinguishing between its two primary components: ICT manufacturing and ICT services. ICT manufacturing encompasses the production of electronic components, computers, communication equipment, consumer electronics, and related hardware—activities that involve material extraction, energy-intensive fabrication processes, and complex global supply chains. ICT services, conversely, include telecommunications, data processing, hosting, software publishing, and related activities—operations that, while seemingly intangible, require substantial physical infrastructure including data centers, network equipment, and cooling systems, all of which consume significant energy.

The present paper undertakes a comprehensive statistical analysis of greenhouse gas emissions from the ICT sector across the twenty-seven European Union countries, examining both manufacturing and services components.

2. METHOD

The analysis focuses on multiple dimensions of emissions including total greenhouse gases (encompassing CO_2, N_2O in CO_2 equivalent, CH_4 in CO_2 equivalent, and fluorinated gases), carbon dioxide specifically, methane (both in absolute terms and CO_2 equivalent), and nitrous oxide from both ICT manufacturing and ICT services. By examining emissions on a per capita basis, the study enables meaningful comparisons across countries of varying population sizes and economic scales.

The analysis reveals substantial variation in emission profiles across European countries, reflecting differences in the scale and composition of national ICT sectors, energy sources employed in production and operations, regulatory frameworks, and technological sophistication. These variations offer valuable insights into potential pathways for emission reduction, highlighting both challenges and opportunities for aligning digital transformation with environmental sustainability objectives.

3. RESULTS AND DISCUSSION

3.1. Total greenhouse gases from ICT manufacturing (kg per capita)

The analysis of total greenhouse gas emissions from ICT manufacturing reveals a highly skewed distribution across the 27 European countries examined. The majority of countries demonstrate relatively low emission levels, while a small number of nations exhibit significantly elevated values.

Table 1 Greenhouse gases (CO2, N2O in CO2 equivalent, CH4 in CO2 equivalent, HFC in CO2 equivalent, PFC in CO2 equivalent, SF6 in CO2 equivalent, NF3 in CO2 equivalent) from ICT manufacturing (kg per capita)

Greenhouse gases from ICT manufacturing (kg per capita)	Countries	No of countries
0.00 - 3.70	BG, CY, DK, EL, ES, FI, FR, LU, LV, PL, PT, SE, SI	13
3.70 - 7.40	AT, BE, CZ, DE, LT, NL, SK	7
7.4 - 11.1	HR, IT, RO	3
11.1 - 14.8	EE, MT	2
14.8 - 18.5	HU	1
18.5 - 22.2	IE	1
Total		27

Source: Compiled by author from EUROSTAT Database

The largest group within low emission cluster (0.00-3.70 kg per capita) comprises thirteen countries (48% of the sample): Bulgaria, Cyprus, Denmark, Greece, Spain, Finland, France, Luxembourg, Latvia, Poland, Portugal, Sweden, and Slovenia. This cluster represents nations with minimal ICT manufacturing emissions intensity, suggesting either limited ICT manufacturing activities or highly efficient production processes with lower environmental impact per capita.

Seven countries occupy this intermediate range with medium-low emission (3.70-7.40 kg per capita) – (26% of the sample): Austria, Belgium, Czechia, Germany, Lithuania, Netherlands, and Slovakia. These nations demonstrate moderate ICT manufacturing emission levels, indicating a more substantial manufacturing presence compared to the lowest category while maintaining relatively controlled emission intensities.

Three countries fall into the category of medium-high emission group (7.40-11.10 kg per capita) – (11% of the sample): Croatia, Italy, and Romania. This group exhibits notably higher emissions, suggesting either more carbon-intensive manufacturing processes or a larger proportional contribution of ICT manufacturing to their economies.

High emission countries (11.10-18.50 kg per capita): Estonia and Malta represent the high-emission tier (7% of the sample), with

emissions ranging from 11.10 to 14.80 kg per capita. These elevated levels may reflect specialized manufacturing activities or specific structural characteristics of their ICT manufacturing sectors.

Hungary (14.80-18.50 kg per capita) and Ireland (18.50-22.20 kg per capita) stand as individual outliers with exceptionally high emissions. Ireland, in particular, demonstrates the highest ICT manufacturing emissions per capita among all analyzed countries, potentially indicating a concentration of emissions-intensive ICT manufacturing operations or methodological particularities in emissions allocation.

