European Commission

ICT Impact study

Technical Assistance

Assistance to the European Commission

ICT Impact study

FINAL REPORT

Prepared by

VHK and Viegand Maagøe for the European Commission

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Energy

Prepared by

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ACRONYMS

ADSL	Asymmetric Digital Subscriber Line
AI	Artificial Intelligence
ATM	Automated Teller Machine
B, b	Byte (8 Bits), Bit
BBU	Baseband Unit
BLE	Bluetooth Low Power
BR	Blu-Ray
BRAS	Broadband Remote Access Server
BSC	Base Station Controller
BTS	Base Transceiver Station
CCAP	Converged Cable Access Platform
CDMA	Code-Division Multiple Access (2G, 3G)
CoC	Code Of Conduct
COTS	Commercial Of The Shelf
CPE	Consumer Premises Equipment
DC	Data Centre
D-CCAP	Distributed CCAP
DOCSIS	Data Over Cable Service Interface Specification
DSL	Digital Subscriber Line
DTH, DTC	Direct To Home, Direct To Cable
DPPE	Data Centre Performance Per Energy
DSLAM	DSL Access Multiplexer
DVB-T/C/S	Digital Video Broadcasting - Terrestrial/Cable/Satellite
DVD	Digital Versatile Disk
DG CONNECT	EC Directorate-General for Communications Networks Content And Technology
DG ENER	EC Directorate-General for Energy
DG GROW	Directorate-General for Internal Market, Industry, Entrepreneurship And SMEs
EB	Exabyte (10^{18} Byte)
EC	European Commission
EDGE	Enhanced Data Rates For Gsm Evolution (2G)
EIA	Ecodesign Impact Accounting
EN	European Norm
EPON	Ethernet Passive On
ETSI	European Telecommunications Standards Institute
FAN	Fixed Access Network
FTTH, FTTB, FTTP	Fibre To The Home, Building, Premises
GB	Gigabyte (10^{9}), Gigabit, Gigabit Per Second
Gb	Gigabit Gigabit
Gbps	Gb Per Second
GBRS	General Packet Radio Service (2g)
GbE	Gigabit Ethernet
GEO	Geostationary (Satellite)
G.Fast	A DSL Protocol
GHG	Greenhouse Gas
GGSN	Gateway GPRS Support Node
GPP	Green Public Procurement
GSM	Global System For Mobile Communications (2G)
HAPS	High Altitude Pseudo Satellite
HD	High Definition (1920 X 1080) Resolution
HDR	High Dynamic Range (In Image/Video
HLR	Home Location Register
HSPA, HSPA+	High Speed Packet Access (3g, 4g)
I-CCAP	Integrated CCAP
ICT	Information And Communication Technology
IEA	International Energy Agency
IEC	International Electrical Committee
IEEE	Institute Of Electrical And Electronics Engineers
IETF	Internet Engineering Task Force
IE	Imaging Equipment
IP/TCP	Internet Protocol, Transmission Control Protocol
ipm	Images Per Minute
IPS	Internet Service Provider
ISO	International Standards Organisation
IOPS	Instructions Per Second
IoT	Internet Of Things
ITU	International Telecommunication Union
JRC	Joint Research Centre (Ec)
kB, kb, Kbps	Kilo (10^{3}) Bytes, Kilo Bit, Kilobit Per Second
kVA	Kilo (10^{3}) Volt Ampere (Battery Capacity)
LAN	Local Area Network
LEO	Low Earth Orbit
LPWA	Low Power Wan
LTE	Long Term Evolution (4g)
M2M	Machine-To-Machine
MIMO	Muliple Input Multiple Output
MB, Mb, Mbps	Mega (10^{6}) Byte, Megabit, Megabits Per Second
MEO	Medium Earth Orbit
MME	Mobility Management Entity

ms	millisecond (10^{-3} s)
MSAN	Multi-Service Access Node
MSC	Mobile Switching Centre
NAS	Network Attached Storage
NR	New Radio (5G)
OLT	Optical Line Terminal
ONU	Optical Network Unit
PDN	Packet Data Network
PGW	Packet Gateway
PHY	Physical (Layer)
PON	Passive Optical Network
POP	Point Of Presence
POS	Point Of Sales
POTS	Plain Old Telephone System
PSTN	Public Switched Telephone Network
PUE	Power Usage Effectiveness
QAM	Quadrature Amplitude Modulation
RAN	Radio Access Network
RF	Radio Frequency
RFID	Radio Frequency Identity Device
RMD	Remote MAC-PHY Device
RNC	Radio Network Controller
RPD	Remote PHY Device
RRH	Remote Radio Head
RRU	Remote Radio Unit
SD	Standard Definition (1280x720 Px) Resolution
SERT	Server Efficiency Rating Tool
SGSN	Serving GPRS Support Node
SGW	Serving Gateway
SIC	Server Idle Coefficient
SNIA	Storage Networking Industry Association
STB	Set Top Box
TB, Tbps	Terabytes (10^{12}), Terabits Per Second
TETRA	Terrestrial Trunked Radio
UHD, 4K	Ultra-High Definition (3840x2160 Px) Resolution
UMTS	Universal Mobile Telecommunications System (3g)
UPS	Uninterruptable Power Supply
VDSL	Very High Speed Digital Subscription Line.
VHK	Van Holsteijn En Kemna (Part Of Study Team)
VLR	Visitor Location Register
VSAT	Very Small Aperture Terminal
WAN	Wide Area Network
WLAN	Wireless LAN
ZB	Zetabyte (10^{21} Bytes)

Conversion table diagonal inch of display to square dm (format 16:9)

Inch	dm²	**Inch**	dm²
1	0.03	**31**	26.49
2	0.11	**32**	28.23
3	0.25	**33**	30.02
4	0.44	**34**	31.87
5	0.69	**35**	33.77
6	0.99	**36**	35.73
7	1.35	**37**	37.74
8	1.76	**38**	39.81
9	2.23	**39**	41.93
10	2.76	**40**	44.11
11	3.34	**41**	46.35
12	3.97	**42**	48.63
13	4.66	**43**	50.98
14	5.4	**44**	53.38
15	6.2	**45**	55.83
16	7.06	**46**	58.34
17	7.97	**47**	60.9
18	8.93	**48**	63.52
19	9.95	**49**	66.2
20	11.03	**50**	68.93
21	12.16	**51**	71.71
22	13.34	**52**	74.55
23	14.58	**53**	77.44
24	15.88	**54**	80.39
25	17.23	**55**	83.4
26	18.64	**56**	86.46
27	20.1	**57**	89.57
28	21.61	**58**	92.75
29	23.19	**59**	95.97
30	24.81	**60**	99.25

EXECUTIVE SUMMARY

This impact study on Information and Communication Technology (ICT) is a 9-month study project for the Commission Services, running from 28.10.2019 untill 28.7.2020, with three tasks:

1. Retrieving EU27 commercial and energy consumption data for 8 main ICT categories systems, for the period 2010-2025, to be elaborated using modelling by JRC-IPTS;
2. Clustering the energy data by networking and end-use sectors as well as extending the analysis by two extra ICT categories with a focus on benefits in professional sectors (building automation and industrial sensors);
3. Preparing selected topics for EU policy options, amongst others to be used in the context of the Ecodesign and Energy Labelling Working Plan 2020-2024, which partially runs in parallel to this project.

Task 1

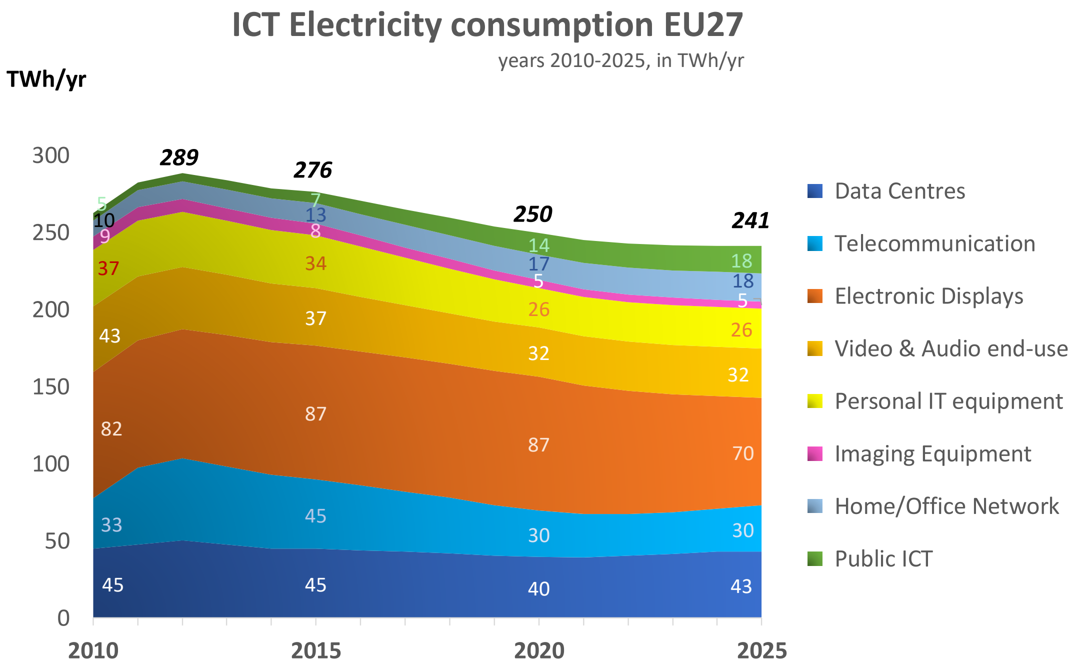
After an introductory chapter 1, chapters 2 to 9 of this report deal with the 8 main ICT categories as given by the Commission services for Task 1. Chapters 2 (data centres), 3 (telecommunication) and 8 (home/office network) deal with systems aspects first and then with the elements of the systems. The other chapters deal with categories of end-use devices: electronic displays, (other) video and audio devices, personal IT equipment, imaging equipment (e.g. copiers and printers) and public ICT equipment. Each chapter follows mostly the same order: definition of the product, market data (sales & stock), performance - metric and energy use, energy efficiency improvement options and a summary table where appropriate.

Investigation of task 1 shows that, in the most recent year for which Eurostat publishes data (2018), the ICT products consume almost 260 TWh or ~10% of the EU27 electricity consumption. This is less than electricity consumption for light sources, more than electricity for water heaters and comparable to the annual electricity consumption of Spain or Turkey. In terms of net final energy consumption, i.e. following the accounting principles of the Eurostat energy balance sheets, ICT consumes 2% of the EU27 total.

Electricity use for ICT is declining after peaking in the year 2012 at 289 TWh/yr, the ICT electricity use decreased on average by 1.7% annually and is expected to reach 240 TWh/yr by 2022. Despite the exponential increase in data traffic and ICT product performances over the period, the energy efficiency of ICT-related products increased even more.

The efficiency improvement is due to Moore's law, which indirectly implies that as the density of transistor chips doubles every 2-3 years, so too does their energy efficiency. It is also due to the huge leap in (LED) backlight-efficiency for displays, solid state data storage (SSD), artificial intelligence (AI) and machine-learning (ML) in servers and switches, full optical fibre in data networks, increased speed in satellite communication, green power purchasing and waste heat recovery by data centres, energy saving communication protocols for people and the Internet-of-Things (IoT), etc..

The figure below, taken from the summary Chapter 10, gives the estimated EU27 electricity consumption for the 8 main ICT categories investigated in Task 1 between the years 2010 and 2025.



On the demand-side, video sharing is the most important service rendered by ICT in terms of data traffic and bandwidth. Video on demand, movies, social media clips and game streaming take up close to 85% of the bandwidth of the data centres. Electronic displays (TVs, monitors, signage displays) are by far the largest end-use devices. The ever-increasing display resolution, now 4K and perhaps 8K in the future is the main driver for the fast increasing data-traffic. Video-conferencing –currently not a significant contributor, could become a new driver for more bandwidth.

Audio-equipment, so far unregulated, could be a candidate for energy policy measures, especially in combination with videos. Public ICT is the only category where energy consumption is clearly rising, especially due to hotspots and security cameras.

The category with the largest uncertainty as regards energy consumption is probably the personal IT equipment, e.g. desktop PCs, notebooks, tablets, etc. On the one hand there are anecdotal reports of energy increasing trends, such as extreme gaming, bitcoin mining through blockchains and individual binge-watching of videos on notebooks and tablets replacing collective TV-watching. On the other hand, mid-market notebooks and PCs can be found with energy consumption that is only a fraction of Energy Star limits. And, there is the continuing trend of miniaturisation (PC→notebook→tablet→smartphone) that is lowering personal IT energy use. Reliable, unbiassed databases and surveys on the subject are scarce.

Each main category covers 3 to 10 product groups. The EU27 electricity consumption from 2010-2025, in TWh/yr, is specified in the detailed table hereafter.

ICT Electricity Use EU27

(in TWh/year)	**2010**	**2015**	**2020**	**2025**
Servers	18.66	18.66	22.05	27.24
Storage	1.80	1.80	4.35	4.45
Networks	0.53	0.53	0.74	1.06
Cooling etc.	23.74	23.74	12.40	10.07
Total Data Centres	**44.73**	**44.73**	**39.54**	**42.82**
Fixed Area Network (FAN)	13.49	18.40	17.70	17.90
Radio Area Network (RAN)	17.60	24.00	10.50	11.00
Satellite & terrestrial TV	1.91	2.60	1.80	1.20
Total Telecommunication	**33.00**	**45.00**	**30.00**	**30.10**
Television sets	66.99	71.34	64.38	43.50
Monitors	13.05	6.96	2.61	2.61
Signage Display	0.87	8.70	20.01	23.49
Total Electronic Displays	**80.91**	**87.00**	**87.00**	**69.60**
DVD/Video player	1.91	2.35	0.61	0.00
Video-projector	1.83	1.57	0.96	0.44
Game consoles	6.79	6.26	5.66	5.13
Interactive whiteboards	0.01	0.15	0.22	0.30
Video-conferencing	0.09	0.17	0.27	0.44
MP3-player	0.09	0.06	0.04	0.02
Home audio	18.79	13.35	10.09	10.09
Connected audio	0.00	0.00	0.00	0.01
CSTB	13.05	13.05	13.05	13.05
Digital TV services	0.00	0.00	0.74	2.70
Total video & audio end-use	**42.56**	**36.97**	**31.64**	**32.16**
Standard notebooks	4.96	6.54	5.19	5.56
Gaming notebooks	1.06	1.40	1.35	2.52
Standard desktop PCs	16.61	11.11	6.40	6.15
Gaming desktop PCs	6.43	4.30	2.23	1.90
Integrated desktop	1.10	0.74	0.69	0.67
Thin clients	0.59	0.38	0.33	0.32
Workstations	1.20	1.26	1.34	1.49
Tablets /Slatesl	0.10	2.58	1.87	1.34
E-book readers	0.00	0.01	0.01	0.01
Smartphones	0.45	1.58	1.65	1.75
Home/Office fixed phones	4.15	4.42	4.48	4.13
Total personal IT equipment	**36.66**	**34.30**	**25.54**	**25.84**
Mono laser Multi-Functional (MFD)	1.49	1.34	0.97	0.80
Colour laser MFD	2.06	1.91	1.20	0.93
Mono laser printer	1.82	1.15	0.65	0.48
Colour laser printer	1.06	1.21	1.12	1.13
Mono laser copier	0.73	0.31	0.05	0.00
Colour laser copier	0.17	0.30	0.12	0.00
Inkjet MFD	0.57	0.51	0.40	0.35
Inkjet printer	0.34	0.09	0.01	0.01
Professional printer / MFD	0.51	0.72	0.80	0.77
Scanner	0.03	0.03	0.03	0.05
3D printer	0.00	0.00	0.16	0.16
Total Imaging Equipment	**8.77**	**7.58**	**5.52**	**4.67**
Home Network-attached storage equipment (NAS)	0.57	1.00	1.42	1.52
Home/office network equipment	8.79	11.54	14.28	15.06
IoT Cellular Gateway	0.22	0.22	0.22	0.52
IoT Home/Office Gateway	0.70	0.69	0.69	1.39
Total Home/Office Network	**10.28**	**13.44**	**16.61**	**18.49**
Automated Teller Machines (ATM)	0.51	0.37	0.17	0.17
Point-of-Sales equipment	3.00	2.68	2.35	2.02
Ticket machines	0.04	0.04	0.04	0.04
Hot spots	0.26	0.78	4.79	6.96
Toll-related	0.03	0.03	0.03	0.03
Video-cameras	1.13	3.53	6.53	8.61
Total Public ICT	**4.97**	**7.43**	**13.90**	**17.84**
TOTAL	**262**	**276**	**250**	**242**

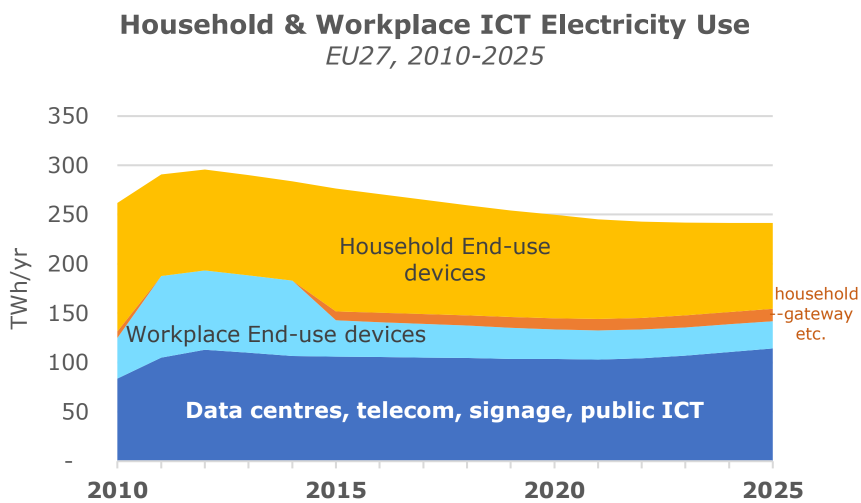
Task 2

In chapter 11 which is the first of three chapters dealing with Task 2, energy consumption is divided, on the one hand into residential (household) and non-residential (work-related) devices and on the other hand in end-devices and ICT networks (including public devices and signage displays).

As the table and diagram show, the electricity use of end-use devices in 2020 has decreased by over 20% since 2010 and is expected to continue to decrease. Conversely, the electricity use of non-end-use devices in the workplace, mainly due to the increase of signage displays and public ICT, is expected to rise.

Electricity consumption ICT devices EU27, 2010-2025, Task 2

ICT Devices	Residential (TWh/yr)				Non-residential (TWh/yr)				Total (TWh/yr)			
year-->	2010	2015	2020	2025	2010	2015	2020	2025	2010	2015	2020	2025
Data Centres	-	-	-	-	**44.7**	**44.7**	**39.5**	**42.8**	**44.7**	**44.7**	**39.5**	**42.8**
Telecommunication	-	-	-	-	**33.0**	**45.0**	**30.0**	**30.1**	**33.0**	**45.0**	**30.0**	**30.1**
Televisions & monitors	66.7	67.6	59.2	40.4	13.4	10.7	7.8	5.7	80.1	78.3	67.0	46.1
Signage displays	-	-	-	-	**0.9**	**8.7**	**20.0**	**23.5**	**0.9**	**8.7**	**20.0**	**23.5**
Video & audio end-use	37.3	32.3	27.8	28.5	5.3	4.7	3.9	3.7	42.6	37.0	31.7	32.2
Personal IT equipment	25.1	23.9	17.3	17.6	11.6	10.4	8.3	8.2	36.7	34.3	25.5	25.8
Imaging Equipment	1.2	0.8	0.6	0.5	7.6	6.7	4.9	4.2	8.8	7.6	5.5	4.7
Home/Small Office Network	**6.9**	**9.1**	**11.4**	**12.6**	**3.4**	**4.3**	**5.2**	**5.9**	10.3	13.4	16.6	18.5
Public ICT	-	-	-	-	**5.0**	**7.4**	**13.9**	**17.8**	**5.0**	**7.4**	**13.9**	**17.8**
TOTAL	**137**	**134**	**116**	**100**	**125**	**143**	**134**	**142**	**262**	**276**	**250**	**242**
of which												
Non end-use devices	*7*	*9*	*11*	*13*	*87*	*110*	*109*	*120*	*94*	*119*	*120*	*133*
End-use devices	*130*	*125*	*105*	*87*	*38*	*33*	*25*	*22*	*168*	*158*	*130*	*109*



Building Automation and Controls Systems (BACS) are sensor-, control-, communication- and actuator systems in buildings and are used to regulate space- and water heating, cooling, ventilation, lighting, solar shading, security, safety, etc. for the comfort of inhabitants, for the physical condition of the building and for the reduction of energy– and other resources use. Chapter 12 discusses that if all current BACS were to be replaced by efficient versions, e.g. through appropriate policy measures, the annual sales would be enough to save 158 GWh per year in electricity self-consumption. If the complete stock of BACS were to be replaced, an electricity saving of 5 TWh/year on self-consumption alone would be possible. At the moment, BACS cover only 0.8% of the total potential EU market, saving 8 TWh/year in building energy consumption. Given that the investment in the average BACS has an economical payback period of 5.4 years, it seems that all conditions for a considerable energy saving potential, both in self-consumption and in its primary function should be fulfilled.

Smart industrial sensors (chapter 13) measure, process, store and communicate data on vibration, temperature and other performance parameters of new and existing industrial motors that are typically part of fans, pumps, compressors and other industrial equipment. Their purpose is to inform technical staff on sub-optimal performance in order to take measures to increase product life, reduce down-time of the processes in which the motors are engaged, lower energy use, perform optimal 'condition based maintenance' (CBM), etc. They are usually battery-driven and use very little energy (1 button-cell every 5 to 10 years). The industrial motor stock >0.75kW in the EU is estimated to be over 100 million units and is projected to consume 1294 TWh of electricity by 2030. Even at a conservative 5-10% saving this comes down to a large saving potential from smart industrial sensors.

Task 3

Due to COVID-19 measures, the Commission decided to make some changes in the Task 3 activities originally foreseen, i.e. to expand on desk research rather than on meetings with (potential) stakeholders. Two subjects were chosen for their eligibility in the ongoing Ecodesign and Energy Label Working Plan 2020-2024 study (EELWP). These were the Uninterruptable Power Supply (UPS) and Home Audio equipment. One topic, specifically consumer behaviour in the context of ICT, was selected in view of upcoming research activities in that field by the EC DG JRC in Seville.

Further to investigations carried out on UPS in 2014, there are now new developments in battery technology which enable substitution of the lead-acid by Li-ion batteries as well as smart-grid possibilities that make the UPS an eligible product in the context of the EELWP. Chapter 14 mentions that presently, an electricity saving potential of 10 TWh/year in 2030 vis-à-vis 2020 seems realistic.

Home audio equipment (chapter 15) is a sector where significant energy savings have taken place in the EU over recent decades, i.e. from an estimated 31 TWh/yr in the year 2000 to an estimated 14 TWh electricity consumption today. The sector has seen drastic changes over that period: from analogue to digital, from physical data to streaming, etc. Nonetheless, despite considerable uncertainty over the data, the latest consumer tests suggest that there is still a large disparity in energy consumption of soundbars, smart Wi-Fi speakers and digital radios. From the material efficiency point of view, the use of neodymium (critical raw material) in some magnets for speakers could be of interest.

Chapter 16 discusses consumer behaviour as the driving force behind the large increase in data-traffic of ICT-devices. More specifically, the most recent information of reliable sources on time expenditure of media-activities was retrieved and analysed. The chapter contains a myriad of tables and diagrams from the EU and individual Member States. These raw data will be further investigated by JRC Sevilla and it is too early to draw conclusions, but it is remarkable that in fact –although there are large differences between the age-groups—the average time expenditure per person on traditional media (TV, radio) has not changed very significantly over the last decade. Internet use and streaming video/audio have increased, especially among the 'millennials' (14-30 year-old age group), but perhaps not as much as many sources would like to make us believe.

CONTENTS

Table of tables

Table of figures

1 INTRODUCTION

1.1 Tasks

The "ICT Impact study" will provide the Commission Services with the following information, split into three tasks:

Task 1 – Data retrieval for future modelling (by JRC)
For the ICT products listed in Table 1 of the request for services,

1. sales and stock most recent available
2. appropriate performance metric, incl. capacity and load
3. energy efficiency to allow benchmarking and annual energy use for most recent year
4. representative technology and best available for most recent year

Task 2 – ICT cluster analysis
For studies of last 5 years on present and forecasted energy consumption and improvement potential

1. for cat. I, II and VIII (data centres + office/mobile network + public ICT) + signage
2. workplace end-use devices
3. household end-use devices
4. building automation
5. other controls

Task 3 – Preparing for policy options

1. analyse trends of above groups + synergies
2. identify problem areas
3. consider similar studies
4. identify increase energy consumption ICT
5. assess impact of connectivity + smart on overall system
6. prioritise product groups
7. propose policy options

This interim report covers Task 1, but also includes some data retrieval for Task 2 and 3. Each chapter describes each product group (see section 1.3 below) their sales and stock, volume trends where available and relevant, metrics relevant for assessment of energy use (performance, efficiency, for average-BAT, where available and/or relevant) and the resulting indicative energy (electricity) consumption.

1.2 Methodology and deliverables

1.2.1 Contract

The study is mainly a desk-research study, focusing on data that is available and reliable for the most recent years.

The deliverables are:

- an interim report on Task 1 after 4 months (ca. 1 March 2020);
- a draft final report on Task 1, 2 and 3 at the latest 7 months after signature of the contract (June 2020), to be finalised after processing of comments by Commission Services.

The Task 1 interim-report is to feed into future modelling work by JRC IPTS (Sevilla).
The Final Report is to feed into the preparatory study by the EC, DG GROW for the Ecodesign Working Plan 2020-2024. Also, the Final Report serves as a strategic background note for the European Commission in general, regarding the resources use by ICT products and services.

The study is conducted jointly by VHK and Viegand Maagøe. Lay-out and reporting style follows EU-corporate identity. Copyright stipulations of the EU regarding the use of images apply.

1.2.2 Statistics

As of 1 February 2020 the UK is no longer part of the European Union. For EU statistics this means a transition period, where both aggregates, i.e. EU27_2020 (2020+) and EU28 (2013-2020) apply for *Eurostat*.[1] [2] Most secondary sources will still refer to the EU28, also with projections for 2020. For the annual energy use statistics such as the *Ecodesign Impact Accounting EIA* there is an agreement with DG ENER, Unit C.4 to use EU28 data for the year 2020 because it is an important reference year for many policy goals. The EU27 data will apply to EIA as from 1.1.2021 onwards.

For this ICT study the study team will use EU27 wherever a conversion or elaboration of the original data to EU-data is needed. However, where original EU28 data for 2020 are used directly, e.g. from EIA, there will be no conversion in order to maintain traceability. Where needed, these data can be converted by readers using the conversion factors proposed below.

Eurostat
After Brexit in January 2020 the EU28 became the EU27, but most Eurostat statistics are before that date and needed to be converted here. The Table below gives an overview.

From the table it is concluded that for predominantly residential ICT products and services a factor **0.87**, based on number of households, between UK28 and UK27 is applied. For strictly ICT business applications a factor **0.85**, based on Gross Domestic Product (GDP), is more appropriate.

[1] https://ec.europa.eu/eurostat/help/faq/brexit
[2] Also there is the EU27_2007 (2007-2013) for the period before entry of Croatia per 1.7.2013.

Table 1. Conversion of EU statistics
(source: Eurostat misc. databases, extract March 2020)

parameter	unit	EU27* (2020+)	UK	EU28 (2013 -'20)	HR	EU27 (2007 -'13)	RO	BG	EU25 (pre 2007)
inhabitants	million	446	66	**512**	4	508	20	7	481
	vs. EU28	*0.871*	*12.9%*	***1***	*0.8%*	*0.992*	*3.9%*	*1.4%*	*0.939*
households	million	194	29	**223**	1.5	221.5	7.5	2.7	211.3
	vs. EU28	***0.870***	*13.0%*	***1***	*0.7%*	*0.993*	*3.4%*	*1.2%*	*0.948*
land area	x1000km2	4211	244	**4455**	57	4398	238	111	4049
	vs. EU28	0.945	5.5%	**1**	1.3%	0.987	5.3%	2.5%	0.909
GDP	bn EUR	13484	2425	**15909**	52	15857	205	57	15595
	vs. EU28	***0.848***	*15.2%*	***1***	*0.3%*	*0.997*	*1.3%*	*0.4%*	*0.980*
enterprises	million*	24.9	2.5	**27.4**	0.17	27.23	0.54	0.37	26.32
	vs. EU28	*0.909*	*9.1%*	***1***	*0.6%*	*0.994*	*2.0%*	*1.4%*	*0.961*
employees	million	150	21.5	**129**	1.1	127.9	4.4	2.1	121.4
	vs. EU28	*1.163*	*16.7%*	***1***	*0.9%*	*0.991*	*3.4%*	*1.6%*	*0.941*

**=including financial and insurance sector, excluding is ca. 10% less; HR/RO/BG data*

Cisco

Many authors use data from the Cisco annual internet reports[3]. Some of these data refer to "Western Europe", which is basically the EU-15. The 13 New Member States (NMS) added 26% to the population but gained only 8.7% in terms of the EU's GDP (status 2018). On the other hand, after Brexit the EU28 population decreased by 13% (half of NMS) and as much as 15.2% in GDP (a factor 1.75 of NMS). In other words, for residential ICT products "Western Europe" figures should be multiplied by a factor of 1.10 [0.87*1.26] and for business related products and services by a factor of 0.96 [0.848*1.13]. In aggregate, weighing each factor equally, the Cisco 'Western Europe' population must be multiplied by **1.06** [0.96*1.10/2] to represent EU27 figures.

ITU

The International Telecommunication Union is the official United Nations institute for telecommunication and one of the most reliable sources for telecom statistics globally and regionally. One of the ITU-regions is "Europe", which is ITU Region-B. This Region comprises 33 countries, including the former EU15 (including mini-states like Andorra, Monaco, San Marino, Vatican), the Baltics, EFTA, some Eastern-European countries (Croatia, Bosnia and Herzegovina, Hungary, Slovenia) and Turkey[4]. The total population is about 555 million people (2018). In comparison, the EU27 countries have 446 million inhabitants (**81%**).

EMEA

EMEA stands for Europe, Middle-East and Africa and is a business region often used in annual reports of companies. Its Eastern border just excludes Russia and just includes Turkey and Iran, spanning 116 countries.[5] Its GDP is €24 750 bn ($27.5 trillion, status 2018). In terms of GDP the EU27 is now ~**55%** of EMEA (EU28 was 64% of EMEA).

[3] Cisco is global market leader in telecom equipment and -support and publishes annual reports to indicate trends. www.cisco.com

[4] https://www.itu.int/online/mm/scripts/gensel29?_search_region=B&_languageid=1

[5] http://istizada.com/list-of-emea-countries/

1.3 Scope and structure of the report

1.3.1 Structure

This report follows the order of product groups and categories requested by the European Commission, given in paragraph 1.3.1.

These product groups/categories are not all at the same aggregation level: Chapters 2 and 3 (groups i. and ii.) on data centres and telecommunication relate to systems where the hardware, software and services work together as one. Performance, energy use and -efficiency should therefore also be analysed together. To a lesser extent, more choice on hardware is given and this is also true for Chapter 8 (group vii.) that deals with home/office local networks and gateways.

Having said that, for policy makers in Ecodesign and related areas the focus is very often on hardware, i.e. several products like servers, storage devices, etc. and these are regulated as if they were stand-alone devices. In order to accommodate this aspect, chapter 2 has a larger focus specifically on the hardware-components and shows the results as reference values from Ecodesign preparatory and impact assessment studies –even though these results tend to be older.

From the industry side, the hardware –and especially the *Application Specific IC* chips (*ASICs*)—pertains to the communication protocol that determines the performance of the system. Chapter 3 therefore focusses on the communication protocols and services, although hardware is incorporated as well.

Chapters 4 (electronic displays), 5 (audio/video), 6 (personal IT equipment), 7 (imaging equipment) and 9 (ICT in public spaces) are mainly groups of end-user devices where each product is best treated individually.

As appropriate and where possible, the study team has tried to follow the same format throughout the report:

- Definition
- Market (sales, stock and trends)
- Performance and energy use
- Energy efficiency improvement
- Summary

1.3.2 Product groups or categories

The scope of the study "ICT Impact Study" covers the following product (sub)groups:

i. Data centres

a. infrastructure
b. network
c. storage
d. servers

ii. Telecom networks
   a. broadband communication equipment
   b. network in offices (see also group vii.)
   c. mobile networks
   d. cable / landline networks

iii. Electronic displays
   a. televisions
   b. monitors, displays
   c. signage / public displays

iv. Audio/video
   a. home audio equipment (radio, hifi, mp3, loudspeaker, etc.)
   b. home video equipment (Blu-Ray, DVD, game consoles)
   c. complex set-top boxes, digital TV services
   d. projection devices (beamers, electronic whiteboards)
   e. other: web collaboration, videoconferencing, etc.

v. Personal ICT equipment
   a. desktop PCs, work stations
   b. laptops, tablets
   c. e-readers
   d. fixed phone (home + office)
   e. smartphones

vi. Imaging equipment
   a. printers, copiers, scanners, MFD (home + office)
   b. 3D printers

vii. Home and office equipment
   a. home gateways, IoT access devices (Bluetooth, ZigBee, Z-wave, etc.)
   b. home network equipment (modems, routers, combined, access points, extenders, repeaters)
   c. base stations (see Product Category II – Telecommunication equipment)
   d. office network equipment: servers, switches, routers
   e. networked accessed storage - NAS (home + office)

viii. ICT in public spaces
   a. cash registers
   b. ATM bank cash machines
   c. ticketing machines (vending, access gates)
   d. public WLAN (better covered under vii – home networking equipment)
   e. toll related ICT
   f. security camera's

ix. Building automation
   a. for building management & monitoring

x. Other controls
   a. as agreed during kick-off: 'smart' controls for motor driven systems only

Note that group ix. and x. are not part of Task 1, as agreed with the Commission Services.

1.3.3 Interrelationship of ICT products / product groups

In this study "ICT products" (Information and Communication technology) are understood to be products from both the information technology and the communication technology sectors. The main characteristic these product groups share is that they (increasingly) allow communication between devices through the internet (including home networks using other protocols, but are ultimately connected to the internet). For that reason the study also covers product groups in which the transition from 'traditional media' (analogue, or digital but not network connected) to 'digital media' is in full swing (e.g. for products in the audio/video group).

The internet is a "network of networks" used for the exchange of digital information ("traffic" or "data") from one user to another through networks using the Internet Protocol suite (TCP/IP). Many digital services are enabled or carried through the internet, such as the World Wide Web (browsing), social media, electronic mail, mobile applications, online games, internet telephony, file sharing, video-conferencing and webinars, streaming media services and many company-specific applications (for administration, logistics, ordering, etc.). Such services are increasingly provided by servers (and storage devices) that are hosted in data centres (ICT group i. – this Chapter 2). The data is transported by telecommunication equipment (ICT group ii. – see Chapter 3). Ultimately the end-use devices (such as PC's, smartphones, streaming devices, printers, 'smart' controls; group iii. to viii.) are the devices that provide the actual 'interface' to the end-user in home and professional (office) environments. These can be connected by either cable or radio-waves.

2 Group I. - Data centres

2.1 Definitions

2.1.1 General

According to the most recent international standards[6], a data centre is defined as *a structure, or group of structures, dedicated to the centralized accommodation, interconnection and operation of information technology and network telecommunications equipment providing data storage, processing and transport services together with all the facilities and infrastructures for power distribution and environmental control together with the necessary levels of resilience and security required to provide the desired service availability.*

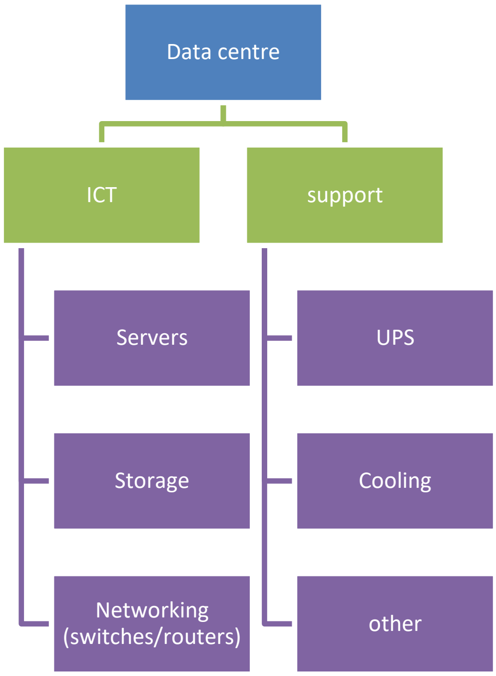


Figure 1. Equipment in data centres

Figure 1 gives an overview of the equipment involved in the ICT and support side of the data centre. European standards[7] distinguish four types of data centres:

[6] Definition which is, according to the 2018 Standardisation landscape for the energy management and environmental viability of data centres (5th edition) of the CEN/CLC/ETSI Joint Coordination Group Green Data Centres, based on

ISO/IEC 30134-1:2016 Information technology — Data centres — Key performance indicators — Part 1: Overview and general requirements.

ETSI ES 205-200 series (2014-2018, various parts), Access, Terminals, Transmission and Multiplexing (ATTM); Energy management;Global KPIs;Operational infrastructure

CENELEC EN 50600-1:2019; Information technology. Data centre facilities and infrastructures. General concepts. (CEN/CLC/ETSI refers to the 2012 version)

[7] EN 50174-2:2018 Information technology. Cabling installation. Installation planning and practices inside buildings, and EN 50600-1:2019 (cit.)

– **co-hosting data centre**: data centre in which multiple customers are provided with access to network(s), servers and storage equipment on which they operate their own services/applications
  Note: Both the information technology equipment and the support infrastructure of the building are provided as a service by the data centre operator
– **co-location data centre**[8]: data centre in which multiple customers locate their own network(s), servers and storage equipment
  Note: The support infrastructure of the building (such as power distribution and environmental control) is provided as a service by the data centre operator
– **enterprise data centre**[9]**:** data centre that is operated by an enterprise which has the sole purpose of the delivery and management of services to its employees and customers
– **hosting data centre:** a data centre within which ownership of the facility and the information technology equipment is common but the software systems are dictated by others.

Data centres of large content providers such as Amazon Web Services, Microsoft corporation, Alphabet Inc. (Google), Alibaba Group, Facebook Inc., Apple, etc. can be found in all categories, although a typical feature is that they use their own software. They may operate large ('*hyperscale')* but also smaller structures. Internet service providers (ISPs) have data centres, but are also known to use colocation. A special category of collective data centres are, i.e. owned by digital giants and

A recent trend is 'edge computing'. Some call 'edge' anything which is not the very core of the network (so centres which can be already fairly large), while others refer to edge as something actually at the very edge of the network, e.g. a processing unit that handles a few sensors. In this report it is understood to relate to the interface between the core network and the access network (see also section 3). These are instances where the content providers move closer to the internet service providers (ISPs), e.g. by physically sharing their servers in so-called Points-of-Presence (PoPs), or by content providers placing cache servers & storage at the internet service providers where (larger) end-use clients can connect directly, e.g. with their *Virtual Private Network VPN*.

Data centres are mainly established in places close to where subsea fibres land ashore, close to core networks and where clients reside (to reduce latency –the delay in transport of data, often expressed in the low tens of milliseconds), close to vast resources of cheap (renewable) energy to reduce cooling costs and/or environmental impacts, or any combination of the above. Data centres provide business but also a large (peak) power draw on the city's energy structure. The IEA recommends policy makers trying to attract data centres to their city or region to check electric grid-(peak power) capacity, and possibilities for its expansion, as one of the critical issues.[10]

[8] A.k.a. '*collective' or 'cloud' or 'public' data centres.*

[9] A.k.a. '*private' or 'traditional' data-centres* for end-users like companies and institutions handling their own data and thus retaining complete control.

[10] https://www.iea.org/commentaries/data-centres-and-energy-from-global-headlines-to-local-headaches

2.1.2 Server definition

The Regulation 2019/424/EU on servers and data storage[11] defines the product group as follows:

(1) 'server' means a computing product that provides services and manages networked resources for client devices, such as desktop computers, notebook computers, desktop thin clients, internet protocol telephones, smartphones, tablets, tele-communication, automated systems or other servers, primarily accessed via network connections, and not through direct user input devices, such as a keyboard or a mouse and with the following characteristics:
(a) it is designed to support server operating systems (OS) and/or hypervisors, and targeted to run user-installed enterprise applications;
(b) it supports error-correcting code and/or buffered memory (including both buffered dual in-line memory modules and buffered on board configurations);
(c) all processors have access to shared system memory and are independently visible to a single OS or hypervisor;
Several related terms are also defined in the regulation like resilient server, large server, multi-node server, etc. The table below describes the different servers applied in data centres.

Table 2. Server types

Product type	Product description
DC Servers(enterprise, blade, rack/tower, volume, mid-range/high-end/mainframe)	
Server	Server means a computing product that provides services and manages networked resources for client devices, such as desktop computers, notebook computers, desktop thin clients, internet protocol telephones, smartphones, tablets, tele-communication, automated systems or other servers, primarily accessed via network connections, and not through direct user input devices, such as a keyboard or a mouse and with the following characteristics: it is designed to support server operating systems (OS) and/or hypervisors, and targeted to run user-installed enterprise applications; it supports error-correcting code and/or buffered memory (including both buffered dual in-line memory modules and buffered on board configurations); all processors have access to shared system memory and are independently visible to a single OS or hypervisor.
Rack server	A server with a form-factor suitable to be mounted in a server rack, where other servers, storage devices and network equipment can be mounted as well. Rack servers are typically used in enterprise server rooms and data centres, when there is a need for more than a few servers.
Blade server	Blade server means a server that is designed for use in a blade chassis. A blade server is a high-density device that functions as an independent server and includes at least one processor and system memory, but is dependent upon shared blade chassis resources (e.g., power supply units, cooling) for operation. A processor or memory module will not be considered a blade server when the technical documentation for the product does not indicate that it scales up a standalone server. Blade servers are typically used in larger data centres.
Resilient server	Resilient server means a server designed with extensive reliability, availability, serviceability and scalability features integrated in the micro architecture of the system, central processing unit (CPU) and chipset. Resilient servers are used in data centres for special purposes
Tower server	A server housed in a tower case similar to tower cases used for desktop computers. This server type is mainly used in enterprise server rooms.

[11] Commission Regulation (EU) 2019/424 of 15 March 2019 laying down ecodesign requirements for servers and data storage products pursuant to Directive 2009/125/EC of the European Parliament and of the Council and amending Commission Regulation (EU) No 617/2013

2.1.3 Storage definition

The Regulation 2019/424/EU on servers and data storage products defines the product group as follows:

(10) 'data storage product' means a fully-functional storage system that supplies data storage services to clients and devices attached directly or through a network. Components and subsystems that are an integral part of the data storage product architecture (e.g., to provide internal communications between controllers and disks) are considered to be part of the data storage product. In contrast, components that are normally associated with a storage environment at the data centre level (e.g. devices required for operation of an external storage area network) are not considered to be part of the data storage product. A data storage product may be composed of integrated storage controllers, data storage devices, embedded network elements, software, and other devices;

Product type	Product description
DC Storage (hard disks, storage controllers, data storage products)	
Data storage online 2, 3 & 4	Data storage product means a fully-functional storage system that supplies data storage services to clients and devices attached directly or through a network. Components and subsystems that are an integral part of the data storage product architecture (e.g., to provide internal communications between controllers and disks) are considered to be part of the data storage product. In contrast, components that are normally associated with a storage environment at the data centre level (e.g. devices required for operation of an external storage area network) are not considered to be part of the data storage product. A data storage product may be composed of integrated storage controllers, data storage devices, embedded network elements, software, and other devices[1]. Data storage products are classified into 6 online classes (1-6) according to a number of performance parameters[12]. The ecodesign regulation (2019/424) covers the main part of the storage products which are Online 2-4. Online 1 includes consumer products and storage components, while online 5 and 6 are large and mainframe products.

2.1.4 Networks definition

DC Network (1/ 10/ 40 GB Ethernet, storage networks)	
Router	Router: A network device that routes network packets from one logical network to another, along a predefined or dynamically discovered path, based on network layer information embedded in the Network packet header (OSI layer #3)[13]. For the purpose of the study, the following routers are included under the DC Networks: Provider Edge Routers, Subscriber Edge Routers at enterprises and core routers at enterprises connecting different locations. Routers in smaller offices and in homes, often combined with a Wi-Fi access point and a switch with up to about 5 ports, are not included.
(Ethernet) switch	Switch: A network device that delivers packet data frames to specific physical ports on the device, based on the destination address of each frame from the Data Link (OSI layer #2) within a logical network[3]. The switches can be categorised according to types:

[12] SNIA Emerald™ Power Efficiency Measurement Specification

[13] ENERGY STAR® Program Requirements for Large Network Equipment

	- modular managed: a system able to be modified regarding the capability and able to configure, manage and monitor the local area network (LAN); - fixed managed: as modular managed, but without the modular capability; - fixed unmanaged: as fixed managed, but without the capability to manage etc. the LAN; and according to maximum bandwidth: 100 Mbps, 1 Gbps, 10 Gbps and 40 Gbps.

2.1.5 UPS definition

Data centres need to remain powered continuously; bearing in mind that the grid supply can experience brown-outs, black-outs, ripples and other variations, that generators need time to start up, and that surge suppressors can help with power spikes but not power-loss, under-voltage and brownout conditions, the centre needs an uninterruptible power supply.

A UPS is a device that:

1. Provides backup power when utility power fails; this has to be either long enough for critical equipment to shut down gracefully so that no data is lost, or long enough to keep required loads operational until a generator becomes available online.
2. Conditions incoming power so that all-too-common sags and surges don't damage sensitive electronic gear.

UPSs come in three varieties or topologies:

1. Single-conversion systems: supply power to IT if input power fails set criteria. It can either be a standby system (only active when utility power fails, switching to battery power) or Line-interactive (which continuously monitors and regulates utility input power, using battery power to guard against abnormalities).
2. Double-conversion systems: first convert utility power by a rectifier/charger to DC power, and then converts it back to AC power by an inverter. This ensures that IT equipment only receives clean, reliable electricity. If utility power fails, the rectifier shuts off and power is drawn from a battery bank.
3. Multi-mode systems features both single- and double-conversion technologies to strike a balance between efficiency and protection. Maximum efficiency is provided under normal conditions, and in extreme conditions some efficiency is sacrificed to deliver maximum protection.

The data centre owner has to decide which level of protection is sought. Traditionally smaller DCs are equipped with single-conversion and large systems, while business critical DCs are equipped with multi-mode systems.

UPSs are rated or categorised according to the following criteria:

- the load they support, from 300 VA to over 5 000 000 VA (close to 5 MW) and whether it's single-phase (smaller systems) or three-phase;
- the form factor, such as rack-mounted or free-standing;
- redundancy (zone architecture, serial architecture or parallel architecture)'
- hot-swappable (exchange parts while system keeps operating);

- battery runtime (typical 15 min. which is sufficient for the generator to power up, more can be added);
- battery management (trickle-charge or charge-and-rest);
- remote monitoring options;
- scalability and modularity: if data centre power needs are difficult to predict, the UPS should allow sizing according to these needs (parallel or modular architecture preferred);
- software and communications: the UPS can 'inform' connected IT hardware of its' status so that servers can power down (as battery continues to be drained) and reboot when power is returned (virtualization can make this quite complex as both virtual machines and host machines need to be managed correctly);
- services and support available.

The backup power can be stored in batteries (sealed or valve regulated lead acid batteries VRLA, or flooded batteries or vented lead acid VLA) or flywheels (more dense, no hazardous materials, but limited to 30 s. standby power, which is usually enough for most utility power failures).

The generator is usually a diesel generator whose runtime is more or less limited by the availability of fuel (size of tank and frequency of fuel supplies). Usually, an engine driven UPS ('rotary system') is less efficient than a 'static' one (battery flywheel) as the rotary systems include losses such as the energy utilized to power controls, flywheels, and pony motors associated with the rotary UPS at zero load and the energy utilized to preheat the engine coolant and lubrication. Frictional and windage losses also have an impact on the overall efficiency[14].