3.2. Total greenhouse gases from ICT services (kg per capita)

The emissions pattern for ICT services demonstrates a markedly different distribution compared to manufacturing, with a more dispersed spread across categories and a concentration in the higher emission ranges.

Table 2 Greenhouse gases (CO2, N2O in CO2 equivalent, CH4 in CO2 equivalent, HFC in CO2 equivalent, PFC in CO2 equivalent, SF6 in CO2 equivalent, NF3 in CO2 equivalent) from ICT services (kg per capita)

Greenhouse gases from ICT services (kg per capita)	Countries	No of countries
less than 11.49	BG, EE, ES, FI, IT, PT, SE, SK	8
11.49 - 12.79	AT, CZ	2
12.79 - 14.09	DK, EL, LT	3
14.09 - 15.39	FR, LV	2
more than 15.39	BE, CY, DE, HR, HU, IE, LU, MT, NL, PL, RO, SI	12
Total		27

Source: Compiled by author from EUROSTAT Database

Eight countries constitute lowest emission group (less than 11.49 kg per capita – (30% of the sample): Bulgaria, Estonia, Spain, Finland, Italy, Portugal, Sweden, and Slovakia. Interestingly, Estonia appears in the lowest services emission category despite being in the high manufacturing emission group, suggesting a structural imbalance between manufacturing and services emissions within its ICT sector.

In lower-middle range (11.49-12.79 kg per capita) we found Austria and Czechia (7% of the sample), representing a transitional category between lower and moderate emission levels.

Denmark, Greece, and Lithuania form the middle range group (12.79-14.09 kg per capita) – (11% of the sample), demonstrating moderate ICT services emissions that align closely with the median distribution.

France and Latvia represent the upper-middle range category (14.09-15.39 kg per capita) – (7% of the sample), positioned just below the highest emission tier.

The largest group with highest emission (more than 15.39 kg per capita) comprises twelve countries (44% of the sample): Belgium, Cyprus, Germany, Croatia, Hungary, Ireland, Luxembourg, Malta, Netherlands, Poland, Romania, and Slovenia. This substantial concentration in the highest category indicates that ICT services emissions are generally more elevated across European countries compared to manufacturing emissions, potentially reflecting the energy-intensive nature of data centers, telecommunications infrastructure, and digital services operations.

3.3. Carbon dioxide from ICT manufacturing (kg per capita)

Carbon dioxide emissions from ICT manufacturing show a highly concentrated distribution, with the vast majority of countries exhibiting low emission levels.

Table 3 Carbon dioxide from ICT manufacturing (kg per capita)

Carbon dioxide from ICT manufacturing (kg per capita)	Countries	No of countries
less than 7.53	AT, BE, BG, CY, CZ, DK, EL, ES, FI,FR, LT, LU, LV, NL, PL, PT, SE, SI, DE, IT, SK	21
7.53 - 10.04	HR, IE, MT, RO	4
more than 10.04	EE, HU	2
Total		27

Source: Compiled by author from EUROSTAT Database

An overwhelming majority of 21 countries (78% of the sample) fall into low emission majority (less than 7.53 kg per capita): Austria, Belgium, Bulgaria, Cyprus, Czechia, Denmark, Greece, Spain, Finland, France, Lithuania, Luxembourg, Latvia, Netherlands, Poland, Portugal, Sweden, Slovenia, Germany, Italy, and Slovakia. This extensive grouping suggests that CO2 emissions from ICT manufacturing are generally well-controlled across most European nations, possibly due to cleaner energy sources in manufacturing processes or limited manufacturing scale.

In the medium emission group (7.53-10.04 kg per capita) we have four countries (15% of the sample): Croatia, Ireland, Malta, and Romania. These nations demonstrate moderately elevated CO2 emissions from manufacturing, potentially indicating more carbon-intensive energy sources or manufacturing processes.

Estonia and Hungary represent the highest emission category (7% of the sample), with CO2 emissions exceeding 10.04 kg per capita. These elevated levels suggest either particularly carbon-intensive manufacturing operations or energy mix characteristics that result in higher CO2 intensity.

3.4. Carbon dioxide from ICT services (kg per capita)

CO2 emissions from ICT services exhibit a more graduated distribution across emission ranges, contrasting with the concentrated pattern observed in manufacturing.