The rotary UPSs are a niche product, representing less than 5% of overall UPS revenue. The rotary systems are not typical for data centres, but rather, other power-critical applications where large power users (motors, or high power amplifiers) repeatedly turn on/off, are.

Not part of the UPS, but nonetheless part of the energy supply system are power distribution units that distribute power to downstream IT equipment. These can be floor-mounted, providing power to a rack, or rack-mounted, providing power to individual servers and other devices, or a combination of both. These power distribution units usually work as switch-mode power supply and are thus able to 'absorb' tiny irregularities of supplied utility power (if not removed by UPS), with a 'ride-through' of typically 10 ms or more.

2.1.6 Cooling definition

One of the main support systems for data centres is the cooling system. This system is responsible for keeping the servers at required operating temperatures.
Basically, there are two main principles for cooling servers (as well as storage and networking equipment) and these are by air or by liquid immersion.

[14] Carl Cottuli, Comparison of Static and Rotary UPS, Revision , by Schneider Electric

Air based cooling

The most common solution to cooling is by air. The cold air is created mostly by chillers and this cools air down to temperatures of about 16ºC. This cold air is then passed over the racks. Most data centres use a cold aisle/hot aisle configuration.

The drawback with using this method is that the control over the flow of air through the cabinets is poorand usually an unnecessary large amount of cooled air is moved.

An improvement is 'hot aisle containment' and 'cold aisle containment' which prevents the mixing of hot/cold flows of air. In hot aisle containment the 'hot' side of the racks are pointed towards each other and connected to a common return air plenum. In cold aisle containment this is reversed. While both options offer better control over the removal of hot air than simple hot aisle/cold aisle, there may still be issues of 'hot spots' (areas that are not sufficiently cooled).

Both methods offer savings over a simple hot aisle / cold aisle layout, but it is said that 'hot aisle containment offers 40% higher savings than cold aisle containment[15] (mainly because hot aisle can operate in economizer mode for longer).

Even more control over cooling performance is brought about through 'in-rack heat extraction' where the cooling system (compressors, providing chilled air) is built into the server rack itself.

[15] https://blog.se.com/datacenter/2011/09/15/for-data-center-energy-efficiency-hot-aisle-beats-cold-aisle-containment/

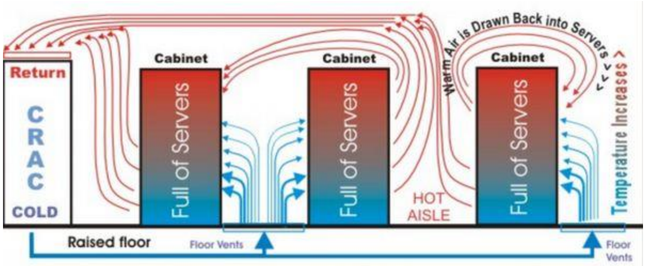


Figure 2. Cold aisle / hot aisle

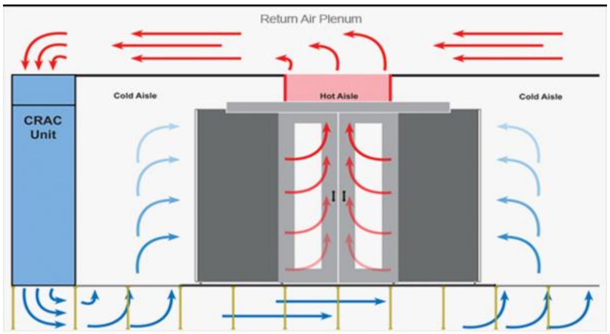


Figure 3. Hot aisle containment

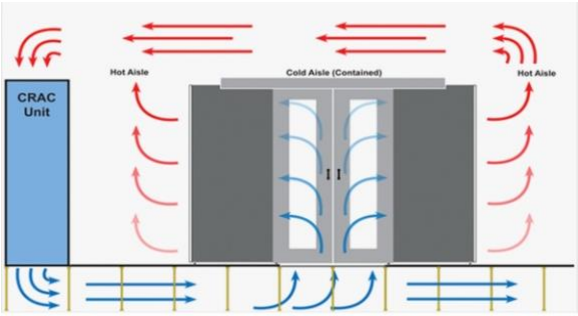


Figure 4. Cold aisle containment

Liquid-based cooling

One method used to remove heat from server racks is by passing cold water through the racks. The risk of leaks however puts off many data centre managers and this system is rarely applied.

Another method used is that of liquid immersion cooling which is relatively new and involves immersion of all the servers components in a bath with a dielectric liquid. This liquid does not conduct electricity, but does conduct heat. According grcooling.com such a system can cut cooling energy by up to 95%, and allows a PUE of less than 1.05. The technology is apparently gaining popularity in server farms mining for bitcoins which requires intensive processing.

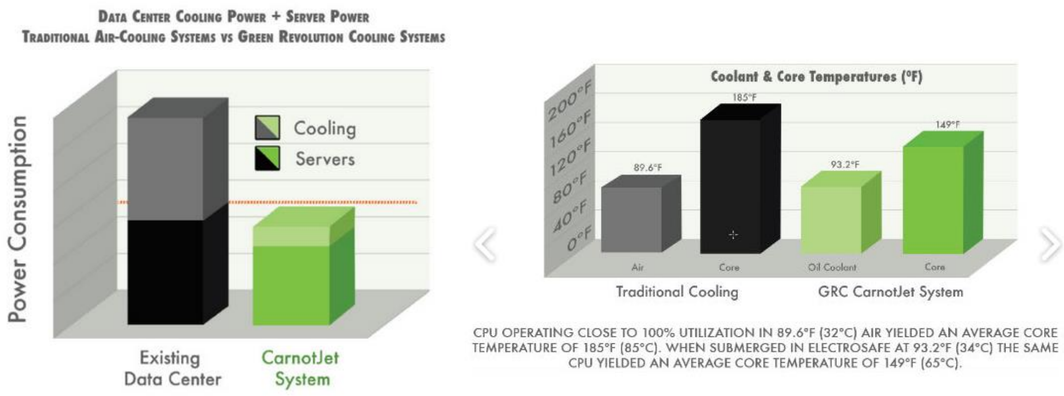


Figure 5. Benefits of liquid immersion cooling vs. traditional[16]

2.2 Market

2.2.1 Data centre market

Private data centres have been around since the early 1970s. The collective data centres and hyperscale centres took off at the advent of the internet in the beginning of the 1990s.

In November 2019, Cloudscene_2019[17] presented a total of 6867 colocation data centres globally, of which 2273 were in the EU28 (33%), or 1814 without the UK.

Table 3. Number of colocation data centres in Europe and globally (Cloudscene, Nov 2019)

Number of data centres, by Cloudscene[18]	#	% of EU27	% of global
EU27 (excl. UK)	1814	100%	26%
EU28	2237	123%	33%
all Europe, incl. Turkey	2418	133%	35%
global	6867	379%	100%

The Cloudscene statistics cover mainly commercial colocation centres that offer connectivity to various internet exchange providers. It is assumed that these figures do not include the many private data centres comprising universities, hospitals, banks, (local/regional/national) governments and authorities,private enterprises nor the hyperscale data centres (compare data in Table 16).

Figure 6 gives an overview of colocation centres per Member State.

The highest uncertainty concerns the number of traditional private data centres.

[16] https://www.grcooling.com/iceraq

[17] Cloudscene_2019: data extracted from website november 2019 [https://cloudscene.com/browse/data-centers]

[18] https://cloudscene.com/datacenters-in-europe (accessed 26-11-2019)

Borderstep_2015 [19] calculated that in the case of Germany and for a total of less than 2500 data centres of >100 m^2 (typical bottom value for colocation facilities) there are probably approximately 18000 server rooms (11-100m^2) and approximately 31000 server closets (<10m^2), resulting in at least 51470 centres in total. This is shown in Figure 7. The trend over the period 2008-2013 represents standstill or -8% decrease in small facilities <100 m^2 and an increase in large facilities of up to 40%. Figures on data traffic in Table 13, Table 16 and Figure 13 show that, although using different definitions/parameters and thus different absolute figures, this trend is global and persists.

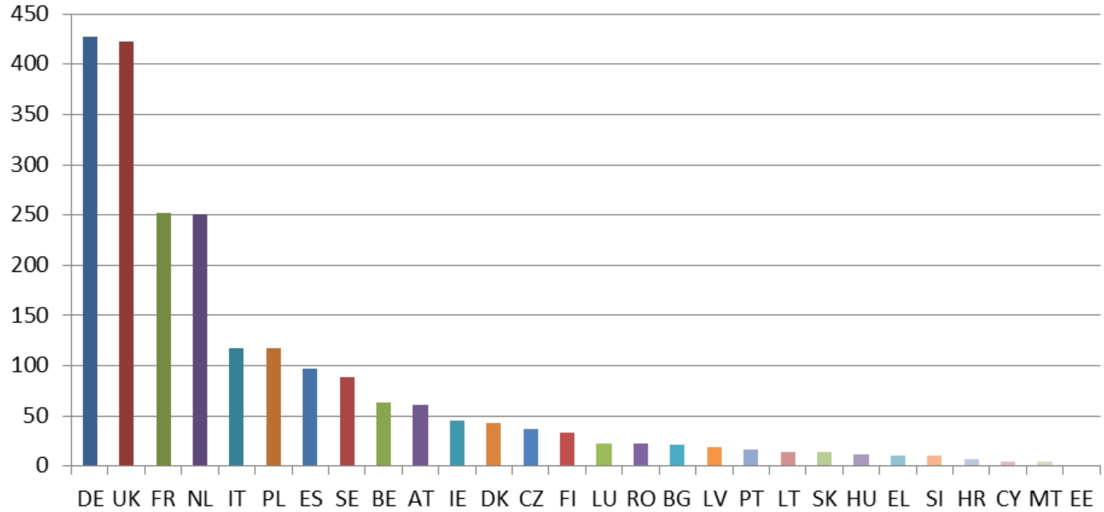


Figure 6. Number of data centres (colocation, from service providers) by Member State (Cloudscene, Nov 2019)

Data center size	No. of data centers in Germany (2013)	Change Rate 2008 - 2013	Colocation data center	Cloud computing and hosting data center	Private data center	Public data center
Server closet up to 10 m^2	Approx. 31,000	-8%				
Server room 11-100 m^2	Approx. 18,000	+/-0%				
Small data center 101-500 m^2	Approx. 2,100	+23%				
Medium sized data center 501-5,000 m^2	Approx. 300	+27%				
Large data center more than 5,000 m^2	Approx. 70	+40%				

Figure 7. Number and size of data centres in Germany (Borderstep 2015)

The number of data centres , especially when they differ so much in size, says little about their energy consumption (see next section).

19

The size of the floor area (net or gross) can range from a single room of less than 10 m^2 to hyperscale facilities of almost 600 000 m^2[20]). The <u>average</u> floor size of larger data centres nears 100 000 m^2, of which 54-60% is net floor area for the IT equipment.[21]

The following sections describe the sales/stock efficiencies and energy consumption (where available) for servers, storage, network equipment, UPS and cooling systems and for data centres overall..

2.2.2 Server market data

Servers represent on average between 65-75% of the total IT hardware energy consumption, the remainder being consumed by storage devices and networking equipment (interconnects, switches, routers, etc.). Note that often the actual number of servers in a data centre is usually smaller than the maximum that can be housed and conditioned (most centres are sized to allow for growth).

The most typical server type is the 2 sockets rack server constituting more than half of sales in 2015 followed by the 1 socket rack server and the 2 sockets blade server, each covering around 16% of the sales. Remaining server types constitute about 17%.

Table 4 Server sales and stock estimates. Source: Ecodesign servers regulation IA

Data Centre	**2015**		**2020 (projected)**	
Servers	Sales	Stock	Sales	Stock
Blade 1 socket	169 704	963 702	178 361	958 826
Blade 2 socket	511 811	2 976 130	622 696	3 134 694
Blade 4 socket	27 418	161 603	33 358	167 928
Rack 1 socket	543 057	3 059 884	570 758	3 068 257
Rack 2 socket	1 633 409	9 422 302	1 987 291	10 004 073
Rack 2 socket resilient	27 513	158 101	33 474	168 509
Rack 4 socket	85 773	507 183	104 357	525 339
Rack 4 socket resilient	1 511	8 681	1 838	9 253
Tower 1 socket	231 269	1 299 250	198 599	1 173 426

CISCO_2016 estimates that hyperscale centres will grow from 338 in 2016, 386 in 2017 to 628 in 2021, and will represent 53% of all installed servers. Some 18-19% will be located in Western Europe. Hyperscale centres will account for 87% of public cloud workloads and compute instances. CISCO_2016 identified 24 companies with only 7 headquarters outside the US. The data centre footprint however is more geographically diverse.
According to GXIv3_2019[22] companies deployed nine hubs, 240 cabinets and 340 connections, 'on average'[23].

[20] Range International Information Group, Langfang, China. https://www.datacenters.com/news/and-the-title-of-the-largest-data-center-in-the-world-and-largest-data-center-in

[21] information from DDA_2019 suggests that an increasing part of the gross floor area is net floor area, i.e. where the IT equipment is located (2013: net/gross ratio is 54%, 2019 net/gross ratio is 60%).

[22] GXIv3_2019: Global interconnection Index v3, 2019 by Equinex [https://www.equinix.com/gxi-report/]

[23] GXI-v3 writes: Deployment data includes an analysis of 450 new companies who deployed more than 4,100 implementations worldwide between Q12016 and Q12019. 55% of the studied companies are F500/G2000, with

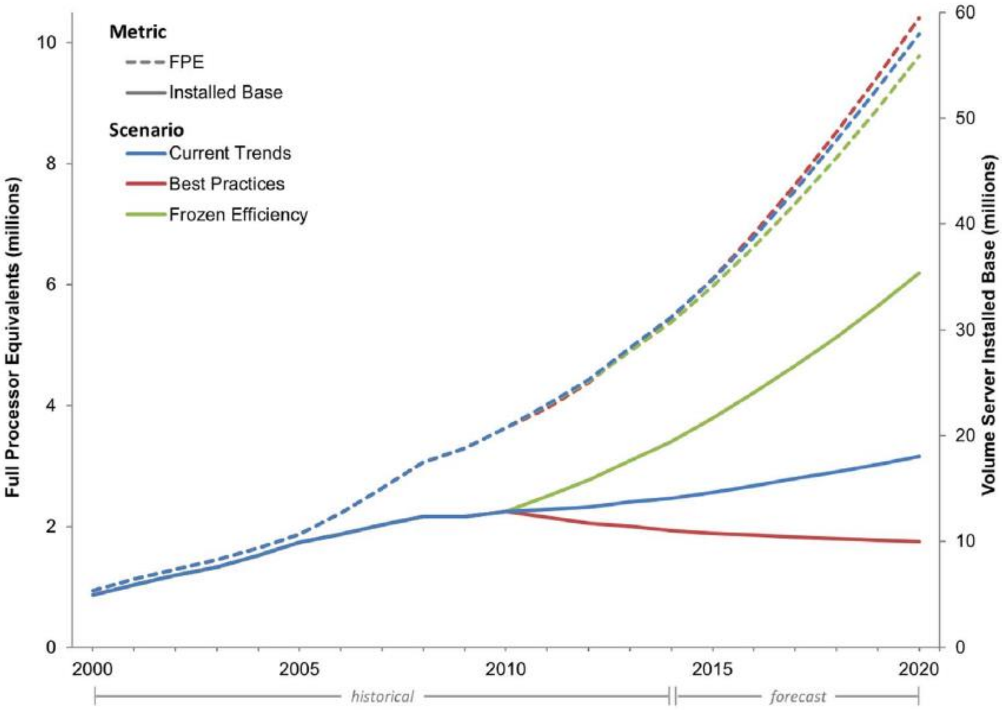


Figure 8. US volume server installed base and corresponding full-processor equivalent 2000-2010, scenarios 2011-2020 (source (Shehabi et al. 2018[24])

2.2.3 Storage market data

The most typical storage equipment is 'online 2' constituting 62% of sales in 2015 followed by 'online 3' constituting, 30%, and 'online 4', 8%. The 'Online 2/3/4' terms refer to the Storage Taxonomy Emerald TM 3.0.1 by SNIA[25] where there are 6 performance categories for 'online' storage, ranging from 'consumer ('online 1') to enterprise mainframe ('online 6'). There are also SNIA Emerald categories for 'near-online', 'removable media library' and 'virtual media library'.

Table 5 Storage sales and stock estimates. Source: Ecodesign servers regulation IA

Data Centre	**2015**		**2020 (projected)**	
Storage	Sales	Stock ('000)	Sales	Stock ('000)
Online 2	282 603	2 019	308 957	2 180
Online 3	135 778	1 151	148 440	1 060
Online 4	35 419	260	38 722	275
		3430		3515

a mix of local and multinational deployments across the regions (35% AMER, 35% EMEA, 30% Asia-Pacific). Since each company (and industry) solves different problems with different priorities at different times, the ratio of cabinets and connections is expected to vary significantly. Total Cabinets and Total Interconnections are across all Metro Locations.

[24] Source: Data center growth in the United States: decoupling the demand for services from electricity use: Arman Shehabi et al 2018 Environ. Res. Lett. 13 124030

[25] www.snia.org/sites/default/files/emerald/Training/EmeraldTraining_Feb-Mar2018/ SNIAEmeraldTraining_Feb-Mar2018_Storage_Taxonomy_Emerald_3.0.1.pdf

2.2.4 Network market data

Global sales and estimated stock figures are available from the Ecodesign preparatory and impact assessment study 2013-2014 and can serve as a reference.
Table 5 gives switches sales in '000 ports, with a total of 91 million switches sold in 2013. Fixed managed switches constituted the main part of sales (58%) followed by fixed unmanaged switches (37%) and modular managed switches (5%).

Table 6 Switches sales 2013, in '000 number of ports.
Source: Ecodesign servers regulation IA[26] [27]

Ethernet Switches	Modular managed	Fixed managed	Fixed unmanaged
100 Mbps	94	16506	16282
1 Gbps	3550	33054	17750
10 Gbps	630	3116	0
40 Gbps	16	70	0
Total	**4290**	**52746**	**34032**
Overall total		**91068**	

Table 7 specifies 2013 router sales, where low-end routers constitute the main part of sales (71%) followed by high-end (17%) and mid-range (12%)

Table 7. Router sales and stock 2013, in '000 units.
Source: Ecodesign servers regulation IA[26] [27]

Routers	***High-end sales*** *('000 units)*	***Mid-range sales*** *('000 units)*	***Low-end sales*** *('000 units)*	***Total sales***	***Total stock***
High-end	34	23	140	197	1400

Standard switches used in data centres were usually equipped with either 24 or 48 ports in 2013-2014. Thus in Table 8 the stock of switches installed (in units) has been calculated on the basis of these average port numbers per switch.

Table 8. Network equipment 2014 stock estimates in units.
Source: Ecodesign Preparatory Study on Servers and Data Equipment[27]

Network equipment	**Router** (10^6 units)	**Switch 24port** (10^6 units)	**Switch 48port** (10^6 units)
Stock	1.4	2	4

These are historic data for the entire switches and routers market mentioned as a first reference. If and where appropriate they will be expanded into subsequent phases of the study, where –amongst others-- the market has to be subdivided into switches and routers for data centres and for other applications e.g. in the access network or private (enterprise) server rooms, etc.. As an illustration of some recent market numbers see the text box.

[26] https://ec.europa.eu/transparency/regdoc/rep/10102/2019/EN/SWD-2019-106-F1-EN-MAIN-PART-1.PDF
[27] Bio by Deloitte with Fraunhofer IZM, Lot 9 -Ecodesign Preparatory Study on Enterprise Servers and Data Equipment, for the EC, July 2015. https://op.europa.eu/en/publication-detail/-/publication/6ec8bbe6-b8f7-11e5-8d3c-01aa75ed71a1

IDC Market Information Switches & Routers 2019

Information from IDC[1] suggests a global 2019 market for Ethernet switches of approx. €25bn/year ($7bn 2nd quarter 2019) and for routers €13bn/year ($4bn in the same quarter). Global year-on-year (revenue) growth rates for routers are in the order of 3.5-4.5% .
Revenue market shares in the 2nd quarter of 2019 are Cisco 51%, Huawei 10%, Arista 7%, HPE 6%, Juniper 3%, Others 23%. The reference products for large data centres are 25 and 100 Gbps switches. Port shipments for 100Gb switches rose 58.3% year over year to 4.4 million ports. 100Gb revenues grew 42.9% year over year in 2Q19 to $1.28 billion, making up 18.1% of the market's revenue, compared to 13.2% of the market's revenue a year earlier. 25Gb switches revenue increased 84.8% to $364.1 million, with port shipments growing 74.5% year on year. Lower-speed switches showed moderate growth rates of 5-10%.

2.2.5 UPS market data

Based on the data of the Lot 27 preparatory study into UPS, [EIA_2018] (Ecodesign Impact Accounting[28]) presented the following sales data, up to 2050.

The sales data after 2015 should be regarded with great caution and are an estimate only, based upon trends of the 1990-2015 period. As stated elsewhere in this chapter, the changes in the Data Centre market, especially because of the rise of hyperscale centres, are difficult to predict.

Table 9. Sales of UPS, source EIA 2018

UPS category ('000)	1990	2010	2015	2020	2025	2030	2035	2040	2045	2050
UPS below 1.5 kVA	505	1000	1041	1265	1489	1709	1915	2094	2234	2325
UPS 1.5 to 5 kVA	203	402	419	509	599	687	770	842	898	935
UPS 5 to 10 kVA	13	26	27	32	38	44	49	54	57	60
UPS 10 to 200 kVA	7	13	14	17	20	23	25	28	30	31
UPS Total	**728**	**1441**	**1500**	**1823**	**2145**	**2463**	**2760**	**3018**	**3219**	**3350**

The stock for UPS has been calculated in EIA as well.

Table 10. Stock of UPS, source EIA 2018

UPS category ('000)	1990	2010	2015	2020	2025	2030	2035	2040	2045	2050
UPS below 1.5 kVA	1 880	4 027	4 065	4 791	5 686	6 575	7 421	8 173	8 783	9 208
UPS 1.5 to 5 kVA	1 378	2 994	3 242	3 599	4 285	5 002	5 698	6 334	6 871	7 274
UPS 5 to 10 kVA	105	230	258	281	330	388	444	495	540	574
UPS 10 to 200 kVA	62	140	155	170	198	233	268	301	329	352
UPS Total	**3 425**	**7 392**	**7 720**	**8 840**	**10 500**	**12 199**	**13 830**	**15 303**	**16 523**	**17 408**

[28] VHK, Ecodesign Impact Accounting 2018, for the EC, 2019.

2.2.6 Cooling market data

There is no specific information on the sales or stock of cooling systems. The Ecodesign Regulation on Central Air-heating and-Cooling systems (EU) 2016/2281[29] has a subcategory *High-Temperature Process Chillers* which covers, amongst others, data centre cooling systems.

Table 11. Sales High Temperature Process Chillers, source EIA 2018

('000 units)	1990	2010	2015	2020	2025	2030	2035	2040	2045	2050
Air-cooled Electric Small	9.39	15.27	16.33	17.25	17.99	18.75	19.49	20.23	20.96	21.69
Air-cooled Electric Large	2.97	4.83	5.16	5.45	5.69	5.93	6.16	6.40	6.63	6.86
Water-cooled Electric Small	2.42	3.94	4.21	4.45	4.64	4.84	5.03	5.22	5.41	5.60
Water-cooled Electric Medium	1.85	3.01	3.22	3.40	3.54	3.69	3.84	3.98	4.13	4.27
Water-cooled Electric Large	0.15	0.24	0.26	0.28	0.29	0.30	0.31	0.32	0.33	0.35
TOTAL	16.78	27.29	29.18	30.82	32.15	33.50	34.83	36.15	37.46	38.76

Table 12. Stock High Temperature Process Chillers, source EIA 2018

('000 units)	1990	2010	2015	2020	2025	2030	2035	2040	2045	2050
Air-cooled Electric Small	108	191	215	236	253	265	277	288	299	310
Air-cooled Electric Large	34	60	68	75	80	84	87	91	95	98
Water-cooled Electric Small	28	49	55	61	65	68	71	74	77	80
Water-cooled Electric Medium	21	38	42	47	50	52	54	57	59	61
Water-cooled Electric Large	2.0	3.8	4.3	4.8	5.2	5.5	5.8	6.0	6.2	6.5
TOTAL	193	342	385	423	453	475	496	516	536	556

For colocation and hyperscale data centres the 1000 kW large air-cooled and 1600 kW large water-cooled chillers will be predominantly used (see par. 2.3.6). Multiple cooling chillers per data centre may occur.

Note that the fraction of sales and stock for data centres is not given and –if appropriate— would have to be investigated deeper in subsequent phases of the study.

2.3 Performance and energy use

2.3.1 Data centre overall performance and energy use

PERFORMANCE

Overall data centre performance is typically described in terms of computing (compute instances) and data traffic (e.g. in Exabytes EB or Zettabytes ZB per year).

The Table 13 gives the total number of compute instances (a measure or metric for server activity – see Glossary) to grow from 241.5 million in 2016 to 566.7 in 2021, a CAGR[30] of 19%.

[29] OJ L 346, 20.12.2016, p. 1–50

[30] CAGR=Compound Aggregate Growth Rate= (end year value-start year value)/number of years

Table 13. Global workload and compute instances 2014-2021 (Cisco 2016[31])

Workload and compute instances (in millions)	2014*	2015**	2016	2017	2018	2019	2020	2021	CAGR 2016-2021
Traditional DC	46	44.9	42.1	41.4	40.8	39.1	36.2	32.9	-5%
Cloud DC	83.5	136.0	199.4	262.4	331.0	393.3	459.2	533.7	22%
Total DC	***129.5***	***180.9***	***241.5***	***303.8***	***371.8***	***432.4***	***495.4***	***566.7***	***19%***
Traditional DC	36%	25%	17%	14%	11%	9%	7%	6%	
Cloud DC	64%	75%	83%	86%	89%	91%	93%	94%	

*: CISCO_2014

**: CISCO_2015

CISCO_2016 predicts that average global internet traffic will increase to 3.3 ZB (zettabytes=10^{21} byte=1000 exabyte EB) in 2021[32], but busiest hour peak traffic including internal data processing–i.e. the one that determines peak power draw-- is six times more and predicted to grow to 20.6 ZB. Table 14 gives a split of traffic by type (over 70% is within the data centre) by segment (73% consumer in 2021) and by type (95% cloud data centres in 2021, 87% in 2016).

Table 14. Global data centre traffic (Cisco 2016)

	2016	2017	2018	2019	2020	2021	CAGR 2016-2021
	By type (EB per year)						
DC to user	998	1280	1609	2017	2500	3064	25.2%
DC to DC	679	976	1347	1746	2245	2796	32.7%
within DC	5143	6831	8601	10362	12371	14695	23.4%
	By segment (EB per year)						
Consumer	4501	6156	8052	10054	12401	15107	27.4%
Business	2319	2931	3505	4070	4716	5449	18.6%
	By type (EB per year)						
Cloud DC	5991	8190	10606	13127	16086	19509	26.6%
traditional DC	828	897	952	997	1030	1046	4.8%
Total DC	6819	9087	11557	14124	17116	20555	24.7%

Table 15 gives the latest trends 2018-2023 for Western Europe and globally in number of users, speed, number of networked devices. Penetration of mobile-speeds is mentioned, amongst others with a prediction for 5G (575 Mbps). A newcomer in the statistics are Low Power Wide Area (LPWA) connections, predicted to be taking off over the next few years.[33] The mobile 'machine-to-machine' M2M (also known as the 'Internet of Things IoT'), as a part of the total M2M (including Wi-Fi) devices, are also a relative newcomer.

[31] Cisco, Annual internet report, 2016

[32] Latest Cisco forecast is 4.8 ZB in 2022.

[33] A low-power wide-area network (LPWAN) or low-power wide-area (LPWA) network or low-power network (LPN) is a type of wireless telecommunication wide area network designed to allow long-range communications at a low bit rate among things (connected objects), such as sensors operated on a battery. 0.3 kbit/s to 50 kbit/s per channel. 2-13km range.. E.g. Sigfox devices can send no more than 150 messages of max. 12 bytes per day at max. 50 microwatts. The range is up to 13 km. Source:
Min Chen, Yiming Miao, Xin Jian, Xiaofei Wang, Iztok Humar, Cognitive-LPWAN: Towards Intelligent Wireless Services in Hybrid Low Power Wide Area Networks, 2018. https://arxiv.org/pdf/1810.00300.pdf

Table 15. Trends in data centre usage 2018-2023 (source: Cisco 2020)

Characteristic	Western Europe		Global	
	2018	2023	2018	2023
population (M inhabitants)	421	425	7650	8000
internet users (M)	345	370	3900	5100
mobile users (M)	357	365	5100	5700
avg. fixed broadband speed (Mbps)	45.6	123	45.9	110.4
mobile connect speed (Mbps)	23.6	62.4	13.2	43.9
wi-fi mobile speed (Mbps)	30.8	97	30.3	92
networked devices (bn), *of which*	2.4	4.0	18.4	29.3
networked devices per capita	5.7	9.4	2.4	3.6
3G/4G/5G/LPWA (%)			55/43/0/3%	13/43/16/28%
LPWA connections, all M2M (M)			223	1900
mobile M2M connections (bn)			1.2	4.4

Note that the EU-27 population (446 M in 2018) is 6% more than 'Western-Europe' (421 M in 2018).

Figure 9 shows the predicted evolution of 2018-2023 for the number of connected devices globally.

As regards the intensity of use, it is considered that over 85% of data traffic will be video content by 2022: 82% video, 4% gaming, with possibly some virtual reality thrown into the mix if that becomes popular.[34] Figure 10 gives an overview of the bandwidth needs of current and future connected devices.

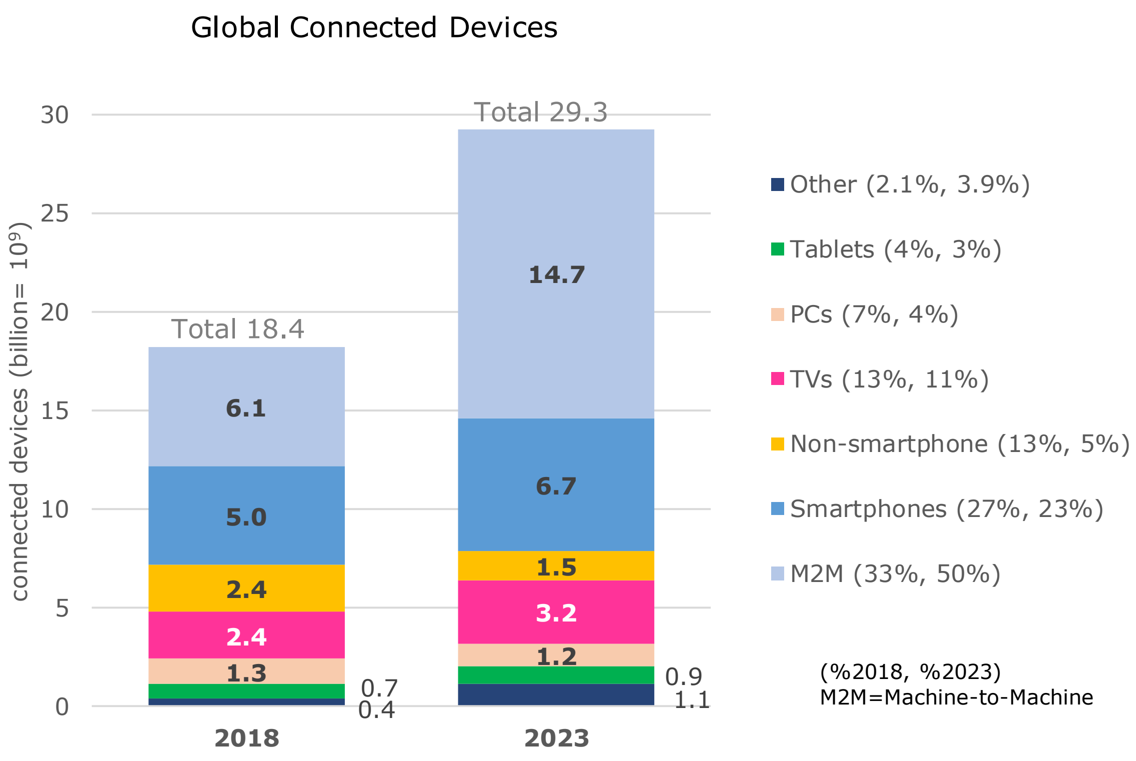


Figure 9. Number of connected devices worldwide in 2018 and 2023

[34] https://newsroom.cisco.com/press-release-content?type=webcontent&articleId=1955935

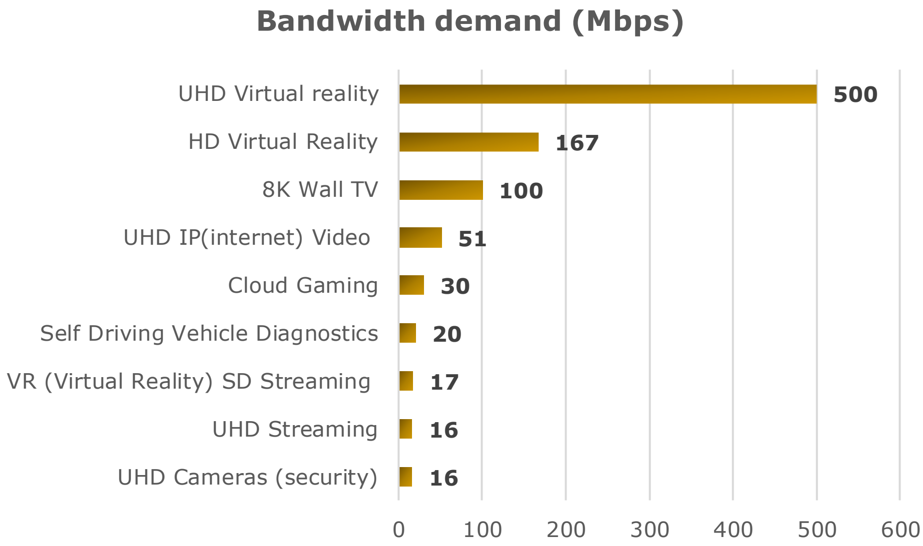


Figure 10. Trends in global data centre energy-use drivers (data source: Shehabi 2020)

Annex B gives a short historical overview of the evolution of the data centre.

ENERGY USE METRICS

The aggregate electricity use of data centres is typically expressed in TWh/year, but –in order to give more insight in the nature of the electricity use, there are some intermediate metrics such as the *Power Usage Effectiveness PUE*, *Data Centre Performance Per Energy DPPE* as well as the *Server and Data centre Idle Coefficients SIC* and *DIC.* These will be discussed hereafter.

PUE – Power Usage Effectiveness

The PUE or Power Usage Effectiveness, which is the ratio between the total facility energy consumption divided by the IT equipment energy consumption only[35] (including servers, storage, switches, routers, excluding cooling, UPS, other).

$$PUE = \frac{Total\ Data\ Centre\ power}{ICT\ only\ power}$$

The metric was developed by the Green Grid in 2016 and became a global standard under ISO/IEC 30134-2:2016 and the European standard EN 50600-4-2:2016.
The PUE allows a fast comparison between data centres on **overhead energy** and has become a marketing term for colocation providers and major IT companies for showing off green credentials. PUE's can be improved by optimising the cooling systems (free cooling, using outdoor air), increasing aisle temperatures, minimising conversion losses (more DC powered equipment).

But the PUE metric does have its problems:

[35] Experts argue that the term should be called 'energy' usage effectiveness (EUE) instead of 'power usage effectiveness' to avoid confusion and wrong assessments (it is preferred to use annual energy values rather than nominal or momentary power values).

- It does not account for differences in climate (data centres in colder regions can allow more free cooling resulting in lower PUEs, even if the same equipment were to be used);
- the need to measure energy over a representative time period so that annual values can be established (although this can be prescribed in procedures in data gathering);
- Furthermore, PUEs may be calculated on the basis of installed capacity, rendering it meaningless as most facilities do not run at full capacity (also this can be prescribed in procedures in data gathering);
- The calculation of the actual energy consumed by IT equipment and the overall energy consumption is also not as straightforward as it first appears. In any case it should not be based upon the rated power indicated on equipment rating plates as the actual average power consumed may be quite different;
- The contribution of solar power installed on or near the facility. If included it results in much lower PUEs but it also obscures the actual effectiveness of the overhead power consumption of that facility without solar power considered;
- The PUE is not actually measuring equipment effectiveness as it does not take into account performance of IT equipment[36], nor recovery of heat, nor use of on-site generated renewable power, etc.
- The metric could be used to artificially increase the perceived 'efficiency' by offloading cooling power from the DC facility (removed from DC total energy) to internal cooling fans (added to IT equipment energy).

Use of the PUE as efficiency metric does not promote the reduction of IT hardware energy consumption because if IT energy decreases faster than overall energy, then PUE increases! This also means that if lowering the PUE is important, the IT hardware energy is probably not looked at.

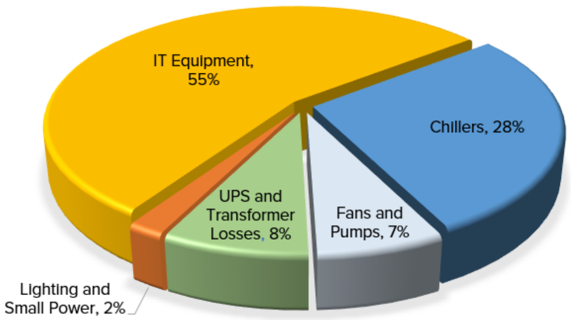


Figure 11. Example of PUE basis for calculation [AGCoombs_2018[37]]

Based on the ratios in the figure above: if IT is reduced by 80% (was 55%, becomes 44%) and chiller energy is assumed to reduce by 80% as well (becomes 22.4%), and assuming other uses are not affected (fans/pumps remains 7%, UPS etc. remains 8% and lighting etc. remains 2% the

[36] As data centers can host hardware not owned/specified by the site-owner, it can be difficult to include this parameter in a performance metric

[37] AGCoombs_2018: https://www.agcoombs.com.au/news-and-publications/advisory-notes/improving-data-centre-infrastructure-efficiencies-2/ (accessed Jan 2020)

overall PUE becomes 83.4%/45% = 1.88, **an increase of 4% the original PUE** of 100/55=1.82. The total energy consumption however has reduced by 16%!

The PUE can also send the wrong signals because of ignoring the actual effective workload performed. Imagine two facilities: facility A has a PUE of 1.1 and handles 0.5 PB of data, whereas facility B has a PUE of 1.2 and processes 1.0 PB of data on an annual basis. On the basis of PUE alone, facility A would be preferred but facility B requires less energy for processing a similar amount of data, and should be preferred.
The PUE may also depend on how the measurement guidelines are interpreted. Google explains that the average PUE for all Google Data Centres is 1.11, although they could boast a PUE as low as 1.06 when using narrower boundaries[38].

DPPE - Data Centre Performance Per Energy

Several organisations, like JEITA[39] and The Green Grid have proposed alternative and/or complementary metrics, addressing the issue that PUE is an incomplete metric for overall data centre energy efficiency.
Jeita proposed the DPPE (Data Centre Performance Per Energy) **[40]**. It is based on the following formula:

$$DPPE = \frac{DC\ Work}{DC\ energy - green\ energy}$$

$$= \frac{IT\ utilisation\ rate * IT\ work\ capacity}{DC\ energy - green\ energy}$$

$$= IT\ utilisation\ rate * \frac{IT\ work\ capacity}{IT\ energy\ max} * \frac{IT\ energy}{DC\ energy} * \frac{DC\ energy}{DC\ energy - green\ energy}$$

$$= ITEU * ITEE * \frac{1}{PUE} * \frac{1}{(1 - GEC)}$$

ITEU represent the actual utilisation of the equipment, ITEE the processing capacity per unit of power (a performance metric), 1/PUE is the overhead energy and with GEC only grid electricity is counted.

As the IT utilisation rate is difficult to measure, it is approximated to :

$$ITEU = \frac{IT\ energy\ measured\ [kWh]}{IT\ energy\ \max\ [kWh]}$$

And:

$$ITEE = \frac{\alpha * Server\ capacity + \beta * Storage\ capacity + \gamma * Network\ capability\ [W]}{Total\ rated\ power\ of\ IT\ [W]}$$

with:

[38] https://www.google.com/about/datacenters/efficiency/

[39] Japan Electronics and Information Technology Industries, www.jeita.or.jp

[40] DPPE: Holistic Framework for Data Centre Energy Efficiency - KPIs fo r Infrastructure, IT Equipment, Operation (and Renewable Energy), Japan National Body/Green IT Promotion Council, August 2012

α = 7.72 W/GTOPS[41]

β = 0.0933 W/GByte

γ = 7.14 W/GBps

$$PUE = \frac{DC\ energy\ consumed\ [kWh]}{IT\ energy\ consumed\ [kWh]}$$

$$GEC = \frac{green\ energy\ consumed\ [kWh]}{DC\ energy\ consumed\ [kWh]}$$

For ITEU the range is 0.2 – 0.7, ITEE generally ranges from 1 for the worst equipment to over 6 (up to 10) for the best equipment in 2010; the PUE ranges from 2.5 to 1.2 (in 2011 it was an average 1.9 for Japan), and the GEC ranges from 0 to 0.3. This results in a combined DPPE score of 0.08 to 5.34 for the worst and best data centre facilities in year 2010.

The GEC could also be interpreted as a form of PEF, as it removes non-carbon energy from the calculation.

Server Idle Coefficient + Data centre Idle Coefficient

The Dutch consultancy Certios.nl proposed the *server idle coefficient* (SIC) and the *data centre idle coefficient* (DIC).

The DIC calculation is performed at the level of the data centre by simply aggregating server calculations.

1. Measure E_{idle} (see above) for all servers
2. Measure E_{total} for all servers

The metric has not been decided yet. Options for data centre idle coefficient DIC are :

- DIC = [Etotal / Etotal – Eidle] (as PUE, 1 = ideal, worse is upwards)
- DIC = [Eidle / Etotal] (as DCIE, 0-100% Idle energy as part of total)
- other suggestions include a 1 (minimum) to 10 (excellent) score

The SIC (for component level) and DIC (at facility level) allow benchmarking of progress in reducing power spent in modes that do not actively contribute to useful output.

Note that this is not a metric that allows calculating the total energy consumption of a DC if a 'demand' is known. Instead it is, like the PUE, a ratio of *overhead* (or not useful) energy versus useful energy.

[41] GTOPS=Giga Theoretical Opeations per Second

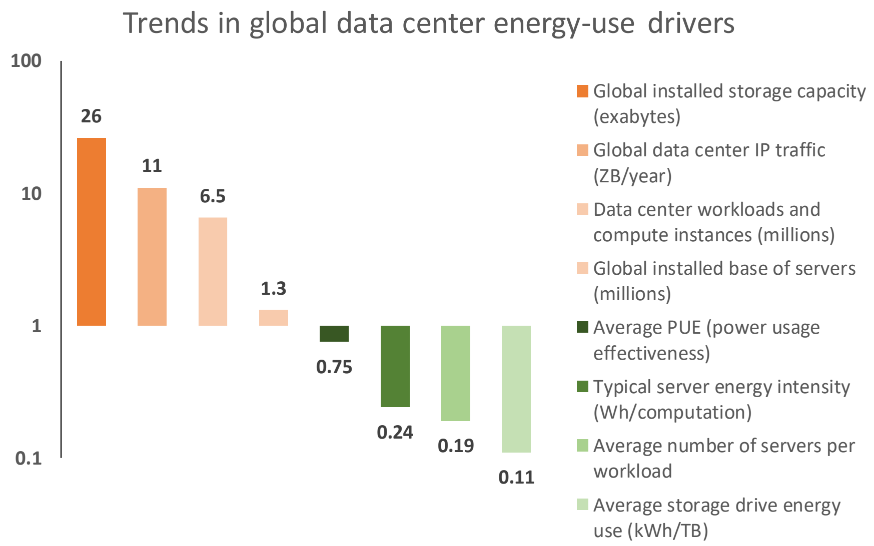
ENERGY CONSUMPTION

The 2020 figures from reliable US research[42] show that the global electricity consumption of data centres has only increased by 6%, from 194 to 206 TWh/yr, over the period 2010-2018.[43]

The Figure 12 below shows the factors that increase the energy use, i.e. installed storage capacity rose 26 fold, data centre IP traffic rose 11 fold, workloads and compute instances rose six fold, and the installed base of physical servers rose by 30%.

At the same time the computing efficiency increased: the power usage effectiveness (PUE)[44] dropped by 25% from 2010 to 2018, server energy intensity dropped by a factor of 4, the average number of servers per workload dropped by a factor of 5, and average storage drive energy use per TB dropped by almost a factor of 10.

The same source also made a projection for a doubling of 2018 workload (no. of compute instances). This is what can roughly be expected in 2023. The result shows a 24% increase in server energy use, roughly equal storage energy use, 32% lower energy use for the infrastructure (mainly cooling) and the network port use energy remains small but slightly higher.



Absolute trend values	2010	2018
Global data centre IP traffic (ZB/year)	1.1	11.6
Data centre workloads and compute instances (millions)	58	372
Global installed base of servers (millions)	35.8	45.1
Global installed storage capacity (EB)	41	1043
Average number of servers per workload	0.62	0.12
Average storage drive energy use (kWh/TB)	197	22
Average PUE (Power Usage Effectiveness)	2.10	1.58

Figure 12. Graph with relative (index 2010=1) and table with absolute energy use increasing and decreasing factors for data-centres 2010-2018 (data source: Masanet 2020)

[42] Researchers from Lawrence Berkeley National Labs, Stanford (Jonathan Koomey), Northwestern University, University of California. Support from the US Dept. of Energy.

[43] Eric Masanet, Arman Shehabi, Nuoa Lei, Sarah Smith, Jonathan Koomey, Recalibrating global data center energy-use estimates, Science 28 Feb 2020: Vol. 367, Issue 6481, pp. 984-986, DOI: 10.1126/science.aba3758

[44] Ratio between total data centre energy and the energy use only for IT equipment in that data center.

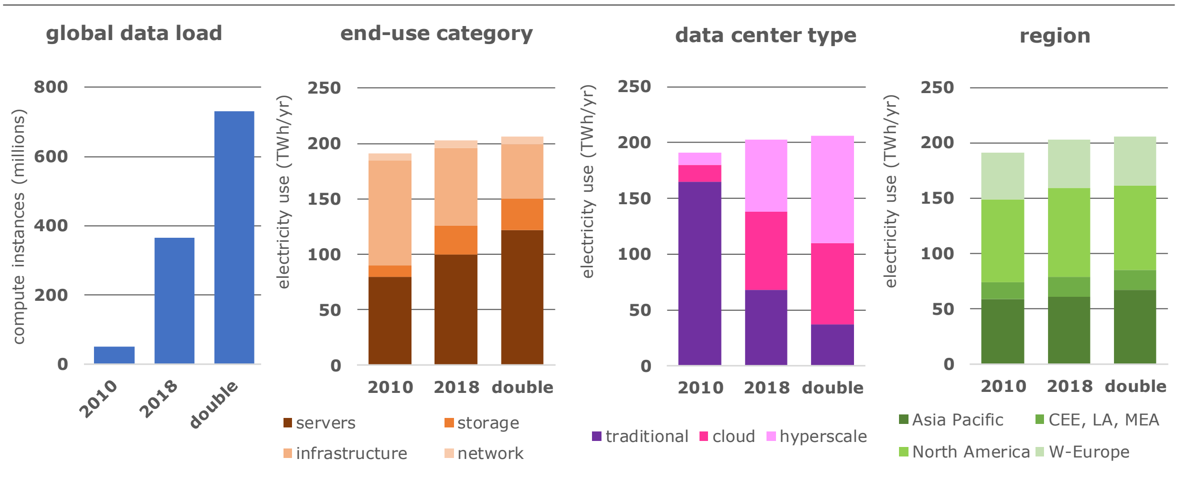


Figure 13. Energy use increasing and decreasing factors for data-centres 2018-2023 (data source: Masanet 2020)

The energy data in Figure 13, i.e. a little over 200 TWh/yr in 2018, is in line with the 2019 IEA-4Ei study.