Table 4 Carbon dioxide from ICT services (kg per capita)

Carbon dioxide from ICT services (kg per capita)	Countries	No of countries
1.3 - 10.12	AT, BG, EE, EL, ES, FI, IT, PT, SE, SK	10
10.12 - 18.94	CY, CZ, DK, FR, HR, LT, LV, NL, RO	9
18.94 - 27.76	BE, DE, HU, MT, PL, SI	6
more than 27.76	IE, LU	2
Total		27

Source: Compiled by author from EUROSTAT Database

Ten countries constitute the group (37% of the sample) of lowest emission tier (1.30-10.12 kg per capita): Austria, Bulgaria, Estonia, Greece, Spain, Finland, Italy, Portugal, Sweden, and Slovakia. Notably, Estonia appears in the lowest services CO2 category while being in the highest manufacturing category, indicating a clear sectoral divergence.

Nine countries occupy the lower-middle tier (10.12-18.94 kg per capita) – (33% of the sample): Cyprus, Czechia, Denmark, France, Croatia, Lithuania, Latvia, Netherlands, and Romania. This substantial grouping represents nations with moderate ICT services CO2 emissions.

Six countries fall into the upper-middle tier (18.94-27.76 kg per capita): (22% of the sample): Belgium, Germany, Hungary, Malta, Poland, and Slovenia, demonstrating elevated CO2 emissions from services operations.

Ireland and Luxembourg represent the highest emission tier (7% of the sample), (more than 27.76 kg per capita): with CO2 emissions substantially exceeding those of other nations. This may reflect the concentration of large-scale data centers and digital infrastructure in these countries.

3.5. Methane from ICT manufacturing (grams per capita)

Methane emissions from ICT manufacturing demonstrate an extremely skewed distribution, with the majority of countries clustered in the lowest emission category.

Table 5 Methane from ICT manufacturing (grams per capita)

Methane from ICT manufacturing (grams per capita)	Countries	No of countries
0.00 - 0.11	AT, BE, BG, CY, EE, EL, FI, FR, IT, LT, LU, LV, PL, PT, SE, SI	16
0.11 - 0.22	DK, ES, HR	3
0.22 - 0.33	CZ, DE, MT	3
0.33 - 0.44	HU, IE, RO	3
more than 0.44	NL, SK	2
Total		27

Source: Compiled by author from EUROSTAT Database

Sixteen countries (59% of the sample) exhibit minimal methane emissions: (0.00-0.11 grams per capita): Austria, Belgium, Bulgaria, Cyprus, Estonia, Greece, Finland, France, Italy, Lithuania, Luxembourg, Latvia, Poland, Portugal, Sweden, and Slovenia. This extensive grouping suggests that methane emissions from ICT manufacturing are generally negligible across most European countries.

Low emission group (0.11-0.22 grams per capita) is composed of Denmark, Spain, and Croatia constitute this category (11% of the sample), showing slightly elevated but still relatively low methane emissions.

Czechia, Germany, and Malta occupy medium-low emission group (0.22-0.33 grams per capita) – (11% of the sample), demonstrating moderate methane emission levels.

Hungary, Ireland, and Romania fall into this category (0.33-0.44 grams per capita) – (11% of the sample), exhibiting notably higher methane emissions from manufacturing operations.

Highest emission countries (more than 0.44 grams per capita) are Netherlands and Slovakia (7% of the sample), with emissions exceeding 0.44 grams per capita, possibly indicating specific manufacturing processes or energy sources with higher methane intensity.

3.6. Methane from ICT services (grams per capita)

Methane emissions from ICT services show a more evenly distributed pattern across emission ranges compared to manufacturing.

Table 6 Methane from ICT services (grams per capita)

Methane from ICT services (grams per capita)	Countries	No of countries
0.10 - 0.93	AT, CY, CZ, EE, EL, IT, PT, SE, SK	9
0.93 - 1.76	BE, DK, FI, FR, IE, MT, SI	7
1.76 - 2.59	BG, ES, NL	3
2.59 - 3.42	HR, RO	2
3.42 - 4.25	HU, LT, LU	3
4.25 - 5.08	DE, LV, PL	3
Total		27

Source: Compiled by author from EUROSTAT Database

Nine countries occupy the category of lowest emission range (0.10-0.93 grams per capita) – (33% of the sample): Austria, Cyprus, Czechia, Estonia, Greece, Italy, Portugal, Sweden, and Slovakia, representing nations with minimal methane emissions from services.