The Table 16 below gives details, from the same study, for the region Western Europe. To find the energy use for the EU27 the findings are multiplied by 1.06. [45]

Table 16. Trends in data centre usage 2018-2023 (source: Masanet 2020)

Western Europe	**2010**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
1. Traditional data centre servers (thousands)	7386	2831	2531	2266	2026	1759	1528
2. Cloud (non-hyperscale) servers (thousands)	117	2700	2536	2510	2413	2750	3130
3. Hyperscale servers (thousands)	437	3155	3801	4292	4943	5510	6143
	7940	*8687*	*8868*	*9068*	*9382*	*10019*	*10801*
SERVERS							
1. Traditional data centre server energy use (TWh)	15.06	5.96	5.49	5.14	4.87	4.48	4.17
2. Cloud (non-hyperscale) server energy use (TWh)	1.54	6.78	6.34	6.15	5.81	6.33	6.91
3. Hyperscale server energy use (TWh)	1.02	7.06	8.45	9.46	10.79	11.89	13.12
	17.6	*19.8*	*20.3*	*20.8*	*21.5*	*22.7*	*24.2*
STORAGE							
1. Traditional data centre storage energy use (TWh)	1.51	1.00	0.76	0.58	0.53	0.52	0.51
2. Cloud (non-hyperscale) storage energy use (TWh)	0.05	1.56	1.34	1.30	1.18	1.22	1.26
3. Hyperscale storage energy use (TWh)	0.17	1.82	2.01	2.21	2.41	2.44	2.47
	1.7	*4.4*	*4.1*	*4.1*	*4.1*	*4.2*	*4.2*
NETWORK PORT USAGE							
1. Traditional data centre network port energy use (TWh)	0.47	0.17	0.14	0.12	0.11	0.10	0.08
2. Cloud (non-hyperscale) network port energy use (TWh)	0.01	0.23	0.19	0.17	0.16	0.19	0.21
3. Hyperscale network port energy use (TWh)	0.04	0.36	0.40	0.41	0.48	0.54	0.61
	0.5	*0.8*	*0.7*	*0.7*	*0.7*	*0.8*	*0.9*
PUE							
1. Traditional data centre PUE	2.23	2.06	1.99	1.93	1.87	1.81	1.76
3. Cloud (non-hyperscale) data centre PUE	1.75	1.62	1.58	1.55	1.52	1.49	1.46
4. Hyperscale data centre PUE	1.23	1.18	1.17	1.17	1.16	1.16	1.15
COOLING etc.							
1. Traditional data centre infrastructure energy use (TWh)	20.93	7.53	6.32	5.43	4.80	4.13	3.62
2. Cloud (non-hyperscale) infrastructure energy use (TWh)	1.20	5.29	4.56	4.19	3.72	3.79	3.86
3. Hyperscale infrastructure energy use (TWh)	0.28	1.67	1.90	2.04	2.23	2.34	2.46
	22.4	*14.5*	*12.8*	*11.7*	*10.7*	*10.3*	*9.9*
TOTAL ENERGY USE (TWh)	***42.3***	***39.4***	***37.9***	***37.2***	***37.1***	***38.0***	***39.3***
EU27 (Western Europe x 1.06)	*44.8*	*41.8*	*40.2*	*39.4*	*39.3*	*40.3*	*41.7*

[45] For comparison: For the EU28 the results for 'Western Europe' need to be multiplie by 1.2, which results for 2018 in a total energy use of 47.3 TWh.

The 2020 study by Masanet et al. is a revisit of a study by Shehabi et al. for the US DoE in 2016[46], with publications also in 2018[47]. The 2016 study already predicted that data centre energy use was not going to increase drastically despite the very large rise in workload.

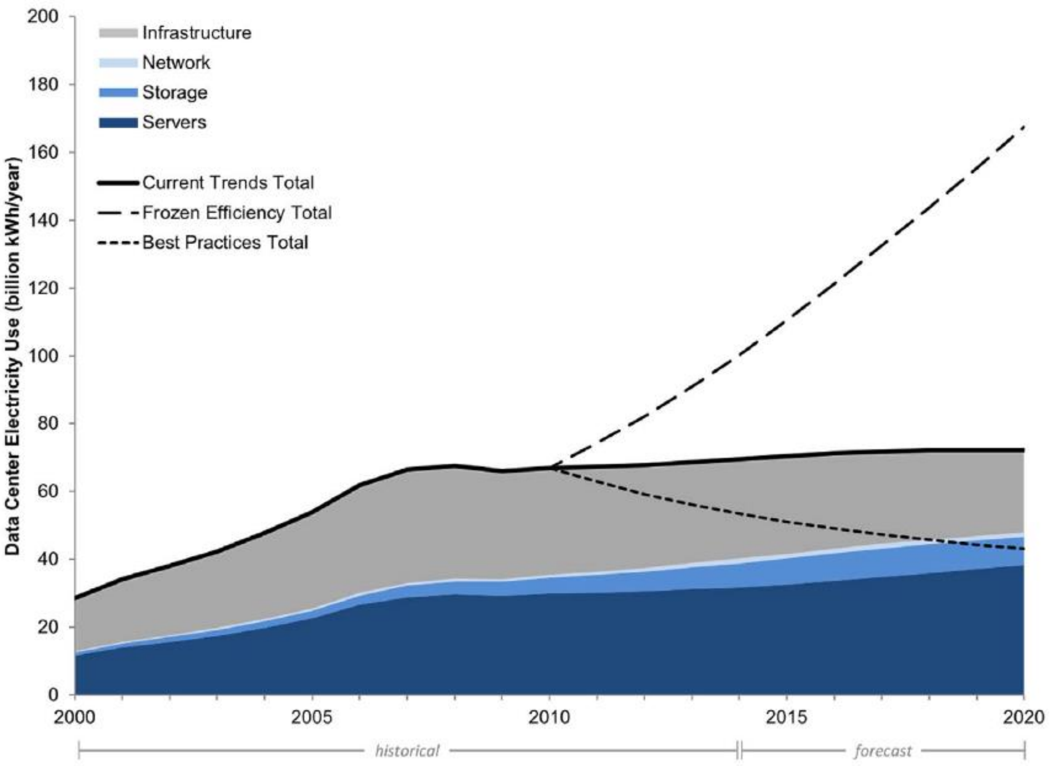


Figure 14. Current trends of US Data Centre equipment electricity use from 2000-2020 with two alternative scenarios from 2010 (source: Shehabi et al 2018)

2.3.2 Server performance and energy use

The server performance is measured using the SERT assessment method described hereafter. The performance is the number of transactions.

Table 17 Server performance

Data Centre Servers	Performance (transactions/s)
Rack 1 socket	7 000
Rack 2 socket	25 000
Rack 2 socket resilient	n.a.
Rack 4 socket	150 000
Rack 4 socket resilient	n.a.

[46] https://eta.lbl.gov/sites/all/files/publications/lbnl-1005775_v2.pdf

[47] Data center growth in the United States: decoupling the demand for services from electricity use: Arman Shehabi et al 2018 Environ. Res. Lett. 13 124030

Blade 1 socket	7 000
Blade 2 socket	25 000
Blade 4 socket	150 000
Tower 1 socket	7 000

The majority of servers are now operating in the cloud, where average utilisation was assumed to be around 47.5% in 2015 for new servers[48]. However, the widespread use of CDNs and geographically located DCs means that there will be diurnal patterns of use.
The efficiency is the number of transactions divided by their power use as described in the SERT efficiency metric.

SERT server efficiency metric

For blade and rack servers, ETSI EN 303 470 (v1.0.0 (2018-06) [49]) describes a metric to establish server energy efficiency for a number of server categories. The standard formalizes the tools, conditions and calculations used to generate a single 'figure of merit' of a single computer server representing its relative efficiency and power impact. The metric is targeted for use as a tool in the selection process of servers to be provisioned. SERT is the standard metric and measures efficiency in transactions per Joule.
The server metric consists of a pre-defined workload for the CPU, memory and storage (based on so-called worklets) during which energy and performance are logged. It is based on the Server Efficiency Rating Tool™ (SERT™) of the Standard Performance Evaluation Corporation (SPEC) and is aligned with the Ecodesign requirements for servers, and developed under standardisation mandate M/462.
Each workload is comprised of worklets. The workload *CPU* is mainly dependent on various processor characteristics; *Memory* basically measures bandwidth and capacity; and *Storage* tests a server's disk I/O bandwidth and latency. The SERT tool also has a metric for idle mode of the server (power only).
The Active state metric consists of measurement of power and performance during several worklets.

- a CPU metric comprising 6 CPU worklets i.e. Compress, LU, CryptoAES, SOR, Sort and SHA256; and 1 hybrid worklet: Hybrid SSJ;
- 2 memory worklets: Flood3 and Capacity3;
- 2 storage worklets: Sequential and Random

The server efficiency is calculated as:

$$Eff_{server} = Eff_{CPU}^{\;W_{CPU}} \times Eff_{Memory}^{\;W_{Memory}} \times Eff_{Storage}^{\;W_{Storage}}$$

where W_{CPU}, W_{Memory} and $W_{Storage}$ are the weightings applied to the CPU, Memory and Storage worklets respectively, and Eff_{CPU}, Eff_{memory} and $Eff_{Storage}$ is the average of the interval readings for the worklets involved. The performance is measured by the number of transactions that can be completed per second. Efficiency is the performance divided by power consumed.
SERT also defines an *idle state metric*. For the purpose of comparing performances idle power allowances ('adders') may be applied.

[48] ErP Servers IA

[49] Environmental Engineering (EE): Energy Efficiency measurement methodology and metrics for servers, Draft ETSO EN 303 470 V1.0.0 (2018-06)

In the Ecodesign regulation for servers (and storage products) the Effserver has to be:

Table 18 Server efficiency minimum requirements

Product type	Minimum active state efficiency in %
1-socket server	9.0
2-socket server	9.5
Blade or multi-node servers	8.0

Table 19. Electricity consumption of servers,

acc. EIA_2018

ES & DS, without effects on infrastructure	1990	2010	2015	2020	2025	2030	2035	2040	2045	2050
ES tower 1-socket traditional	0.0	1.0	0.9	0.6	0.4	0.4	0.3	0.3	0.3	0.3
ES rack 1-socket traditional	0.1	3.2	2.4	2.0	2.0	2.2	2.2	2.2	2.2	2.2
ES rack 2-socket traditional	0.8	14.7	7.8	4.4	5.0	6.0	6.5	6.5	6.5	6.5
ES rack 2-socket cloud		8.2	12.7	13.4	15.6	18.6	20.1	20.1	20.1	20.1
ES rack 4-socket traditional	0.1	1.6	0.8	0.6	0.7	0.9	0.9	0.9	0.9	0.9
ES rack 4-socket cloud		0.9	1.6	2.0	2.4	2.8	3.1	3.1	3.1	3.1
ES rack 2-socket resilient trad.	0.0	0.8	0.4	0.2	0.2	0.3	0.3	0.3	0.3	0.3
ES rack 2-socket resilient cloud		0.4	0.6	0.5	0.5	0.6	0.7	0.7	0.7	0.7
ES rack 4-socket resilient trad.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ES rack 4-socket resilient cloud		0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
ES blade 1-socket traditional	0.1	0.9	0.8	0.7	0.6	0.7	0.7	0.7	0.7	0.7
ES blade 2-socket traditional	0.6	6.7	3.4	2.1	2.4	2.9	3.1	3.1	3.1	3.1
ES blade 2-socket cloud		3.8	5.7	6.5	7.6	9.1	9.9	9.9	9.9	9.9
ES blade 4-socket traditional	0.1	0.8	0.5	0.3	0.3	0.4	0.4	0.4	0.4	0.4
ES blade 4-socket cloud		0.5	0.7	0.8	0.9	1.1	1.1	1.1	1.1	1.1
ES total traditional	2	30	17	11	12	14	14	14	14	14
ES total cloud	0	14	21	23	27	32	35	35	35	35
ES Enterprise Servers total	2	44	38	34	39	46	49	49	49	49

ES & DS, without effects on infrastructure	1990	2010	2015	2020	2025	2030	2035	2040	2045	2050
ES tower 1-socket traditional	0.0	1.0	0.9	0.6	0.5	0.4	0.4	0.4	0.4	0.4
ES rack 1-socket traditional	0.1	3.2	2.4	2.1	2.1	2.2	2.2	2.2	2.2	2.2
ES rack 2-socket traditional	0.8	14.7	7.8	4.7	5.5	6.4	7.0	7.0	7.0	7.0
ES rack 2-socket cloud		8.2	12.7	14.2	16.5	19.5	21.1	21.1	21.1	21.1
ES rack 4-socket traditional	0.1	1.6	0.8	0.7	0.8	0.9	1.0	1.0	1.0	1.0
ES rack 4-socket cloud		0.9	1.6	2.2	2.6	3.0	3.3	3.3	3.3	3.3
ES rack 2-socket resilient trad.	0.0	0.8	0.4	0.2	0.2	0.3	0.3	0.3	0.3	0.3
ES rack 2-socket resilient cloud		0.4	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7
ES rack 4-socket resilient trad.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ES rack 4-socket resilient cloud		0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1
ES blade 1-socket traditional	0.1	0.9	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7
ES blade 2-socket traditional	0.6	6.7	3.4	2.2	2.5	3.0	3.3	3.3	3.3	3.3
ES blade 2-socket cloud		3.8	5.7	6.8	8.0	9.5	10.3	10.3	10.3	10.3
ES blade 4-socket traditional	0.1	0.8	0.5	0.3	0.3	0.4	0.4	0.4	0.4	0.4
ES blade 4-socket cloud		0.5	0.7	0.9	1.0	1.2	1.3	1.3	1.3	1.3
ES total traditional	**2**	**30**	**17**	**12**	**13**	**14**	**15**	**15**	**15**	**15**
ES total cloud	**0**	**14**	**21**	**25**	**29**	**34**	**37**	**37**	**37**	**37**
ES Enterprise Servers total	**2**	**44**	**38**	**36**	**41**	**48**	**52**	**52**	**52**	**52**

It is estimated that by 2030, the effect of the Ecodesign requirements for servers set out in this Regulation will result in direct annual energy savings of approximately 2.4 TWh and indirect (i.e. related to infrastructure) annual energy savings of 3.7 TWh, summing up to a total saving of 6.1 TWh.

Table 20 shows average and BAT efficiencies of servers by category.

Table 20 Server efficiency.

	2015		2018	
Servers	Typical Efficiency	BAT	Typical Efficiency	BAT
Blade 1 socket				9
Blade 2 socket		15		14
Blade 4 socket				9.6
Rack 1 socket	8	9		11
Rack 2 socket	10	20		13
Rack 2 socket resilient				5.2
Rack 4 socket				16
Rack 4 socket resilient				4.2
Tower 1 socket	8	10		9.4

Source: 2015 - Ecodesign servers IA; 2018 - ENERGY STAR for Servers v3.0 efficiency criteria

Server Idle Coefficient

Although the SERT metric gives an indication of how efficient the server handles instructions, most servers spend relatively large amounts in idle mode, not processing many instructions, whereas their energy consumption stays relatively constant (as if the server is 'always on').

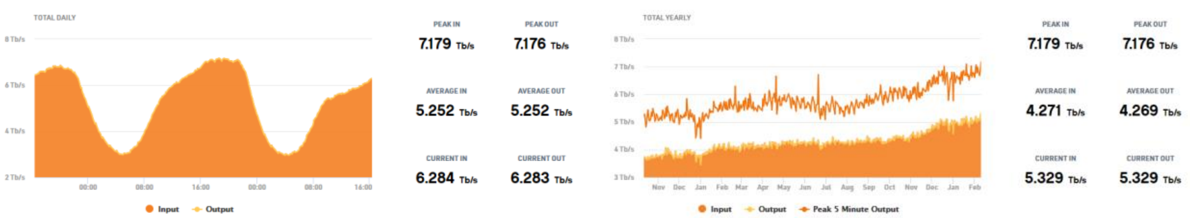


Figure 15. Daily traffic statistics– showing diurnal patterns in usage[50]

Actual energy consumption is therefore not representative of the useful work, but identifying the useful output of servers is difficult. In fact, experts can only agree that the 'idle-mode' is the only mode that is not providing useful output.
There are two relevant factors: The actual power consumed in idle mode, and the time spent in idle mode. The first is sort of covered by the 'idle state metric' of the SERT tool, the second has no current metric. The Dutch consultancy Certios.nl proposes the *server idle coefficient* (SIC) to make improvements in idle mode visible (a similar coefficient at data centre level is the *data centre idle coefficient* (DIC)).

As power consumption and CPU load are constantly monitored in modern servers the amount of idle-energy can be determined with limited investments. As servers can report on power draw (in Watt) as well as CPU loading (either in clock cycles or %) determining the idle coefficient of a specific server is possible with very limited investments. The server idle coefficient can thus be calculated as follows:

1. Record server power consumption during "idle period" -> Pidle
2. Determine Eidle(n) for all time intervals: Eidle (n) = [100%-CPU%(n)]Pidle * interval length(n)
3. Total idle energy: Eidle = Sum [Eidle (n)]
4. Total energy: Etotal = Sum [P(n) * interval length(n)]

[50] https://www.ams-ix.net/ams/documentation/colocation-traffic-ams

The server idle coefficient of a server is then calculated as (several options):

- SIC = [Etotal / Etotal – Eidle] (as PUE, 1 = ideal, worse is upwards)
- SIC = [Eidle / Etotal] (as DCIE, 0-100% Idle energy as part of total)
- other suggestions include a 1 (minimum) to 10 (excellent) score

A similar calculation can be performed at the level of the data centre (simply aggregating server calculations).

2.3.3 Network performance and energy use

Performance of switches and routers is typically expressed in typology, bandwidth and ports. For instance, the latest generation is a 32-port 400 Gbps managed Ethernet switch, which can also be used as a 128-port 100 Gbps[51]. Furthermore, switches are often indicated by the brand & type of their core IC (chip), the switch *application-specific integrated circuit (ASIC)*.

2.3.4 Storage performance and energy use

Storage equipment is generally optimised for one type of workload and would only meet the efficiency of one test. The efficiencies cover Online 2 to Online 4 storage equipment.[52]

Table 21. Storage efficiency.

	2020	
Workload type/ test	**Typical**	**BAT**
Transaction/Hot Band*	10 IOPS/W	28 IOPS/W
Streaming/Sequential read	1.5 MiBps/W	2.3 MiBps/W
Streaming/Sequential write	0.5 MiBps/W	1.5 MiBps/W

**in IOPS=Input/ Output Operations Per Second*

Source: ENERGY STAR for storage v2.0 draft [1].

The Regulation (EU) 2019/424 has minimum energy efficiency requirements for the power supply units (PSU) and power factor of servers and data storage products. There are two tiers for the requirements, i.e. per 1.3.2020 and per 1.3.2023 as laid down in the table below.

Table 22. Minimum PSU efficiency and power factor requirements (2020 --> 2023)

	Minimum PSU efficiency				Minimum power factor
% of rated load	10%	20%	50%	100%	50%
Multi output	-	88%->90%	92%->94%	88%->91%	0.9->0.95
Single output	-->90%	90%->94%	94%->96%	91%->91%	0.95

The table below shows the electricity consumption of storage devices with implementation of the Ecodesign measures.

[51] https://www.nextplatform.com/2019/03/20/how-to-benefit-from-facebooks-new-network-fabric/

[52] Online 2 to 4 are categories defining the features and functionalities for an online, random-access storage product, as defined by the Storage Networking Industry Association SNIA. See latest specifications at: https://www.snia.org/sites/default/files/technical_work/Emerald/SNIA_Emerald_Power_Efficiency_Measurement_Specification_V3_0_3.pdf

Table 23. Electricity consumption of storage, with measures, acc. EIA_2018

ES & DS, without effects on infrastructure	1990	2010	2015	2020	2025	2030	2035	2040	2045	2050
DS Online 2	0.4	6.5	8.7	11.7	14.6	17.4	18.3	18.3	18.3	18.3
DS Online 3	0.1	1.0	1.3	1.7	2.1	2.5	2.6	2.6	2.6	2.6
DS Online 4	0.3	3.7	4.9	6.4	8.0	9.6	10.0	10.0	10.0	10.0
DS Data Storage products total	**1**	**11**	**15**	**20**	**25**	**29**	**31**	**31**	**31**	**31**

It is estimated that by 2030, the effect of the Ecodesign requirements for data storage products set out in this Regulation will result in direct annual energy savings of approximately 0.8 TWh and indirect (i.e. related to infrastructure) annual energy savings of 2 TWh, summing up to a total saving of 2.8 TWh.

2.3.5 UPS performance and energy use

Performance of the UPS is typically expressed in terms of capacity (in kVA). The product life, i.e. the number of charging cycles, also plays a role. In this study, only electric battery back-ups are considered. Alternatively, especially for longer black-outs, diesel-generators may (also) be used.

The energy consumption considered for UPS is the difference between the input energy and the output energy, i.e. only UPS losses are taken into account. Unit energy is computed as (Input Energy - Output Energy) = (LOAD/efficiency - LOAD)*8760, where 8760 are the hours in a year. Efficiency data are derived from Ricardo-AEA 2014 Preparatory Ecodesign Study Lot 27 for UPS. [53]

The outcomes for various UPS sizes is given in Table 24, with efficiencies from 88.1% for UPS below 1.5 kVA up to 92.7% for UPS above 10 kVA.

Table 24. UPS load and efficiency parameters (source: VHK, EIA 2018[28] [54])

UPS	(1) kW input	(2) Avg. Level	(3) Avg. Eff.	(4) kW output
UPS below 1.5 kVA	0.54	67.5%	88.1%	0.32
UPS 1.5 to 5 kVA	2.87	75.0%	89.8%	1.93
UPS 5 to 10 kVA	6.25	75.0%	92.3%	4.33
UPS 10 to 200 kVA	94.5	50.0%	92.7%	43.80

Table 25 gives the electricity consumption of UPS.

Table 25. UPS electricity consumption, in TWh electric**(source: VHK, EIA 2018[28])**

UPS (electricity in TWh/yr)	1990	2010	2015	2020	2025	2030	2035	2040	2045	2050
UPS below 1.5 kVA	0.7	1.5	1.5	1.8	2.2	2.5	2.8	3.1	3.3	3.5
UPS 1.5 to 5 kVA	2.7	5.8	6.3	6.9	8.3	9.7	11.0	12.2	13.3	14.0
UPS 5 to 10 kVA	0.3	0.7	0.8	0.9	1.0	1.2	1.4	1.6	1.7	1.8
UPS 10 to 200 kVA	1.9	4.2	4.6	4.6	5.0	5.8	6.7	7.5	8.2	8.8
Total UPS	**5.6**	**12.3**	**13.2**	**14.2**	**16.4**	**19.2**	**21.9**	**24.4**	**26.5**	**28.2**

[53] Ricardo-AEA, ErP Lot 27 – Uninterruptible Power Supplies, Ecodesign preparatory study for the European Commission DG ENER, June 2014.

[54] The nominal active power is the reference INPUT load (1), taken from prep.study final consolidated report table 56. UPS normally operate at partial loads as indicated in prep. study table 110. The sum-product of load levels (25, 50, 75, 100% of nominal) and shares of times spent at these load levels gives an average load level (2). Table 102 in the prep.study provides the efficiencies for each load level. The sum-product of these efficiencies, the load levels and the times spent at these load levels provides a load-and-time-weighted average efficiency (3). The OUTPUT load for use in EIA (4) is computed as nominal input power * average load level * average efficiency. This value is then used as a LOAD constant for all years, identical in BAU and in ECO.

2.3.6 Cooling

As mentioned in paragraph 2.2.6, there is information on high temperature process chillers, which is typically what would be used for data centres. The load for these chillers follows a similar approach as it is developed for the electric comfort chillers and air conditioners/heat pumps, but with the following differences: 1) the cooling season is extended as process chillers operate all year long; 2) the standard rating conditions are at slightly different operating temperatures to reflect better the performance at lower outdoor temperatures; 3) this is also reflected in the bins that describe the cooling season. The methodology for taking measurements is intended to be the same as applied in EN 14825 and related standards.

The table below gives the average load in terms of power demand and number of operating hours. For cooling of colocation and hyperscale data centres the 1000 kW large air-cooled and 1600 kW large water-cooled chillers will be most appropriate. Note that there are of course other applications besides data centres for HT process chillers.

Table 26. HT-Chiller output power and hours/yr
(source: VHK, EIA 2018[28])

High Temperature Process Chillers)HT/PCH		OutputPower P (kW)	Hours/yr
AE-S Air-cooled Electric Small	kWh cool/a	145	5964
AE-L Air-cooled Electric Large	kWh cool/a	1000	2825
WE-S Water-cooled Electric Small	kWh cool/a	250	4418
WE-M Water-cooled Electric Medium	kWh cool/a	750	4375
WE-L Water-cooled Electric Large	kWh cool/a	1600	3984

Table 27. HT-Chiller electricity consumption, Business-as-Usual (without Ecodesign)
(source: VHK, EIA 2018[28])

HT Chillers, Electricity in TWh/yr	**1990**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Air-cooled Electric Small	23.2	36.4	39.8	42.5	44.1	44.9	45.5	46.0	46.6	47.1
Air-cooled Electric Large	22.2	34.7	37.9	40.3	41.6	42.2	42.7	43.1	43.6	44.1
Water-cooled Electric Small	4.7	7.7	8.4	9.0	9.3	9.5	9.6	9.7	9.8	9.9
Water-cooled Electric Medium	9.4	15.0	16.4	17.6	18.3	18.6	18.9	19.2	19.4	19.6
Water-cooled Electric Large	1.8	3.0	3.3	3.5	3.7	3.8	3.9	4.0	4.0	4.1
TOTAL	**61**	**97**	**106**	**113**	**117**	**119**	**121**	**122**	**123**	**125**

Table 28. HT-Chiller electricity consumption, with Ecodesign
(source: VHK, EIA 2018[28])

HT Chillers, Electricity in TWh/yr	**1990**	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Air-cooled Electric Small	23.2	36.4	39.8	41.4	41.4	41.0	41.3	42.2	43.3	44.4
Air-cooled Electric Large	22.2	34.7	37.8	39.1	38.5	37.2	36.7	37.0	37.8	38.8
Water-cooled Electric Small	4.7	7.7	8.4	8.9	9.0	9.1	9.2	9.4	9.6	9.8
Water-cooled Electric Medium	9.4	15.0	16.4	17.4	17.8	18.1	18.5	19.0	19.4	19.6
Water-cooled Electric Large	1.8	3.0	3.3	3.5	3.6	3.7	3.7	3.7	3.8	3.9
TOTAL	**61**	**97**	**106**	**110**	**110**	**109**	**109**	**111**	**114**	**117**

2.4 Energy efficiency improvement

2.4.1 General

For the data centres as a whole there are three main options to save fossil energy, i.e. to become carbon neutral.

- Improve energy efficiency of the equipment, including computing efficiency;

- Recover waste heat for cooling (heating) the data centre or use as input for district heating
- Use renewable energy sources

Energy efficiency of equipment

Energy efficiency improvement of the equipment is stimulated through legislation for the single components in a data centre: servers and storage in Ecodesign Regulation 2019/424/EU on servers and data storage[55], the Code of Conduct (CoC) for data centres that aims at infrastructure efficiency (PUE Power Usage Efficiency, i.e. the ratio between energy use of the whole centre and of the IT equipment only), Code of Conduct for UPS, etc.. In the following paragraph this will be discussed per component.

Code of Conduct for Data Centres[56]

The Code of Conduct for Data Centres is a voluntary initiative managed by the European Commission's Joint Research Centre, with the aim to inform and encourage data centre operators and owners to reduce energy consumption in a cost-effective manner without decreasing mission critical data centre functions.

The assessment is made against a set of best practices to reduce energy losses which include the usage of energy efficient hardware, installing free cooling and cold aisle containment.

370 data centres have requested to join the EU Code of Conduct since the start of the programme in 2008 and 329 have been approved as participants.

In addition there are 249 endorsers on the programme, who are vendors, consultants or industry associations.

All participants have the obligation to continuously monitor energy consumption and adopt energy management in order to look for continuous improvement in energy efficiency.

One of the key objectives of the Code of Conduct is that each participant benchmarks their efficiency overtime, using the Code of Conduct metric (or more sophisticated metrics if available) in order to to have evidence of continuous improvements in efficiency.

The 2018 awards for the Code of Conduct for data centres[57] were presented to facilities with a PUE ranging from between 1.28 (small data centre) to 1.09 (large data centre). Very low PUEs down to 1.07 are currently only reached by hyperscale facilities from major IT companies such as Google, Facebook, etc.

Waste heat recovery

In countries with a modern district heating network like Sweden, Denmark and Finland, it is an obvious choice to use the waste heat from (liquid) cooling of the IT equipment for district heating. The figure below gives an example of the approach in Stockholm

[55] Commission Regulation (EU) 2019/424 of 15 March 2019 laying down ecodesign requirements for servers and data storage products pursuant to Directive 2009/125/EC of the European Parliament and of the Council and amending Commission Regulation (EU) No 617/2013

[56] https://ec.europa.eu/jrc/en/news/eu-code-conduct-data-centres-10-years-improved-energy-efficiency

[57] https://ec.europa.eu/jrc/en/news/eu-code-conduct-data-centres-10-years-improved-energy-efficiency

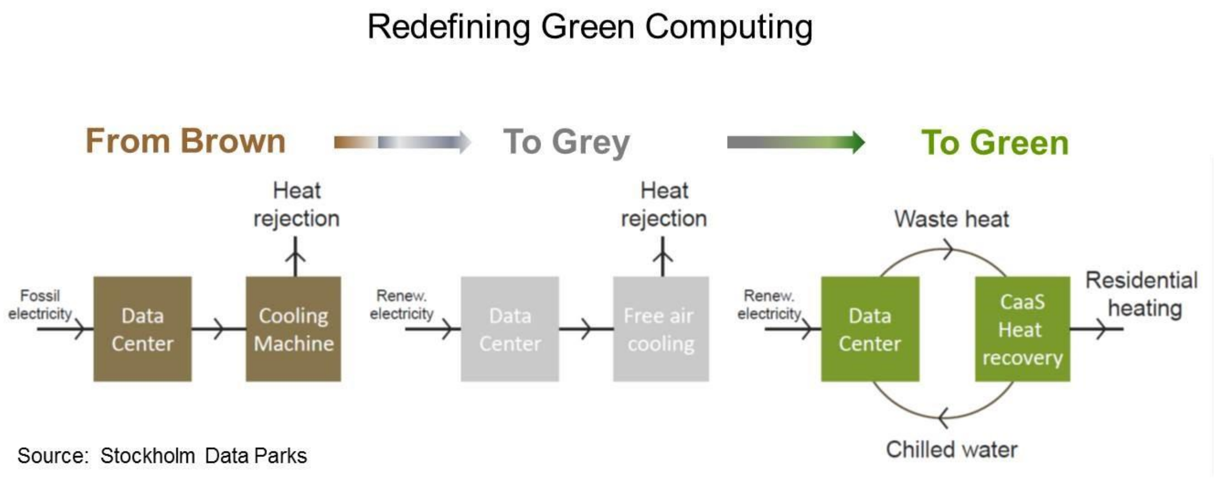


Figure 16. Energy strategy for Stockholm data parks

If there is no district heating nearby the heat can be used for cooling e.g. by using adsorption or absorption heat pumps that run on relatively lower temperatures (60 °C). Last but not least, the heat can also be used to run an electric heat pump (with inverter) at an extra high COP (Coefficient of Performance).
In a whitepaper the German Eco data centre association explains some of the heat recovery options. [58]

Green power purchasing

According to Cloudscene [59] [60] many of the top 30 IT companies are purchasing green power for their operations. The GPP Tech and Telecoms Top 30 (GPP = Green Power Partnership) include some important players in the global data centre market.
Google announced in 2018 that its worldwide operations are now 100% powered by wind and solar, making Google the first public cloud, and a company of its size, to have achieved this feat. For every kilowatt-hour (KWh) of electricity they consume, they purchase one KWh of renewable energy from a wind or solar farm that was built specifically for Google. In that sense Google is part owner of windmill parks in Europe as well.

Apple's data centres have been running on 100% renewables since 2013. In 2017, the company announced that its global facilities across 43 countries are now fully carbon-neutral. Apple will have 1.4GW of renewable energy capacity spread across 11 countries when all of its existing and pending projects are complete. Apple has also extended its 100% renewables commitment to its supply chain.

Facebook released that it's reducing its greenhouse gas emissions by 75% and that its global operations will run on 100% renewable energy by the end of 2020. Since its commitment to greener operations in 2013, Facebook has signed PPAs for more than 3GW of solar and wind energy.

Microsoft makes the largest purchase of solar energy in the US, signing a PPA for 315MW of energy from the 500MW Pleinmont I and II solar farms in Virginia, US. These are

[58] https://international.eco.de/topics/datacenter/white-paper-utilization-of-waste-heat-in-the-data-center/
[59] https://cloudscene.com/news/2017/07/greendatacenters/ Published 26 July 2017
[60] https://cloudscene.com/news/2019/03/data-center-giants-invest-in-renewable-energy/

750,000 solar panels installed across more than 2,000 acres, and will generate approximately 715,000 MWh per year.
Amazon Web Services (AWS) has been criticized in a recent report by Greenpeace for not living up to its 2014 commitment to using100% renewable energy. Amazon and AWS rebutted this and claimed that figures were inaccurate; indeedas of December 2018they have 1 GW capacity in 56 renewable energy projects, expected to supply over 3TWh annually. AWS also added that it remains firmly committed in its goal of achieving 100% renewable energy across its global network by 2030 with the company stating in its latest sustainability report that it achieved 40% renewable energy by the end of 2019. [61]

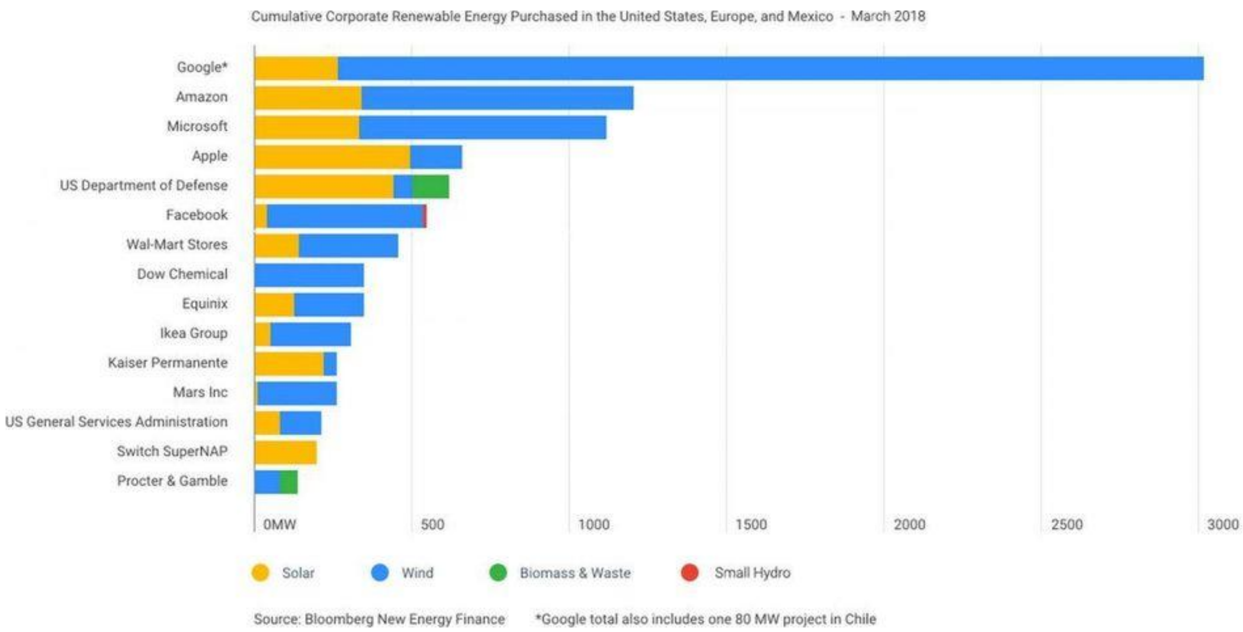


Figure 17. Cumulative Corporate Renewable Energy purchased in the US, Europe and Mexico – March 2018 (source: Forbes 2019[62])

2.4.2 Servers

Power Management

Modern servers have several 'power states', modes that allow the server to process requests at slower speeds ('P-states') or in which parts of the server are brought into low power modes or sleep modes ('C-states'). The goal is to reduce power consumption at lower workloads.
Normally these power management settings are not enabled, as the operator does not want to risk reduced performance, even if studies show that the activation of P- or C-states has little noticeable effect on the server performance.
A coalition of hardware companies and 'users' (Booking.com, KPN and Albert Heijn, etc.) in the Amsterdam area will investigate if they can safely activate low power modes at their servers[fd_2020] [63]. DCs in the Amsterdam area currently consume 2 TWh annually,

[61]https://sustainability.aboutamazon.com/pdfBuilderDownload?name=goals&name=sustainable-operations&name=sustainability-in-the-cloud

62 https://www.forbes.com/sites/energyinnovation/2018/04/12/google-and-apple-lead-the-corporate-charge-toward-100-renewable-energy/#20d38bb91b23

63 fd_2020: 'Ecomodus' op server moet Amsterdam forse stroombesparing opleveren, financieel dagblad (https://fd.nl/, accessed 21-2-2020)

equivalent to some 700,000 households (comparable to the inner city of Amsterdam) which prompted the Amsterdam council in 2018 to announce a stop to having more data centres in the area.
The reason low power modes are not enabled at servers is that owners/users of servers are afraid of lower performance, combined with low priority for saving energy.
Enabling low power modes can reduce the power draw of servers in these conditions by some 40%. Overall the savings could be between 10-30% (as servers will not run in low power continuously).

Utilisation
According to [Koomey_2017] some 25% of physical servers 'do nothing', and some 30% of 'virtual servers' do 'nothing'. Removing such servers from the racks could achieve significant savings.

This has a relation to the content as well: According to experts a significant share of the data stored and processed is ROT (Redundant, Obsolete and Trivial) and could be removed. Cleaning up ROT not only reduces operational expenses but capital expenses too.

2.4.3 Storage

As is the case with servers, the performance of storage is measured by tests. The Emerald™ Program[64] and its measurement procedure, the SNIA Emerald™ Power Efficiency Measurement Specification, was designed to measure performance in order to assess efficiency. This is also based on synthetic tests. However, there is no single metric for overall performance and the tests describe different aspects of the overall performance of the storage equipment.
The metrics used for efficiency are:

- Hot band test IOPS/W Tests the number of small data requests that can be performed per second from frequently accessed data per Watt;
- Sequential read (MiBps[65]/W) is how many million Bytes of data that can be read continuously per second per Watt;
- Sequential write (MiBPS/W) is how many million Bytes of data that can be written continuously per second per Watt;
- Ready Idle (GB/W) the total storage capacity divided by the power in ready idle state.

Storage equipment is generally optimised for one type of workload and would only meet the efficiency of one test. The efficiencies cover Online 2 to Online 4 storage equipment. Table 12 presents the storage equipment efficiency (typical and BAT) for workload type and test according to the test method.
In general, storage performance is measured in terms of total storage capacity (GB) and access (read/write) speed (GB/s) and IOPS (Input/Output operations per second). Different storage products may be designed for maximum IOPS, access speed or total capacity depending on the intended use. SNIA is used for ENERGY STAR but the data does

64 SNIA (Storage Networking Industry Association) Emerald™ Program
65 Computing terminology differs from SI and distinguishes between Mi = 1,000,000 and M=1,048,576. It is also measuring in B = Bytes not b=bits. 8bits=1Byte.

not include performance. Utilisation while active for storage equipment is estimated to be around 55%[66], but diurnal use patterns are expected.

2.4.4 Networks

Switch efficiency is measured in Mb/J (or Mbps/W) while router efficiency is measured in Mbps/W data switched. This efficiency is measured either at 100% utilisation or multiple utilisation levels depending on the type of equipment and metric.

Router performance continues to increase as do efficiencies alongside this. Newer information suggests core router efficiency has reached around 1000 Mb/J in 2017 [67]. The figure below presents the router efficiency (typical) for workload type and test according to the test method.

Router performance continues to increase as do efficiencies alongside this. Newer information suggests core router efficiency has reached around 1000Mb/J (1 Gbps/W) in 2017[68].

Table 29 Router efficiency. source: ITU-T L.1340 Informative values on the energy efficiency of telecommunication equipment (2014)

Equipment	Sub type	Typical efficiency (Mb/J)
Router	Access router	12-50
Router	Edge router	35-100
Router	Core router	50-300

Table 30 Switch efficiency. source: ITU-T L.1340 Informative values on the energy efficiency of telecommunication equipment (2014)

Equipment	Sub type	Typical efficiency (Mb/J)
Switch	Access switch	20-300
Switch	High speed	20-300
Switch	Distribution/aggregation	20-200
Switch	Core	50-400
Switch	Data centre	50-400

2.4.5 UPS

The Lot 27 study identified several *Best Available Technology BAT* options for UPSs.

Table 31. UPS BAT options (source Lot 27 preparatory Ecodesign study)

Component	Improvement	BAT/BNAT
Intelligent multi-mode operation	Up to +2% increase in efficiency	BAT
Improved Lead-acid batteries	Better performance and lifetime	BAT
Lead-carbon batteries	Increased cycle life	BNAT
Lithium-ion batteries	+20% of efficiency	BNAT
Supercapacitors	Better performance and lifetime	BNAT
Fuel cells	Better performance	BNAT
Transformerless UPS	+3% of efficiency and 25% less weight	BAT

66 Technical assistance study for the assessment of the feasibility of using "points system" methods in the implementation of Ecodesign Directive (2009/125/EC). Task 5. Extended Case study: Data Storage System. Final report. June 2017

67 Nokia 7950 Extensible Routing System

68 https://lafibre.info/images/datacenter/201703_Nokia_7950_XRS_R15.pdf

High-frequency transformer	alternative to the transformer-less topology	BAT
Three-level converter	reduction of 35% on the semiconductor losses	BAT
Transformer-less + Three-level converter + elimination of active components	+3% of efficiency and 46-60% less weight	BNAT
Delta-conversion lineinteractive UPSs	Better performance	BAT

The use of transformer-less designs can also apply to (rack) power distribution. By removing a number of conversions (from DC to AC and then back to DC) and filtering steps, the overall power conversion efficiency is increased from 80.75% to 91.2% (over 10% fewer losses). This avoids losses in EMI (electromagnetic interference) and PFC (power factor correction).

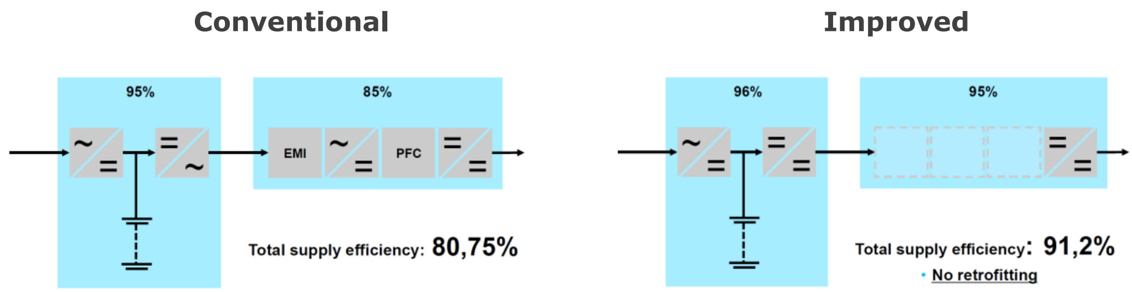


Figure 18. Power distribution improvement

Facebook and Google use the open compute project (OCP) rack design that uses 48V DC UPS battery cabinet to achieve savings of up to 20%, where the only conversion is DC to DC to sub-components of servers such as CPUs, RAM and hard disks in the market[69].

The latest development is the introduction of Li-ion batteries, which are more efficient and have a longer product-life, instead of lead-acid batteries short-time back-up and gas-fired fuel-cell back-ups for longer-time black-outs. There is even a US data centre fully gas-fired and powered by 6MW fuel-cell.[70]

2.4.6 Cooling

The use of economizers or free cooling has been mentioned: At low load levels, and where outdoor temperatures are lower than indoor temperature, one can remove heat without the need to further actively cool the air. Similarly one can use surface water[71] (or ground water, or even rain water[72]) as a thermal source for cooling air. Direct use of cool outside air may be hindered by local circumstances, pollution in particular. These systems share the principle that the cooling water is cooled by an ambient source.
Air based cooling efficiency can be improved by evaporative cooling, whereby the evaporation energy of water provides a cooling effect on the air stream. This technology

[69] https://www.reportbuyer.com/product/5741687/data-center-ups-market-global-outlook-and-forecast-2019-2024.html
[70] http://www.fchea.org/in-transition/2018/11/12/whs20dthibvg3pvhfjekribqhs0bbt
[71] applied by Google's environmentally data centre in Hamina, Finland
[72] Apparently used by Facebook

works best in dry climates or low humidity environments. The technology is not completely free, and estimated to cost around 25% of traditional HVAC cooling, because of the need for clean water and air movement[73]. Indirect adiabatic cooling, or state point liquid cooling as applied by Facebook and Nortel Air Solutions, also rely on evaporative cooling, but uses an indirect air stream to cool down air, especially cutting down on water usage.
Other options to improve cooling efficiency and/or reduce cooling costs are DCIM (data centre integrated management) or data centre smart assistants, which is essentially software that tracks (among others) the CPU/GPU temperatures of servers and other equipment in real time and can help identify hotspots before they become problematic[74]. Measurement of operational temperatures and humidity levels can also be applied at rack level, with doors closed, using a *data centre cooling robot*[75]. Such systems can help identify problems such as those related to poor cable wiring (obstructing air flow) or reversed mounting of equipment (blowing hot air the wrong way out).

2.5 Summary

The graph below summarizes the best estimate of the electricity consumption 2010-2025 for the EU27, mainly based on Table 13 converted to EU27. Overall it seems that energy efficiency improvement and growth in data centre usage are fairly balanced.

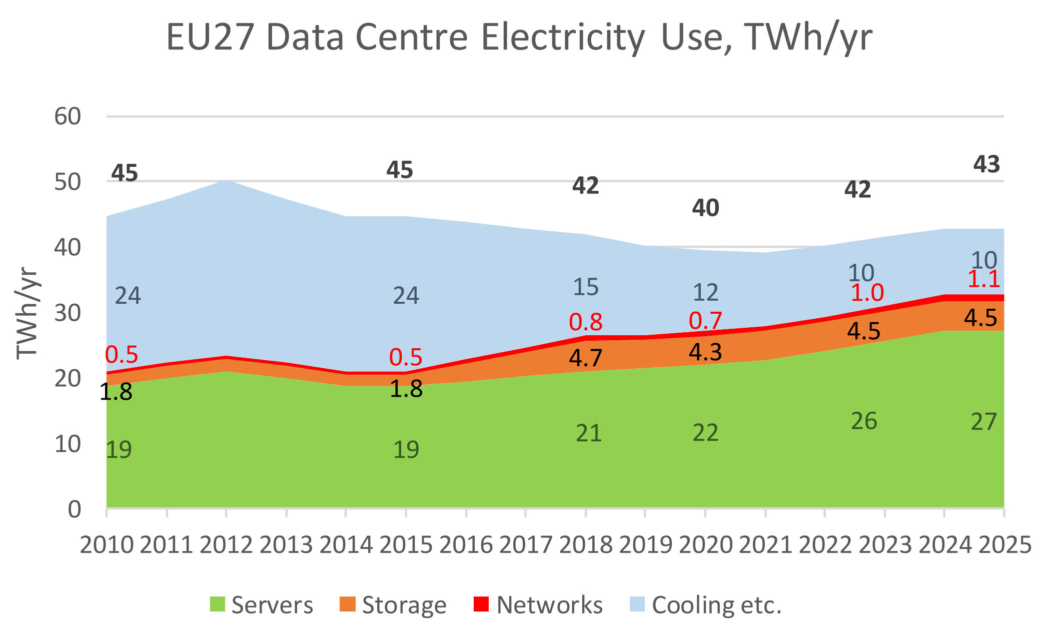


Figure 19. EU27 data centre electricity use 2010-2025

[73] https://www.datacenterknowledge.com/facebook/facebook-s-new-data-center-cooling-design-means-it-can-build-more-places

[74] https://adeptdc.com/

[75] https://www.datacenterknowledge.com/design/robot-monitors-data-center-cooling-behind-closed-cabinet-doors

3 Group II. – Telecom networks

3.1 Definition

3.1.1 Introduction

The specific contract for this study describes the product groups of telecommunication networks as shown in the table below.

Table 32. Product groups in the Telecommunication networks category

II. Telecommunication networks
Broadband communication Equipment
Network in offices (1 GB/10+ GB LAN, WLAN)
Mobile networks (mobile radio, aggregated/core, satellite TV, TETRA, 2G, 3G, 4G, 5G, PUE for cooling and power supply)
Cable (fixed, landline) networks (i.e. PSTN/KSDN, TV-cable, ADSL, VDSL, FTTLA, FTTH/B, FTTH, PUE for cooling and power supply)

The formal definition of *telecommunication* according to ITU (Radio Regulation, ed. 2012, Art. 1.3) is: *Any transmission, emission or reception of signs, signals, writings, images and sounds or intelligence of any nature by wire, radio, optical or other electromagnetic systems.*[76]

Telecommunication engineering and management is a vast subject, with many thousands of abbreviated definitions for hardware, software and service concepts (including security). Technical standardisation is covered mainly by three international standardisation institutes:

- **ITU**, The International Telecommunication Union[77], a United Nations (UN) organisation that develops/maintains technical standards (ITU-T) like e.g. PSTN Public Switched Telephone Network protocol that governs most of digital traffic. It also allocates global radio spectrum and satellite orbits and aims to improve access to ICTs to underserved communities worldwide.
- **IEEE**, the Standards Association of the Institute of Electrical and Electronics Engineers[78], known for e.g. Ethernet protocol (IEEE 802.11) covering LAN (Local Area Network) communication.
- **ETSI**, European Telecommunications Standards Institute[79], is one of the three European Standardisation Organisations (ESOs), together with CEN and Cenelec, producing EN (European Norm) standards.

[76] https://www.itu.int/pub/R-REG-RR-2012
[77] www,itu,int
[78] standards.ieee.org
[79] www.etsi.org

Apart from these , there are also relevant standards by **ISO**[80], **IEC**[81] **, IETF**[82] and various regional bodies. For carbon (and energy use) footprint methodology in the ICT sector the ICTFootprint project gives an overview[83]. The **GHG Protocol** is reported to be leading for ICT.[84] A glossary has been added in the Annex.

Telecom networks have not been assessed as part of an Ecodesign study. There have been attempts to describe telecommunications in the context of e.g. the EU's Digital Agenda, Green Public Procurement (GPP) and many other contexts but studies are rarely directed by non-experts.

To introduce a complex topic as the telecommunications network in a fairly comprehensive, compact and understandable way, the study team produced a number of diagrams [85] showing the elements and abbreviations of the hardware, software and services involved. The information is by definition incomplete but an effort has been made to be as up-to-date as project resources allowed.

Office (W)LAN network equipment, using similar gateways and routers as the home networks, is not singled out hereafter as it is covered in section 8 (home/office equipment).

3.1.2 Hardware

Figure 20 shows the telecommunication hardware, ranging from the network ports of the ***data centres*** (orange icons), addressed in the previous section, to the gateways of the ***home/work network*** *including the end-use devices*, described in the following sections of this report.

CORE NET

In between there is the IP (Internet Protocol) **Core Network**, the so-called "world wide web (www)" that handles the traffic between the **content/cloud providers** and the **Internet Service Providers (IPS)**. It consists almost entirely of a high-volume, high-speed **optical fibre network (ON)**. This includes intercontinental **undersea cables**, which amount to –in a worst case estimate- a total length of more than 2 million km when put all together.[86] The undersea cables not only contain optical fibre cables, but also copper to transport the power to the repeaters (signal boosters) that are placed every few hundred km.[87]

[80] International Standards Organisation www.iso.org
[81] International Electrotechnical Commission, www.iec.ch
[82] Internet Engineering Task Force, www.ietf.org
[83] https://ictfootprint.eu
[84] https://www.ghgprotocol.org/sites/default/files/ghgp/GHGP-ICTSG%20-%20ALL%20Chapters.pdf
[85]Copyright©VHK 2020. Reproduction is authorised provided the source is acknowledged.
[86] Study team estimate based on 285 cables of on average 7500 km Based on
[87] http://www.techteledata.com/how-submarine-cables-are-made-laid-operated-and-repaired/

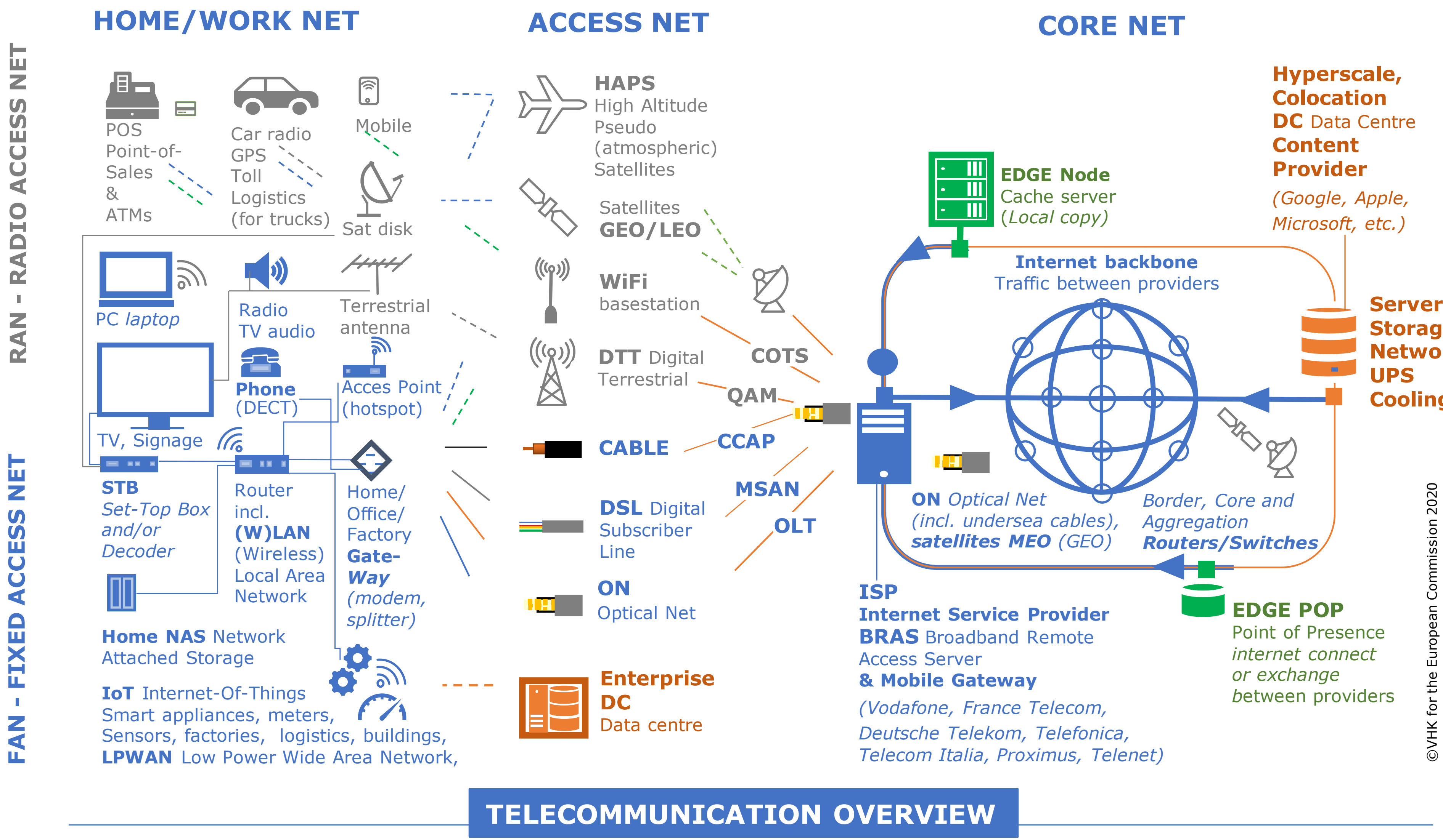


Figure 20. Illustrative overview of telecom network (source: VHK 2020)

Specific broadband applications (e.g. the US government, maritime internet, etc.) are complemented by the latest fast **MEO** (Medium Earth Orbit) **satellites.** For remote locations there is a relatively slow but functional communication via VSAT (Very Small Aperture Terminals) disks using geostationary (**GEO**) **satellites**.

The digital traffic follows the (updated) PSTN protocol and uses package-switching, i.e. little (compressed) data blocks which are loaded onto the fibre cables in timeslots of X milliseconds (ms), not only correctly connecting sender and receiver, but doing so as fast and efficiently as possible. The equipment that does this consists of **border-, core- and aggregation routers and switches**, operating at start, middle and end of data stream.

The figure also shows two instances of 'edge computing' (green icons): **Edge Points of Presence (POPs)**, where the ISP and content/cloud provider physically 'share' the same equipment on location typically with a process called 'peering', and **Edge Nodes** where the content/cloud provider operates and pays for cache servers in an ISP facility. The aim is to improve speed and volume throughput of data traffic to the benefit of both types of providers. For example, Google operates 22 data centres (of which 5 are in Europe), is present in over 90 internet exchanges and at over 100 interconnection facilities (190 POPs) as well as 7000 Edge Nodes around the world.[88] [89]

ACCESS NET

The access network provides the communication between the worldwide web and the gateway of the end-user, typically through the Internet Service Provider ISP. There is a distinction between the **Fixed Access Network FAN** using landlines (blue icons), and the **Radio Access Network RAN** using radio waves (grey icons). The starting point for access is typically the data traffic from the **Broadband Remote Access Servers BRAS** or similar servers of the ISP, usually –except for some satellite applications—transported from/to the **Optical Line Terminal OLT**.

The hardware of the network can be characterised by the vehicles for communication:

- **HAPs** *High Altitude atmospheric Pseudo-Satellites* which are still experimental, but intended to be used –apart from surveillance applications—as relays between satellite ground stations and *MEO/GEO* satellites to improve performance. See also Figure 21 and the paragraph on energy efficiency for details.
- **Satellites**, for *Low/ Medium/ Geostationary Earth Orbit LEO/MEO/GEO*:

  LEO satellites –including the EU's Galileo, the US *Global Positioning System GPS* satellites—are used for *Global Navigation Satellite Systems GNNS*.

  MEO is used mainly for fast satellite internet (voice included). An example is the *'O3b' ('the Other 3 billion')* satellites by market leader SES.

  GEO satellites are the standard communication means for Sat(elite)-TV with the satellite-version of *Digital Video Broadcasting DVB-S* and remote communication e.g. using the *Very Small Aperture Terminals VSAT.*

[88] https://peering.google.com/#/infrastructure
[89] https://www.reddit.com/r/Stadia/comments/b58pmg/google_said_they_have_over_7000_edgenode_locations/

See also Figure 21 and Figure 22 for more details. Satellite communication requires a ground-station converting the data traffic to/from ISP towards a large transceiver uplink disk, a solar-driven satellite with various gateway and downlink antennae and at the end-user a smaller receiver disk as well as a decoder e.g. a kind of **set top box STB** near the TV.

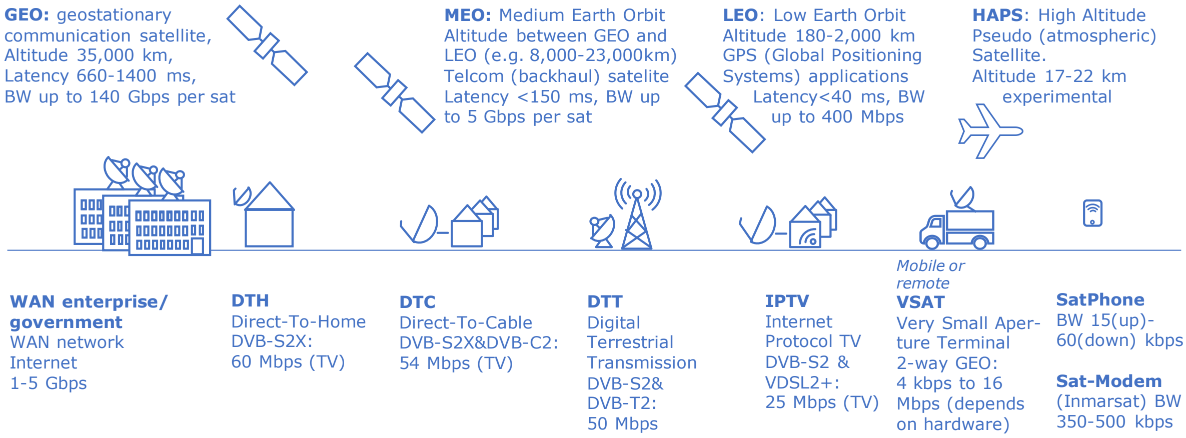


Figure 21. A selection of satellite telecommunication applications (VHK 2020[90])

Latency relates to round-trip in milliseconds, bandwidth (max. values)

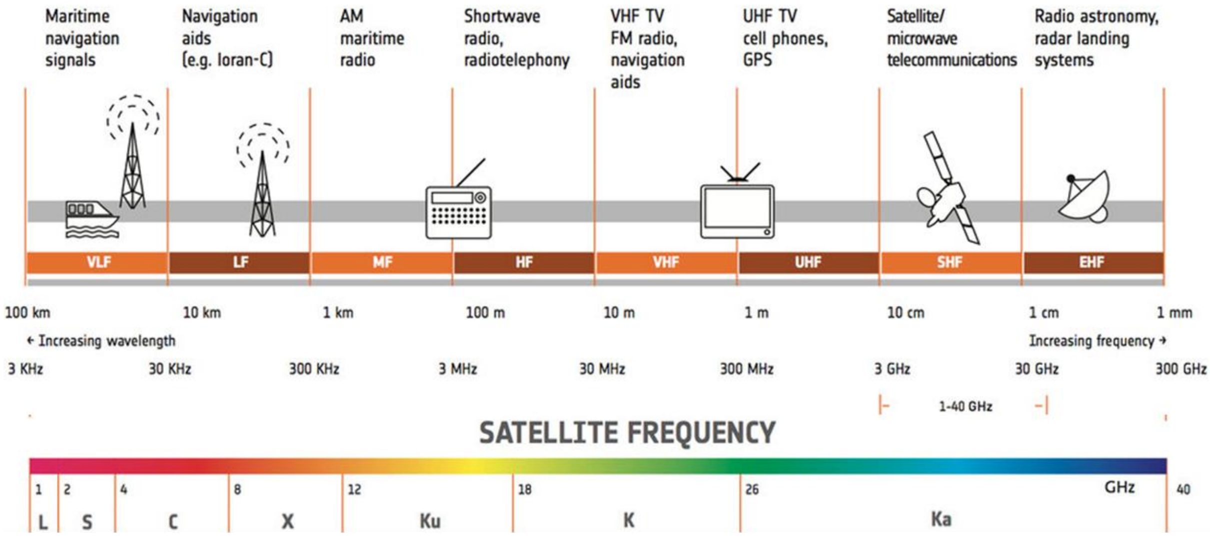


Figure 22. Radio frequencies (source: ESA, access 2020[91]).

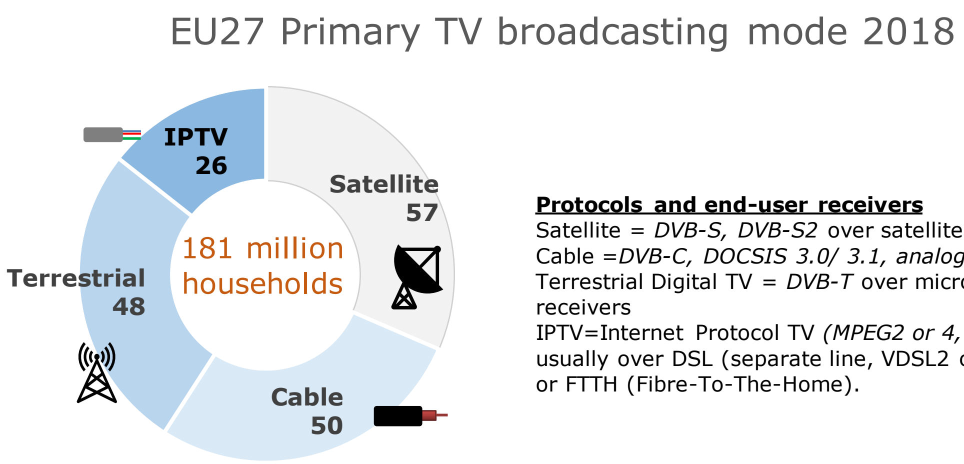
Notes: L-band for LEO satellites (GPS, maritime); S-band for weather radar, NASA-sat; C-band for VSAT satellite communication in remote areas; Ku-band is used in Europe for SAT-TV (Astra), Ka-band for MEO ('O3b') and GEO satellites.

[90] For more reading see http://www.satsig.net/ or SES Annual report at https://www.ses.com/sites/default/files/SES_AR_2018_A4_0319_web_0.pdf

[91] https://www.esa.int/Applications/Telecommunications_Integrated_Applications/Satellite_frequency_bands

- ***Mobile** cellular networks* realise wireless communication between core network and end-users (mobile phones, computers, etc.) through *base station* transceivers[92] creating a *Wide Area Network WAN* to mobile end-use devices (phones, laptops, access points) but also increasingly to subscribers using the mobile access network instead of a fixed home gateway. The base stations are nowadays connected to the ISP servers[93] at the core network with optical fibre cables[94]. The base station has transceiver antennas at 2.4 and 5 GHz frequency, an *Uninterruptable Power Supply UPS* battery back-up and electronics consisting of a *Baseband Unit BBU* processing external data traffic with the *Remote Radio Unit RRU* . The RRU processes, amplifies and converts the *Radio Frequency RF* to/from the radio antennae.

- ***DTT** Digital Terrestrial Television* broadcasts TV/radio channels to the end-user using (radio) transmission towers. It was the first follow-up of the analogue broadcasting, using the *DVB-T*(errestrial) protocol, involving *MPEG* video-compression and *Quadrature Amplitude Modulation QAM* at the transmission end. At the end-user DTT requires an aerial antenna and –currently often integrated—a relatively simple decoder[95]. It is the primary TV option for over a quarter of EU27-households (see Figure 22), mostly as *Free-To-Air (FTA)*.



Protocols and end-user receivers
Satellite = *DVB-S, DVB-S2* over satellite dish receiver
Cable =*DVB-C, DOCSIS 3.0/ 3.1, analogue** over coax cable
Terrestrial Digital TV = *DVB-T* over microwave radio receivers
IPTV=Internet Protocol TV *(MPEG2 or 4, H.264 compression),* usually over DSL (separate line, VDSL2 or VDSL2-Vplus) or FTTH (Fibre-To-The-Home).

Figure 23. Estimated primary TV broadcasting mode of EU27 households in 2018 (source: VHK 2020, based on cable-europe.eu, CSES 2016 and others).

Abbreviations: *DVB-S/C/T* is Satellite/Cable/Terrestrial Digital Video Broadcasting; DOCSIS is Data Over Cable Service Interface Specification; DSL is Digital Subscriber Line; VDSL is Very-high-bitrate DSL; Note that households without TV (<10 million) are not included,

[92] Transceivers is a combination of transmitter and receiver antennas

[93] The most recent trend is a 'virtualised cloud core' through a *common-off-the-shelf COT*S server.

[94] Legacy networks may use cable or microwave transceivers between core and base station. Instead of only connecting to the digital packet data network (PDN), they may also connect to the Plain Old Telephone System POTS. Instead of COTS core to RRU connections the ISP may also use an integrated PGW (Packet Gateway), SGW (Serving Gateway) and MME (Mobility Management Entity). It can also integrate legacy functionality.

[95] In legacy Ecodesign regulation (EC) No 107/2009 of 4 February 2009 called a Simple Set Top Box SSTB

- ***Cable*** networks communicate to/from the core Cable Modem Termination System CMTS by optical fibre, satellite (*DTC, Direct-To-Cable*) or still copper coax cable to the *Integrated* (*I-CCAP*) or *Distributed* (*D-CCAP*) *Converged Cable Access Platform* and subsequently copper (coax) cables to the end-users homes/offices, whereby the last copper line in Europe is gradually being replaced by optical fibre *(see below)*. At the end-user/subscriber there is a decoder, often combined with modem and router in one product. Cable networks, using the *DVB-C*(able) protocols, started out as a medium for TV broadcasting, which is still an important end-use (see Figure 23), but is now a universal digital interface for voice (via *VoIP Voice over Internet*), internet and TV/radio. The Cable standard protocol – and also that of the complex set top box in paragraph 5.9—is the *Data Over Cable Service Interface Specification DOCSIS 3.0* and later *3.1*.

- ***DSL*** *Digital Subscriber Line* is the successor of the analogue telephone line[96] and the first, now legacy *Integrated Services Digital Network ISDN*, both governed by the circuit-switched *Public Switching Telephone System PSTN* protocol. The DSL starts as an *optical line terminal (OLT)* to a *Multi-Service Access Node MSAN*, from where a copper phone line, or increasingly also an optical fibre, goes to the end-user premises. In older versions, it might also be the package-switched OLT and the circuit-switched PSTN that go from the core network to a *DSL Access Multiplier DSLAM* and then to the home or office. There, the cable was traditionally split into a voice and a data (modem) cable, but now it is usually an integrated modem/router with voice VoIP, television (IPTV) and data connected through the Internet. DSL was initially called '*Asymmetric*' DSL[97] (*ADSL*), then *'Very high speed'* (VDSL), later VDSL2 and most recently *G.Fast*. DSL, like the whole Internet, is governed by the *Transmission Control Protocol TCP* (a.k.a. TCP/IP).

- ***ON*** *Optical Network* has no tradition of its own, but is gradually being introduced by Cable and DSL providers to replace the copper landlines to the premises of the end-user: *Fibre-To-The-Home FTTH* or *Fibre-To-The-Building FTTB*[98]*.* In that sense it is a simple but very fast continuation of the optical core network, i.e. the OLT, passes directly from the Optical Network Unit ONU to the end-user premises. In the EU27, with 181 million households in 2018, there were 29 million subscribers and 78 million 'homes passed' (where the fibre goes to the front door but not connected), with Spain, France and Romania being the top three Member States in optical fibre market penetration.[99] Specific denominations of optical network include *Passive ON (PON)*, *Gigabit ON (GPON)*, *Ethernet Passive ON (EPON)*, etc..

- ***Enterprise Data Centres*** were taken into account in the previous section of this report for their energy consumption for in-house administration, phones or logistics. But they are also special in other ways: they can be a special client of the core network, e.g. at the Points Of Presence when expanding their *Local Area Network*

[96] A.k.a. plain old telephone system *POTS* using the *Public Switching Telephone System PSTN*. With the times PSTN evolved from analogue into a digital circuit-switched version. That is, a dedicated circuit (also referred to as a channel) is established for the duration of a transmission, such as a telephone call. This contrasts with packet switching networks, in which messages are divided into small segments called packets and each packet is sent individually. The Internet is based on a packet-switching protocol, TCP/IP Transmission Control Protocol/Internet Protocol.

[97] Meaning that it is designed so that the download speed is much higher than the upload speed.

[98] The combination is often referred to as FTTH/B

[99] https://www.ftthcouncil.eu/documents/FTTH%20Council%20Europe%20-%20Panorama%20at%20September%202018.pdf

LAN to become a wider network with subsidiaries or branch offices through *Virtual Private Network VPN* or similar cases. Also, they are often the centre of a company's *Internet-of-Things IOT*, i.e. industrial sensors, *Point-Of-Sales POS* terminals, production machines, building automation, utility meters, etc. communicating directly through *Bluetooth*, *Low Power Wide Area Network LPWA* or *Wi-Fi*.

3.1.3 Software protocols

LAYERS

Communication protocols are a set of rules enabling reliable and speedy information transfer between sender and receiver. They determine the hardware (and v.v.) and are at least as important as hardware for the energy efficiency and performance of telecommunication.

The Open System Interconnection (OSI) reference model is a seven-layer model to show how data transmission between source,intermediate and end-user devices takes place in networking. The Table below gives an overview:

Table 33. Open System Interconnection (OSI) reference model and TCP/IP equivalents (source: HowToNetwork.org [100])

TCP/IP Layer 5: Application	OSI Layer 7: **Application**	Provides services to the lower layers. Enables program-to-program communication and determines whether sufficient resources exist for communication. Examples are e-mail gateways (SMTP), TFTP, FTP, and SNMP (Simple Network Management Protocol).
	OSI Layer 6: **Presentation**	Presents information to the Application layer. Compression, data conversion, encryption, and standard formatting occur here. Contains data formats such as JPEG, MPEG, MIDI, and TIFF.
	OSI Layer 5: **Session**	Establishes and maintains communication sessions between applications (dialogue control). Sessions can be simplex (one direction only), half-duplex (one direction at a time), or full duplex (both ways simultaneously). Session Layer keeps different applications data separate from other applications. Protocols include NFS, SQL, X Window, RPC, ASP, and NetBios Names.
TCP/IP Layer 4	OSI Layer 4 : **Transport**	Responsible for end-to-end integrity of data transmissions, and establishes a logical connection between sending and receiving hosts via virtual circuits. Windowing works at this level to control how much information is transferred before acknowledgement is required. Data is segmented and reassembled at this layer. Port numbers are used to keep track of different conversations crossing the network at the same time. Supports **TCP**, UDP, SPX, NBP. Segmentation and error correction works here, but not detection.
TCP/IP Layer 3	OSI Layer 3: **Network**	Routes data from one node to another and determines the best path to take. Routers operate at this level. Network addresses are used here for routing (packets). Routing tables, subnetting, and control of network congestion occur here. Routing protocols, regardless of which protocol they run over, reside here. Examples include RIP, **IP**, IPX, ARP, IGRP, and AppleTalk.
TCP/IP Layer 2	OSI Layer 2: **Data Link**	Sometimes referred to as the LAN layer. Responsible for the physical transmission of data from one node to another. Error detection occurs here. Packets are translated into frames here and hardware address is added. Bridges and switches operate at this layer. Contains the LLC and MAC Sublayers.
TCP/IP Layer 1	OSI Layer 1: **Physical**	Puts data onto the wire and includes Physical Layer specifications, such as connectors, voltage, physical data rates, and DTE/DCE interfaces. Some common implementations include Ethernet/IEEE 802.3, FastEthernet, and Token Ring/IEEE 802.5.

The five-layer TCP/IP protocol suite, named after two layers in the suite, follows the OSI model but has merged three layers of the OSI-model into one.

[100] https://www.howtonetwork.org/design/ccda/chapter-1-network-fundamentals/network-fundamentals-the-osi-model/

Most of the protocol names that are used in common language, like Ethernet, Wi-Fi or 4G etc., pertain to Layers 1 and 2; together these layers are also known as the 'access layers'. These will be discussed hereafter. For more details of the OSI model consult the literature.[100]

WI-FI – CABLE - DSL

The figure below shows the typology and progress in performance of Wi-Fi (based on wireless network standard IEEE 802.11) and landline protocols for Cable (DOCSIS) and DSL (VDSL, G.fast) networks over the past few years.

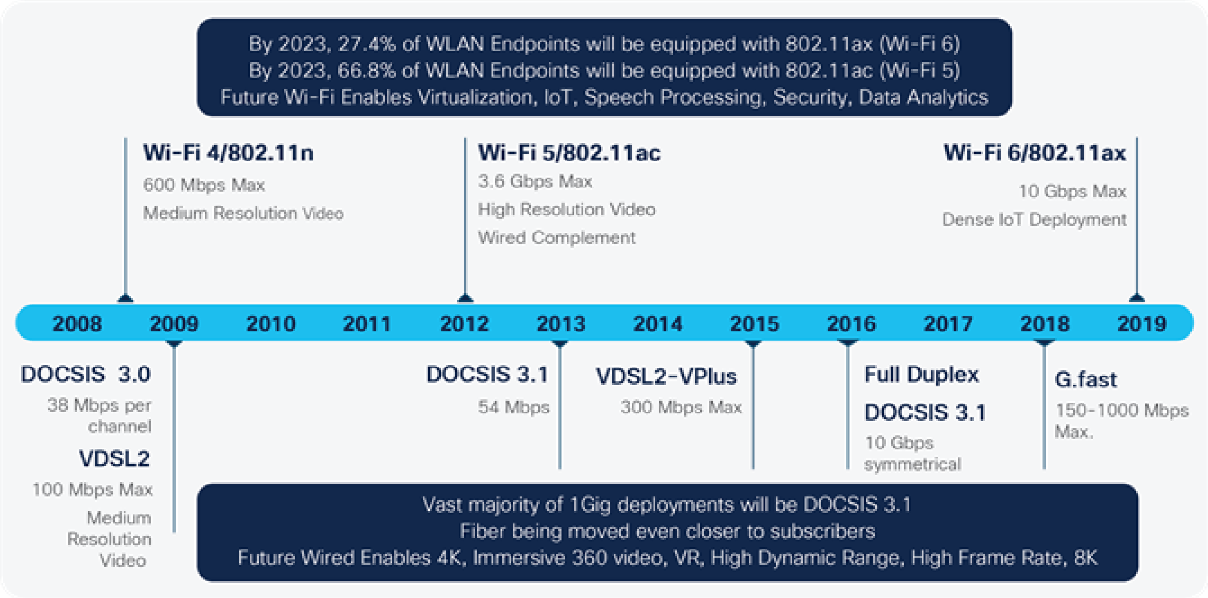


Figure 24: Evolution of WiFi technology 2008-2019 (source: Cisco, 2020)

ETHERNET

The Ethernet standard for the *physical PHY* datalink-layer of wired local area networks LAN is based on the IEEE 802.3. Ethernet is now also used for wireless WANs (core to base station networks). It has standards for different bandwidths and media (twisted pair or coax copper cables, optical fibres in single or multiple mode, at various ranges of lengths) several physical formats, indicated by a code with first 2-4 digits indicating speed (in Mbps or Gbps), then the word 'BASE' and then the type of twisted pair/optical fibre depending on the speed. The lowest Ethernet bandwidth, at which Ethernet started out with in the 1980s, was 10Mbps for a single twisted pair cable of 0.2" (*10BASE2*) or a 0.5" coax cable (*10BASE5*). The highest bandwidth for communication today is 400Gbps for a single mode glass fibre (e.g. *400GBASE-ER8*). For industrial Ethernet the 1.2 Terabit per second (1 Tbps= 1000 Gbps) microchip has already been reported [101].

Note also that intermediate Ethernet standards, i.e. slower than the best possible ones, were developed to accommodate the wishes of data centres and providers. However, they were not always prepared to follow the pace of having to change all their equipment.

[101] http://esc.microsemi.com/cgi-bin/download_p.pl?res_id=350921&filename=2171507_Microsemi_META-DX1_Product_Brief_350301.pdf

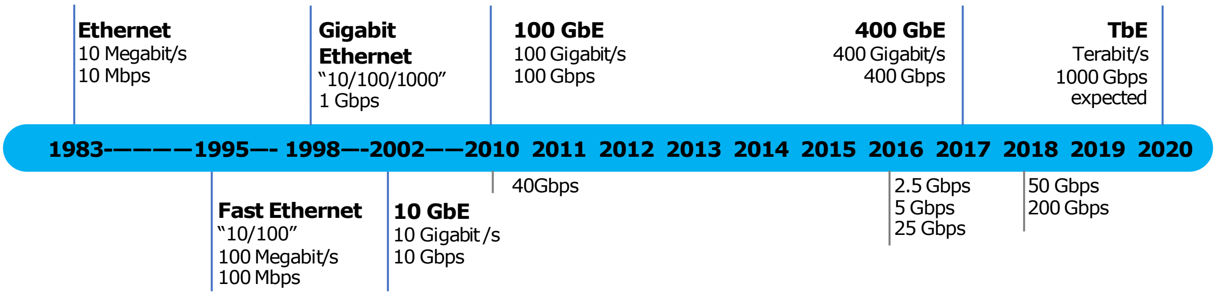


Figure 25: Ethernet milestones and maximum bandwidths (source: VHK 2020[102])

MOBILE NETWORKS

Mobile network protocols (and fitting technologies) are given in the figure below.

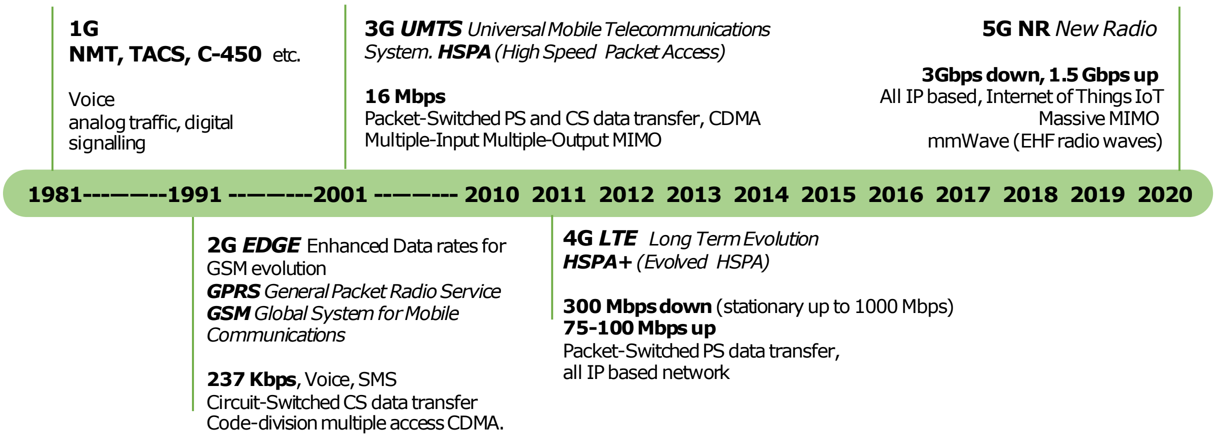


Figure 26: Mobile network protocol milestones and maximum bandwidths (source: VHK 2020[103])

TERRESTRIAL TV

For DTT the protocols are DVB-T (first used in 1998), with maximum bitrate of 64-QAM which is 24 Mbps. With the DVB-T2 protocol, introduced in 2010, the bitrate of 64-QAM was about 50% higher (37 Mbps), and maximum bitrate of 256-QAM was 50 Mbps. Note that usually compression is used for the TV signal (MPEG 2 or 4, H.264, H.265 codec).

SATELLITES

For satellite DVB-S and DVB-S2 there is only anecdotal information as regards their performance.

Initial tests of LEO satellites in July 2019 showed a bandwidth of 400 Mbps and a latency of 32 ms according to its owner, satellite internet operator OneWeb.[104]

For MEO satellites of the O3b type the leading operator SES reports in its recent annual report bitrates for mobile users (cruise ships) of 1 Gbps and for fixed power users (e.g.

[102] Picture by VHK, based on miscellaneous sources.

[103] Picture by VHK, based on miscellaneous sources.

[104] https://www.lightreading.com/gigabit/wireless-satellite/onewebs-leo-satellites-clock-400-mbit-s-latency-of-32-ms-in-initial-tests/d/d-id/752812

government) of 5 Gbps,using all of its 12 antennae per satellite. Latency is reported at <150 ms for a round-trip.

For GEO communication satellites ViaSat-2 is probably largest with a capacity of 260 Gbps. For 2021 the launch of the first Viasat-3 satellite with a capacity of 1 Tbps (1000 Gbps) is planned.

See Figure 21. A selection of satellite telecommunication applications (VHK 2020) for an overview of satellite latencies and bandwidths found.

3.1.4 Services

As mentioned in the previous section regarding Data Centres, 82% of the telecom service is allocated to video and 3-4% to gaming, i.e. also mostly video. The remaining 15% is split between voice, non-video social media, private cloud storage, business cloud computing of administration, logistics, commercial applications, production automation and the (rest of) Internet-of-Things, i.e. communication between hardware devices (which are referred to as 'Things').

PRIVATE HOUSEHOLDS

Figure 5 shows the bandwidth that is required for the different types of video. In 2018 a penetration rate of 25% for UHD (4K) television sets was estimated. At usual pace of sales this will be 50% in 2020. This does not necessarily mean 50% of transmissions, because only VOD transmissions are in 4K. All public networks broadcast typically in HD. As regards the bitrates, the codec is very important. For instance at H.264 (Advanced Video Coding AVC) a UHD streaming video would be 40 Mbps, whereas at H.265 (High Efficiency Video Coding HEVC, or High Efficiency Image File Format HEIF) the bitrate is about 20 Mbps (between 13 and 25 Mbps depending on other parameters).

Table 34. Video bitrates 2020 from storage medium & streaming

Video format-→	**SD ('Near HD')**	**HD**	**UHD (4K)**
Resolution	1280x720 px (0.92 Mpx)	1920x1080 px (2.1 Mpx)	3840x2160 px (8.5 Mpx)
Storage/full download			
Storage medium	**DVD**	**Blu-Ray**	**Ultra Blu-ray**
Storage space	8.5 GB	50 GB	100 GB
Nominal bitrate (codec)	10-11 Mbps (H.264)	54 Mbps (H.265)	182 Mbps (H.265, movies)
Streaming video bitrates			
	SD ('Near HD')	**HD**	**UHD (4K)**
Netflix	3 Mbps	5 Mbps	25 Mbps
Amazon Video	0.9 Mbps	3.5 Mbps	15 Mbps
Apple TV	3 Mbps	6 Mbps	13 Mbps
YouTube	1.5 Mbps	3 Mbps	13 Mps

Source: https://techtalk.currys.co.uk/tv-gaming/tv/how-fast-does-my-internet-need-to-be-to-stream-4k-movies/ (published 4 Feb, 2020)

The internet was used mainly to send/receive e-mails (75%), to find information about goods and services (68%), for instant messaging (67%) and online news (63%). A majority of people also used the internet to use banking facilities (58%), to participate in social networks (57%), to look for health information (55%), for listening to music (53%) and for telephoning or for video calls (52%).

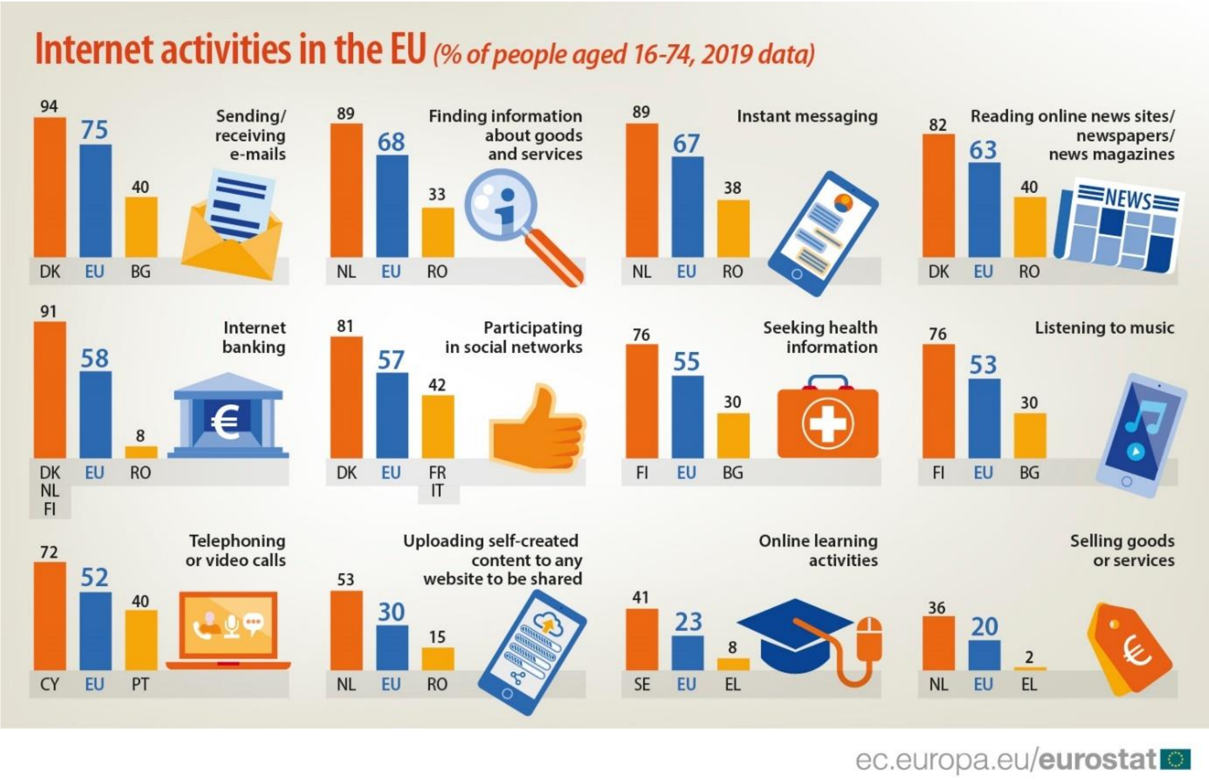


Figure 27: Use of Internet by private households 2019 (source: Eurostat[105], 2019)

ENTERPRISES

On cloud computing Eurostat reports[106]

- 26 % of EU enterprises used cloud computing in 2018, mostly for e-mail and storage of files;
- 55 % of those firms used advanced cloud services relating to financial and accounting software applications, customer relationship management or to the use of computing power to run business applications;
- In 2018, many more firms used public cloud servers (18 %) than private cloud servers (11 %), i.e. infrastructure for their exclusive use;
- Compared to 2014, the use of cloud computing increased particularly in large enterprises (+21 percentage points).

Figure 25 gives an overview of cloud computing enterprises per country.

[105] https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20200127-1?inheritRedirect=true&redirect=%2Feurostat%2Fweb%2Fdigital-economy-and-society%2Fpublications

[106] https://ec.europa.eu/eurostat/statistics-explained/index.php/Cloud_computing_-_statistics_on_the_use_by_enterprises#Use_of_cloud_computing:_highlights

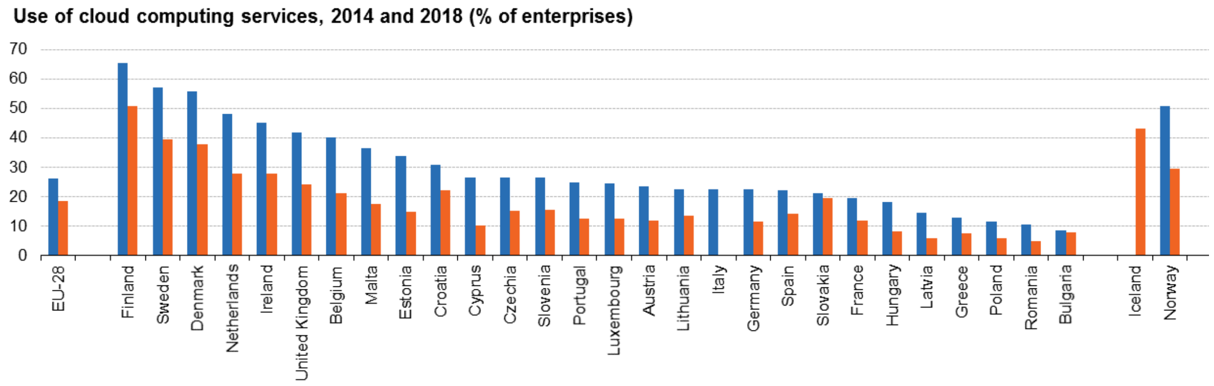


Figure 28: Use of cloud computing 2014 [orange] and 2018 [blue] (source: Eurostat[107], Dec. 2018)

Table 35. E-commerce in the EU27, 2019 (source: Eurostat isoc_ec_eseln2)

Percentage of enterprises	Max	EU27	Min
having received orders via computer mediated networks	39	**20**	11
selling online (at least 1% of turnover)	36	**17**	7
having received orders via a website or apps (web sales)	32	**16**	10
which sold via a website or apps - B2B and B2G	19	**11**	4
which sold via a website or apps - B2C	28	**13**	9
having done electronic sales to the own country	38	**19**	10
having done electronic sales to other EU countries	18	**9**	3
having done electronic sales to the rest of the world	12	**5**	2
received orders placed via a website or apps from customers in foreign	15	**7**	3
which sold via a website or apps - via their own website or apps	29	**14**	8
which sold via a website or apps - via an e-commerce marketplace	11	**6**	1

For the use of e-commerce by enterprises, Eurostat data are listed in Table 30. For other telecom uses by enterprises, see Table 31.

Table 36. Integration of internal processes, Integration Customer/Supply chain, Big Data in EU27, 2017-'18 (source: Eurostat isoc_eb_iip/isoc_eb_ics/ isoc_eb_bd)

Percentage Enterprises	%
using Radio Frequency identification (RFID) technologies (as of 2014)	**13**
using RFID technologies for after sales product identification or as part of the production and service delivery	**5**
using RFID technologies for person identification or access control (as of 2014)	**11**
using RFID technologies as part of production and service delivery process (as of 2014)	**4**
using RFID technologies for after sales product identification (as of 2014)	**2**
who have ERP software package to share information between different functional areas	**36**
using software solutions like Customer Relationship Management (CRM)	**34**
using Customer Relationship Management to analyse information about clients for marketing	**21**
using Customer Relationship Management to capture, store and make available clients information to other business functions	**33**
sending eInvoices, suitable for automated processing	**25**
sending eInvoices, not suitable for automated processing	**59**
sending paper invoices	**82**
Analysing big data from any source	**12**
Use own 3D printers	**2**
Use 3D printing services provided by other enterprises	**2**
Use industrial robots	**5**
Use service robots	**2**

[107] https://ec.europa.eu/eurostat/statistics-explained/index.php/Cloud_computing_-_statistics_on_the_use_by_enterprises#Use_of_cloud_computing:_highlights

eHealth

Information on e-Health, i.e. funding, use of social media, telehealth, national policies, etc. can be found on the WHO's[108] and the European Commission's webpages.The European Commission defines digital health and care as tools and services that use information and communication technologies (ICTs) to improve prevention, diagnosis, treatment, monitoring and management of health and lifestyle.[109] The Commission's Communication on the Transformation of Digital Health and Care[110] of April 2018 has 3 pillars:

1. Secure (patient) data access and (health care providers) sharing (across national borders);
2. Connecting and sharing health data for research, faster diagnosis and improved health, amongst others improve the development and surveillance of medical products;
3. Strengthening citizen empowerment and individual care through digital services.

Concrete data products are patient summaries, e-prescriptions and e-dispensations and electronic health records (EHR).

eGovernment

The EU's eGovernment action plan 2016-2020[111] has 20 actions as well as three pillars:

- Digitise & Enable, modernising public administration with efficient and effective services;
- Connect, i.e. deliver public services across borders;
- Engage, digital interactions to get involved in designing/delivering new services.

Concrete data products are official identity documents and permits as well as electronic voting.

For more information on EU policy see the Single Digital Market website [112] and section 9 of this report.

3.2 Market

Subscribers and global bandwidth

For the European region (EU27 inhabitants make up 81 %) ITU gives the following subscription and bandwidth data[113] [114]:

[108] http://www.euro.who.int/en/health-topics/Health-systems/e-health/data-and-statistics
[109] https://ec.europa.eu/health/ehealth/overview_en
[110] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2018:233:FIN
[111] See https://ec.europa.eu/digital-single-market/en/node/81744
[112] https://ec.europa.eu/digital-single-market/en/sitemap
[113] https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2019.pdf
[114] ITU, Measuring the Information Society Report 2018, Volumes 1 and 2, 2019.