Seven countries constitute the lower-middle range (0.93-1.76 grams per capita) group (26% of the sample): Belgium, Denmark, Finland, France, Ireland, Malta, and Slovenia, demonstrating moderate-low emission levels.

Middle range (1.76-2.59 grams per capita) – here we found Bulgaria, Spain, and Netherlands form this category (11% of the sample), positioned in the median emission range.

In the upper-middle range (2.59-3.42 grams per capita) we have Croatia and Romania (7% of the sample), showing elevated methane emissions from services.

High emission group (3.42-4.25 grams per capita) is composed of Hungary, Lithuania, and Luxembourg (11% of the sample), demonstrating notably high methane emissions.

Germany, Latvia, and Poland constitute the highest emission category (11% of the sample), with methane emissions exceeding 4.25 grams per capita, potentially reflecting large-scale data center operations or specific infrastructure characteristics.

3.7. Methane in CO2 equivalent from ICT manufacturing (grams per capita)

The distribution of methane expressed in CO2 equivalents from manufacturing mirrors the pattern observed for absolute methane emissions, albeit with adjusted numerical values reflecting the Global Warming Potential (GWP) factor of 28 for methane.

Table 7 Methane (CO2 equivalent) from ICT manufacturing (grams per capita)

Methane (CO2 equivalent) from ICT manufacturing (grams per capita)	Countries	No of countries
0.00 - 3.22	AT, BE, BG, CY, EE, EL, FI, FR, IT, LT, LU, LV, PL, PT, SE, SI	16
3.22 - 6.44	ES, HR	2
6.44 - 9.66	CZ, DE, DK, MT	4
9.66 - 12.88	HU, IE, RO	3
more than 12.88	NL, SK	2
Total		27

Source: Compiled by author from EUROSTAT Database

Sixteen countries (59% of the sample) fall into the category of minimal emission cluster (0.00-3.22 grams CO2 eq. per capita): Austria, Belgium, Bulgaria, Cyprus, Estonia, Greece, Finland, France, Italy, Lithuania, Luxembourg, Latvia, Poland, Portugal, Sweden, and Slovenia, indicating negligible methane contribution to greenhouse gas emissions from manufacturing.

Low emission group (3.22-6.44 grams CO2 eq. per capita) is composed of Spain and Croatia constitute this small category (7% of the sample).

In the Medium Emission Group (6.44-9.66 grams CO2 eq. per capita) we found four countries (15% of the sample): Czechia, Germany, Denmark, and Malta.

Hungary, Ireland, and Romania demonstrate elevated methane-related GHG emissions (11% of the sample) (9.66-12.88 grams CO2 eq. per capita):

Netherlands and Slovakia represent the highest tier (7% of the sample), with methane contributions exceeding 12.88 grams CO2 equivalent per capita.

3.8. Methane in CO2 equivalent from ICT services (grams per capita)

Methane in CO2 equivalents from services demonstrates a broader distribution across categories, reflecting the higher overall methane emissions from services compared to manufacturing.

Table 8 Methane (CO2 equivalent) from ICT services (grams per capita)

Methane (CO2 equivalent) from ICT services (grams per capita)	Countries	No of countries
3.60 - 26.88	AT, CY, CZ, EE, EL, IT, PT, SE, SK	9
26.88 - 50.16	BE, DK, FI, FR, IE, MT, SI	7
50.16 - 73.44	BG, ES, NL	3
73.44 - 96.72	HR, RO	2
96.72 - 120.00	HU, LT, LU	3
120.00 - 143.28	DE, LV, PL	3
Total		27

Source: Compiled by author from EUROSTAT Database

Nine countries occupy the category of lowest range (3.60-26.88 grams CO2 eq. per capita) – (33% of the sample): Austria, Cyprus, Czechia, Estonia, Greece, Italy, Portugal, Sweden, and Slovakia.

Lower-middle range group (26.88-50.16 grams CO2 eq. per capita) is composed by seven countries (26% of the sample): Belgium, Denmark, Finland, France, Ireland, Malta, and Slovenia.

Bulgaria, Spain, and Netherlands form the category of middle range group (50.16-73.44 grams CO2 eq. per capita) – (11% of the sample).

Croatia and Romania represent the tier of upper-middle range (73.44-96.72 grams CO2 eq. per capita) – (7% of the sample).

Hungary, Lithuania, and Luxembourg have high emission (96.72-120.00 grams CO2 eq. per capita) – (11% of the sample).