- 33.6 fixed telephone and 31.9 fixed broadband subscriptions per 100 inhabitants. This is the ihghest in all ITU regions of the world (the Americas with 22.5% and 22% respectively come in second);
- 118.4 mobile cell phone subscriptions and 97.4 mobile broadband subscriptions per 100 inhabitants. This is the second highest behind CIS in mobile cell phones (140.1) and second behind the Americas in mobile broadband (104.4);
- The average bandwidth usage in Europe is 211 kbps which is probably comparable to that of North America. The Arab states (112 kps) have the third highest bandwidth usage. Global average bandwidth is 118 kbps. Inside the EU27, the Benelux, Baltics, Malta and Romania were the Member States with the highest internet bandwidth usage in 2019 (see map below).

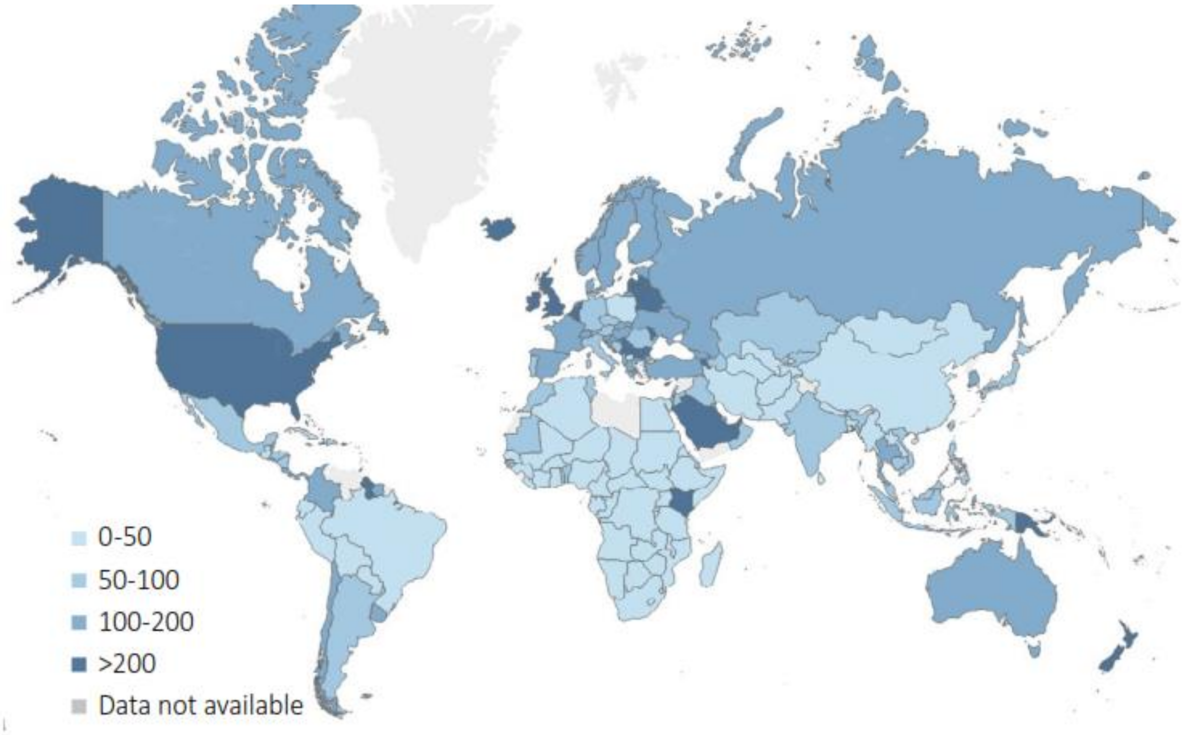


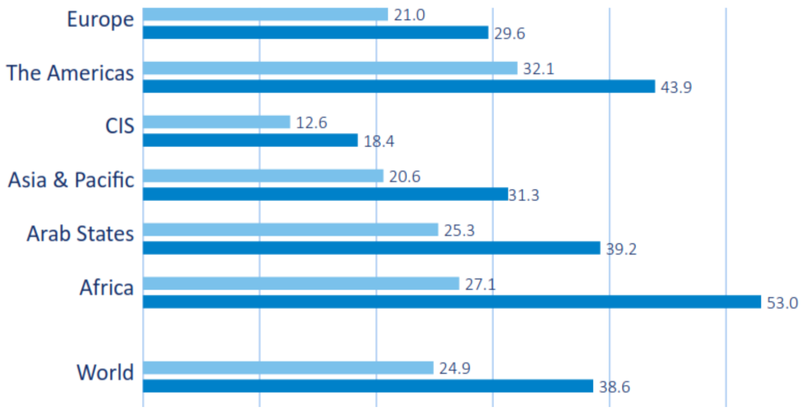
Figure 29: International bandwidth usage per Internet user (kbit/s), 2019 (source ITU Facts & Figures 2019, figures are estimates)

In 2018 the internet traffic per capita in western Europe was 44 GB per month. For the EU27 this will be 6% more than western Europe and at 446 million inhabitants this results in 250 EB annually. By 2022, this figure is forecast to go up to 117 GB which would mean 665 EB in 2022.[115] Mobile data currently represents 6 % of European internet traffic, and thisratio is forecast to reach 10 % by 2022.

Prices, expenditure and revenue

In terms of prices for mobile broadband, Europe is at the same level as Asia and (probably because combined with Latin-America) North America. The lowest prices are found in the CIS countries and the highest prices in Africa. Assuming that most of EU27 will have a high usage bundle, the total subscriptions costs for mobile broadband will be in the order of € 120 bn in the year 2019 for the 450 million EU27 citizens.

[115] https://data.consilium.europa.eu/doc/document/ST-10211-2019-ADD-1/en/pdf



Light Blue bars= Low Usage bundle; **Dark Blue bars**= High Usage bundle

Note: Simple averages, based on the economies for which data on mobile-broadband prices were available. High usage refers to a bundle including 140 minutes of voice, 70 SMS, and 1.5 GB of data. Low usage refers to a bundle including 70 minutes of voice, 20 SMS, and 500 MB of data.

Figure 30: Bundled mobile broadband prices, PPP$[116], 2019 (source ITU Facts & Figures 2019, figures are estimates, for more details see also ICT Price Basket Methodology[117])

In 2018, households in the EU28 spent over €200 bn (equivalent to 1.3% of EU GDP) on 'communications' (telecom and postal services). In the EU27 the total expenditure was about €180bn. This is roughly €95/household and represents 2.3% of households' total consumption expenditure. In BG, EL, RO it was more than 4%; in AT, DK, LU it was less than 2%. Of all the main items of household expenditure, communications was the item that saw the most significant decrease in spending over the last decade in the EU. It fell from 2.8% of total household expenditure in 2008 to 2.3% in 2018 (or -0.5 percentage points (pp)).[118] Note that EC DG CONNECT monitors mobile broadband prices.[119]

The table below gives an estimate of spending on ICT in 2017 by market research company IDC. Considering that the EU27 is about 80% of 'Europe' and €/$=0.9, the $268bn European telecom spending translates into about €193bn for the EU27.

Table 37. Spending on ICT in 2017 (source: IDC[120])

Region $M	Hardware	Software	Services	Telecom	Total
Asia	$415,144	$69,342	$167,325	$465,940	$1,117,752
USA	$236,415	$249,415	$438,649	$333,023	$1,257,502
Europe	$198,538	$121,771	$273,819	$268,521	$862,650
ROW	$146,278	$37,087	$91,640	$344,819	$619,824
TOTAL	$996,376	$477,615	$971,434	$1,412,303	$3,857,728

2017 Spending %	3D Printing	AV/VR	AI	IoT	Robotics
Asia	19%	30%	7%	50%	64%
USA	36%	40%	79%	25%	16%
Europe	36%	15%	11%	20%	14%
Rest of the Worls	9%	15%	4%	4%	6%
TOTAL	100%	100%	100%	100%	100%

According to ITU the total telecoms services revenues have stagnated in Europe (EU27 is 80%) since 2015. Mobile and fixed voice revenues have fallen by 16 % since 2014. An increase in mobile data and internet services was accompanied by a decline in voice services (fixed and mobile). Overall, the revenue in 2018 was practically the same as in

[116] Purchase Price Parity in $, i.e. taking into account relative purchase power.
[117] https://www.itu.int/en/ITU-D/Statistics/Pages/definitions/pricemethodology.aspx
[118] https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20191203-1
[119] https://ec.europa.eu/digital-single-market/en/news/mobile-broadband-prices-europe-2019
[120] https://www.idc.com/promo/global-ict-spending/regional-markets

2015, i.e. € 213bn. For the EU27 this means about €170bn, which is in the same ballpark as household spending.

EU Bandwidth

The EU target is to achieve 100% coverage of broadband and 50% coverage of Next Generation Access NGA in 2020. NGA means access with a bandwidth >30 Mbps, i.e. VDSL, Fibre-To-The-Premises FTTP, DOCSIS 3.0. The table below indicates that the targets will mostly be met and several Member States are underway to also meet the 2025 Connectivity targets[121]: A 100% coverage for all households >100 Mbps (upgradable to 1 Gbps) plus all schools, transport hubs and main providers of public services as well as digitally intensive enterprises should have access to 1 Gbps up-/download broadband.

Table 38. Broadband Coverage in Europe in 2018 in 000 households (Source: Broadband Coverage in Europe 2018, a study by IHS Markit and Point Topic for the European Commission[122])

Coun-try	House holds	DSL***	VDSL	FTTP	WiMAX	Cable***	DOCSIS 3.0	HSPA	LTE	Satellite	*DTT (2010)*
AT	3 936	3 802	3 362	513	477	2 118	2 084	3 919	3 914	3 936	*276*
BE	4 914	4 907	4 641	69	729	4 715	4 715	4 913	4 914	4 914	*147*
BG	2 930	2 493	43	1 113		1 952	1 886	2 930	2 893	2 930	*527*
HR	1 500	1 496	1 153	351	3	484	484	1 490	1 463	1 500	*870*
CY	305	305	244	2		161	161	304	297	305	*235*
CZ	4 408	4 094	3 510	1 693	3 303	1 834	1 827	4 278	4 382	4 408	*1 807*
DK	2 738	2 608	1 648	1 762	144	1 874	1 874	2 738	2 738	2 738	*493*
EE	610	442	336	330	10	431	400	598	605	460	*134.2*
FI	2 695	2 331	1 307	1 012		918	918	2 694	2 694	2 695	*835*
FR	30 333	30 330	5 953	11 461		8 684	8 684	30 277	30 132	30 333	*13 650*
DE	40 744	39 685	31 332	3 463	4 197	26 117	26 035	37 199	39 725	40 744	*4 889*
EL	4 307	4 151	2 829	17	7			4 270	4 229	4 307	*3 101*
HU	4 440	3 828	1 940	1 595		3 389	3 175	4 377	4 405	4 440	*533*
IS	133	130	126	90				132	131		
IE	1 759	1 639	1 601	227	492	857	857	1 726	1 686	1 759	*246*
IT	25 293	25 214	22 239	6 033	11 849			25 164	25 007	25 293	*18 970*
LT	1 238	866	28	750	13	426	225	1 234	1 228	1 238	*520*
LV	750	305	145	659	310	263	220	750	740	750	*247.5*
LU	240	214	188	152		202	202	238	237	240	*33.6*
MT	175	175	126	55		175	175	175	175	175	*75.25*
NL	7 663	7 662	5 989	2 688		7 289	7 289	7 632	7 632	7 663	*920*
NO	2 409	2 259	1 440	1 414		1 181	1 181	2 405	2 405	2 343	
PL	13 669	8 765	4 839	3 980	320	5 618	5 474	13 669	13 662	13 669	*3 554*
PT	4 063	3 495	-	2 851		2 289	2 289	4 032	4 031	4 063	*853*
RO	7 481	4 322	642	4 694	4 987	3 250	2 819	7 481	7 203	7 481	*1 047*
SK	1 941	989	767	1 352	968	597	597	1 875	1 890	1 941	*408*
SI	869	835	480	531	22	544	520	860	865	869	*208.56*
ES	17 971	16 138	2 115	13 908	10 753	8 792	8 792	17 953	17 887	17 971	*12 759*
SE	4 786	4 341	1 065	3 458		1 795	1 721	4 784	4 786	4 786	*622*
CH	3 740	3 720	3 367	1 135		3 154	3 154	3 733	3 736	3 740	
UK	*31 178*	*30 209*	*27 961*	*1 189*		*15 607*	*15 607*	*31 153*	*31 138*	*31 178*	*11 536*
Total	*229 218*	*211 750*	*131 416*	*68 547*	*38 584*	*104 716*	*103*	*224 983*	*226 830*	*228 869*	*79 498*
EU 28	***222936***	***205 641***	***126 483***	***65 908***	***38 584***	***100 381***	***99 030***	***218 713***	***220 558***	***222 786***	***79 498***
EU 27	**191758**	**175 432**	**98 522**	**64 719**	**38 584**	**84 774**	**83 423**	**187 560**	**189 420**	**191 608**	**67 962**

Notes:
† Broadband coverage data at the end of June 2017;
** Fixed broadband coverage includes DSL, VDSL, FTTP, DOCSIS 1.0/2.0, DOCSIS 3.0, WiMax*
*** Next Generation Access NGA (>30Mbps) includes VDSL, Fibre-To-The-Premises FTTP, DOCSIS 3.0*

[121] https://ec.europa.eu/digital-single-market/en/policies/improving-connectivity-and-access
[122] https://ec.europa.eu/digital-single-market/en/news/study-broadband-coverage-europe-2018

*** *DSL figures include VDSL coverage; Cable figures include DCOSIS 3.0 coverage*

Note that the DTT column stems come from a 2011 source and are taken from the 2016 impact assessment[123]on the 2017 Commission Decision (EU) 2017/2019 on the use of the 470-790 MHz frequency band in the Union[124].. This is the latest source that could be found giving DTT market share per Member State. The Commission Decision relates to a bandwidth by DTT but especially in countries with low DTT-penetration (France, Germany, Belgium) there were plans to vacate the bandwidth completely and use it for mobile broadband. This would create problems with neighbouring countries which use the band for DTT. The Commission Decision demands that the DTT bandwidth is limited to max. 700 MHz, i.e. the part above 700 MHz is used for mobile broadband. For the sub-700 MHz range each Member State decides for itself but in agreement with its neighbours.

In any case, the market penetration of DTT is decreasing. The most recent figures for the whole of Europe indicate that currently 48 million EU27 households use DTT as their primary TV (see Figure 23) as opposed to the 67 million households in 2010 mentioned in the table.

The use of satellites for broadband is increasing, both as a backhaul for the core network and as a (private) broadband internet service in its own right for government and large enterprises. Companies like OneWeb, Space X and Amazon are investing heavily in LEO satellite programs. SES is already on the market with its low latency, high bandwidth MEO satellites. ViaSat will launch its first Tbps ViaSat-3 geostationary satellite in 2021. As a support-act, High-Altitude Pseudo Satellites HAPS, i.e. *Unmanned Aerial Vehicles UAVs*, might be roaming above a height of 17 km as a relay to satellites or as high resolution surveillance vehicles.

[123] European Commission, SWD(2016) 20 final, Brussels 2.2.2016

[124] Decision (EU) 2017/899 of the European Parliament and of the Council of 17 May 2017 on the use of the 470-790 MHz frequency band in the Union, OJ L 138, 25.5.2017, p. 131–137

3.3 Performance and Energy Use

3.3.1 Metric

The performance metric for telecommunication technology is bandwidth and for time-critical operations the latency, i.e. the time elapsed between sending and receiving and/or a round-trip, expressed in milliseconds. The relevant bandwidth at end-user level is *Megabits per second Mbps* or *Gigabits per second Gbps*. Aggregated units can be *GB (1 GigaByte=8 Gigabit)* per month or per year at end-user level. At the level of energy policy, globally or regionally (EU27 in our case), this can be aggregated to *EB (Exabytes 10^{18} Bytes)* or *ZB (Zettabytes=10^{21}Bytes)* per year (1 year≈31.54 million seconds).

The bandwidth is typically used for the peak capacity in data communication. However, the energy consumption should relate to the actual use and the actual Gbytes delivered. This is usually a small fraction.

The time-critical operations for which low latency is relevant are Human reaction times. These are in the order of 100 milliseconds and applications that involve or replace human actions are typically one order of magnitude faster, like Augmented Reality (AR), Remote Motion Control, Autonomous Driving and more.[125]

The energy consumption is typically measured in *Wh* of *kWh* electricity at end-user level and in *TWh* electricity (*1 Terawatt hour=10^{12}Wh=10^{9}kWh*) per year at regional or global level. Power consumption at end-user level can be expressed in *Watts W*. Note *1 W= 1 J/s (Joule per second)*. Energy use can be assessed at peak performance or as an average of a typical duty cycle.

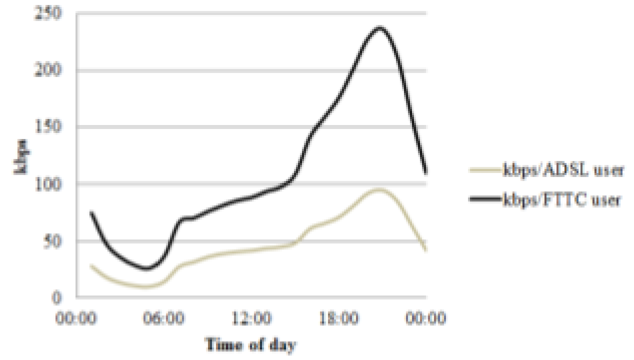


Figure 31: Average daily internet traffic pattern UK residential user (Source (Krug, Shackleton, & Saffre, 2014)

The energy efficiency metric is by definition energy consumption per unit of performance. so in principle kWh/GB. Many authors use the reciprocal GB/kWh, i.e. how many GB one can get out of a kWh. At global or regional level the measure would be TWh/EB or EB/TWh. The energy efficiency can relate to peak performance and an average for a typical duty cycle. A typical daily duty cycle is given below.

[125] Design Aspects of Low Latency Services with Time-Sensitive Networking. Available from: https://www.researchgate.net/publication/323696804_Design_Aspects_of_Low_Latency_Services_with_Time-Sensitive_Networking [accessed Mar 29 2020].Energy Efficiency Improvement Options

3.3.2 Sources

Until 2015 there were several studies on the energy consumption of telecommunication. The European Commission,in 2014, commissioned a study from the Öko Institut and TU Berlin.[126]. The German energy agency dena performed a meta study[127] on the basis of 10 available studies, amongst others from Fraunhofer IZM[128], ADEME & Cap Gemini[129], Imperial College[130], EMPA[131] , Borderstep and others.
In the work of Aslan 2017[132] over a dozen studies were examined and a timeline developed. Differences in system boundary, assumptions used, and the year to which the data apply significantly affect such estimates. Methodology used is not a major source of error as has been suggested in the past. He provided a new estimate of 0.06 kWh/GB for 2015. Figure 32 gives an overview.

A very extensive study by IEA 2017[133] of the energy consumption of networks was carried out by Eric Masanet. The study works with a moderate and high efficiency scenario. The latter gives a projection from 190 to 160 TWh/year (2015 to 2021). In the moderate efficiency scenario, which today (2020) seems unlikely, there is an increase.

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[126] Öko Institut and TU Berlin, Study on the practical application of the new framework methodology for measuring the environmental impact of ICT – cost/benefit analysis, for the EC DG Connect (Digital Agenda), 2014.

[127] dena-METASTUDIE, Analyse der mit erhöhtem IT-Einsatz verbundenen Energieverbräuche infolge der zunehmenden Digitalisierung, Berlin, November 2017

[128] Fraunhofer IZM, entwicklung-des-ikt-bedingten-strombedarfs-in-Deutschland, 18.11.2015

[129] ADEME u. Capgemini Consulting (2015): Assessment of electricity consumption in the ICT layer in Smart Grids.

[130] Imperial College (2015): The impact of information technology on energy consumption and carbon emissions.

[131] EMPA (2014): The Energy Intensity of the Internet: Home and Access Networks

[132] Aslan, J. et al. (2017), Electricity Intensity of Internet Data Transmission, Untangling the Estimates, Journal of Industrial Ecology, Vol. 22, No. 4, p. 785.

[133] IEA, Digitalization & Energy, OECD/IEA, 2017 (Website: www.iea.org)

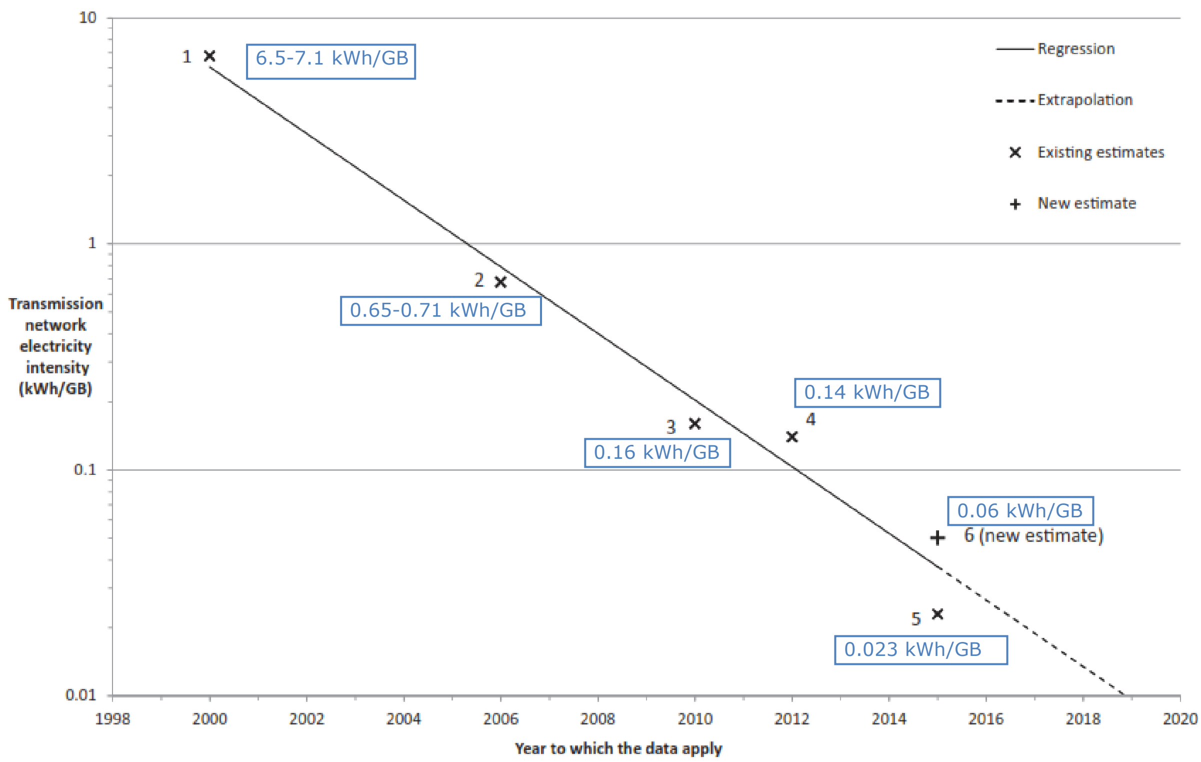

Figure 32: Timeline 2000-2015 of electricity intensity of transmission networks (source: Aslan 2017)

Graph to show estimates for electricity intensity for the transmission network system boundary only, identified from the criteria derived in this study. The y-axis shows the value of electricity intensity (kWh/GB) for each estimate; note the Log10 scale. The x-axis shows the year in which the data for each estimate is based. Regression uses average estimates for years in which a range is given and uses all data points on the graph from 2000 to 2015 (including our newly derived estimate for 2015). Data points: (1) median estimate of 6.5 to 7.1 kWh/GB derived from Taylor and Koomey (2008) estimates for the year 2000; (2) median estimate of 0.65 to 0.71 kWh/GB derived from Taylor and Koomey (2008) estimates for the year 2006; (3) estimate of 0.16 kWh/GB for 2010 derived from Malmodin and colleagues (2014); (4) estimate of 0.14 kWh/GB for 2012 derived from Krug and colleagues (2014); (5) Estimate of 0.023 kWh/GB from Malmodin and Lund´en (2016); and (6) estimate of 0.06 kWh/GB for 2015 is a new estimate proposed in this study, based on Krug and colleagues (2014) with updated data for 2015 from Krug (2016). kWh/GB=kilowatt-hours per gigabyte.

Pikhala 2018 gives a thorough discussion of 5G access network, illustrated with Finnish data.[134] It explains why, despite –or because of—the vast increase in the number of base stations 5G will be 40% to 80% more efficient than 4G. The picture below shows the development of efficiency of mobile transmitted data as could be established from data of main operators in Finland. It explains how the electricity consumption between 2010 and 2017 could rise by only 12% (519 to 583 GWh/a), whereas the Finnish mobile data transmitted rose by a factor of 45 and went from less than 0.1 EB to 4.5 EB.[135]

[134] Pihkola, H. et al., Evaluating the Energy Consumption of Mobile Data Transfer—From Technology Development to Consumer Behaviour and Life Cycle Thinking, Sustainability 2018, 10, 2494; doi:10.3390/su10072494

[135] Also see Pål Frenger and Richard Tano, More Capacity and Less Power: How 5G NR can Reduce Network Energy Consumption, Ericsson Research 2019. Download: https://www.ericsson.com/en/reports-and-papers/research-papers/how-5g-nr-can-reduce-network-energy-consumption

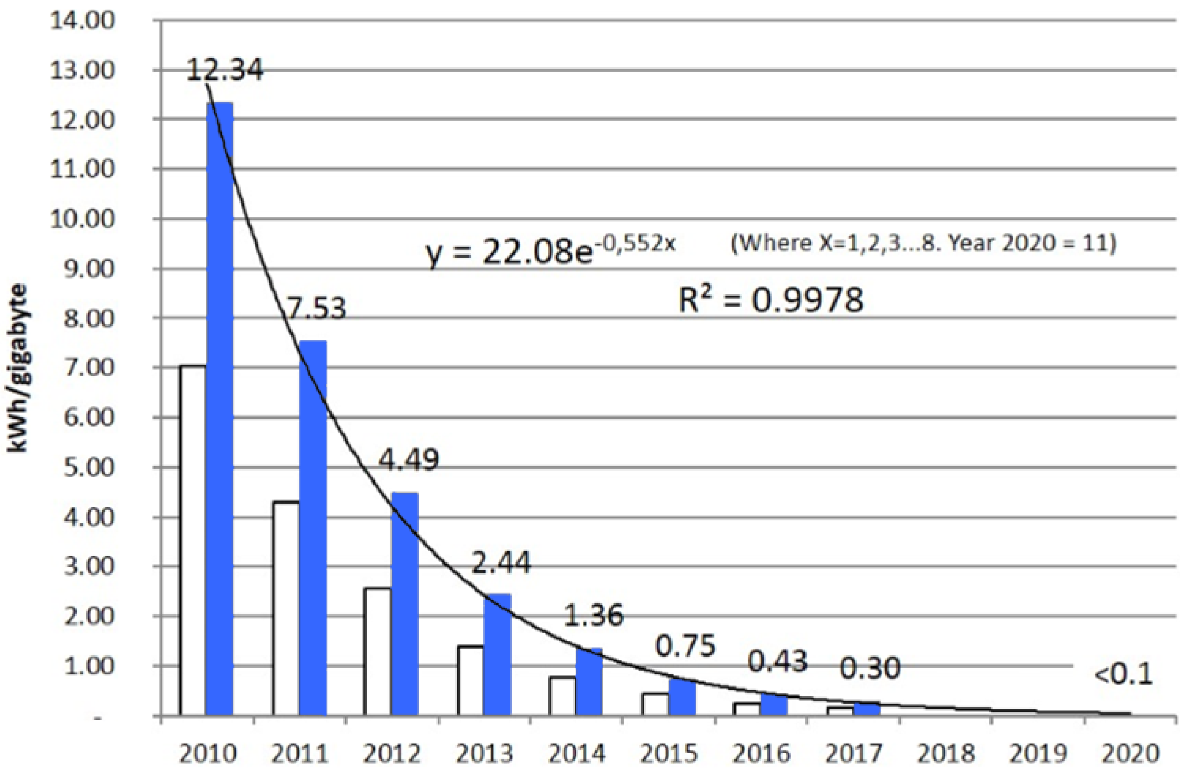

Figure 33: Development of energy efficiency of transmitted mobile data (kWh/gigabyte) in Finland during 2010–2017. (source: Pikhala 2018)

Grey bars represent estimated consumption for production networks and white bars for base stations only. Exponential trends (y = y(x)) until 2020 were estimated by means of
least squares fit using the data in the grey histogram. X in these equations refers to numbers 1 to 8; and 11 corresponding to years from 2010 through to 2017; and 2020.

The most recent publication on networks (and data centres) is the IEA-4E publication from 2019.[136] This publication projects an electricity use of 140 TWh for core and access networks worldwide in 2020 and 2025. This is 20 TWh/year less than the high efficiency scenario of the afore mentioned 2017 IEA study.
The EU27 uses approximately 20% of worldwide energy, i.e. 28 TWh/year according to the 2019 IEA-4E study and 32 TWh/year according to projections in the high-efficiency scenario of the 2017 IEA study.

Figure 34 shows that the WAN energy consumption decreases over the period 2014 to 2020 from over 210 TWh to 140 TWh. It then continues to decrease to 120 TWh until 2022 and then increases slowly to 140 TWh in 2025. It then stays at that level until 2030.
The EU27 are responsible for approximately 20% of global energy use. This means 28 TWh/year in 2020 and 2025.

A recent IEA report[137] stresses that projections for WAN energy use have a considerable degree uncertainty, i.e. depend on the mode and speed of 5G introduction. The IEA references an STL Partners study on 5G for Huawei[138], which sketches 4 different global

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[136] IEA-4E, Intelligent Efficiency For Data Centres & Wide Area Networks, Report Prepared for IEA-4E EDNA, May 2019.

[137] https://www.iea.org/reports/data-centres-and-data-transmission-networks#recommended-actions

[138] https://carrier.huawei.com/~/media/CNBGV2/download/program/Industries-5G/Curtailing-Carbon-Emissions-Can-5G-Help.pdf

energy and carbon emission scenarios for mobile networks: no, slow, medium-speed and fast roll-out of 5G in the period 2020-2030. The medium-speed scenario is presented as the default and is similar to what is projected in Figure 34, i.e. no significant global carbon emission increase till 2025 and even a slight saving in the 2025-2030 period despite a large increase in data traffic. The fast 5G roll-out saves 30% more and the slow roll-out scenarios saves 15% less than the medium speed 5G roll-out. The no 5G roll-out has double the carbon emissions of the medium-speed roll-out scenario.

The IEA mentions that while a 5G antenna currently consumes around three times more electricity[139] than a 4G antenna, power-saving features such as sleep mode could narrow the gap to 25% by 2022. Network infrastructure providers and operators are projecting that 5G could be up to 10 to 20 times more energy-efficient than 4G by 2025-30.[140]

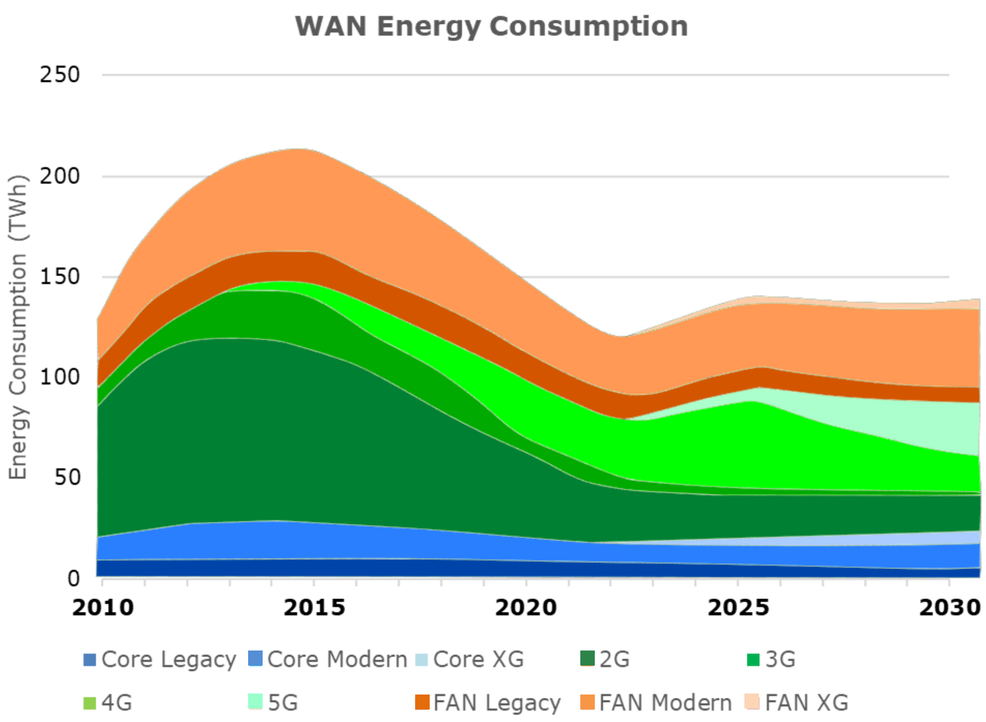

Figure 34: Global electricity consumption access and core network 2010-2030 (source: IEA-4E 2019 [141])

Figure 35 shows how the energy efficiency (lines and right Y-axis in TWh/EB) of the core, RAN and FAN networks increase more than the data traffic (surfaces and left Y-axis in EB) over the period 2013-2022. Amongst others it is expected that next generation FAN (optical fibre) and RAN networks (5G) will have similar efficiencies.

[139] https://hellofuture.orange.com/en/5g-energy-efficiency-by-design/
[140] https://www.huawei.com/ke/news/2019/7/opening-remarks-chairman-lianghua-2018-csr
[141] Image VHK 2020

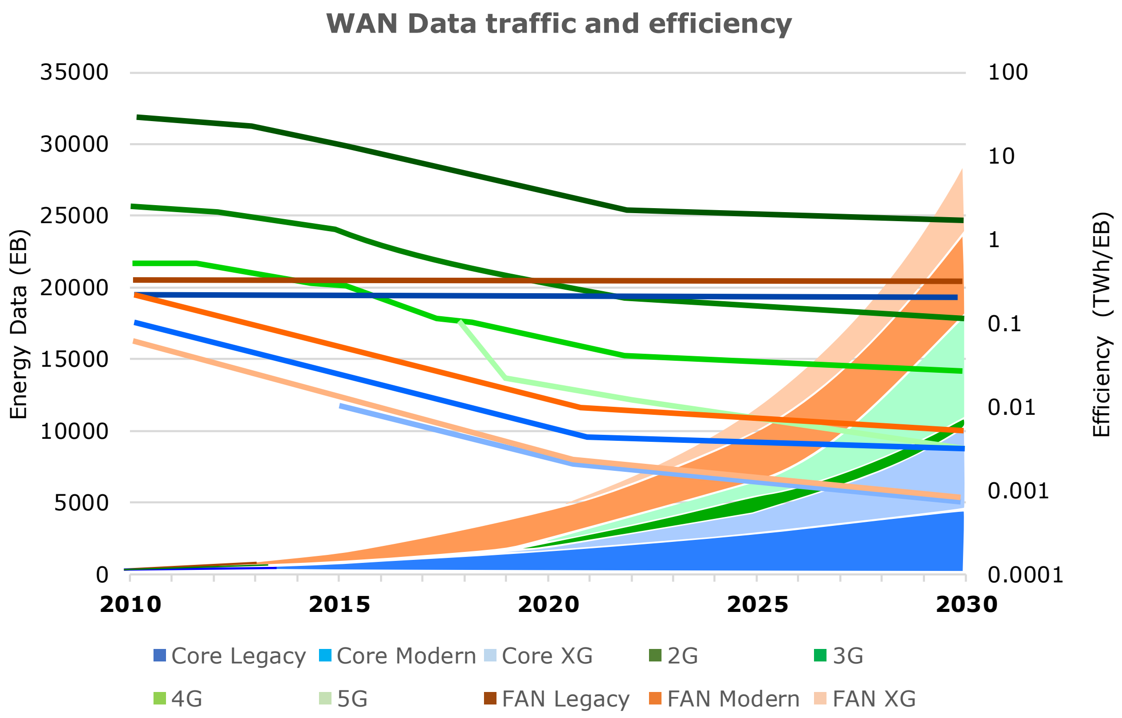

Figure 35: Telecommunication network data traffic and efficiency 2010-2030 (source: IEA 4E 2019)

Left y-axes and the stacked columns depict (real and projected) data traffic in EB (10^{18} Bytes). Right y-axis and the solid/dashed curves depict the (reverse) energy efficiency in TWh (10^{12} Wh) per EB. Note that 'XG' stands for Next Generation. WAN is Wide Area Network which is intended as another name for the whole telecom network.

Figure 36, Figure 37 and Figure 38 give details for the three main parts of the telecom network. The energy consumed is split by the diurnal pattern or high utilisation during the day (green) and low utilisation at night (orange). As expected, this shows that most of the energy (approximately 70%) is used during the high utilisation period.
In addition, each utilisation level is then broken down into 'peak' and 'additional', distinguished by the lighter shading. The peak energy represents the amount of energy that would be consumed during the processing of the data if the equipment were theoretically able to operate at the calculated peak efficiency level. The additional energy being used is therefore due to the DC/WAN not perfectly scaling power proportionately with utilisation and indicates potential energy savings available from intelligent efficiency techniques. For legacy data centres, the additional energy is 80% of the total energy consumed and significantly higher than the theoretical peak energy. As a proportion of total energy, this is reduced greatly by cloud and similar modern DCs to 40%, although it is still far from being eliminated.
In addition, because the total energy consumed by cloud is higher than traditional data centres, the additional energy in absolute terms is still larger than traditional data centres and should remain a key area of focus. .

The additional FAN energy is very high due to the very low average network utilisation level which is only 5%. While some modern FAN equipment has different power levels for different utilisation levels, the average is too low for this to have a significant effect. The next generation of FAN equipment is expected to have better power management and thus to have low total energy consumption in the near term. Given the high total energy consumption and additional energy consumption, the modern FAN should be a focus for energy savings.

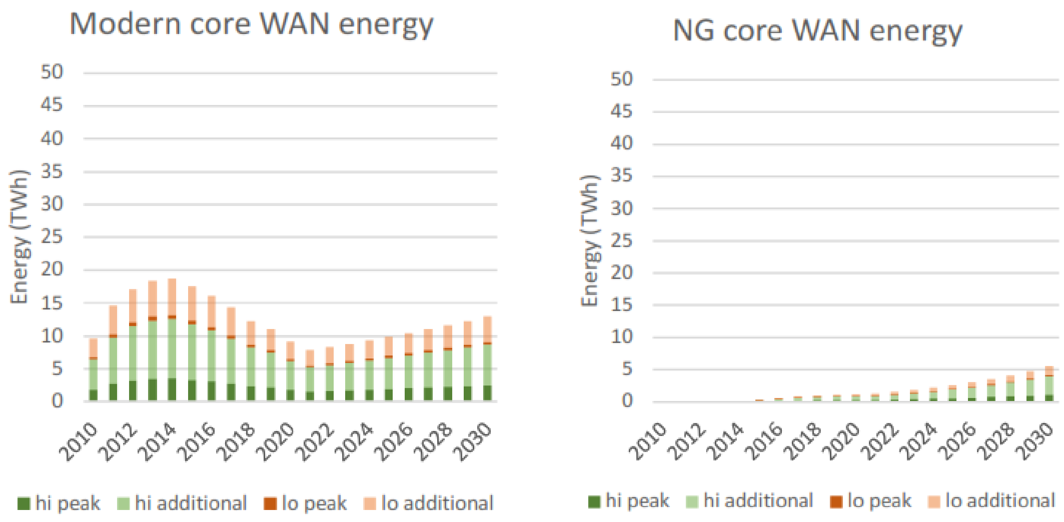

Figure 36: Core network energy use 2010-2030, with modern(current) and new generation technology (source: IEA 4E 2019)

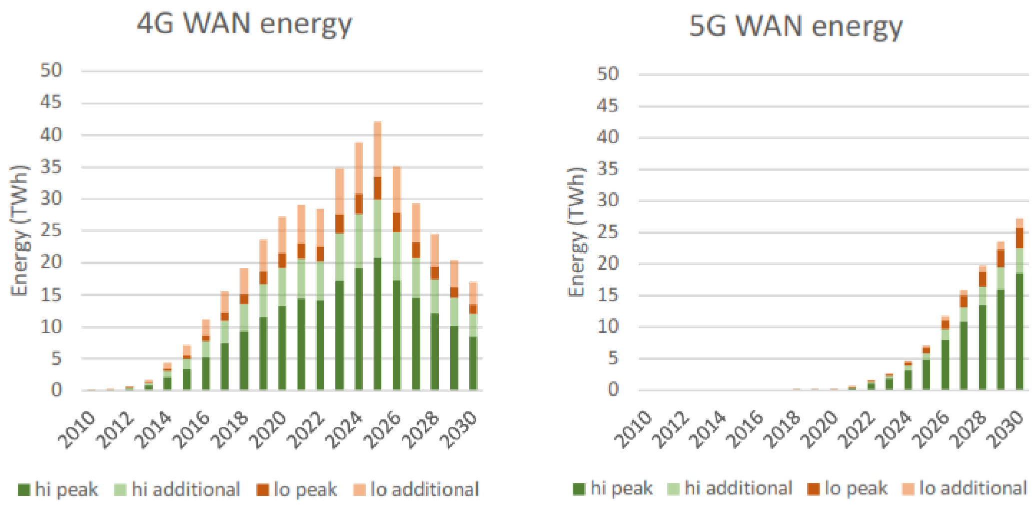

Figure 37: Mobile access network energy use 2010-2030, with modern(4G) and new generation (5G) technology (source: IEA 4E 2019)

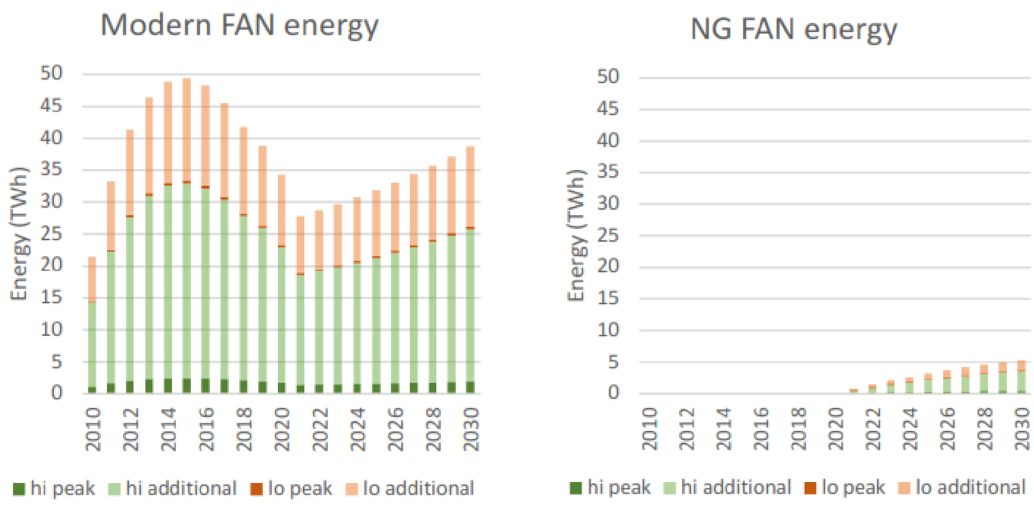

Figure 38: Fixed access network energy use 2010-2030, with modern and new generation technology (source: IEA 4E 2019)

The most recent confirmation of the high energy efficiency and thus modest carbon emissions is given in the IEA's new video streaming emissions calculator, released in March 2020.[142]

3.4 Energy efficiency improvement

Based on the 2019 IEA 4E study recommendations (first four of the list) and two last suggestions from the study team, the following suggestions for improving telecommunication are proposed:

- **Phase out/migrate legacy technology**: A policy to assess legacy operations (e.g. 2G, 3G) then switch off and migrate to modern or next generation solutions whenever environmentally and economically feasible;
- **Increase equipment utilisation rate:** Optimising virtualisation (e.g. smart buffering at end-user, in cache servers and POPs; the so-called 'edge computing'), switching off unused equipment, use networks to the most of their capacity during the shortest time;
- **Use AI:** The core network consumes very little energy (13% of total telecom). Nonetheless, savings of up to 75% can potentially be made here. To maximise this, SDN management and orchestration will need to have explicit energy efficiency rules which would probably be achieved most effectively with Artificial Intelligence AI, Machine Learning ML, etc.. [143]
- **Reducing data traffic:** Traffic can be further reduced by good design of software and service. Efficiency has already doubled every 2 years, mainly because of better communication protocols and (video) compression techniques. An example of the

[142] https://www.iea.org/commentaries/the-carbon-footprint-of-streaming-video-fact-checking-the-headlines?utm_campaign=IEA%20newsletters&utm_source=SendGrid&utm_medium=Email#calculator

[143] IEA mentions that "However, the biggest energy savings will have an impact on the service level and this must be taken into consideration to find the optimum balance."

latter is the recent switch from Advanced Video Coding (AVC, H.264) to High Efficiency Video Coding (HEVC, H.265) and this has cut video data traffic (85% of the total traffic) in half! At a traffic management level, software developers, network architects, hardware developers and service providers can still develop and integrate routing schemes to minimize the hops and reroutes of targeted services.

- **Discourage 8K and 4K VR:** At this point time,, the difference between HD and 4K video resolution is only visible to humans (with 20/20 vision) when looking from a distance of 1 metre or less to a 50" or larger display. A 4K feature movie is 100 GB and requires a 20-25 Mbps (VHEC compressed) bandwidth streaming. An 8K feature movie has a resolution that is only detectably better than 4K in a cinema screen or when displays try to outperform video projectors in business and education, but it takes up 400 GB and 80-100 Mbps. In other words, the whole progress of the 2025 targets in the EU Digital Agenda, i.e. having 100 Mbps connectivity, will eventually be spent on having 8K instead of 4K movies. Virtual reality in 4K is still experimental but follows the same reasoning.
- **Optimise power management:** Reduce idle power by variable-control packet switching. This means making a split between the energy-efficient control layer and the fast user/data transport layer (C/U decoupling).[144] Increase the time in energy-saving sleep/'off'-mode by targeting a smaller group of users (e.g. smaller distance range of base stations). These are the improvements that 5G is expected to bring relative to 4G in addition to , bringing about energy savings of 40-80% (depending on user density)[145].

- **Increase hardware efficiency[146]:**
  - Continue the replacement of copper by optical fibre (**FTTP** Fibre To The Premises) in the access network, because in comparison to copper cable, optical fibres lose considerably less signal strength (3% over 100m, versus copper 94% over 100m), have a higher bandwidth, are a bit faster[147], more light-weight and with a smaller diameter. The main disadvantage is that they are more expensive than copper;
  - Replace base-station lead-acid battery back-up (UPS) with **Li-ion batteries** that are more efficient, live longer, etc. [148]
  - Bring about the ultimate small improvements at the level of **rectifiers** (99% instead of 98%) and power supplies;
  - Where edge computing storage applies, use **Solid State Drives SSDs** instead of Hard Disk Drives HDDs, because they are faster and more efficient. Also use AI and ML for servers.

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[144] Yan and Fang, Reliability evaluation of 5G C/U-planedecoupled architecture for high-speed railway, EURASIP Journal on Wireless Communications and Networking 2014,2014:127 http://jwcn.eurasipjournals.com/content/2014/1/127

[145] For latest information on 5G deployment see Blackman, C., Forge, S., *5G Deployment - State of Play in Europe, USA and Asia*, Report for the European Parliament ITRE, 2019. Accessible at http://www.europarl.europa.eu/supporting-analyses

[146] Many inspired by 10 emerging trends from Huawei for in telecom energy for the next 5 years (Feb. 2020). https://sciencebusiness.net/author/communication-huawei

[147] Optical fibre oper ates at 31% below the speed of light, i.e. 200,000 km/s, but also –with the right current and voltage—can reach speeds close to that. Fastest are radio waves, i.e. travelling at the speed of light (around 300,000 km/s) but at –for satellites—considerable disctances (e.g. up to 35 000 km single trip for geostationary satellites and only when not disturbed (rain, clouds, etc.).

[148]

- **ICT power supply convergence**: ICT convergence requires diversified and optimised power supply solutions, e.g. optimal PoE (Power over Ethernet), USB-powered devices, Powerline communication, DC-DC power supply e.g. from renewable (solar) electrical power, etc..
- **Solar energy powered** mobile base stations where there is enough space for the Photo-Voltaic PV panels. LPWA Base stations in the IoT are more compact.[149] All communication satellites and (experimental) HAPS are solar powered.

- **Atmospheric satellites (HAPs).** Explore possibilities for these unmanned air vehicles that work on solar power and orbit at a >17km height. They have very low latency and very high visibility of the earth's surface. Through ESA and being the HQ of leading satellite operators like SES and others satellite telecom could/should be an area for growth. See pictures next page.

Many of these improvements will already have been taken into account in the IEA projections of 140 TWh (28 TWh for EU27) for global telecommunication in 2020 and 2025.

[149] Compare LoRaWAN protocol. Note that these compact base stations can only be used for Low Power WAN.

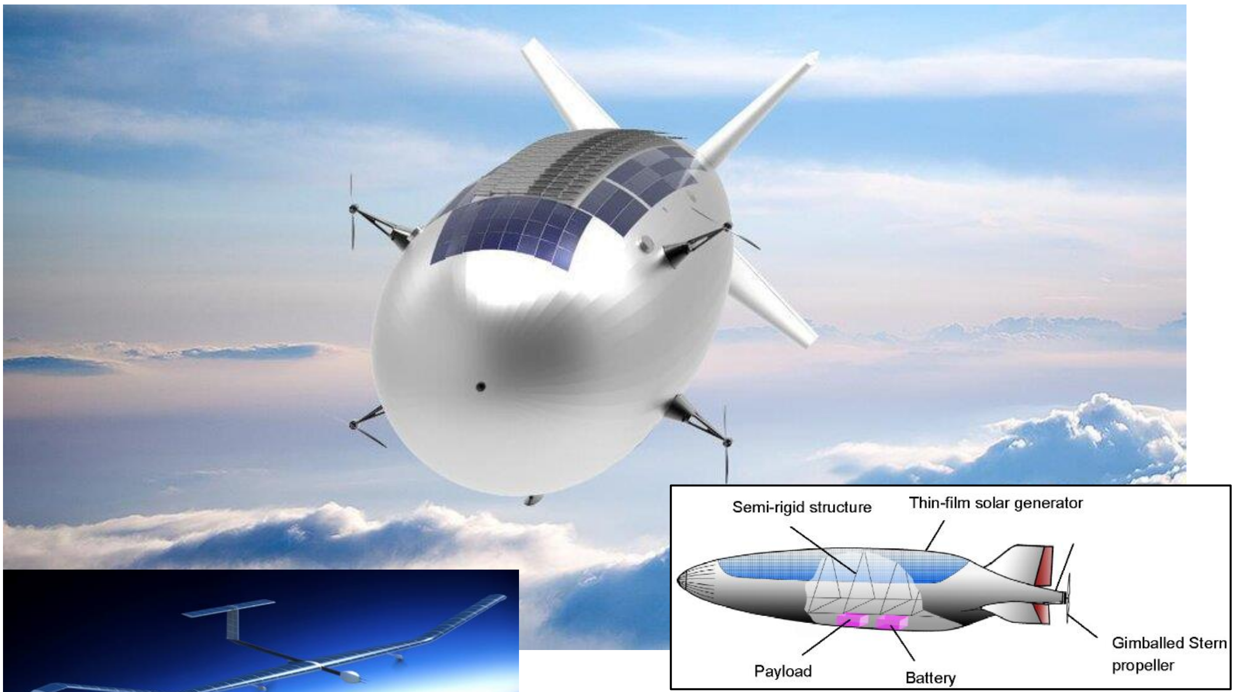
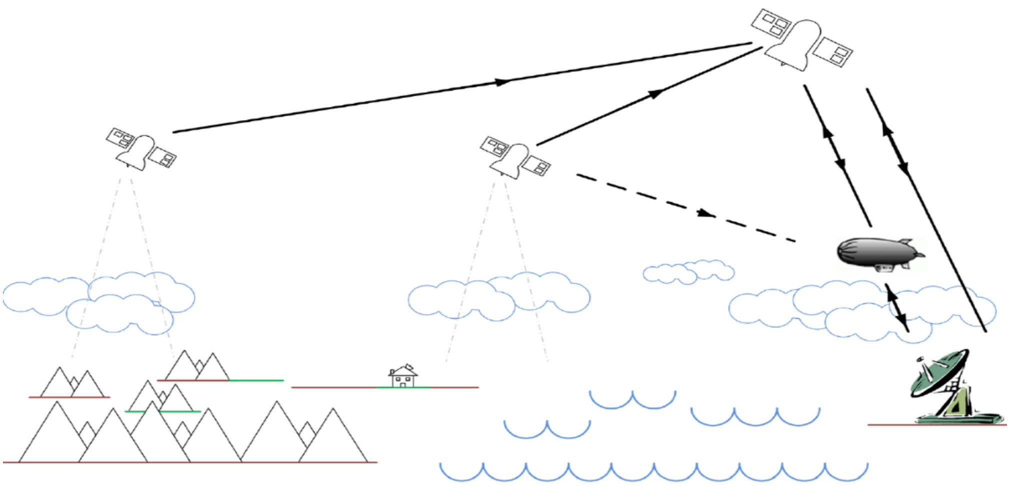


Figure 39. Aerostatic HAPS High-Altitude Pseudo-Satellite (source: European Space Agency ESA 2020[150])

Figure 40. Zephyr S. Aerodynamic HAPS by Airbus and HISPASAT (source ESA[150]).

The picture on top shows Thales Alenia aerostatic HAPS concept, designed by the HAPPIEST team and measuring 181 metres in length, weighing 16 tonnes for an operational payload of 250 kg. HAPS apps: surveillance for emergencies and marine safety as a relay between ground-station and satellite.



[150] https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Could_High-Altitude_Pseudo-Satellites_Transform_the_Space_Industry

3.5 Summary

Note that the energy consumption of 42TWh/year[151] in 2015, 28 TWh/year for 2020 and 2025 relates only to the telecom side of the internet use. To this a small electricity use, in the order of 5-10%, for satellite TV[152] and DTT has to be added. The values below are an estimate.

Table 39. **Summary telecom data and energy parameters EU-27**

Year		**2015**	**2020**	**2025**
EB data transmitted				
o/w	FAN	230	590	1280
	RAN	20	75	220
	Total	250	665	1500
TWh/EB intensity				
	FAN	0.08	0.03	0.014
	RAN	1.20	0.14	0.05
TWh electricity use data				
o/w	FAN	18.4	17.7	17.9
	RAN	24.0	10.5	11.0
	Total	42.4	28.2	28.9
TWh el sat & DTT		2.6	1.8	1.2
TWh Total		**45**	**30**	**30**

[151] 210 TWh for 2015 globally. EU27 is 20%

[152] E.g. based on the carbon footprint in the SES annual report

4 GROUP III. – ELECTRONIC DISPLAYS

4.1 Definition

In Commission Regulation (EU) 2019/2021 [153]on electronic displays the following definitions are relevant to this product group:

1) *'electronic display' means a display screen and associated electronics that, as its primary function, displays visual information from wired or wireless sources;*
2) *'television' means an electronic display designed primarily for the display and reception of audiovisual signals and which consists of an electronic display and one or more tuners/receivers;*
3) *'tuner/receiver' means an electronic circuit that detects television broadcast signal, such as terrestrial digital or satellite, but not internet unicast, and facilitates the selection of a TV channel from a group of broadcast channels;*
4) *'monitor' or 'computer monitor' or 'computer display' means an electronic display intended for one person for close viewing such as in a desk-based environment;*
5) *'digital signage display' means an electronic display that is designed primarily to be viewed by multiple people in non-desktop based and non-domestic environments. Its specifications shall include all of the following features:*
    a) *unique identifier to enable addressing a specific display screen;*
    b) *a function disabling unauthorised access to the display settings and displayed image;*
    c) *network connection (encompassing a hard-wired or wireless interface) for controlling, monitoring or receiving;*
    d) *the information to display from remote unicast or multicast but not broadcast sources;*
    e) *designed to be installed hanging, mounted or fixed to a physical structure for viewing by multiple people and*
    f) *not placed on the market with a ground stand;*
    g) *does not integrate a tuner to display broadcast signals;*

Note that video projectors and all-in-one video conference systems are excluded from the scope of the Ecodesign regulation, but they are included here in section 5. Also excluded are virtual reality (VR) devices, medical displays, displays with a surface smaller than 100 cm2 and displays integrated in other Ecodesign-regulated or certain WEEE-regulated product categories (e.g. home appliances and machinery with a display). Digital interactive whiteboards, also in section 5, are excluded from the efficiency requirements, but other requirements apply. The same goes for digital signage-, professional-, broadcasting-, security-displays as well as status displays and control displays. In as much as is possible these will be included in this section 4.

[153] COMMISSION REGULATION (EU) 2019/2021 of 1 October 2019 laying down ecodesign requirements for electronic displays pursuant to Directive 2009/125/EC of
the European Parliament and of the Council, amending Commission Regulation (EC) No 1275/2008 and repealing Commission Regulation (EC) No 642/2009

4.2 Market

Sales of electronic displays peaked around 2010 then fell in the crisis years afterwards and is now —in the year 2020— back to pre-crisis levels of almost 70 million units per year. Monitors and signage displays add another 14 million and 3 million units respectively.

Table 40 Sales electronic displays 1990-2030

Display type	1990	1995	2000	2005	2010	2015	2020	2025	2030
DP TV, standard (NoNA)	26000	28857	34286	46261	56240	420	0	0	0
DP TV, LoNA	0	0	0	467	8880	21000	13000	0	0
DP TV, HiNA ('Smart')	0	0	0	472	8880	20580	39000	60000	69000
DP TV total	26000	28857	34286	47200	74000	42000	52000	60000	69000
DP Monitor	10000	12857	16571	21800	25000	14000	14000	14000	14000
DP Signage	0	0	0	0	400	1750	4000	3000	3000
DP Electronic Displays, total	36000	41714	50857	69000	99400	57750	70000	77000	86000

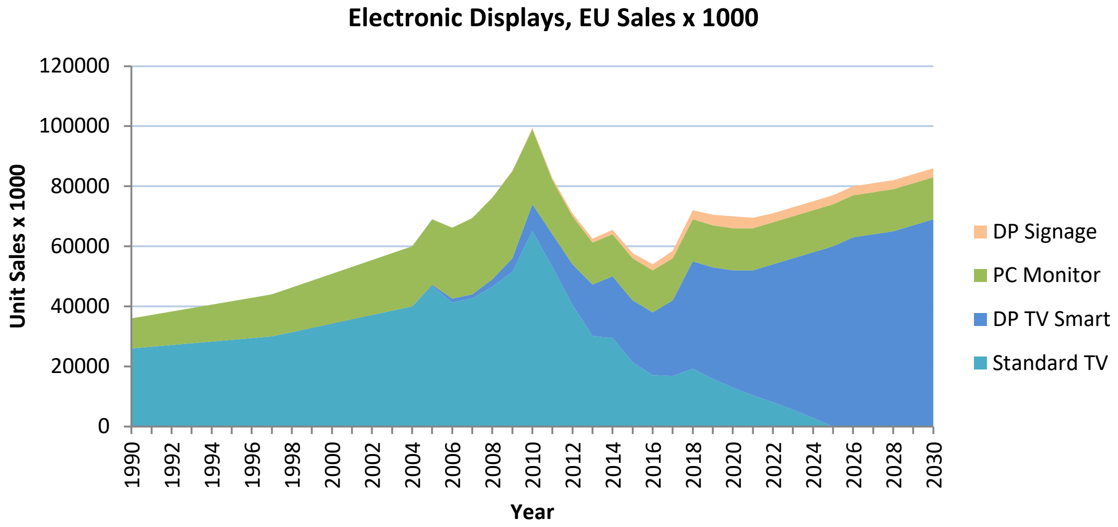


Figure 41. Stock electronic displays 1990-2030

The stock of displays shows a steady increase to almost 600 million units in 2018, increasing to 700 million units in 2030

Table 41 Stock electronic displays 1990-2030, in '000 units

Display type	1990	1995	2000	2005	2010	2015	2020	2025	2030
DP TV, standard (NoNA)	215000	258571	322571	355689	327042	230827	92267	0	0
DP TV, LoNA	0	0	0	467	18449	97743	164473	109050	27000
DP TV, HiNA ('Smart')	0	0	0	472	18880	97880	240510	410950	581000
DP TV total	215000	258571	322571	356629	364371	426450	497250	520000	608000
DP Monitor	13000	69071	99714	128943	172000	130000	98000	98000	98000
DP Signage	0	0	0	0	630	6848	21250	30500	30500
DP Electronic Displays, total	228000	327643	422286	485571	537001	563298	616500	648500	736500

No/Lo/HiNA=No/Low/High Network Availability

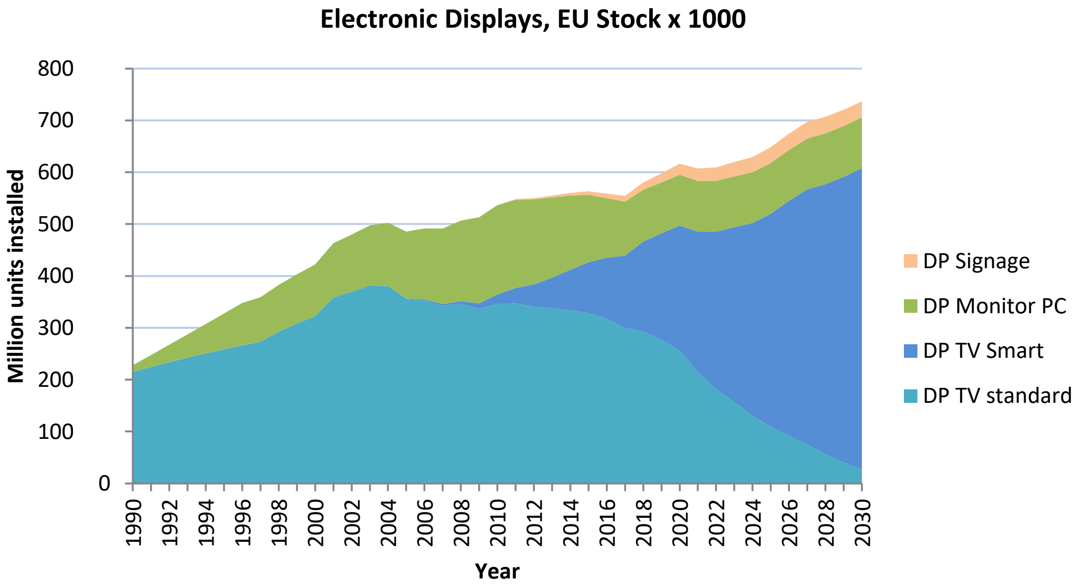


Figure 42. Stock electronic displays 1990-2030

The total display area is close to 332 square kilometres, of which over ¾ are made up of televisions

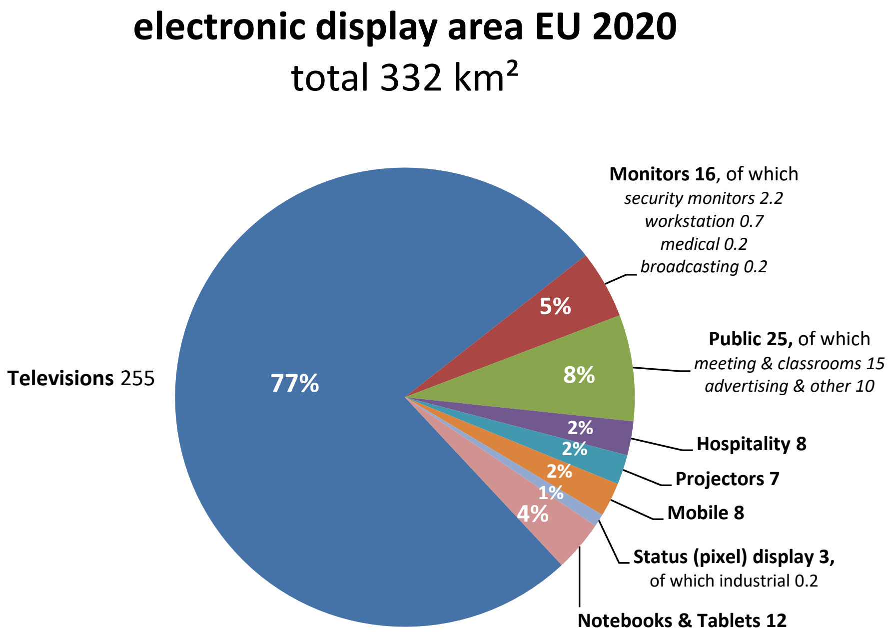


Figure 43. Detailed market segmentation electronic displays

Table 42. Forecast of electronic display surface area in EU 2020 (VHK estimate, IA report 2018)

Display	Surface diag. *inch*	Surface area *dm²*	Stock units *million*		Total area *km²*		Note
Television	44	53	494		262.4		
Regular TV	44	53		477		255	EIA, stock 2020 [Note 1]
Hospitality TV	36	36		16.7		7.4	
hotel rooms & other lodgings	40	44		14		6.2	11.6 m beds (MEErP)
hospital beds	40	44		2.7		1.2	2.7 m curative beds (MEErP)
Regular monitors	24	16	81		12.7		
desktop PC	24	16		64		10.2	EIA, stock 2020
thin client	21	12		4.8		0.6	EIA, stock 2020
notebook external	24	16		11.7		1.9	remainder
Special monitors	24	16	8.5		3.3		
security monitors	33	60		3.7		2.2	[Note 2]
medical displays (incl. integrated)	27	20		0.8		0.2	[Note 3]
broadcasting displays	27	20		0.8		0.2	[Note 4]
professional displays (CAD, Graphics)	28	22		3.2		0.7	EIA, stock 2020
Regular signage display	55	83	30		24.4		
retail & banks (indoor, excl. ATM)	43	50		11		5.7	[Note 5]
meeting rooms (incl. video conference)	75	155		5		7.8	5 m meeting rooms (169 million m² floor area)
classrooms (incl. smart boards)	70	135		5		6.8	5 m class rooms (93 m students + vocational)
airport/train/metro stations	55	83		1.2		1.0	[Note 6]
bars, hotels (public area), restaurants	44	53		2		1.1	0.2m hotels, 0.8 m restaurants, 0.7m bars
waiting rooms (e.g. healthcare)	44	53		2		1.1	10k hospitals, 2 m doctors
outdoors	55	83		1.1		0.9	estimate (10% of retail)
Special signage display			4		7.1		
superlarge (>100", video-wall)	110	333		0.02		0.07	estimate
projectors	80	176		4		7	EIA, stock 2020
Integrated displays			1605		23.2		
Mobile devices	5.5	0.8		1000		7.6	EIA, stock 2020
cell phones	5	0.6		500		3.2	estimate (>100% penetration)
GPS (incl. car-systems)	7	1.3		250		3.2	estimate (number of cars)
(video) cameras	4	0.4		150		0.6	estimate (3/4 of households)
other mobile display (games, MP3, etc.)	5	0.6		100		0.6	estimate
Integrated status (pixel) display	7.2	1.35		198		2.9	[Note 7]
ATMs (banks)	30	25		1		0.3	0.42m ATMs (source: EAST)
pro (EP colour) copier/printer	6	1		14.2		0.1	10% of 145 m imaging equipment
premium vending machines	9	2		0.38		0.01	10% of 3.77 m units (www.vending-europe.eu)
commercial & pro refrigeration	6	1		2.1		0.02	10% of 21 m units
Industrial tools/ovens/laundry	9	2		10		0.2	maximum estimate VHK
heating boilers/thermostats	6	1		12.8		0.1	10% of 128 m boilers
central air conditioners	8	1.6		2.3		0	30% of 7.5 m units
smart meters/domotique	8	1.6		45		0.7	30% of 150 m meters/dedicated panels
ventilation units	6	1		5.6		0.1	10% of 56 m units
hh el. ovens	6	1		21		0.2	10% of 209 m electric household (hh) ovens
hh microwave	6	1		10		0.1	10% of estimated 100 m units
hh refrigeration	9	2		30.8		0.6	10% of 308 m units
hh (dish) washing, drying	6	1		39.5		0.4	10% of 395 m units
hh audio systems (fixed)	6	1		4		0.04	2% of 200 m units in use
Integrated computer displays				401		12.2	
all-in-one PC	24	16		2		0.3	2.4% share of desktop (DigiTimes 26.8.2014)
notebook	14	5		62		3.1	EIA, stock 2020
tablet (incl. E-book readers)	10	2.6		337		8.8	EIA, stock 2020
Integrated in means of transport						0.5	
traffic info & advertising display	24	16		1.37		0.2	[Note 8]

passenger TV (plane, train)	15	6.2	4.5	0.3	long-haul train carriages 25k; planes 20k; 100 displays per carriage or plane
TOTAL			2222 m	333.1 km²	[Note 9]

[1] Source: European Commission, Ecodesign Impact Accounting (EIA) - Part 1, prepared by VHK, 2014 (EIA). Stock data for the year 2020.

[2] Security monitors: Estimate based on 30 m security cameras with monitor, 1 monitor/8 cameras, (average 42" per 15 cameras and one 21" spot monitor --> average 60 dm²-->33")

[3] Medical displays (high resolution, grayscale-calibration option): Total annual sales is around 40 000 units of medical imaging equipment, of which 1000 MR, 2000 CT, 10000 X-Ray, 500 NM (e.g. PET), 25000 Ultrasound ('echo').[source: COCIR 2011]. Assuming 12-13 years life, 0.5 m units are in stock. There are around 0.4 m medical practices (of which 0.16 m in hospitals), 0.16 m dental practices, 0.05 m veterinary practices, which may not all need medical grade monitors. Total EU-stock for medical monitors is thus estimated at 0.8 m units.

[4] Broadcasting displays (colour-calibration option) 0.1 m video/TV enterprises in EU (VHK, MEErP-Part 2, 2011) at assumed 80 screens/enterprise

[5] Retail & car showroom displays: 3.5 m retail companies, 0.8 m car showrooms; 0.22m bank offices (ATM-displays not included here). Average 2-3 displays/outlet (varies between 50 per consumer electronics store and 0 for specialist food stores). Size is the area average between large (>55") and small (<24").

[6] 0.15 m displays at 10k train- & 2.8k subway stations (3-4 platforms/station, 3 displays per platform), 1 m displays at bus stops (1 display/bus stop), 0.05 m displays at 350 larger and ca. 2000 small airports (100 displays/large airport, 8 displays/small airport). Average size of 55" (83 dm²) .

[7] Stock 2020 data from EIA, size & share estimated by VHK. Only pixel-based displays are included. It is assumed that the other 3 billion status displays in the EU that are pilot lights (0.1-0.2W, 16h/d, 80% share) or LCD segment displays (0.3, 16 h/d, 10% share), LED segment displays (0.5-1W, 4h/d with APD, 10% share) and other non-pixel based displays are not intended to be included in the scope. Calculating with above data in brackets, they represent an energy use of (very) approximately 3 bn x 365 days x (0.1 x 16 x 80% + 0.3 x 16 x 10% + 0.7 x 4 x 10%) = 2.2 TWh/yr or --given the uncertainties of the estimate-- between 1 and 4 TWh per year.

[8] 0.37m displays in 7k metro trains (35 k carriages, 2 displays/carriage) and 30k railway trains (150k passenger train carriages), 1 m displays in 0.5m buses (2 displays/bus). Average size 24" (16 dm²) in vehicles.

[9] According to EIA (EFSBAU sheet), the Business-as-Usual (BAU) efficiency in the 2020 stock is 1.1 W/dm² (TV) and 2.4 W/dm² (monitor), so on-mode average is 1.43 W/dm² (basis 75% TV). Total 4 h/d for 365 d -->1460h/yr. Total 1 dm²=2.1 kWh/yr and 1 km2=0.21 TWh/yr. Hence the BAU 2020 electricity consumption is 0.21*340= 71 TWh/yr in approximately on-mode. For an ECO-scenario EIA estimates (EFSECO-sheet) 0.6 W/dm² (TV) and 0.57 W/dm² (monitor), so on-mode average 0.6 W/dm². Total 4 h/d for 365 d -->1460h/yr. Total 1 dm²=0.88 kWh/yr and 1 km2=0.09 TWh/yr. Hence the ECO 2020 electricity consumption is 0.09*340= 31 TWh/yr in approximately on-mode. This figure, based on the original IA-study 2012, needs to be verified/updated here.

The most significant trend is the ever increasing screen size, as shown in the figure below

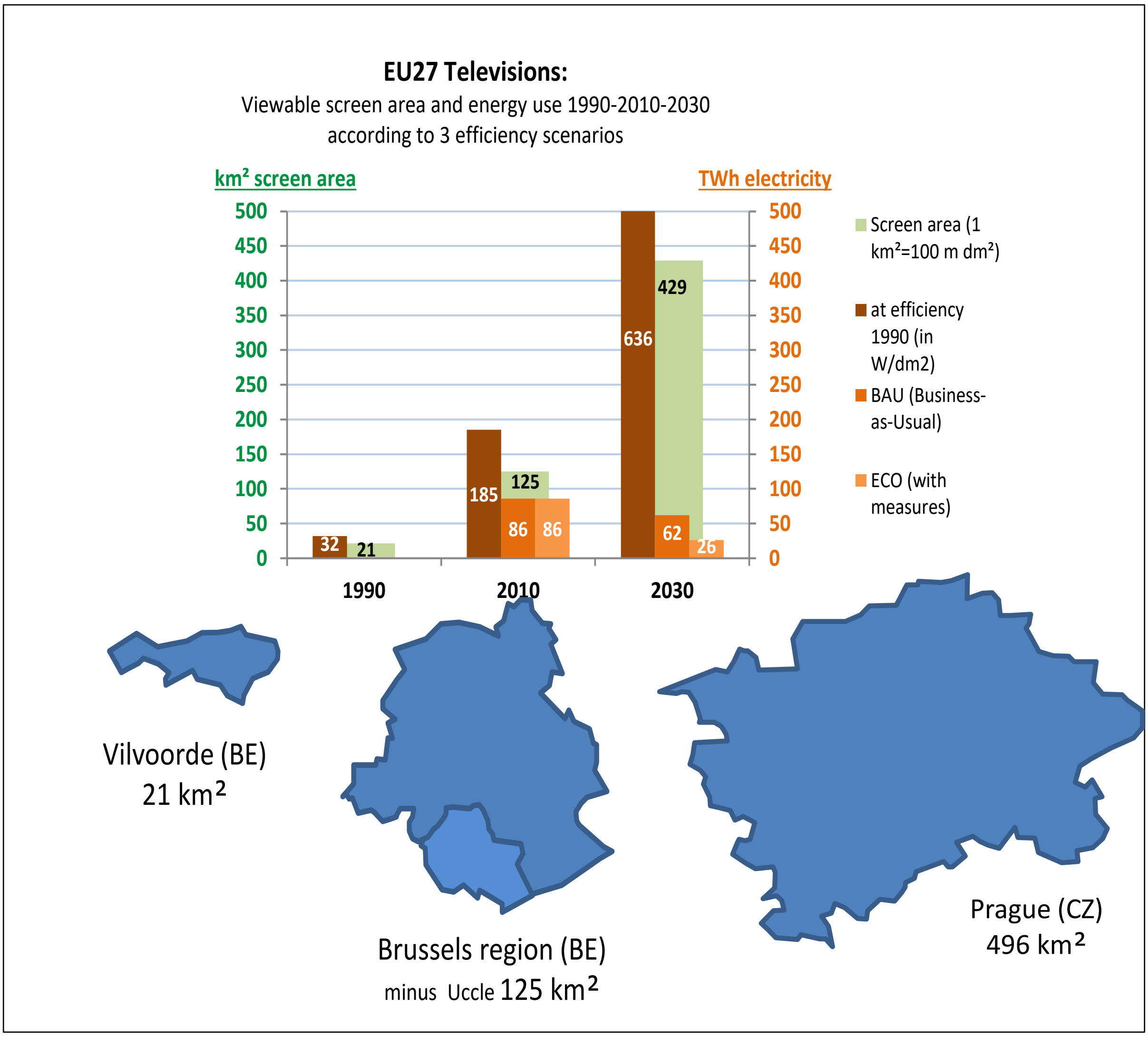


Figure 44. EU television screen area and energy use 1990-2010-2030

Apart from that, there are timelines for most of the parameters in this section.

4.3 Performance and energy use

The load for displays is expressed as hours spent per power mode (on/standby) and the size of the unit, as viewable area.

Table 43. Load/efficiency metrics

Display type	unit	1990	1995	2000	2005	2010	2015	2020	2025	2030
DP TV viewable area (avg. all types)	dm²	10	11	13	19	28	43	51	59	68
DP TV share of UHD / 3D / HDR	%	0%	0%	0%	0%	2%	10%	25%	38%	50%
DP TV viewing time (on-mode)	h on / d	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0
DP TV standby time	h sb / d	6,0	9,5	13,0	16,5	10,0	10,0	10,0	10,0	10,0
DP Monitor viewable area	dm²	5,0	6,4	7,9	9,6	11,4	13,5	15,9	17,9	20,1
DP Monitor share of UHD / 3D / HDR	%	0%	0%	0%	0%	2%	10%	25%	38%	50%
DP Monitor viewing time (on-mode)	h on / d	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0
DP Monitor standby time	h sb / d	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0
DP Signage viewable area	dm²	16	18	21	32	46	71	84	97	113
DP Signage display time (on-mode)	h on / d	12,0	12,0	12,0	12,0	12,0	12,0	12,0	12,0	12,0
DP Signage standby time	h sb / d	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8

Table 44. EU Total load

Display type	unit	1990	1995	2000	2005	2010	2015	2020	2025	2030
DP TV viewable area (avg. all types)	km²	21	29	40	69	102	185	253	306	415
DP TV viewing time (on-mode)	M years / a	36	43	54	59	61	71	83	87	101
DP TV standby time	M years / a	54	102	175	245	152	178	207	217	253
DP Monitor viewable area	km²	1	4	8	12	20	18	16	18	20
DP Monitor viewing time (on-mode)	M years / a	2	12	17	21	29	22	16	16	16
DP Monitor standby time	M years / a	2	12	17	21	29	22	16	16	16
DP Signage viewable area	km²	0	0	0	0	0	5	18	30	34
DP Signage display time (on-mode)	M years / a	0	0	0	0	0	3	11	15	15
DP Signage standby time	M years / a	0	0	0	0	0	1	2	2	2
DP Elec.Displays, total viewable area	km²	22	33	48	82	122	207	287	353	469
DP Elec.Displays, total on-mode time	M years / a	38	55	70	81	90	96	110	118	133
DP Elec.Displays, total standby time	M years / a	56	114	191	267	181	200	225	235	272

Table 45. Electricity consumption (including impact 2019 reviewed regulation), in TWh

Display type	1990	1995	2000	2005	2010	2015	2020	2025	2030
DP TV on-mode, total all types	29	36	47	74	75	79	67	42	38
DP TV standby, standard (NoNA)	4	7	9	9	2	1	0	0	0
DP TV standby, LoNA	0	0	0	0	0	1	1	1	0
DP TV standby, HiNA ('Smart')	0	0	0	0	0	2	5	7	9
DP TV standby, total all types	4	7	9	9	3	3	6	8	10
DP TV total on-mode + standby	33	43	56	83	77	82	74	50	47
DP Monitor on-mode	1	5	9	13	15	8	3	3	2
DP Monitor standby	0	1	1	1	1	0	0	0	0
DP Monitor total	1	6	10	14	15	8	3	3	2
DP Signage on-mode	0	0	0	0	1	9	20	24	20
DP Signage standby	0	0	0	0	0	1	3	4	3
DP Signage total	0	0	0	0	1	10	23	27	23
DP Electronic Displays, total on-mode	30	41	55	87	91	96	91	68	59
DP Electronic Displays, total standby	4	7	10	10	3	5	9	12	13
DP Electronic Displays, total	34	49	66	97	94	100	100	80	72

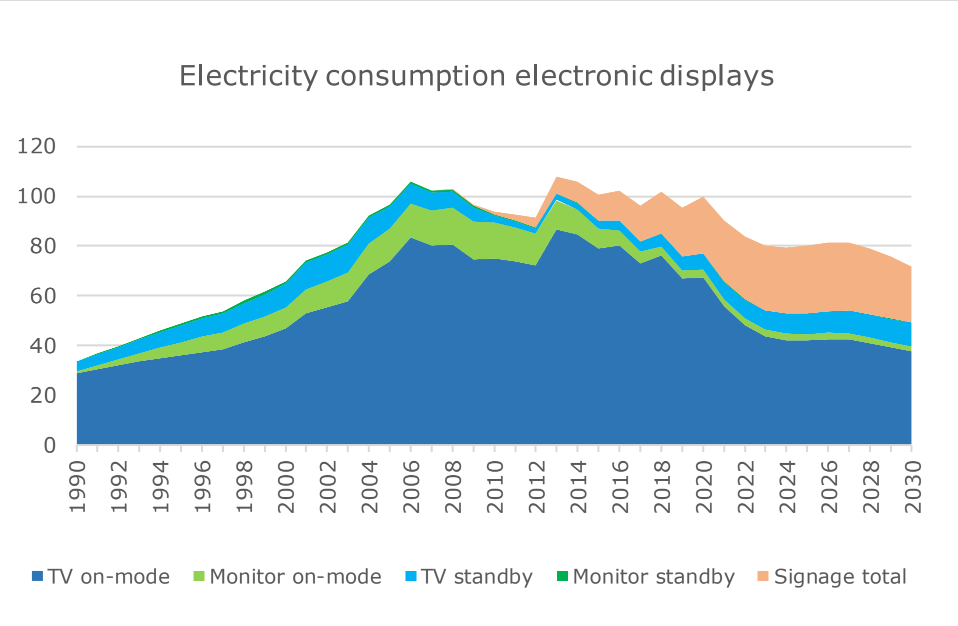


Figure 45. Electricity consumption electronic displays

4.4 Energy Efficiency Improvement

Table 46. Efficiency installed stock

Display type	unit	1990	1995	2000	2005	2010	2015	2020	2025	2030
DP TV on-mode power (avg. all types)	W/dm2	9.2	8.5	7.9	7.3	5.0	2.8	1.6	0.9	0.6
DP TV standard (NoNA) standby power	W	8.0	7.4	6.2	4.2	2.0	0.8	0.5		
DP TV LoNA standby power	W				2.0	2.0	2.0	2.0	2.0	2.0
DP TV HiNA ('Smart') standby power	W				0.0	0.0	5.1	5.6	5.0	4.4
DP Monitor on-mode power	W/dm2	9.2	8.2	7.6	7.3	5.1	2.9	1.2	1.0	0.6
DP Monitor standby power	W	9.0	8.0	6.2	4.3	2.4	0.9	0.3	0.2	0.2
DP Signage on-mode power	W/dm2					8.0	4.2	2.6	1.8	1.3
DP Signage standby power	W/dm2					8.0	4.2	2.6	1.8	1.3

The Table 47 below gives the efficiency of new sales, further illustrated by the old and new energy label classifications in Figure 46.

Table 47. Efficiency new sales

Display type	unit	1990	1995	2000	2005	2010	2015	2020	2025	2030
DP TV on-mode power (avg. all types)	W/dm²	8.8	7.7	7.7	5.6	3.7	1.3	1.0	0.6	0.4
DP TV standard (NoNA) standby power	W	8.0	6.3	4.5	2.8	1.0	0.2	0.1	0.1	0.1
DP TV LoNA standby power	W	0.0	0.0	0.0	2.0	2.0	2.0	2.0	2.0	2.0
DP TV HiNA ('Smart') standby power	W	0.0	0.0	0.0	0.0	0.0	6.4	5.0	4.5	4.0
DP Monitor on-mode power	W/dm²	8.8	7.7	7.7	5.6	3.7	1.3	1.2	0.7	0.4
DP Monitor standby power	W	9.0	7.1	5.1	3.2	1.3	0.4	0.3	0.2	0.2
DP Signage on-mode power	W/dm²	17.7	15.4	15.4	11.1	7.4	2.5	1.9	1.3	0.8
DP Signage standby power	W/dm²	17.7	15.4	15.4	11.1	7.4	2.5	1.9	1.3	0.8

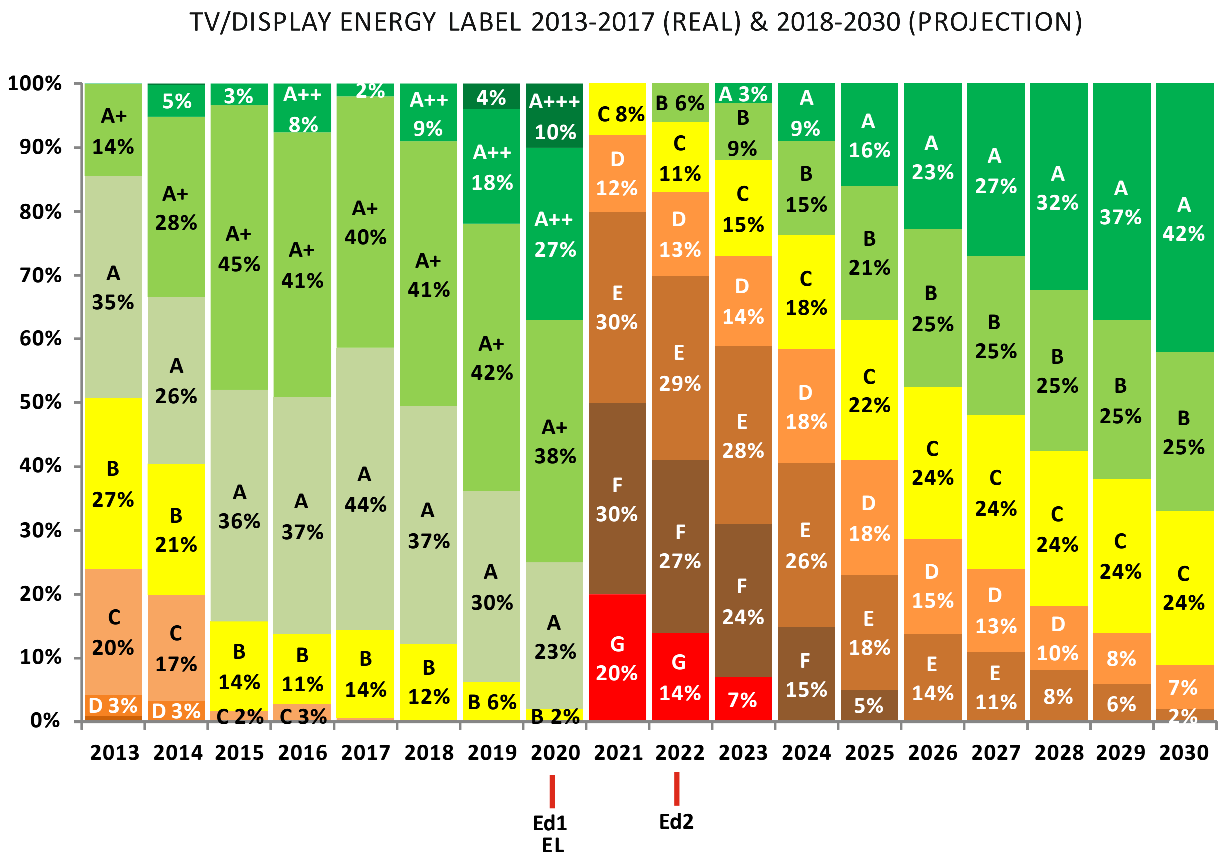


Figure 46. Energy label class distribution of standard electronic display models available in the EU over the period 2010-2030 (actual 2010-2016 and projections 2017-2030) with new Ecodesign and Energy Label measures

The Energy Efficiency energy label classes

$$EEI = \frac{(P_{measured} + 1)}{(3 \times [90 \times tanh(0,02 + 0,004 \times (A - 11)) + 4] + 3) + corr_{lum}}$$

5 GROUP IV. – AUDIO / VIDEO

The group audio/video is split up into sections describing the product definition, sales, stock and energy metrics (performance, efficiency) plus trends for the following groups:

1. video players/recorders
2. video projectors / beamers
3. video game consoles
4. interactive whiteboards
5. videoconference systems
6. MP3 players
7. stand-alone home audio
8. network connected home audio
9. complex set-top boxes
10. digital TV services

5.1 Video player/ recorder

5.1.1 Definition

According to final report ENTR Lot 3 Sound and Imaging Equipment[154] a video player/recorder is a stand-alone device with the following primary functions:

- Decodes to an output audio/video signal from recorded or recordable media via a powered or integrated media interface such as an optical drive (DVD, Blu-Ray), USB or HDD interface;
- Has no tuner unless it records on a removable media in a standard library format;
- Is mains powered;
- Does not have a display for viewing video;
- Is not designed for a broad range of home or office applications.

The above definition includes dedicated video recorders/-players, but not those integrated in game consoles, as these are discussed separately.

5.1.2 Market

Video players/recorders were introduced onto the consumer market over 50 years ago, first as Video Cassette Recorders (VCRs) using magnetic tape with VHS ultimately the dominant format. In the beginning of the millennium, DVDs (Digital Versatile Discs) became the new home video recording- and player standard. DVDs are optical disks using laser read-write technology. Around 2008 the Blu-ray format, using blue lasers for higher storage density, was gaining popularity. DVD/Blu-ray systems may also be equipped with a hard disk drive (HDD). The largest competitors for DVD/Blu-ray systems currently are devices for streaming video (e.g. Netflix, YouTube, postponed viewing) and 'media-centres' with HDD-storage for home videos.

[154] AEA with Intertek, Lot 3 – Sound and imaging equipment, Ecodesign preparatory study for EC DG Grow, November 2010.

The Lot 3 study, quoting Futuresource[155], mentions EU sales of 21 million DVD and Blu-Ray players/recorders in 2009 and expected sales of around 35 million in 2012. At that time (2010) unit sales were already predicted to decline from 2012 onwards but still believed to be at a level of 27 million units in 2020.

Table 48. Sales of DVD/Blu-Ray players and recorders in the EU27 (Futuresource in Lot 3 study)

	2009	2012
DVD Player	11.63	3.57
DVD recorder	6.28	6.31
Blu-ray player	3.14	15
Blu-ray recorder	0	10
Totals	21.05	34.88

Recent market reports on the DVD/Blu-Ray player market are rare, particularly for Europe. Many of the major consumer electronics firms like Samsung and Oppo have stopped production and the turnover of the videodiscs (not the players, but indicative for the trend) has halved over the 2014-2018 period[156]. It is believed that most of the DVD/Blu-Ray players are sold inside game consoles like Xbox (UHD-DVD) and Playstation (Blu-Ray) and 'media-centres'. This will be discussed in the next paragraph.

The Ecodesign Impact Accounting 2018 (EIA) projects that in 2020 only 4 million DVD/BluRay players will be sold in the EU and that there will be no significant sales after 2021-2022.
The stock of products-in-use, set at a peak in 2015 of 264 million units (more than 1 per household) is believed to have dropped to no more than 40.9 million units in 2020 and will have almost vanished in 2025.

Prices in the Lot 3 study (2010) and thus also EIA were 108 euros/unit (in 2010 euros). In EIA this is kept constant. DVD-players now sell for less than 50 euros[157] but when including Blu-Ray players, a short survey of internet sales prices shows that the 108 euros might still apply. Table 49 shows recent internet prices and power use (W) in active mode.

Table 49. Active energy consumption (W) and prices (2019 euros) of DVD/BluRay players/recorders (source: VHK 2019 based on internet search)

Brand	Type	Energy Active (W)	Price (euro)
1	4K UHD Blu-Ray player	14 W	299
2	4K UHD Blu-Ray player	15 W	193
3	4K UHD Blu-Ray player	32 W	449
4	4K UHD Blu-Ray player	15 W	158
5	HD Blu-Ray player	0,3 W	249
6	HD Blu-Ray player	19 W	379
7	HD Blu-Ray player	9,5 W	89
8	HD Blu-Ray player	8,8 W	77

[155] http://www.futuresource-consulting.com/
[156] https://tweakers.net/nieuws/151508/markt-voor-blu-rays-en-dvds-is-binnen-vijf-jaar-gehalveerd.html
[157] https://www.telegraph.co.uk/news/2018/10/23/death-dvd-players-john-lewis-stop-stocking/

5.1.3 Energy

The energy consumption is measured with a 24h duty cycle which depends on type, but is typical: 0.25h/d record, 0.75h/d play, 9h live-pause (only types with HDD), fast start / on-idle / standby / off hours depend on type. Standby power 0.5 W, on-power varying from 10-30 W, idle power varying from 5-20 W. The average energy consumption for all types leads to 16 kWh/a, 44 Wh/d or 1.8 W (weighted average of all modes, incl. standby). The EU-Load is based on a use of 1 h per day.

5.1.4 Summary

The table below gives a summary of the main parameters.

Table 50: VIDEO DVD players/recorders (EIA 2018)

Parameter	1990	2010	2015	2020	2025	2030	2035	2040	2045	2050
SALES (000 units)	39	35400	30500	4000	0	0	0	0	0	0
STOCK (000 units)	60	135545	166000	40900	3000	0	0	0	0	0
PRICE (euros 2010)	108	108	108	108	108	na	na	na	na	na
EFF. TEC (kWh/yr)	16	16	16	16	16	na	na	na	na	na
ELECTRICITY (TWh/yr)	0,0	2,2	2,7	0,7	0,0	0,0	na	na	na	na

5.2 Video projectors/ beamers

5.2.1 Definition

A projector is an optical device, for processing analogue or digital video image information, in any broadcasting, storage or networking format to modulate a light source and project the resulting image onto an external screen. Audio information, in analogue or digital format, may be processed as an optional function of the projector.
Markets range from home theatre to cinemas, from conference rooms to pico-portable projectors, from sports bars to supersize indoor advertising.
There are several projector technologies: DLP, 3LCD, LCOS and LIP:

- DLP stands for Digital Light Processing with a chip comprised of microscopic mirrors and a spinning colour wheel to generate an image.
- LCD (Liquid Crystal Display) projectors, also called 3LCD because of the colour-split, use liquid crystal displays in its optics rather than physical moving parts.
- LCoS means 'liquid crystal on silicon' and is a sort of DLP-LCD hybrid which uses liquid crystal chips and a mirrored backing.

Possible light sources are halogen lamps, HID (High Intensity Discharge), LED (Light Emitting Diodes) lamps and laser projectors using a solid state laser.[158]

5.2.2 Market and history

The projection of (sequences of) static pictures started in the 17th century with the Laterna Magica, a box with a candle, a lens and a picture on glass. At the turn of the 20th century, cinema video projection started with wide (70mm and then 35mm) celluloid film

[158] For further reading see e.g. https://www.electropages.com/blog/2019/06/dlp-vs-lcd-vs-led-vs-lcos-vs-laser-shedding-light-projector-technology

projectors[159], using carbon- and later Xenon arc lamps. Since the mid-2010s this analogue capture and distribution on film stock is almost completely replaced by digital capture and distribution, i.e. using Xenon-arc lit (1-7 kW) projectors with 4K resolution, mainly DLP based although laser and other technologies also exist. The most recent development are microLED-walls, i.e. huge (modular) electronic displays with enough resolution and (better) brightness and colour quality (covered under signage displays). If that trend persists, there will soon be no cinema projectors anymore.

Home movie capture and projection started out with the 8mm celluloid film camera, replaced in the 1970s-80s by capture on magnetic tape (8mm, VHS, etc.) displayed on television (CRT and later LCD/LED) or other electronic displays. Home slide projection was popular in the 1960s-1980s but is now also replaced by showing digital photos on electronic displays of all types (TV, monitor, tablet, cell-phone). A popular use of projectors in the US rather than in Europe is in home theatres, i.e. a room in the house is dedicated for showing movies on large screens (100 inch diagonal or more). Still today this is an important market for projectors, although the competition of 4K (and soon 8K) 80-90 inch electronic displays is coming closer. Also mainly in the US projector television, i.e. DLP/LCD/LCoS projectors encased with backlit screens brought large size TVs to the home at the turn of the century, i.e. before plasma and LCD flat screens.