Highest emission tier (120.00-143.28 grams CO2 eq. per capita) is formed by Germany, Latvia, and Poland (11% of the sample), demonstrating the most substantial methane-related greenhouse gas contributions from ICT services.

3.9. Nitrous oxide from ICT manufacturing (grams per capita)

Nitrous oxide emissions from ICT manufacturing show the most concentrated distribution among all analyzed pollutants, with an overwhelming majority of countries in the minimal emission range.

Table 9 Nitrous oxide from ICT manufacturing (grams per capita)

Nitrous oxide from ICT manufacturing (grams per capita)	Countries	No of countries
0.00 - 0.12	AT, BE, BG,CY,CZ, DK, EE, EL, ES, FI, FR, HU, IE, IT, LT, LU, LV, NL, PL, PT, SE, SI	22
0.12 - 0.24	RO	1
0.24 - 0.36	HR, MT	2
more than 0.36	DE, SK	2
Total		27

Source: Compiled by author from EUROSTAT Database

Twenty-two countries (81% of the sample) exhibit minimal N2O emissions (0.00-0.12 grams per capita):: Austria, Belgium, Bulgaria, Cyprus, Czechia, Denmark, Estonia, Greece, Spain, Finland, France, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Netherlands, Poland, Portugal, Sweden, and Slovenia. This extensive grouping indicates that nitrous oxide emissions from ICT manufacturing are generally negligible across most European nations.

Low emission (0.12-0.24 grams per capita): Romania alone occupies this category (4% of the sample).

Medium emission group (0.24-0.36 grams per capita) is formed by Croatia and Malta (7% of the sample).

Highest emission countries (more than 0.36 grams per capita) are Germany and Slovakia (7% of the sample), with emissions exceeding 0.36 grams per capita.

3.10. Nitrous oxide from ICT services (grams per capita)

N2O emissions from ICT services exhibit a more graduated distribution across multiple categories, contrasting sharply with the concentrated manufacturing pattern.

Table 10 Nitrous oxide from ICT services (grams per capita)

Nitrous oxide from ICT services (grams per capita)	Countries	No of countries
0.10 - 0.29	BG, EE, EL, ES, FI, IT	6
0.29 - 0.48	CY, CZ, FR, HU, LT, PT, SE	7
0.48 - 0.67	AT, DK, HR, RO	4
0.67 - 0.86	BE, DE, MT, NL, PL, SI	6
0.86 - 1.05	IE	1
1.05 - 1.24	LU, LV, SK	3
Total		27

Source: Compiled by author from EUROSTAT Database

Six countries occupy the lowest emission range (0.10-0.29 grams per capita): (22% of the sample): Bulgaria, Estonia, Greece, Spain, Finland, and Italy.

Seven countries constitute the group of lower-middle range (0.29-0.48 grams per capita) – (26% of the sample): Cyprus, Czechia, France, Hungary, Lithuania, Portugal, and Sweden.

Middle range (0.48-0.67 grams per capita): Austria, Denmark, Croatia, and Romania form this category (15% of the sample).

Upper-middle range (0.67-0.86 grams per capita): Six countries occupy this tier (22% of the sample): Belgium, Germany, Malta, Netherlands, Poland, and Slovenia.

Ireland alone represents this category high emission (0.86-1.05 grams per capita) – (4% of the sample). And the highest emission tier (1.05-1.24 grams per capita) is formed by Luxembourg, Latvia, and Slovakia (11% of the sample), with N2O emissions exceeding 1.05 grams per capita.

If we look at Manufacturing vs. Services Emission Patterns we found Divergent Distribution Characteristics: A fundamental observation emerges when comparing manufacturing and services emissions across all pollutant types: ICT manufacturing emissions demonstrate consistently more concentrated distributions with the majority of countries clustered in lower emission categories, while ICT services emissions show more dispersed patterns with substantial numbers of countries in higher emission ranges. This structural difference suggests that ICT services activities (including data centers, telecommunications, and digital infrastructure) are inherently more emissions-intensive on a per capita basis than ICT manufacturing activities across the European landscape.

Analyzing the Country-Specific Patterns we observe Consistent Low Emitters: Certain countries consistently appear in the lowest emission categories across multiple pollutant types for both manufacturing and services. Bulgaria, Finland, Portugal, and Sweden demonstrate this pattern, suggesting comprehensive low-emission profiles across their entire ICT sectors. These nations may benefit from cleaner energy mixes, efficient operations, or smaller-scale ICT sector activities relative to their populations.