Professional projectors for business and classroom presentations have moved from initially static pictures such as overhead sheets (1960s), slides (1970s-80s) and digital media (1990s-now) to digital presentations containing also short video material. The 'beamers' used for such presentations range from Xenon-arc lit projectors for 3 metre (diagonal) screens in conference rooms to portable LED-lit pico-projectors for table-top presentations. Although business and classroom projectors are still probably one of the main applications of projectors in the EU, even here there is fierce competition from ever larger and better performing electronic displays.[160]
The overall trend, presented at the ISE Trade Fair 2020 in Amsterdam was towards very strong –20 to 30k lumen and relatively compact laser projectors for light shows and commercial events.[161]

The Lot 3 study states that commercial market research data on projectors appears to underestimate total EU27 sales by 30% in comparison with the 1.7 million products estimated as total EU 27 sales by unrelated stakeholder sources. This may be explained by the complicated cross-over of internet based direct sales of projectors into a mix of CE product sales sites. Further confusion in commercial market data is caused by the large schools projector market in the EU27 (over 800,000 units sold in 2008) The larger proportion of these are obtained through bulk procurement contracts placed directly with manufacturers and do not necessarily register in commercial market research data.
On that basis, EU-sales of 1.6 million units in 2008 and 1.7 million units in 2012 were estimated. Given the average product life of 5 years this came to an EU-stock of 8 million units in 2008-2012.

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[159] Preceded of course by a host of inventive other solutions. See https://en.wikipedia.org/wiki/History_of_film_technology#Development_of_the_film_industry

[160] Better brightness & contrast, possibly touch-screen functionality, better colour quality, etc..

[161] E.g. NEC was demonstrating its 20k lmn single-chip DLP solution, the PX20000UL, with only 43/45db fan noise, whilst Panasonic launched its "super compact" 30k lmn PT-RQ35. Epson also demonstrated a compact 30k lmn, LaPh solution, the EB-L30000U. (Futuresource report)

In their most recent market report of the 2nd quarter of 2019, Futuresource consulting states that the worldwide projector market shrank by 17.8% 'YoY' in CY2019 Q2, to 1.5m units, with values falling by 10.2% to $2.1billion.[162] This means a global market of around 6 m units per year with an average price of $1400 per unit. Assuming a 20% EU-market share, this comes down to 1.2m units sold in the EU in 2019. If that trend continues, i.e. the 17.8% YoY decrease this means 0.98 million units in 2020. This is slightly more than the projection in EIA, which came to sales of 0.725 million units and a stock of 5.4 million units in 2020. On the other hand, the assumption that global numbers also apply to the EU gives a considerable amount of uncertainty.

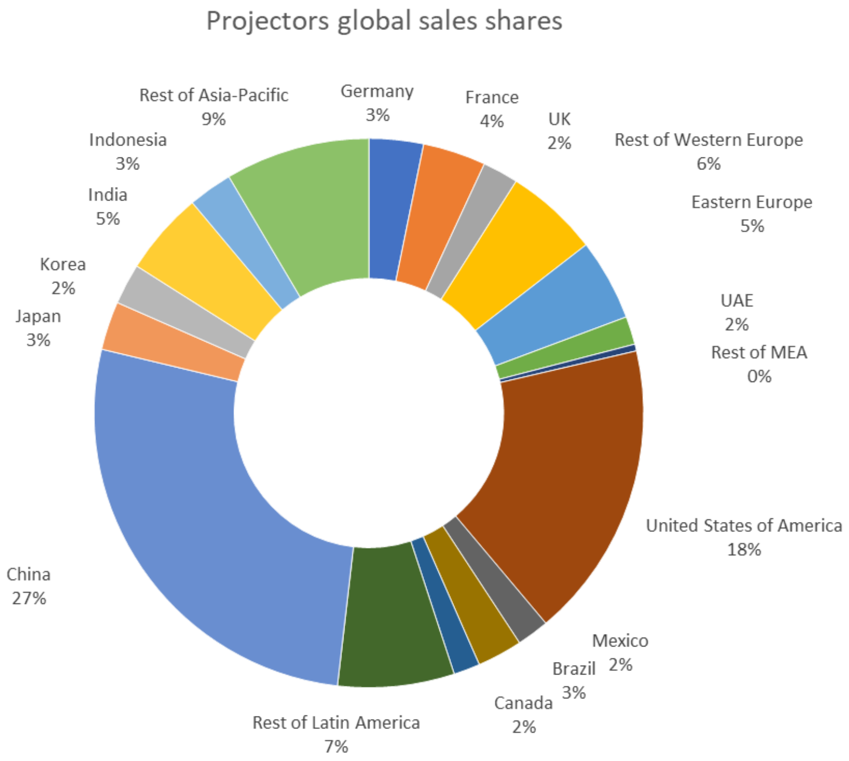

Figure 47: Regional shares of global projector sales (Futuresource consulting 2019)

5.2.3 Energy

Energy efficiency of video-projectors is not regulated or labelled in the EU, but has been subject of an Ecodesign preparatory study (DG GROW, Lot 3[163]). In this study, the energy consumption is determined from a representative 24 hour cycle for the most common types in the EU:

- Classroom projectors: on-play 3 h @ 275W, standby 6 h @ 1W, off-mode 15 h @ 0.5W, total 318 kWh/a, 871 Wh/d, 36 W.
- Office projectors: on-play 1.5h @250W, standby 8h @1W, off-mode 14.5h @0.5W, total 158 kWh/a, 433 Wh/d, 18 W.

[162] https://futuresource-consulting.com/reports/posts/2019/september/futuresource-front-projector-market-track-worldwide-q2-19/?locale=en

[163] AEA with Intertek, Lot 3 – Sound and imaging equipment, Ecodesign preparatory study for EC DG Grow, November 2010.

– Home projectors: on-play 0.5h @200W, standby 20h @1W, off-mode 3.5h @0.5W, total 49 kWh/a, 134 Wh/d, 5.6 W.

The overall weighted average is 200 kWh/a. The EU-Load is based on a weighted average on-mode use of 2.1 h per day. Standby- and off-mode energy is negligible in comparison to on-mode energy use. The authors of the Lot 3 study recommend an energy efficiency metric in Watts electricity consumption per lumen of Effective Flux (Total Projected Light output) in on-mode. For a standard projector in 2012 the reference limit value would be 0.09 W/lm at 4,000 lumen. From this the values of other lumen-categories are derived in the table below. For 2015 a reference limit of 0.05 W/lm was considered.

Table 51: Recommended efficiency limits for video projectors by AEAT 2010

Effective Flux (Total Projected Light output) X lm	Efficiency Limit W/lm	correction factors relaxing the efficiency limit
X < 2,500	0.105	*Short throw projector:*1.3* •
2,500 ≥ X < 4,000	0.095	*Wide projector: *1.1* •
4,000 ≥ X < 5,000	0.085	*Home cinema projector: *1.4*
X ≥ 5,000	0.080	

For standby- and off-mode the limit values of Commission Regulation No. 1275/2008, as well as a mandatory auto power down function, were considered appropriate.
Based on the proposed 2012 energy efficiency requirements the savings compared with the baseline could be 0.55 TWh in 2015 and 0.58 TWh in 2020. The 2020 saving would increase to 1.3 TWh if the claimed step change in light source efficiency occurred (2015 limit of 0.05W/lm).
The Commission did not follow-up on the study recommendations so there were no Ecodesign or Energy Labelling measures.

5.2.4 Summary

Table 52: VIDEO projectors (EIA 2018)

Parameter	1990	2010	2015	2020	2025	2030	2035	2040	2045	2050
SALES (000 units)	30	2100	1781	725	313	0	0	0	0	0
STOCK (000 units)	60	10658	9204	5403	2284	422	0	0	0	0
PRICE (euros 2010)	1404	1404	1404	1404	1404	1404	na	na	na	na
EFF. TEC (kWh/yr)	200	200	200	200	200	200	na	na	na	na
ELECTRICITY (TWh/yr)	0.0	2.1	1.8	1.1	0.5	0.1	na	na	na	na

5.3 Video game consoles

5.3.1 Definition

In the EU, video games consoles are subject to a Self-Regulatory Initiative (SRI) under the Ecodesign Directive (ENTR lot 3). Signatories are the three main producers: Microsoft (Xbox), Sony (Playstation) and Nintendo. The most recent version is SRI 2.6.3 (2018) and the latest compliance report by the Independent Inspector (Intertek) was released in October 2019[164]. All information on the SRI is available on a dedicated website www.efficientgaming.eu.

In the SRI game consoles are defined as follows:

> *Games Console is a computing device whose primary function is to play video games. Games Consoles share many of the hardware architecture features and components found in general personal computers (e.g. central processing unit(s), system memory, video architecture, optical drives and/or hard drives or other forms of internal memory). Games Consoles covered by this SRI are those that:*
>
> - *Utilise either dedicated handheld or other interactive controllers designed to enable game playing (rather than the mouse and keyboard used by personal computers); and*
> - *are equipped with audio-visual outputs for use with external televisions as the primary display; and*
> - *use dedicated Console operating systems (rather than using a conventional PC operating system); and*
> - *may include other secondary features such as optical disc player, digital video and picture viewing, digital music playback, etc.; and*
> - *are mains powered devices that use more than 20 watts in Active Game mode with either Sales stock.*

Furthermore, there are definitions of the consoles given by their resolution (UHD, HD, Standard) and/or interface (Gesture and Speech Recognition Natural User Interface, NUI). Defined operating modes are Active Gaming, Media Playback, Navigation, Standby (as in EU Regulation (EU) No 1275/2008, Annex II), Networked Standby (as in EU Regulation (EU) No 801/2013).

5.3.2 Market

Sales of game consoles started in the early 1970s with game consoles like Atari Pong and evolved over the next 50 years to what is now Sony's Playstation, Microsoft's Xbox (Series X announced 2020), Nintendo Switch and Wii. The Playstation 5, announced for the autumn of 2020, will feature a solid state drive, 4K-BluRay 100 GB disks and GPU-based ray tracing. The Xbox X series has the same specs and boasts a 12 teraflops calculating power[165]. The overall trend is ever more photo-realistic images and more and more gaming over the internet ('cloud gaming', 'game streaming' [166]).

[164] Intertek, Independent Inspector Annual Compliance Report – Games Consoles Self-Regulatory Initiative, Reporting Period 2018, Oct. 2019.

[165] Meaning 12 Tflops/s= 12 trillion (10^{12}) floating point operations per second.

[166] https://www.theverge.com/2019/4/18/18274498/game-streaming-services-pc-mac-ps4-android-cloud-google-stadia

The 2019 Commission's Review Study shows the sales of the 7th and 8th generation from 2007 to 2017 in Europe. The average sales over that period are 11.5 million per year with peak values of around 16 million units per year.

Table 53. Sales of 7th and 8th generation game consoles in Europe (source: CSES et al. 2019)

CONSOLE	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
PS3	3418	4171	4801	5317	6259	5009	3150	1544	553	215	48
XBOX 360	2026	3926	3399	4089	4155	2949	1607	654	211	81	21
WII	5111	8386	6800	5656	4099	190	824	223	28	0	0
PS4	0	0	0	0	0	0	1682	6053	6859	6795	8094
XBOX ONE	0	0	0	0	0	0	765	143	2242	2302	2138
WII U	0	0	0	0	0	411	628	931	875	346	52
SWITCH	0	0	0	0	0	0	0	0	0	0	3404
TOTAL	10555	16483	15000	15062	14513	8148	6439	7597	9101	9097	13636

The European stock of installed 8th generation game consoles in 2018 is estimated at 57 million units, of which 37 million are Playstations, 11.5 million Xboxes and 8.2 million Switches. Including an extra 15% for legacy 7th generation game consoles that are still actively used, the stock amounts to a rounded 65 million units. This indicates an average product life of around 6-7 years. At an average TEC of 100,2 kWh/year the total energy use is approx. 6,5 TWh/yr at the end of the decade. .

5.3.3 Energy

The following tables detail the power cap and Auto-Power Down (APD) requirements for the SRI.

Table 54: Power consumption caps (W)

MODE	TIER	EFFECTIVE FROM	HIGH DEFINITION CONSOLES (W)	ULTRA HIGH DEFINITION CONSOLES (W)	
NAVIGATION MODE	Tier 1	01-jan-14	90 [1]	90 [2]	
	Tier 2	01-jan-16	90 [1]	90 [2]	
	Tier 3	01-jan-17	70 [1]	70 [2]	
	Tier 4	01-jan-19	50 [1]	Media Capable 50 [2]	Gaming capable 70 [2]
MEDIA PLAYBACK DVD MEDIA PLAYBACK BLU-RAY DISK STREAMING HD	Tier 1	01-jan-14	90 [1]	-	-
	Tier 2	01-jan-16	90 [1]	90 [1]	
	Tier 3	01-jan-17	70 [1]	90 [1]	
	Tier 4	01-jan-19	60 [1]	Media Capable 60 [2] 110 [3]	Gaming capable 70 [1]
ADDITIONAL POWER CAP USING A NATURAL USER INTERFACE	Tier 1	01-jan-14	+20	-	
	Tier 2	01-jan-16	+20	+20	
	Tier 3	01-jan-17	+15	+20	
	Tier 4	01-jan-19	+15	+15	

[1] measured at HDvideo resolutions
[2] measured at HD and 4K (UHD) video resolutions
[3] measured at 4K (UHD) video resolutions

AUTO-POWER DOWN (ABP)

TITLE	Requirement
NAVIGATION MODE APD	APD to trigger within 60 minutes to the power limits for standby
ACTIVE GAMING APD	APD to trigger within 60 minutes to the power limits for standby
DISC-BASED MEDIA PLAYBACK APD	APD to trigger within 4 hours to the power limits for standby
MEDIA STREAMING PLAYBACK APD	APD to trigger within 4 hours to the power limits for standby

Non-energy requirements in the SRI, i.e. resource efficiency and end-of-life design requirements, relate to product-life extension (spare parts, upgradeability, reparability) and increased re-use and recycling opportunities (marking etc.). From 1.1.2020 there will be information requirements as to whether plastic casing contains brominated flame retardants and whether or not there is mercury in the LCD display[167].

The average energy consumption is calculated from a TEC (Typical Electricity Consumption) duty cycle. In the most recent Commission Review Study the following duty cycle and typical power consumption values were assessed for different scenario calculations:

Table 55. Typical Electricity Consumption TEC 2019 of 8th generation game consoles (source: CSES e. Al. 2019)

		UHD gaming capable		*HD+UHD media capable*			*HD (onTV)*
console-->		**PS4 Pro**	**Xbox One X**	**PS4 slim**	**Xbox One S**		**Switch**
mode	*h/d*	W	W	W	W	*h/d*	W
Active gaming	*1.67*	135,93	148,69	73,14	66,59	*1*	11,42
Streaming & Media	*0.98*	78,58	51,61	47,18	35,3	*0,56*	8,1
Navigation and other	*0.47*	63,74	49,32	44,07	28,3	*0,28*	5,02
Standby	*5.12*	1,77	0,29	1,88	0,34	*0*	0
Low Power download	*0.15*	52,69	40,76	41,55	16,91	*0*	0
Rest mode	*15.21*	0,95	13,48	1	7,12	*21,71*	0,28
Off	*0.4*	0,25	0,29	0,24	0,33	*0,45*	0,35
wght. average power Pavg in W		***15.2***	***22,3***	***9,2***	***11,3***		***1,0***
TEC in kWh/year (Pavg*8,76)		**133**	**195**	**80**	**99**		**9**
Weighted average TEC kWh/yr*		***100.2***					
Consumer price		***€391***	***€443***	***€299***	***€259***		***€322***

**=based on installed stock 65% PS4, 20% Xbox, 15% Switch*

In the 2010 Lot 3 preparatory study it was estimated that an SRI (a.k.a. Voluntary Agreement) for Game Consoles would yield a saving of 1.1 TWh/year in 2020, i.e. saving around 10% of the projected use for that year in a 'Business-as-Usual' (BAU) scenario. This figure is also reflected in the 2018 Ecodesign Impact Accounting report.

The SRI that started in 2014 is more stringent than is assumed in the Lot 3 study: The 2017 SRI Review Report of the sector claims a saving of 2.4 TWh/yr in 2016 and projects –with Tier 4 implemented—a saving of 5.1 TWh/yr for UHD-capable game consoles in 2020. [168] The 2019 SRI Review Report by the industry claims an energy saving of 6.8TWh/year in the EU since the beginning of the SRI in 2014.

The 2019 Commission's Review Study[169] more or less confirms the claims of the industry review, showing the 2020 baseline (BAU, i.e. without SRI) for the 8th generation of game consoles, which is practically the whole installed base, to be 13.2 TWh/yr in 2020. The

[167] This occurs when the backlight uses fluorescent light sources. 'Mercury-free' means less than 0.1% Hg.

[168] Koomey, J. et al., REPORT ON THE 2017 REVIEW OF THE GAME CONSOLE SELF-REGULATORY INITIATIVE, July 2017.

[169] CSES, Ökopol, TU Wien, Review Study of the Ecodesign Voluntary Agreement for the Product Group "Videogames Consoles", study for the European Commission, 2019.

actual EU energy consumption, with the figures from SRI, is estimated at 6.6 TWh/yr in that year, i.e. a saving of 50%.
In their Jan. 2020 position paper[170], the green NGOs (ECOS, Coolproducts, EEB) are nonetheless critical of the latest proposed SRI. Amongst others, they propose to shave 20W off the proposed power caps in navigation mode, so 50W instead of 70W and 30W instead of the proposed 50W limits in Tier 4.
Please note that –to a large extent-- 'savings' is subjective. The 'Business-as-Usual' benchmark, i.e. what would have happened without a policy measure, is not known. In the 2010 Lot 3 preparatory study it was proposed to use the computational efficiency in gigaFLOPs per Watt input power in Play Game ('active') mode as a measure. At that time a HD game offered 2210 gigaFlops at 99 Watts, which comes down to (rounded) 22 gigaFLOPs/W. On that basis the Lot 3 study concluded that for a future games console providing graphics processing power at 4.64 teraFLOPS the Game Play mode power demand based on current efficiencies would be 211 W. Following that logic, the PS4 Pro (4.2 teraFLOPS[171]) should use around 200W in active gaming mode. Instead, as the table above shows, it uses only 136W, so one-third less. The Xbox One X (6 teraFLOPS) should use 272 W in active mode but uses only 149W, i.e. 45% less. Another yardstick for the relative saving is the comparison with the best graphics cards (GPUs) around. In that sense, while in 2010 there was still a difference by a factor of two in processing power compared to the best game consoles, the new Xbox X series is up there with the best, at a lower price[20] .
All in all, this shows some consistency with the savings in the numbers mentioned in the various studies, especially when also factoring in the improved performance and efficiency of the storage devices.

5.3.4 Summary

The table below is a corrected time series of sales, stock, price, TEC of the new products and EU energy consumption with ('ECO') and without ('BAU') the Self-Regulatory Initiative. The data are mainly derived from the 2019 Commission's review study. The largest uncertainty is in the data for the BAU scenario, i.e. what would have happened without the SRI. For that reason, the BAU scenario data are slightly more conservative than in the aforementioned review study.
Note that the energy use of the infrastructure for game streaming is not included here, as this is included in the figures for data centres (section 2) and telecommunication equipment (section 3).

Table 56: VIDEO game consoles summary table

Parameter	1990	2010	2015	2020	2025	2030	2035	2040	2045	2050
SALES (000 units)	-	11500	11500	11500	11500	11500	11500	11500	11500	11500
STOCK (000 units)	-	65000	65000	65000	65000	65000	65000	65000	65000	65000
PRICE (euros 2010)	na	389	389	389	389	389	389	389	389	389
TEC BAU (kWh/yr)	na	120	140	200	250	250	250	250	250	250
TEC ECO (kWh/yr)	-	120	110	100	90	90	90	90	90	90
ENERGY BAU (TWh/yr)	-	7,8	9,1	10,4	11,1	11,1	11,1	11,1	11,1	11,1
ENERGY ECO (TWh/yr)	-	7,8	7,2	6,5	5,9	5,9	5,9	5,9	5,9	5,9
ENERGY SAVE (TWh/yr)	-	-	1,9	3,9	5,2	5,2	5,2	5,2	5,2	5,2

[170] https://ecostandard.org/wp-content/uploads/2020/01/10.01-ECOS-eNGO-Comments-on-Games-Consoles-VA.pdf
[171] https://www.thumbsticks.com/xbox-series-x-12-teraflops-big-deal-good-number/

5.4 Interactive whiteboards

5.4.1 Definition

In Ecodesign Regulation (EU) 2019/2021 on electronic displays[172], 'digital interactive whiteboards' are exempted from requirements in Annex II, A and B (on-mode energy efficiency limits). In Art. 2 of the regulation they are defined as follows:
(14) 'digital interactive whiteboard' means an electronic display which allows direct user interaction with the displayed image. The digital interactive whiteboard is designed primarily to provide presentations, lessons or remote collaboration, including the transmission of audio and video signals. Its specification shall include all of the following features:

a) *primarily designed to be installed hanging, mounted on a ground stand, set on a shelf or desk or fixed to a physical structure for viewing by several people;*
b) *to be necessarily used with computer software with specific functionalities to manage content and interaction;*
c) *integrated or designed to be specifically used with a computer for running the software in point (b);*
d) *a display screen area greater than 40 dm2;*
e) *user interaction by finger or pen touch or other means such as hand, arm gesture or voice;*

5.4.2 Market

Standard whiteboards have been used commonly as a way for people to share messages, present information and engage in collaborative brainstorming whilst also developing ideas. . With the same cooperative goals in mind, interactive whiteboards have the ability to connect to the Internet and instantly digitize tasks and operations.

The technology behind interactive whiteboards varies between large format screens with a standalone system on a chip (SOC) and combinations of video projectors or smart projectors that use a tablet or other devices with drivers for user interaction. Forms of operation are often either by infrared or resistive touch, magnetic or ultrasonic pen.

Futuresource reports quarterly global sales of 702,000 interactive displays in 2019Q3. This is a small decrease year-on-year but still 5% better than the previous quarters. Overall 2019 sales can thus be estimated at 2.8 million. Assuming a 20% market share for the EU, this means an annual market of 560,000 units.[173]

In the EU28 there were a little less than 100 million people enrolled in school (excluding pre-school) of which 29 mln. in primary, 23 mln. in lower secondary, 24 mln. in upper/post-secondary schools and 19 mln. in tertiary education. The average classroom size was 24-25 pupils in primary/secondary school[174], so assuming that there are 25 per 100 mln.

[172] COMMISSION REGULATION (EU) 2019/2021 of 1 October 2019 laying down ecodesign requirements for electronic displays pursuant to Directive 2009/125/EC of the European Parliament and of the Council, amending Commission Regulation (EC) No 1275/2008 and repealing Commission Regulation (EC) No 642/2009, OJ, L315, 4.12.2019, p. 241

[173] https://www.futuresource-consulting.com/reports/categories/pro-av/pro-displays/interactive-displays/

[174] The OECD Teaching and Learning International Survey (TALIS) 2013 Results - Excel Figures and Tables.

people enrolled and one whiteboard per "classroom", the total potential EU market for educational interactive whiteboards is 4 million. In addition, , there might be an interactive whiteboard market for the 0.2 million vocational training institutes and in-company training sessions. This might bring the total market potential to 5 million units. Assuming, as in the case of projectors, a product life of 6-7 years, the sales in a mature EU market would be in the range of 700-800,000 units per year. This means that compared to the 560,000 units mentioned before, there is still some (small) potential for growth in the EU.

5.4.3 Energy

Table 10 below shows recent models of sales on the internet. Average normal energy consumption is 107W with a peak power of up to 294W and a standby power of 9W. The latter is mainly due to 4 models with a standby power in the range of 15-77W; the others have a standby power in the range of 0.3 to 5W. The average product has a screen area (diagonal) of 73" and a product weight of 70 kg and an UHD (4K=3840x2160 px) resolution.

No publication of a typical electricity consumption (TEC) duty cycle could be retrieved but, – assuming an average classroom use similar to the video-projectors—the on-mode would be 3 h, standby 6 h and off-mode 15 h. Using the averages mentioned before, and 0.5 W for off mode power, this would lead to 321 Wh/d in on-mode, 54 Wh/d in standby and 7.5Wh/d. In total this is 382.5 Wh/d and –at 220 working school days per year—84 kWh/year.

Table 57: Interactive whiteboards, selected models Dec. 2019 (misc.internet sources, VHK 2019)

Brand	Model	Energy usage normal (W)	Energy usage maximum (W)	Stand by (W)	Screen area (")	Weight (kg)	Reso-lution
SMART Board™ Interactive Whiteboard	V280				77	13,6	4096 × 4096
SMART Kapp® 84 board		15			84	25,9	
SMART Kapp® 42 board		10			42	16	
SMART Display 2075		205		<0,3	75	31,6	UHD
SMART Board 6075	SPNL-6275	190	315	19	75	84	UHD
SMART Board 6065 V2	SPNL-6265-V2	113	189	15	65	60,9	UHD
SMART Board® 7000 series	7275		260	2	75	103	UHD
SMART Board® 7000 series	7375		260	2	75	103	UHD
SMART Board® 7000 series	7286		280	2	86	117	UHD
SMART Board® 7000 series	7386		280	2	86	117	UHD
Ricoh	D8400		564	50	84	104	UHD
Ricoh	D7500		420	0,5	75	93	UHD
Ricoh	D6510		350	0,5	65	60	HD
Ricoh	D5520		255	0,5	55	46	HD
AVERAGE		107	317	9	73	70	UHD

Note that, while digital interactive whiteboards are exempted from on-mode energy limits, they have to comply with the other power limits in regulation (EU) 2019/2021, i.e. 0.3 W in off-mode, 0.5W in standby (allowances: +0.2W with status display, +0.5W with presence detector, +1W with touch functionality if usable for activation), 2 W in networked standby (with the same allowances as for normal standby, +4W with High Network

Availability). Several Auto Power Down requirements apply as well as the Material Efficiency requirements regarding recycling and recovery, plastics marking, flame retardants, cadmium logo, repair and re-use. Last but not least, the availability of software and firmware updates is addressed.
Prices for example for a 77” board are close to €1000.

5.4.4 Summary

The table below is a time series of sales, stock, price, TEC and EU energy consumption.

Table 58: Interactive whiteboards

Parameter	1990	2010	2015	2020	2025	2030	2035	2040	2045	2050
SALES (000 units)	0	200	420	560	700	750	750	750	750	750
STOCK (000 units)	0	200	2000	3000	4000	5000	5000	5000	5000	5000
PRICE (euros 2010)	-	2000	1500	1000	900	850	850	850	850	850
TEC (kWh/yr)	-	84	84	84	84	84	84	84	84	84
ENERGY (TWh/yr)	-	0.017	0.17	0.25	0.34	0.42	0.42	0.42	0.42	0.42

5.5 All-in-one video conference systems

In Ecodesign Regulation (EU) 2019/2021 on electronic displays ‘all-in-one video conference systems’ are exempted. In Art. 2 of the regulation they are defined as follows:

5.5.1 Definition

(11) ‘all-in-one video conference system’ means a dedicated system designed for video conferencing and collaboration, integrated within a single enclosure, whose specification shall include all of the following features:

a) support for specific video conference protocol ITU-T H.323 [175]or IETF SIP[176] as delivered by the manufacturer;
b) camera(s), display and processing capabilities for two-way real-time video including packet loss resilience;
c) loudspeaker and audio processing capabilities for two-way real-time hands-free audio including echo cancellation;
d) an encryption function;
e) HiNA (High Network Availability as defined in Art. 2 of Regulation (EC) No 1275/2008);

In the networked standby regulation (EU) 801/2013 177, amending art. 2, there is a definition of ‘tele-presence’:

[175] ITU-T H.323, TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU (12/2009), SERIES H: AUDIOVISUAL AND MULTIMEDIA SYSTEMS, Infrastructure of audiovisual services – Systems and terminal equipment for audiovisual services, Packet-based multimedia communications systems

[176] Internet Engineering Task Force (**IETF**), Session Initiation Protocol

[177] COMMISSION REGULATION (EU) No 801/2013 of 22 August 2013 amending Regulation (EC) No 1275/2008 with regard to ecodesign requirements for standby, off mode electric power consumption of electrical and electronic household and office equipment, and amending Regulation (EC) No 642/2009 with regard to ecodesign requirements for televisions. OJ, L255, p.1, 23.8.2013

"tele-presence system" means a dedicated system for high-definition video conferencing and collaboration which includes a user interface, a high-definition camera, a display, a sound system and processing capabilities for encoding and decoding video and audio;

5.5.2 History & Market

Video conferencing has now been around for a few decades starting with troublesome ISDN-based systems (H.320) but currently using ASDL or better over the internet. The 'all-in-one' systems are intended for boardroom meetings, featuring a configuration of compatible camera, microphone, speaker system with sometimes a codec and sometimes a display. These components can be physically integrated but can also be separate. Examples of video conferencing hardware and 2019 US prices are given in the table below

Table 59: Videoconferencing systems US (source: Cawley, 2019178)

brand	price	configuration includes
Polycom RealPresence	$3,000 to $17,000	microphone, camera, codec
Cisco Webex DX	$3,250and $4,490	14- and 23"screens with mounted cameras
Avaya XT	$8,000-$10,000	9-way multi-party calling, camera, codec
Lifesize Icon	$3,000+	audio, double screen support, camera
Logitech MeetUp	$900-$1,080	all-in-one camera
Polycom Studio	$950	sound bar, microphone, camera
AVer EVC	$9,000	camera, microphone, codec
GoToMeeting – GoToRoom	$1,600-$2,000	camera-speaker-microphone, codec, display
ezTalks Rooms	$700-$2,800	display-camera-speaker-microphone combo
PTZOptics Camera	$1,870-$1,980	camera-microphone-speaker

Video Conferencing software includes: *Webex, Lifesize, RingCentral Meetings, Skype for Business, Zoom, Join.me* and *GoToMeeting*.

According to Futuresource, video conferencing global hardware shipments increased by 50% in 2018, reaching 1.4 million units, with a projected CAGR of 27% 2022.[179] Revenues reached $3.8 billion ($2700/unit) and over four million meeting rooms are now equipped with video conferencing technology.
Assuming a 20% regional share for Europe this means 0.28 million units in 2018 and 0.45 million units in 2020. With 24.9 million enterprises and 129 million employees in the EU27 [180] as well as a trend to more remote working and more (possibly remote) meetings, these numbers can be expected to grow substantially.

5.5.3 Energy

For the energy use of video conference rooms there are only manufacturer's data to go by.. For a system with one or more displays:

- Cisco Webex Room 55 (meeting room up to 7 people, 55"display with integrated camera and speakers, microphone, touch controller.): Max. Power 142W, Sleep-mode 40 W.
- Cisco Webex Room 70 (as 55 but with 70"display): single screen: 258W. dual screen: 470W in normal operation.

[178] Conor Cawley, Best Video Conferencing Equipment 2020, March 28th 2019. https://tech.co/web-conferencing/best-video-conferencing-equipment#pricequote

[179] https://futuresource-consulting.com/press-release/professional-av-press/video-conferencing-hardware-to-ship-36-million-units-

[180] Eurostat extracted March 2020 for 2017 in EU27 (EU28 minus UK), https://ec.europa.eu/eurostat/statistics-explained/images/5/57/BD_2019_publ_data_28.1_clean-update-REV.xlsx Note that depending on source and scope these numbers can be 10% less (e.g. OECD) or much more (e.g. including all self-employed)

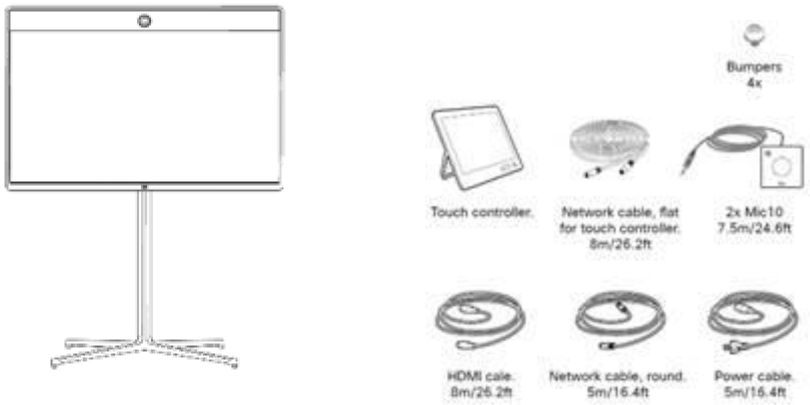

Figure 48. Cisco Webex Room 55 system

For a system without display:

- Dolby Voice Room that is used e.g. by GoToMeeting and that includes a voice hub, microphone, camera and speaker, the active mode power is 24W (peak 30W) and the idle mode is <3.8W.[181]
- Cisco Webex Room Kit: 20W in normal mode (70W peak)[182]

Taking the average on-mode of Room 55 and the Voice Room, the on-mode power of a video conferencing system is estimated at 80W. For standby/idle 20W power is assumed. Assuming the usage pattern as for an office projector: Office projectors: on-play 1.5h @80W, standby 8h @20W, off-mode 14.5h @0.5W, total 287 Wh/d, 220 days→ 63 kWh/year.

5.5.4 Summary

At this moment there is not enough information to conclude what the energy use is beyond normal PC use of specific video conferencing product/facilities. If appropriate this will be investigated later in the study.

5.6 MP3-players

5.6.1 Definition

MP3-files and other digital audio file formats can be played on almost any electronic device with an external (e.g. USB memory, SD card) and/or internal (SSD, HDD, etc.) memory as well as either a headphone connect and/or wired/wireless speaker(s). The players can be battery charged or mains operated. Examples range from smartphones to televisions, from smart speakers (discussed hereafter) to car radios and PCs. Stand-alone MP3-players also still exist but targeted at niche markets.

[181] https://www.dolby.com/us/en/professional/products/dolby-voice-room/data-sheet.pdf
[182] https://www.cisco.com/c/en/us/products/collateral/collaboration-endpoints/spark-room-kit-series/datasheet-c78-738729.html

5.6.2 History & Market

MP3 players came onto the market as the compact on-the-go audio gadget in 1999[183] , following up on e.g. the more bulky portable disc and cassette players like the Sony Walkman. After about a decade and the rise of the smartphone, the interest in dedicated mp3 waned. Large manufacturers like Apple brought out their last innovative models (iPod) in about 2015. While the format has been surpassed by AAC and others, there are still (semi-) dedicated MP3-players being sold in some niche markets. For instance, the iconic Apple iPod still plays music but is now more of a handheld game console. Other mp3-players connect to streaming audio through WiFi and to speakers with Bluetooth; as such they replace what used to be (mini) HiFi audio installations. The largest niche is probably the mp3 player for runners who do not want the weight and the damage-risk of bringing their smartphones with them whilst exercising.

Dedicated MP3 players vary in price and range from 5 to 350 euros. If they are only used for listening to audio, they charge in 2-3 hours and last for 30-80 hours of audio play. Energy use of audio-only types is typically (far) below 1 kWh/year.
The last more or less serious market report stems from 2015 and reports a global market of about 10 million units in that year, with 27% of sales in China and almost 20% in the US. Assuming that sales in Europe are at about 20% , this translates to about 2 million units sold. Today (2020) it is probably less.[184]

5.6.3 Energy

At the very most it is estimated that 50 million dedicated MP3 players might still be used on a regular basis. Assuming a 1 kWh/year electricity use per unit, this means 0.05 TWh/year. This is definitely the worst case scenario and could also be half of that number. Still, even at worst case numbers, the energy use is negligible in a policy context.

5.6.4 Summary

Dedicated MP3 players appear only in niche markets. Energy use in the worst case scenario is estimated at 0.05 TWh/year per year.

[183] https://www.techtimes.com/articles/207213/20170513/the-mp3-is-dead-heres-a-brief-history-of-mp3.htm
[184] https://www.marketwatch.com/press-release/global-mp3-player-market-2020-industry-analysis-chain-economics-segment-overview-forecast-2024-2020-01-24

5.7 Stand-alone home audio equipment

5.7.1 Definition

Stand-alone home audio equipment comprises radios with or without tape/CD recorders and hi-fi stereo equipment. This includes micro- and rack systems as well as receivers[185], amplifiers, tuners, CD players/recorders, tape players/recorders, etc. . Sound systems (sound bars or dedicated speakers) for televisions can be considered for inclusion; these started out by normal stereo equipment being connected to the TV in the 1980s before moving to dedicated TV sound systems later on. Speaker systems, which are in themselves –with a few exceptions[186]-- not energy-using but rather energy-related products, are an essential part of home audio equipment. The category is called 'stand-alone', even though radio receivers work with antennae.

5.7.2 History & market

Audio equipment in the home in the form of radios, started almost 100 years ago. Audio furniture incorporating radio record players and speakers came into Europe in the 1950s. Portable radios and record players in the 1960s, tape recorders (for audio enthusiasts) then followed. Cassette-recorders (portable and in-systems) took off in the late 1960s. In the 1970s, HiFi stereo component systems became popular, integrated or stacked as 'towers' of single components. CD-players, being the first medium for digital music were introduced in the 1980s. In the 1990s, as mentioned above, specific sound systems for TVs entered the market, e.g. with 'surround sound' with 5+1 speakers, while nowadays 'sound bars', integrated multi-speaker systems, seem to be the more popular, less invasive sound solution. The mid-1990s also saw the beginning of streaming (digital) audio, i.e. in the form of mp3 files that was discussed the previous section. In the most recent years this developed in *streaming audio* also becoming popular in (wireless) network connected audio products (NCAP) that will be discussed in the next section.

Estimates of the stock of individual audio products is given in combination with the energy use in the next paragraph.

5.7.3 Energy

European investigations of the on-mode energy consumption of audio equipment are rare. They are not specifically investigated in the DG GROW Lot3 study on sound and imaging equipment. There are some small surveys, like the 2016 report by Shift[187]. The most comprehensive study carried out in the US is from 1999 by Rosen and Meier of LBNL[188]. The next table shows the results from that study only slightly adjusted for the EU27 in the sense of fewer hours of television usage (4h/day instead of 6.5 in the US) and the outcome per household is multiplied by EU27 (i.e. excl. UK) total households.

[185] Meaning an amplifier with integrated tuner.

[186] E.g. self-powered (sub)woofer systems

[187] Shift Innovatie -Analyse huishoudelijke apparaten, studie voor klimaatbureau HIER, Nov. 2016

[188] Karen B. Rosen and Alan K. Meier, Energy Use of Home Audio Products in the U.S., LBNL, December 1999

Table 60: Home audio equipment stock and energy use in EU27, year 2000 (source: VHK 2020 on the basis of Bosen and Meier 1999)

Parameter	Unit	Clock radio	Portable stereo	Compact stereo audio only	Compact stereo +TV use	Component stereo audio only	Component stereo +TV use	Total
Ownership	hh≥1unit	84%	56%	40%		65%		
Units/owner	#units	1.5	1.2	1.16		1.12		
Saturation	units/hh	126%	67.0%	38.6%	7.4%	30.0%	43.0%	312%
Usage (h/day)								
Tuner/Line-play	h/d	0.36	0.72	0.72	4	0.72	4	3.4
Tape/CD-Play	h/d		0.72	0.72	0.72	0.72	0.72	1.3
Idle	h/d	0	3.12	4.56	3.28	4.56	3.28	6.9
Standby	h/d	23.64	12.2	18.00	16.00	18.00	16.00	58.4
Disconnect	h/d		7.24					4.9
Power (W)								
Tuner/Line-play [1][4]	W	2.0	5.0	21.0	21.0	42.9	42.9	46.8
Tuner/Line-idle [2]	W			20.0	20.0	42.9	42.9	40.5
Tape-Play	W		5.9	22.0	22.0	47.1	47.1	48.5
Tape-idle	W		4.0	20.0	20.0	42.9	42.9	43.2
CD-Play	W		8.6	24.0	24.0	47.1	47.1	51.2
CD-idle	W		5.8	21.0	21.0	42.9	42.9	44.9
Standby [3]	W	1.7	1.8	9.8	9.8	3.0	3.0	10.0
Energy per unit (kWh/year)								
Radio/Line Play	kWh/yr	0.3	1.3	5.5	30.7	11.3	62.6	
Tape/CD Play	kWh/yr		1.9	6.0	6.0	12.4	12.4	
Line/Tape/CD Idle	kWh/yr		5.6	50.8	36.5	107.1	77.0	
Standby	kWh/yr	14.7	8.0	64.4	57.2	19.7	17.5	
TOTAL	kWh/yr	15	17	127	130	150	170	
Energy per EU household (kWh/year)								
Radio/Line Play	kWh/yr	0.3	0.9	2.1	2.3	3.4	26.9	35.9
Tape/CD Play	kWh/yr	0.0	1.3	2.3	0.4	3.7	5.3	13.1
Line/Tape/CD Idle	kWh/yr	0.0	3.7	19.6	2.7	32.1	33.1	91.3
Standby	kWh/yr	18.5	5.4	24.9	4.2	5.9	7.5	66.4
TOTAL	kWh/yr	18.8	11.3	48.9	9.7	45.1	72.9	207.0
TOTAL EU27(excl. UK), TWh/yr								
Year 2000 (165 m. households)		3.1	1.9	8.1	1.6	7.4	12.0	34.1

[1] Play-mode power: Receiver 35W, Amplifier 32W, Tuner 7.4W, Tape 8.9W, CD-player 10.3W, Rack system 51W. Split: 80% receiver systems, 10% amplifier systems, 10% rack system. Weighted over different configurations, weighted average Tune/Line play-mode is 42.9W, Tape/CD play-mode 47.1W

[2] Idle-mode (=on, but no music) power: Receiver 33W, Amplifier 30W, Tuner 7.4W, Tape 6.5W, CD-player 8.3W, Rack system 49W. Split: 80% receiver systems, 10% amplifier systems, 10% rack system. Weighted over different configurations, weighted average Tune/Line idle-mode is 42.9W, Tape/CD idle-mode 47.1W

[3] Standby power: receiver 1,8; amplifier 1,1; tuner 1,5; tape player 1,6; CD player 1,8

[4] TV-use in US was 6.5 h (1999) but in the EU 4h

The above data was checked for consistency with the standby power and usage pattern in the 2006 Fraunhofer preparatory study for the standby Ecodesign regulation[189]. The Fraunhofer study found 1.5W standby power for the radios in 2005. It also shows 2005 sources for portable stereos with active standby power up to 6.4W. The same study finds 8W standby power and 1.5W off-mode power for the compact stereo system in 2005. Fraunhofer (2006) also gives some power data from 1999-2001 sources, i.e. micro-midi systems with average 3.2-11.3W in standby and 1.3-8.1W in off mode. For an integrated stereo system 19.1W in active standby, 9.4W in passive standby and 3.5W in off-mode.
As regards usage, Fraunhofer (2006) assumes for the radios 1h/d in on-mode and 23h/d in standby. For mini audio systems the study estimates 3.4h/d 'on' (includes 'idle', i.e. on

[189] Fraunhofer IZM, EuP Preparatory Study Lot 6 "Standby and Off-mode Losses", for the EC, Oct. 2007.

but no music), 17.1h standby, 1.4 off, 3.4h disconnected. The saturation of the audio system is assumed to be 60%.

Based on these data, the study team finds it plausible to assume that the data from the LBNL 1999 US study with a small correction for TV usage (4h instead of 6h), can also be used for the EU in the year 2000.

The total EU energy consumption in the year 2000 is thus estimated to be 34.2 TWh/year. This is around 5% of the EU27 electricity consumption in that year. Note that 40% of the energy use, i.e. 13.7 TWh/year, is due to audio enhancement of the TV sound; strict audio use is 20.4 TWh/year. Also note that, during this time, 76% of electricity use was due to idle and standby mode.

The table also allows to calculate that in a 'Business-as-Usual' (BAU) EU total for 2018 (194 m. households) the energy use would be 40.1 TWh/yr. However, due to Ecodesign measures on standby (and auto power down) in Regulation (EC) No 1275/2008 [190] as well as similar measures around the world, this figure has to be adjusted downwards.

A more recent (2016) survey for the Dutch NGO HIER shows an on-mode energy use for

- a small micro-system of 24W in on-mode and 0.2W in standby, resulting in 19 kWh/yr at 2 h/d active use (1h playing, 1h idle before power down);
- a large micro-system of 52W in on-mode and 0.5W in standby, resulting in 42 kWh/yr at 2 h/d active use (1h playing, 1h idle before power down);
- an average soundbar of 30W on-mode and 0.45W in standby resulting in 47 kWh/yr at 4h/d on.

5.7.4 Summary

In total, assuming a 50% saturation for each of the three devices above, electricity consumption is 54 kWh/year. Including a portable radio, 1 h/d at 2W in on-mode and 0.5W in standby, and some personal audio this gives around 60 kWh/household per year. The EU total in 2018, not yet taking into account the networked audio, would thus be 11.6 TWh/year, i.e. 28.5 TWh/yr, i.e. two-thirds lower than in the BAU. Having said that, the market penetration of soundbars is likely to continue as will the rise of networked connected audio.

5.8 Network Connected Audio Products (NCAP)

5.8.1 Definition

A *smart speaker* is a type of wireless speaker and voice command device with an integrated virtual assistant that offers interactive actions and hands-free activation with the help of one (or several) "hot words" (for activation)[191]. Some *smart speakers* can also act as a smart device that utilizes Wi-Fi, Bluetooth and other wireless protocol standards to extend usage beyond audio playback, such as to control home automation devices. This can include, but is not limited to, features such as compatibility across a number of services and platforms, peer-to-peer connection through mesh networking, virtual assistants, and others. Each can have its own designated interface and features in-house, usually launched

[190] COMMISSION REGULATION (EC) No 1275/2008 of 17 December 2008 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for standby and off mode electric power consumption of electrical and electronic household and office equipment OJ, L339, 18.12.2008, p. 45 (audio equipment is included, as stated in Annex I)

[191] Source: https://en.wikipedia.org/wiki/Smart_speaker

or controlled via application or home automation software[192]. Some smart speakers also include a screen to show the user a visual response.

A smart speaker with a touchscreen is known as a smart display[193] [194]. While similar in form factor to tablet computers, smart displays differ in their emphasis on a hands-free user interface and virtual assistant features[195].
A *wireless speaker* is a speaker that is connected to a home network (usually through wifi) to 'stream' audio, to speakers connected to that same home network and often can be controlled through an app on a smartphone. *Wireless speakers* can incorporate smart speaker technology as defined above.

5.8.2 Market

As of winter 2017, it is estimated by NPR and Edison Research that 39 million Americans (16% of the population over 18) own a *smart speaker*[196].
Mordor Intelligence estimates the global Bluetooth audio streaming device market in 2018 to be 880 million units, up from 400 million units in 2013 and projected to reach 1230 million units in 2022.[197] The European market is 25% of the global market for this product according to another source.[198] At the predicted rates the average EU households would own several bBluetooth speakers and this seems too optimistic.

Instead, we assume half of the Mordor global estimates and take 20% for the EU27. This means EU27 sales are at 88 million in 2018, up from 40 million in 2013 and moving up to 123 million in 2022. With a product life of 5 years, this still means 272 million smart/wireless speakers installed in 2020, on average more than one per EU27-household.

5.8.3 Energy

Networked Audio Products are in the scope of the Ecodesign regulations on (networked) standby. The current standby regulations give 0.5/1/1W power limits for off-mode/standby/standby + status display. For HiNA networked standby the limit is 8W and for other networked standby it is 2W. Draft proposals of the Commission for a revision aim of 0.3W in off-mode and 2W in other-than-HiNA limits.
Internet sources state that the most recent generations of *smart (and/or wireless) speakers* will use between 1.7 and 4 W in standby, 30-50% more with normal use (25% volume) and twice as much with maximum volume [199] [200] [201]. With WiFi disabled, the standby/idle mode will use around 1W less.