Hungary and Ireland are Manufacturing-Intensive Emitters. They consistently occupy higher emission categories for manufacturing-related pollutants, particularly for total greenhouse gases and specific compounds. This pattern suggests specialized or concentrated ICT manufacturing activities with higher emission intensities in these countries.

Services-Intensive Emitters, like Luxembourg, Ireland, and Germany frequently appear in higher emission categories for ICT services across multiple pollutant types. This pattern likely reflects

the concentration of large-scale data centers, digital infrastructure, and telecommunications operations in these countries, which are inherently energy and emissions-intensive.

We have also Balanced Profiles: Some countries, such as Denmark, Netherlands, and Belgium, demonstrate moderate-to-high emissions across both manufacturing and services categories, suggesting more balanced ICT sector structures with substantial activities in both domains.

4. CONCLUSIONS

This comprehensive statistical analysis of greenhouse gas emissions from the ICT sector across the twenty-seven European Union countries reveals a complex and heterogeneous landscape characterized by substantial inter-country variation, distinct patterns between manufacturing and services components, and differentiated emission profiles across various pollutant types.

Perhaps the most striking finding of this analysis is the fundamental structural difference in emission patterns between ICT manufacturing and ICT services across all examined pollutant categories. ICT manufacturing emissions consistently demonstrate highly concentrated distributions, with the majority of countries clustered in lower emission ranges and only a small number of nations exhibiting elevated levels. In contrast, ICT services emissions display more dispersed patterns with substantial proportions of countries occupying higher emission categories.

This asymmetry suggests that ICT services activities—encompassing telecommunications infrastructure, data centers, hosting services, and digital platforms—are inherently more emissions-intensive on a per capita basis than ICT manufacturing across the European landscape. The energy demands of maintaining continuous digital connectivity, processing vast quantities of data, ensuring redundancy and reliability, and cooling infrastructure appear to generate more significant environmental impacts relative to population than the production of ICT hardware, at least when measured at the national level.

This finding has profound implications for emission reduction strategies within the ICT sector. While manufacturing emissions can be addressed through production efficiency, cleaner manufacturing processes, and supply chain optimization, services emissions require different interventions focused on data center efficiency, renewable energy procurement, network optimization, and fundamental questions about the energy intensity of digital infrastructure and services proliferation.

The statistical evidence presented in this analysis demonstrates that the environmental impact of the ICT sector across Europe is substantial, variable, and structurally complex. As European nations pursue ambitious digital transformation agendas while simultaneously committing to climate

neutrality, the emissions profile of the ICT sector—particularly the services component—emerges as a critical policy domain requiring sustained attention, innovation, and coordinated action.

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]

These statistics on the air emissions of the ICT sector provide insights about the scale of the different pollutants and greenhouse gasses emissions produced by the ICT sector, how big part of those emissions come from the ICT manufacturing and ICT services sub-sectors, as well as the share of those emissions in the emissions of total economy. The definition of ICT sector used for the purpose of producing these statistics follows the OECD official definition: "The production (goods and services) of a candidate industry must primarily be intended to fulfil or enable the function of information processing and communication by electronic means, including transmission and display" (OECD Guide to Measuring the Information Society 2011). Operationalized definition of the ICT

sector and its components in terms of economic activities (and their codes) according to NACE rev.2 fulfilling the OECD definition includes:

ICT sector - Total	**ICT Manufacturing**	C26.1	Manufacture of electronic components and boards
		C26.2	Manufacture of computers and peripheral equipment
		C26.3	Manufacture of communication equipment
		C26.4	Manufacture of consumer electronics
		C26.8	Manufacture of magnetic and optical media
		G46.5	Wholesale of information and communication equipment
	ICT Services	J58.2	Software publishing
		J61	Telecommunications
		J62	Computer programming, consultancy and related activities
		J63.1	Data processing, hosting and related activities; web portals
		S95.1	Repair of computers and communication equipment

AI DISCLOSURE

The author acknowledge the use of generative AI tools to assist in the preparation of this manuscript. This tool was used solely for language editing and structural suggestions, under the complete control and responsibility of the authors. The author reviewed and edited all AI-assisted content and takes full responsibility for the accuracy and integrity of the published work.

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