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[192] https://whatis.techtarget.com/definition/smart-speaker

[193] *Brown, Rich. "Echo Show, Nest Hub, Facebook Portal and more: How to pick the best smart display in 2019". CNET. Retrieved 2019-06-19.*

[194] *Faulkner, Cameron (9 October 2018). "How Google's new Home Hub compares to the Echo Show and Facebook Portal". The Verge. Retrieved 2019-06-19.*

[195] *Lacoma, Tyler (October 26, 2018). "What is a smart display?". Digital Trends.*

[196] *The Smart Audio Report from NPR and Edison Research, Fall-Winter 2017 (PDF)*

[197] https://www.mordorintelligence.com/industry-reports/global-bluetooth-speaker-industry

[198] https://www.grandviewresearch.com/industry-analysis/portable-bluetooth-speakers-market

[199] https://www.howtogeek.com/348219/how-much-electricity-does-the-amazon-echo-use/

[200] https://www.the-ambient.com/features/power-smart-home-tech-yearly-cost-374

[201] https://support.sonos.com/s/article/256?language=en_US

The 2017 review study on standby by Viegand Maagoe[202] gives an overview of collected data on networked standby in *smart/wireless speakers* (and audio equipment). When searching the market for these products, the study team found that there are some *smart speakers*, typically multi-room speakers, which can connect to several other devices (speakers and audio sources). The kind of network they are establishing is called a mesh network which is a network topology in which each node relays data to and the network. The individual speakers function as end devices but at the same time multiple clients (other speakers and audio sources) can connect to them. The study team consider these speakers to have HiNA functionality because they "...provide IEEE 802.11 (Wi-Fi) connectivity to multiple clients", which is the part of the definition in the Regulation of 'wireless network access point', which again makes the product a HiNA product or with HiNA functionality. These products were therefore removed from the dataset for the figure below.
There are variations of this Wi-Fi mesh network e.g. with a combination of Bluetooth streaming to one speaker, which distributes the audio to one or multiple speakers. Of the 41 non-HiNA wireless speakers and audio equipment, 22 are under 2 W and the rest between 2.3 W and 6.0 W. One outlier consumes 13 W but it is not completely certain if the consumption is for networked standby rather than another state with additional functionality.

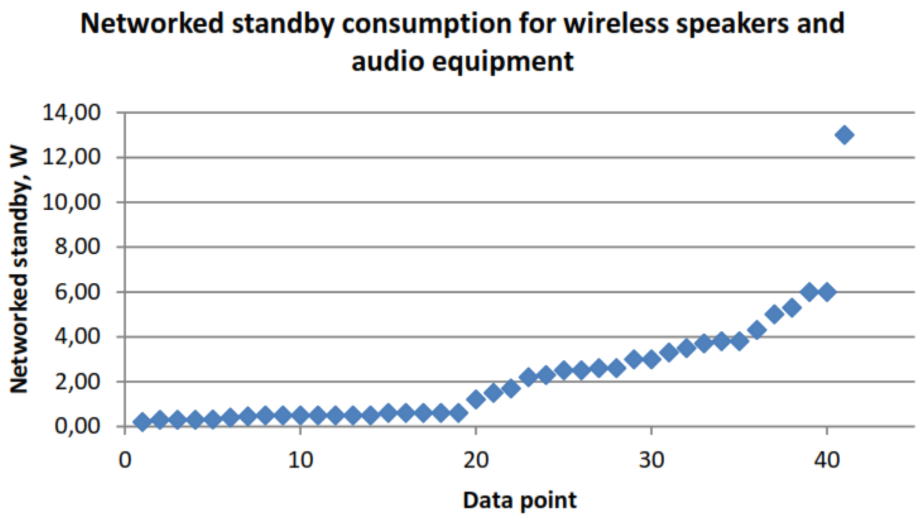

Figure 49: Wireless speaker networked standby power (Viegand Maagoe 2017)

In 2016 an IEA report was published on NCAP in the IEA 4E Annex[203]. It describes 3 possible set-ups for network connected speakers or amplifiers and measured power use especially in standby mode for:

1. Smartphone to LAN to NCAP;
2. Smartphone via Bluetooth to NCAP (WiFi);
3. Wifi Router with multiple sources (external streaming services, NAS, smartphone) and multiple NCAP 'sinks' (amplifier, speaker or adapter-to-stereo-system).

The results of the measurements are shown below.

Table 61. Measurement results of purchased products

	NCAP	Function	Active	Idle	Network Standby	Deep Standby
System1	Product a	Speaker	3.1	1.6	1.3	n.a.
System1	Product b	Adapter	3.0	1.5	1.3	n.a.

[202] Viegand Maagoe: Review study on Standby Regulation(EC) No 1275/2008, Final report-Draft version for the EC, 7 April 2017.

[203] Kaufmann, L. and Kyburz, R., Network Connected Audio Products, measurements and analysis, report for IEA 4E EDNA, July 2016.

System2	Product c	Speaker	6.0	5.0	n.a.	n.a.
System2	Product d	Amplifier	19.5	6.1	n.a.	n.a.
System3	Product e	Speaker	3.5	3.1	2.1	0.5

5.8.4 Summary

The market data especially for this product are not very reliable. For the moment we will assume a 2020 stock of 272 million units as a place holder, operating 1h/day for 365 days at 5W and 23h 1W standby. This gives 28Wh/d and thus 10 kWh/unit per year. With 272 units installed this gives 2.7 TWh/yr.

5.9 Complex set-top boxes (CSTBs)

5.9.1 Definition

Complex set-top boxes (CSTBs) are subject to an Ecodesign-regulated Voluntary Agreement (VA) since 2011,and this was last updated in 2017 [204]. In the VA, the CSTB is defined as:

A CSTB is a device equipped to allow conditional access to TV broadcasts by descrambling using dynamically allocated keys, where the primary function of the device is the reception, descrambling and processing of data from digital broadcasting streams and related services. It may also have audio and video decoding and output capability and/or the ability to provide content to one or more dedicated Thin-Client/Remote CSTBs via a home network, and/or gateway and routing functions.

For the purposes of the Voluntary Agreement a device shall not be considered to be a CSTB unless it can fulfil the functions of a CSTB when activated by the operator of the network.

A Simple STB, as defined in Annex F, is outside the scope of this Voluntary Agreement. For avoidance of doubt, the use of fixed key descrambling or the inclusion of an HDMI interface and/or Huffman coding does not make a STB that would otherwise be classified as a Simple STB into a Complex STB. Also excluded from the scope of this Voluntary Agreement are devices whose primary function is something other than the reception of television signals, such as, but not limited to:

- *Computers fitted with digital TV tuners or TV add-in cards;*
- *Games consoles with digital TV tuners;*
- *Digital receivers with recording function based on removable media in a standard library format (VHS tape, DVD, Blu-ray disc and similar);*
- *Digital TVs with integrated receiver decoder;*
- *External plug in digital receivers for computers (e.g. USB).*

5.9.2 History and Market

Since 2008 CSTBs have been pushing the *simple set-top boxes* out of people's homes and have reached almost full saturation in the EU. Most competition comes from pay-TV operators (Netflix, Apple TV, etc.) also using other platforms such as PCs, tablets and smartphones, possibly linked to a larger display. Market researchers state that the current

[204] Voluntary Industry Agreement to improve the energy consumption of Complex Set Top Boxes within the EU, Proposal from the industry group, Version 5.0,
2nd September 2017. See www.cstb.eu

multi-screen trend may also help, as providers also start to offer multimedia home gateway (MHG) STBs.

The VA was negotiated, when there were no specific rules. It covered 70% of devices deployed on the European market. In November 2016 the Commission published updated guidelines for VAs. VAs are now required to have a market coverage of 80%. At the Consultation Forum in June 2018, the Commission gave the signatories until the end of Q1 2019 to bring up their market share, otherwise they would withdraw their support and launch the regulatory process. The regulatory process should take about 5 years[205].

According to EIA 2018 the EU28 sales of CSTBs have risen from 34 million units per year in 2010 to 44 million units in 2020. Given the HISreport of 269 million global sales for 2017 this would mean an EU market share of 17%, which is plausible[206].

With a product life of 5 years EIA expected an EU28-stock of 80 million in 2010, 195 million in 2015 and 218 million units in 2020. For the new EU27 the sales and stock are expected to be about 13% lower, i.e. a stock of 193 million and sales of 39 million units. From 2020 onwards it is expected that the market will have stabilised and sales and stock will stay at roughly the same level.

5.9.3 Energy

The VA has 20 signatories: 10 equipment manufacturers, 6 service providers and 4 other signatories. The Independent Inspector for the VA (Ecofys) found a compliance rate of 98-99% in its 2017 report but also found some issues linked to the testing of the compliant devices.[207].

The 2017 review study on standby by Viegand Maagoe[208] gives an overview of the average power and annual energy consumption according to the TEC-cycle under various agreements and measures.

Table 62. Average power of complex set-top boxes according to the EU voluntary agreements, EU Code of Conduct and Energy Star (source: Viegand Maagoe, 2017)

Scheme	Adder Type and kWh/year	Average power W
Voluntary Industry Agreement to improve the energy consumption of Complex Set Top Boxes within the EU Version 3.1 19 June 2013 Tier 2	DOCSIS 3.0 50 kWh/yr	5.7
Voluntary Industry Agreement to improve the energy consumption of Complex Set Top Boxes within the EU Proposal from the industry group, Version 4.0 16th July 2015 Tier III	DOCSIS 3.0 30 kWh/yr	3.4
Code of Conduct on Energy Efficiency of Digital TV Service Systems Version 9 1 July 2013 Tier 2	DOCSIS 3.0 25 kWh/yr	2.9
ENERGY STAR Product Specification for Set-top Boxes Version 4.1 Rev. Oct-2014	DOCSIS 20 kWh/yr	2.3

[205] Minutes annual meeting CSTB VA 20181121

[206] https://technology.ihs.com/438415/defying-multiscreen-challenge-set-top-box-market-to-achieve-record-shipments-in-2013

[207] http://cstb.eu/wp-content/uploads/2013/02/2017-10-24-Report-Independent-Inspector-2015-2016_final.pdf

[208] Viegand Maagoe: Review study on Standby Regulation(EC) No 1275/2008, Final report-Draft version for the EC, 7 April 2017.

ENERGY STAR Product specification for Set-top Boxes Draft 2 Version 5.0	DOCSIS 3.X 45 kWh/yr	5.1

The table below shows the evolution of the average energy use as reported within the VA. The Independent Inspector found that a steady decrease in consumption could be observed in previous periods, both for manufacturers and for service providers. It is quite likely that this was related to the accelerated implementation of APD. However, in the sixth reporting period, the average energy consumption of service provider's CSBT increased. The reason could be due to the trend towards more functionalities per CSBT which in turn were deactivated in fewer cases during the signatories' performance test.

Table 63: Average yearly energy consumption of CSTBs, averaged according to sales, for all reporting periods. (source: Ecofys (Independent Inspector for the VA), Oct. 2017)

Selection of CSTBs (periods from 1 July to 31 June)	Equipment manufacturers kWh/year (% of allowance)	Service providers kWh/year (% of allowance)
2015-2016 (6th period)	49 (37%)	73 (64%)
2014-2015	50 (41%)	64 (65%)
2013-2014	73 (61%)	87 (77%)
2012-2013	88 (52%)	118 (64%)
2011-2012	85 (54%)	118 (66%)
<2011 (inception)	70 (46%)	117 (67%)

This is an important issue: although equipment manufacturers make products that would enable energy use of 49 kWh/year, it is the setting by the provider that determines the actual energy use. Hence, the 73 kWh/year of the service providers is most likely to be representative of the actual energy consumption of the new CSTBs sold in 2016.

5.9.4 Summary

Given a product life of 7-8 years and assuming that there will still be some progress in efficiency especially with the more ambitious VA version 5.0, the 73 kWh/yr will also be representative of the CSTB stock in 2020. At 193 million installed units this means a CSTB energy consumption of 14.1 TWh/yr in the EU27 for 2020. This is very close to the forecast in EIA 2018, i.e. 15.1 TWh/yr for the EU28.

5.10 Digital TV services

5.10.1 Definition

Digital TV services are services where (subscription) video on demand (SVOD or VoD) is provided, either through CSTB (from cable, satellite, etc.), the internet (smart TV, PC, tablet, smartphone) and/or the 3G/4G (5G) mobile network.

Video on Demand is defined in an extensive study of the European Commission on the subject[209] as *"A service in which the end-user can, on demand, select and view a video content and where the end-user can control the temporal order in which the video content is viewed (e.g. the ability to start the viewing, pause, fast forward, rewind, etc.) NOTE - The viewing may occur sometime after the selection of the video content."*

[209] European Audiovisual Observatory, ON-DEMAND AUDIOVISUAL MARKETS IN THE EUROPEAN UNION, study for the European Commission DG Communications Networks, Content & Technology, 2014.

Examples are Netflix, Apple TV, HBO, Amazon Prime, etc. but also pay-TV apps from almost all TV and phone providers. Often, but not necessarily always, they use dedicated hardware interfaces to enhance their services e.g. hire a movie on a smartphone and broadcast onto a large monitor/TV with Chromecast, TV Smart Stick, etc..

5.10.2 Market

No sales statistics on the dedicated hardware interfaces could be found but there is a considerable amount of information on how much time consumers spend with the various streaming media as well as postponed and live TV viewing.
Nearly 3,000 streaming services operate in Europe, 1,300 offer video-on-demand (VoD). In 2019 25% of households had SVoD, varying between 75% in Denmark and 10% in Hungary. Most EU subscribers have Netflix or Amazon, which operate across the EU. By 2023 69% of Western European homes are expected to have SVoD. This will be almost three times more than in 2019.[210]

5.10.3 Energy

The energy use of the hardware interfaces is in the order of 0.35 to 2 W. When streaming/playing HD movies 2 to 3 W is typical, for 4K movies it can be over 5 W in HDR. The table below shows the latest power data from Apple.

Table 64: Power Consumption for Apple TV 4k and HD (230V)

Mode	4K	HD
Sleep/Network standby (W)	0.35	0.36
Streaming movies (W)	3.01	2.32
Streaming HDR movies (W)	5.07	
Power supply efficiency (%)	87.2	86.6

If indeed 25% of EU27 households (48 million in 2018) have SVoD --dedicated devices or not-- which are used in on-mode 4 hours a day (say 3 W) and 20h in standby (0.5 W), then the annual energy use is 8 kWh/household and 0.4 TWh/year in the EU27. If 69% of households have SVoD (with their own devices), the energy use would be 2.2 TWh/yr in the EU27.
Naturally, a substantial part of energy use is invisible to the end-user as it takes place in data centres where the streaming of videos represents a major share of the data stream (see section on data centres).[211] In the future, especially with 5G mobile networks, one of the big questions will be if such VoD services should necessarily come from large central data centres or if local storage (compare 'edge computing') is often not a faster and more efficient way of spreading the video content.

[210] https://www.detect-project.eu/2020/01/16/3746/

[211] See sections 2 and 3 on telecom. In 2020 the efficiency of telecom is 0.03 TWh/EB. And the data centre uses a bit more, say 0.04 TWh/EB . So total 0.07 Wh/GB. A HD-movie is 50 GB so 3.5 Wh/movie. Suppose a feature movie is 75 minutes (1.25h) then the average wattage is 3.5 Wh/1.25h= 2.8W. A4K movie is 100 GB so 5.6W. These are preliminary findings.

6 Group V. – Personal IT equipment

6.1 Definition

The product group of personal IT equipment is defined as shown in Table 1.

Table 65 - Product groups in the personal ICT equipment category.

Personal ICT equipment
Desktop PCs, office computers, workstations
Notebooks/Laptops
Tablets/Slates
E-book readers
Home/Office fixed phones
Smartphones

In Table 66, the product group is expanded to include a more detailed list of desktop PCs, office computers and workstations, since this list has been used in a previous review of the ecodesign regulation for computers[212] (hereafter called "the review study").

Table 66 - Product descriptions.

Product type	Product description
Notebook	A computer designed specifically for portability and to be operated for extended periods of time either with or without a direct connection to an AC power source. It has an integrated display.
Desktop	A computer where the main unit is intended to be in a permanent location and is not designed for portability. It is only operational with external equipment such as display, keyboard and mouse.
Integrated desktop	A computer where display and the computer function as a single unit and receives AC power through a cable.
Tablet/Slate	A product which is a type of notebook computer that includes both an attached touch-sensitive display and can have an attached physical keyboard.
Thin Client	A computer that relies on a connection to a remote computing resource (e.g. computer server, remote workstation) to obtain primary functionality. Designed for use in a permanent location.
Integrated Thin Client	A computer where hardware and display are connected to AC mains power through a single cable. Display and computer are physically combined into a single unit.
Workstation	A high-performance, single-user computer typically used for graphics, CAD, software development, financial and scientific applications among other intensive tasks. It is necessary to have a keyboard, mouse and display to operate it.
E-book readers	A portable electronic device for reading digital books and documents. Designed to operate over long hours by consuming minimal power. Rely on the e-ink technology for their displays.
Smartphones	A mobile phone that performs many of the functions of a computer, typically having a touchscreen interface, internet access and an operating system capable of running downloaded apps.
Feature phone[213]	A feature phone is a type of mobile phone that has more features than a standard mobile phone for calls and text messages, but is not equivalent to a smartphone. Feature phones can make and receive calls, send text messages and provide some of the advanced features found on a smartphone.

[212] https://computerregulationreview.eu/documents

[213] Definition from Techopedia: https://www.techopedia.com/definition/26221/feature-phone

Home/Office fixed phones	A phone that is connected to a landline. Can be either fixed to a location because it is cable connected or a wireless handset (typically DECT phone) that requires charging in a stand, which may also function as a base providing the connection between the handset and the landline.

6.2 Market

The historic development of sales for all categories in this product group can be seen in Table 67. For notebooks, desktops, integrated desktops and tablets/slates, sales are broken down into performance categories, which are described further below.

6.2.1 Computers

The first three product groups in the personal ICT equipment category (desktop PC, office computers, workstations, notebooks/laptops and tablets/slates) have been expanded to reflect the categories determined in the review study, which also provides the sales numbers supplemented with the sales and stock modelling data behind the study. In the study, sales are derived from numerous sources and forecasted and 'backcasted' to present the development and this is combined with lifetime assumptions to calculate the stock. For detailed explanation of the numbers and the data sources, see the review study Task 2 – Markets.

6.2.2 E-book readers

E-book readers experienced a breakthrough in the mainstream consumer market when Amazon started to sell the popular e-book reader called Amazon Kindle in 2008.
Sales of e-book readers in the period from 2007 to 2018 are reported by the Impact Assessment study on chargers for portable devices 2019[215]. The sales in the report are based on import value reported by Comtrade data and units were estimated dividing the sales by the average retail price of an e-book reader sold on Amazon.
The actual decline in forecasted sales might be much higher than estimated because of technological and societal developments. More people tend to read e-books on other devices, such as smartphones or tablets and fewer adults read books in general (counting both paperback books and e-books)[214].

6.2.3 Smartphones and feature phones

Sales of smartphones and feature phones in the period from 2008-2018 are provided by the Impact Assessment study on chargers for portable devices 2019[215]. The smartphone, as we know it today, had its breakthrough in 2007, when Apple introduced the iPhone. Since 2008 the share of smartphones has increased tremendously and in 2018 it accounted for 90% of the market.
The sale of smartphones in 2020 is forecasted by Gartner to be 143 million[216]. From 2020 to 2030 the sales of smartphones have been forecasted by the authors of this report. GSMA, who is a source of global mobile operator data, analysis and forecast, states that in

[214] https://www.rfdtv.com/story/41265863/ereader-market-size-share-2019-global-business-trends-share-progress-insight-modest-analysis-statistics-regional-demands-and-forecast-to-2024

[215] Impact assessment study on common chargers of portable devices

[216] https://www.gartner.com/en/newsroom/press-releases/2019-08-01-gartner-says-worldwide-smartphone-sales-will-decline-

2018 the adoption rate of smartphones in the EU was 73% and it is expected to grow to 83% by 2025[217]. The growth in adoption rate has been used to forecast the sales from 2020 to 2025. From 2025 to 2030 the growth in the smartphone market is estimated to grow only by 1%, because the adoption rate is so high and the growth in population in the EU is stagnating[218].
The market for feature phones is assumed to be declining at a CAGR of 20.6% from 2018-2030, which is a continuation of the decline in sales reported for 2008-2018.

6.2.4 Home/Office fixed phones

The sales for Home/Office fixed phones are reported by the EIA study in 2018[219]. In the EIA study the sales are forecast to continue to grow on the home market until 2020 and after 2020 it is predicted that sales will stagnate. In the office market sales are forecast to continue increasing until 2030 and further. .
Other sources are predicting that the market for office fixed phones will decline in future. In 2020 the worldwide market reached a revenue of 3,410 million USD, which is expected to decline to 2,910 million USD in 2023[220]. With the expected increase in sales of smartphones it seems reasonable that the sales of fixed phones will decline more than reported in the EIA study. However, here we keep the reported forecast of the EIA study, as it is considered a reliable resource.
Sales are reported in the EIA study for the years 1990 and from 2010 to 2050; there are no reported sales in the years from 1995 to 2005 in Table 67.

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[217] https://www.gsmaintelligence.com/research/?file=c5f35990dcc742733028de6361ccdf3b&download

[218] https://www.eea.europa.eu/data-and-maps/indicators/total-population-outlook-from-unstat-3/assessment-1

[219] https://ec.europa.eu/energy/sites/ener/files/documents/eia_status_report_2017_-_v20171222.pdf

[220] https://www.marketwatch.com/press-release/landline-phones-global-market-report-2018-industry-analysis-size-share-trends-scope-growth-future-opportunities-major-key-vendors-and-trends-by-forecast-to-2023-2019-08-22

6.2.5 Total sales

Table 67 - Sales of the product groups under personal ICT

Product type and category	Sales year ('000s)								
	1990	1995	2000	2005	2010	2015	2020	2025	2030
Notebook - Total	-	3 000	6 000	20 000	48 278	42 570	42 464	56 033	70 666
Notebook category 0	-	12	24	81	196	173	123	81	-
Notebook category I1	-	1 506	3 012	10 041	24 237	21 372	15 228	10 047	-
Notebook category I2	-	809	1 617	5 391	13 014	11 476	8 177	5 395	-
Notebook category I3	-	611	1 222	4 075	9 836	8 673	18 075	39 393	69 282
Notebook category D1	-	50	99	330	798	703	501	331	-
Notebook category D2	-	12	24	81	196	173	361	787	1 384
Desktop - Total	20 680	22 278	24 000	28 000	24 091	12 744	14 255	19 669	20 969
Desktop category 0	335	361	389	454	391	207	369	746	1 048
Desktop category I1	3 654	3 937	4 241	4 948	4 257	2 252	2 003	1 874	1 048
Desktop category I2	3 706	3 992	4 301	5 018	4 317	2 284	2 028	1 891	1 048
Desktop category I3	5 452	5 873	6 327	7 381	6 351	3 360	5 008	9 067	11 966
Desktop category D1	3 431	3 696	3 982	4 645	3 997	2 114	1 689	1 165	-
Desktop category D2	4 102	4 419	4 760	5 553	4 778	2 528	3 157	4 925	5 857
Integrated desktop - Total	827	891	960	1 120	964	510	570	787	960
Integrated Desktop category 0	13	14	16	18	16	8	36	25	-
Integrated Desktop category I1	146	157	170	198	170	90	111	77	-
Integrated Desktop category I2	148	160	172	201	173	91	67	86	96
Integrated Desktop category I3	218	235	253	295	254	134	258	434	624
Integrated Desktop category D1	137	148	159	186	160	85	-	-	-
Integrated Desktop category D2	164	177	190	222	191	101	98	166	240
Tablet/Slate - Total	-	-	-	-	3560	40790	39328	42752	46339
Tablet/Slate category 0	-	-	-	-	15	170	117	63	-
Tablet/Slate category I1	-	-	-	-	1825	20909	14961	9201	2317
Tablet/Slate category I2	-	-	-	-	980	11227	8855	6951	4634
Tablet/Slate category I3	-	-	-	-	741	8485	15395	26537	39388
Thin client	-	347	939	1347	1347	1308	1381	1394	1403
Integrated thin client	-	35	94	135	135	131	138	139	140
Workstation	484	521	562	605	646	795	908	1087	1301
E-book readers	**-**	**-**	**-**	**-**	11400	19000	14544	11106	8481
Smartphone sales Europe	-	-	-	-	66000	164000	142924	155100	163012
Home/Office fixed phones	10481	18262	23574	28887	34199	39510	42066	42784	43502
Total sales	**32472**	**27073**	**32554**	**51206**	**190619**	**321358**	**298579**	**330851**	**356772**

6.2.6 Stock

The historic stock development for personal ICT equipment can be seen in **Table 69**.
The stock for computers, e-book readers and smartphones has been calculated using annual sales presented and applying a normal distribution assuming a typical lifetime, see Table 68, as the mean and the standard deviation of 1.

Table 68 - Typical lifetime used for stock model

Product group	Typical lifetime (years)
Notebook	5
Desktop	6
Integrated desktop	6
Thin client	5
Integrated thin client	5
Tablet/Slate	3
Workstation	7
E-book readers	6
Smartphones	2.5
Home/Office fixed phones	8

Computers:
The typical lifetimes for the various computer types have been derived from the review study and the stock modelling data that supports it. For detailed assumptions and assessments behind the numbers and estimates of the lifetime of products, see the review study Task 2 - Markets.

E-book readers:
It has not been possible to find any statistics or studies on the typical lifetime of E-book readers. The lifetime is therefore estimated to be 6 years based on discussions among users on forums[221].

Smartphones:
The typical lifetime of a smartphone is estimated to be 2.5 years based on a study from the Federal Ministry for Economics and Energy in Germany[222].

Home/office fixed phones:
The stock for Home/Office fixed phones is based on reported values from the EIA study 2018[219]. Due to the increase in sales, also reported by the EIA study, the stock on Home/Office fixed phones is expected to increase from 1990 until 2030. In other sources, such as ITU that reports fixed phone subscriptions in all EU countries, it can be seen that there has been a decline in the number of subscriptions since the earliest reported number of 240 million in the year 2000 ; by 2018 203 million subscriptions were reported[223], but as mentioned above, the data from the EIA study is reported here.
The typical lifetime of fixed phones is 8 years according the German study[224].

[221] https://www.quora.com/How-long-is-the-lifespan-of-a-kindle-paperwhite
[222] Entwicklung des IKT-bedingten Strombedarfs in Deutschland - page 169
[223] https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx (Excel sheet fixed-telephone subscribers)
[224] Entwicklung des IKT-bedingten Strombedarfs in Deutschland - page 169

Table 69 – Stock for the product groups under personal ICT

Product type and category	Stock year ('000s)								
	1990	1995	2000	2005	2010	2015	2020	2025	2030
Notebook - Total	**-**	**8 875**	**25 250**	**63 243**	**178**	**261**	**232**	**273**	**350**
Notebook category 0	-	36	103	257	728	1 063	823	571	225
Notebook category I1	-	4 456	12 676	31 750	89 777	131 133	101 540	70 463	27 798
Notebook category I2	-	2 392	6 807	17 049	48 206	70 413	54 522	37 835	14 927
Notebook category I3	-	1 808	5 144	12 885	36 433	53 216	70 673	158 805	300 545
Notebook category D1	-	147	417	1 045	2 954	4 315	3 341	2 319	915
Notebook category D2	-	36	103	257	728	1 063	1 412	3 172	6 004
Standard notebooks (I1,I2,75% of I3)		10 048	28 588	71 604	202 468	295 737	280 563	386 778	362 224
Gaming notebooks (D1, D2, 25% of I3)		635	1 806	4 523	12 790	18 682	22 421	45 192	52 530
Desktop - Total	**20 680**	**125**	**167**	**177**	**199**	**148**	**99 227**	**125**	**147**
Desktop category 0	335	2 028	2 721	2 876	3 234	2 411	1 936	3 853	6 217
Desktop category I1	3 654	22 096	29 655	31 337	35 239	26 277	16 307	15 320	11 685
Desktop category I2	3 706	22 408	30 074	31 780	35 736	26 648	16 531	15 498	11 770
Desktop category I3	5 452	32 963	44 239	46 748	52 568	39 199	29 133	49 589	73 629
Desktop category D1	3 431	20 745	27 841	29 420	33 083	24 670	14 855	11 853	5 653
Desktop category D2	4 102	24 800	33 284	35 172	39 550	29 492	20 465	29 225	38 403
Standard desktops (I1,I2,I3+40%D1&D2)	16 160	97 713	131 139	138 578	155 830	116 200	78 035	78 035	78 035
Gaming desktops (60%D1&D2)	4 520	27 327	36 675	38 755	43 580	32 497	21 192	21 192	21 192
Integrated desktop - Total	**827**	**5 002**	**6 713**	**7 093**	**7 976**	**5 948**	**3 969**	**5 014**	**6 015**
Integrated Desktop category 0	13	81	109	115	129	96	216	251	120
Integrated Desktop category I1	146	884	1 186	1 253	1 410	1 051	844	778	371
Integrated Desktop category I2	148	896	1 203	1 271	1 429	1 066	562	574	636
Integrated Desktop category I3	218	1 319	1 770	1 870	2 103	1 568	1 441	2 472	3 535
Integrated Desktop category D1	137	830	1 114	1 177	1 323	987	228	-	-
Integrated Desktop category D2	164	992	1 331	1 407	1 582	1 180	678	938	1 354
Tablet/Slate - Total	**-**	**-**	**-**	**-**	**3 560**	**139**	**135**	**146**	**158**
Tablet/Slate category 0	-	-	-	-	15	579	459	277	65
Tablet/Slate category I1	-	-	-	-	1 825	71 392	57 920	38 144	15 171
Tablet/Slate category I2	-	-	-	-	980	38 334	32 954	26 305	18 607
Tablet/Slate category I3	-	-	-	-	741	28 972	44 530	81 527	124 807
Thin client	**-**	**865**	**3 424**	**6 911**	**7 406**	**7 449**	**7 536**	**7 634**	**7 692**
Integrated Thin client	**-**	**86**	**342**	**691**	**741**	**745**	**754**	**763**	**769**
Workstation	**484**	**3002**	**4010**	**4320**	**4508**	**5280**	**6184**	**7258**	**8686**
E-book readers	**-**	**-**	**-**	**-**	**27250**	**85301**	**106496**	**93894**	**73532**
Smartphone	**-**	**-**	**-**	**-**	**12811**	**452745**	**475162**	**504011**	**528062**
Home/Office fixed phones	**29461**	**98117**	**14271**	**17989**	**21708**	**254265**	**285937**	**296475**	**301500**
Total stock	**51452**	**14287**	**20755**	**25959**	**77487**	**136091**	**135343**	**145980**	**158267**

6.3 Performance and energy use

The performance metric is per product (sub-)group.

6.3.1 Computer

For computer products, different categories have been established under the Energy Star scheme and as part of the computer regulation[225] for desktops, integrated desktops and notebooks, where slates/tablets and portable all-in-one computers are included under notebooks. This has also been used in the review study. The current version of the categorisation is available in Energy Star Product Specification for Computers v7.1[226].
The outlines of the categorisation, including those for the new Energy Star v.8.0 categories that will be valid from October 2020, are given below.

Table 70 . US Energy Star for Computers v7.x and 8.0 categories

Energy Star v.7.x *(from Oct. 2018)*

Desktop or Integrated Desktop

Cate-gory	Graphics	Perfor-mance score P	Base allowance (kWh)
0	any graphics	P≤3	69
I1	integrated or switchable graphics	3<P≤6	112
I2		6<P≤7	120
I3		>7	135
D1	discrete graphics	3<P≤9	115
D2		P>9	135

Notebook

Cate-gory	Graphics	Perfor-mance score P	Base allowance (kWh)
0	any graphics	P≤2	6.5
1		2<P<8	8
2		P≥8	14

P= no. of CPU cores x base clock speed in GHz

There are functional adders for desktop graphics Frame Buffer Band Width (FB_BW) categories G1 (36 kWh) up to G7 (130 kWh), for notebook graphics based on a FB_BW equation. Also there are adders for RAM memory, >1 storage unit, automated switchable graphics, integrated displays, Energy Efficient Ethernet (EEE) and mobile workstations.

Energy Star v. 8.0 *(from Oct. 2020)*

Desktop*

Cate-gory	Graphics	Perfor-mance score P	Base allowance (kWh)
I1	integrated or switchable graphics	P≤8	26
I2		P>8	46
D1	discrete graphics	P≤8	35
D2		P>8	45

Notebook

Cate-gory	Graphics	Perfor-mance score P	Base allowance (kWh)
0	any graphics	P≤2	6.5
1		2<P<8	8
2		P≥8	14

**= for integrated desktops there are 2 categories (1 and 2) below and above P=8, with base allowances 9 and 27 respectively*

Functional adders for desktop graphics and notebook graphics are both based on a FB_BW equation. Adders still exist for RAM memory, HDD and/or SSD storage units, automated switchable graphics, integrated displays, >1G and 10G Ethernet, mobile workstations.

In the review study Task 7 it is also forecast that the performance of computers will increase in general. This means that a higher percentage of computers will be at the high performing end (I3 and D2).
An approximate average utilisation is given by the usage patterns provided for by the computer test and calculation method for computers' energy efficiency, which is TEC - Typical Energy Consumption. It provides a value of how many kWh a computer uses in a

[225] Commission Regulation (EU) No 617/2013 of 26 June 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for computers and computer servers

[226] ENERGY STAR® Program Requirements. Product Specification for Computers. Eligibility Criteria. Version 7.1

year with defined assumptions of hourly usages in different modes – long idle, short idle, sleep and off. A weighting has been provided for by the Energy Star product specifications[16], see Table 71. The percentages are applied on the total number of 8760 hours in a year.

Table 71 – Mode weightings for computers from Energy Star v. 7.1 product specification[16]. Full network connectivity allows the computer to maintain network presence in sleep or similar modes.

Mode Weightings for Desktop, Thin Clients, and Integrated Desktop Computers

Mode Weighting	Conventional	Full Network Connectivity			
		Base Capability	Remote Wake	Service Discovery / Name Services	Full Capability
T_{OFF}	45%	40%	30%	25%	20%
T_{SLEEP}	5%	15%	28%	36%	45%
T_{LONG_IDLE}	15%	12%	10%	8%	5%
T_{SHORT_IDLE}	35%	33%	32%	31%	30%

Mode Weightings for Notebook Computers

Mode Weighting	Conventional	Full Network Connectivity			
		Base Capability	Remote Wake	Service Discovery / Name Services	Full Capability
T_{OFF}	25%	25%	25%	25%	25%
T_{SLEEP}	35%	39%	41%	43%	45%
T_{LONG_IDLE}	10%	8%	7%	6%	5%
T_{SHORT_IDLE}	30%	28%	27%	26%	25%

Mode Weightings for Workstations

T_{OFF}	T_{SLEEP}	T_{LONG_IDLE}	T_{SHORT_IDLE}
35%	10%	15%	40%

6.3.2 E-book readers

The degree of performance can be determined by a number of factors including screen size and increased functionality such as built-in-light, Wi-Fi, touch screen, a monochrome orcolour screen and whether or not it has Android operating systems capable of running apps.

From an internet search it seems that one trend for e-book readers is that it is moving towards an increase in functionality. E.g. the EnergySistem Ereader Pro 4[227] which has similar functions to a tablet like Wi-Fi and Android operation systems but still with an e-ink screen instead of an LCD screen, which means that the e-book reader will have a much longer battery life than a tablet.

6.3.3 Smartphones

A smartphone has many performance metrics, but it is difficult to determine which one is essential for its overall performance. E.g. battery life, processor power, display size and resolution, the amount of RAM and storage. Various performance benchmark apps exist on

[227] https://www.energysistem.com/en_es/ereader-pro-4-44671

the market[228] and these can be used to measure the performance of different features or components. However, no broadly recognised performance test method exists to the study team's knowledge which capture all main performance criteria. This study therefore, does not include such performance metrics but only explains the trends.

CPU performance has almost doubled for flagship models during the past 3 years, but mid-tier models have experienced a modest improvement. This might be due to the fact that all specifications of smartphones have improved rapidly during the last couple of years, except for in battery performance. Smartphones do now have better processors, screen resolution, cameras and more power demanding apps, but the battery performance is not increasing as much[229]. A comparison made by Qualcomm states that the processor speeds rose by 80% from 2012-2014, but in the same time the battery power only increased by 33%[230]. This leaves the manufactures with two options. Either produce a smartphone with lower performance or provide the phone with a massive battery (more mAh). For now, it seems as though the manufactures are providing the phones with larger batteries, while some are also trying to scale back on the screen tech, e.g. the iPhone XR which lasted 3 hours longer in a battery test than the iPhone XS[231].

6.3.4 Home/Office fixed phones

It has not been possible to find any worthwhile performance metrics for home/office fixed phones.

6.3.5 Energy efficiency metrics

The energy efficiency metric for computers is provided as Typical Energy Consumption (TEC) (described above) for each performance level of the products.

TEC data for computers in Table 72 is derived from the computer review study and the modelling data behind it[232]. Figures in blue font are updates of the computer review study. Please note that typically, the actual energy consumption in real life will be different, because the computers will use more energy in active mode compared to the idle modes.

From the TEC data it can be seen that there is a clear trend towards power consumption in each computer category decreasing, meaning that year on year the computers are able to perform as well as the year before but with lower power consumption.

No recognised energy efficiency metrics for other products in this category have been possible to identify.

The personal IT category is probably the category with the largest uncertainty as regards energy consumption. On one hand there are anecdotal reports of energy increasing trends, such as extreme gaming, bitcoin mining through blockchains and individual binge-watching of series and movies on notebooks and tablets[233]. On the other hand, mid-market notebooks and PCs can be found with energy consumption that is only a fraction of Energy

[228] E.g. https://www.techulator.com/resources/18388-top-10-benchmarking-tools-for-android-smartphones

[229] https://www.washingtonpost.com/technology/2018/11/01/its-not-your-imagination-phone-battery-life-is-getting-worse/

[230] https://www.slideshare.net/QualcommDeveloperNetwork/69-minimize-powerconsumptioninappsschwartz918gg67

[231] https://www.washingtonpost.com/technology/2018/11/01/its-not-your-imagination-phone-battery-life-is-getting-worse/

[232]https://computerregulationreview.eu/sites/computerregulationreview.eu/files/Preparatory%20study%20on%20review%20computer%20regulation%20-%20Task%207%20VM%2019072018.pdf

[233] General trend for individual watching instead of collective watching of TVs.

Star limits. And there is the continuing trend of consumers looking for smaller, lighter and mobile devices (PC→notebook→tablet→smartphone) lowering personal IT energy use.

Reliable databases and surveys on the subjects are scarce, due to the large variety of computers. The frequency of computers in the Energy Star database, for instance, is not a reliable yardstick for sales of the various computers and their processors: One computer ‘chassis’ can equipped for several processor-categories -- depending on the graphics card (I=Integrated/Switchable or D=Discrete) and the number of processor cores multiplied with the base clock speed (I1, I2, I3, D1, D2). The Energy Star rules are such that the manufacturer should declare the worst-case processor in each category for which it claims conformity with Energy Star.

Table 72 – Energy efficiency metric for computers[234]

Product type and category	TEC (kWh/year/device					
	2005	2010	2015	2020	2025	2030
Notebook average overall	40.0	39.1	35.3	29.1	28.9	20.6
Notebook category 0	28.0	27.3	24.7	22.7	20.0	17.0
Notebook category I1	33.0	32.6	29.4	26.0	22.0	18.0
Notebook category I2	34.0	33.6	30.3	27.0	23.0	19.0
Notebook category I3	49.0	48.0	43.3	34.0	25.0	20.0
Notebook category D1	42.0	41.7	37.6	34.7	33.2	31.7
Notebook category D2	113.0	111.2	100.4	75.0	65.0	55.0
average Standard notebooks (I1,I2,75%I3)	*28.5*	*28.2*	*25.4*	*21.3*	*16.5*	*14.1*
average Gaming notebooks (D1, D2, 25%I3)	*96.6*	*95.1*	*85.9*	*69.0*	*64.1*	*54.6*
Desktop average overall	134	132	118	100	93	85
Desktop category 0	71	69	62	57	54	51
Desktop category I1	101	99	89	77	78	74
Desktop category I2	112	110	99	90	86	82
Desktop category I3	127	124	111	96	97	92
Desktop category D1	163	160	144	87	80	73
Desktop category D2	181	178	159	146	120	100
average Standard desktops (I1,I2,I3+40%D1&D2)	*125*	*123*	*110*	*94*	*91*	*84*
average Gaming desktops (60%D1&D2)	*173*	*170*	*152*	*121*	*103*	*89*
Integrated desktop average overall	144	141	126	128	130	132
Tablet/slate average total	-	30.9	20.8	18.6	10	10
Thin client	81	75.2	47.8	40.6	39.5	38.3
Integrated thin client	182	169.4	107.7	91.6	89	86.4
Workstation	312	306.1	274.5	249	235.9	222.9

6.3.6 Energy consumption - Representative technology

In this section estimates for energy consumption for the different products in the group are provided.

6.3.7 Computers

The table in the summary calculates the annual electricity consumption for the period 2010-2025 from the data in the previous tables.

[234] Source: Viegand Maagøe (2018), Internal modelling files that supports the computer regulation. Figures in blue font are recent updates for this report https://computerregulationreview.eu/sites/computerregulationreview.eu/files/Preparatory%20study%20on%20review%20computer%20regulation%20-%20Task%207%20VM%2019072018.pdf

6.3.8 E-book readers

The energy consumption is calculated for the Amazon Kindle Paperwhite being used as a case study as it has not been possible to find any general statistics for energy consumption of e-book readers; Amazon is a market leader with 53% of the market share in 2015[235]. According to Amazon, a Kindle Paperwhite will last 6 weeks on a charge assuming ½ an hour of use per day, when wireless is turned off and the light setting is set to 13[236]. Based on that assumption the Kindle Paperwhite will have to be charged approximately 9 times a year.

To reflect the reality that wireless might be turned on more than what is recommended, it is assumed that the e-book reader is charged a least once per month.

A battery for the kindle paperwhite has a capacity of 5.9 Wh[237]. This results in an annual energy consumption of 0.09 kWh per device assuming a charger efficiency of 75%. The same energy consumption is assumed for all years.

6.3.9 Smartphones

The energy consumption of smartphones has been determined by taking the endurance hours (based on a test by GSMArena)[238] of the top eight most sold smartphones in Europe in 2019[239] and dividing them by the hours used per year. The theoretical number of charges has then been multiplied by two to provide data for a more realistic life scenario. The charges per year is multiplied by the battery capacity in Wh to give energy consumption per year. The energy consumption is then divided by an efficiency of 75 % to estimate the losses in the phone charger. The average energy consumption is rounded up to 4 kWh which corresponds to the assumed energy consumption of the working plan preparatory study on ecodesign[240] and a German report on IT equipment.[241].

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[235] https://www.rfdtv.com/story/41265863/ereader-market-size-share-2019-global-business-trends-share-progress-insight-modest-analysis-statistics-regional-demands-and-forecast-to-2024

[236] https://www.amazon.co.uk/Amazon-Kindle-Paperwhite-Waterproof-Twice-Storage/dp/B07747FR44/ref=sr_1_1?ascsubtag=UUacUdUnU77109YYwYg&keywords=kindle%2Bpaperwhite%2Bnow%2Bwaterproof%2Bwith%2B2x%2Bthe%2Bstorage%2Bincludes%2Bspecial%2Boffers&qid=1578656390&sr=8-1&th=1

[237] https://www.batteri-butik.dk/Batteri-Detaljer/1.64.AMA.2.16,Batteri-til-Amazon-Kindle-Paperwhite-2014.html?gclid=EAIaIQobChMIivvBoo755gIVg9DeCh3jQAtSEAQYASABEgKnCfD_BwE

[238] https://www.gsmarena.com/battery-test.php3

[239] https://www.standard.co.uk/tech/top-smartphones-2019-kantar-samsung-a-series-a4268926.html

[240] VHK, Preparatory Study to establish the Ecodesign Working Plan 2015-2017 implementing Directive 2009/125/EC Task 3 Final Report.

[241] Entwicklung des IKT-bedingten Strombedarfs in Deutschland - page 169

Table 73 – Energy consumption for smartphones

Product	Battery capacity (mAh)	Battery capacity (Wh)	Endurance Rating (hour)	Battery capacity used per endurance hour	Theoretic charges per year	Assumed charges per year	Energy consump-tion kWh/year
Apple iPhone XR	2942	10.9	78	37.7	112.6	225.2	3.3
Samsung Galaxy A40	3100	11.5	73	42.5	120.3	240.7	3.7
Samsung Galaxy A50	4000	14.8	50	80	175.7	351.4	6.9
Apple iPhone 8	1821	6.7	66	27.6	133.1	266.2	2.4
Redmi Note 7	4000	14.8	108	37	81.3	162.7	3.2
Samsung Galaxy S10	3400	12.6	79	43	111.2	222.4	3.7
Samsung Galaxy A70	4500	16.7	103	43.7	85.3	170.6	3.8
Samsung Galaxy S10+	4100	15.2	91	45.1	96.5	193.1	3.9
Average							**3.9**

6.3.10 Home/Office fixed phones

The energy consumption of home/office fixed phones is estimated to be 20 kWh in 2015 and decreasing to 18 kWh per year in 2020 by the German report[242].

6.4 Energy efficiency improvement (BAT)

BAT represents the Best Available Technology on the market in each category. The energy consumption of BAT has the same performance as the other products in the same category, but delivers it with a lower energy consumption.

6.4.1 Computers

BAT for computers is determined by internal modelling files that support the review study Task 7.[243] The BAT TEC level was calculated for each of the product categories within each product type based on the percentage difference between the average TEC and BAT TEC of the category identified as a base case product. Afterwards the percentage difference for the base case product was used for all other product categories of the same product type, assuming the same percentage level of efficiency improvement could be achieved by all products within the category.
For example, the difference between BAT in category I1 desktop computer and average performances in that type of computer is 76 % whereas the difference for all-in-one computers is 47 %. The values for all categories are shown in Table 74.

Table 74 - Estimated BAT TEC per category.

[242] Entwicklung des IKT-bedingten Strombedarfs in Deutschland - page 168
[243] https://computerregulationreview.eu/documents

Product types	Estimated BAT (kWh/year)	Product types	Estimated BAT (kWh/year)
Desktop average total	27.8	**Notebook average total**	10.7
Desktop category 0	14.6	Notebook category 0	7.5
Desktop category I1	20.9	Notebook category I1	8.9
Desktop category I2	23.2	Notebook category I2	9.2
Desktop category I3	26.2	Notebook category I3	13.1
Desktop category D1	33.8	Notebook category D1	11.4
Desktop category D2	37.5	Notebook category D2	30.5
Integrated desktop average total	65.9	**Tablet/slate average total**	8
Integrated desktop category 0	48.6	Tablet/slate category 0	11.3
Integrated desktop category I1	59.5	Tablet/slate category I1	6.9
Integrated desktop category I2	62.2	Tablet/slate category I2	10.6
Integrated desktop category I3	71.5	Tablet/slate category I3	8.3
Integrated desktop category D1	80.4		
Integrated desktop category D2	98.9		
		Thin client	22.3
Workstation	41.8	**Integrated thin client**	50.2

6.4.2 E-book readers

Since there is no worthwhile source mentioning performance metric for E-book readers, it has not been possible to determine a BAT. However, it seems as though this device is developing more functions such as those of a drawing pad[244] and can also be used for listening to audio files[245]. It is assumed that the energy consumption will still be at a low level compared to other products in this category.

6.4.3 Smartphones

As discussed in the section about performance metric for smartphones it was stated that the battery life of a smartphone has become a tradeoff. As things currently stand, it would seem that battery performance limits have been reached and this will not change much until a new game changing innovation comes to play. Looking at battery performance of the top eight most sold phones in 2019, reveals that the iPhone 8 requires the least amount of Watts a year. However, this might be explained by the fact that this is one of the older models on the list, and thus has a lower performance resulting in less energy demand.
Comparing the energy consumption and all the functions of a smartphone to those of a fixed phone reveals just how efficient a smartphone already is. As seen in the above section, a typical smartphone uses approximately 4 kWh a year in contrast to a fixed phone that uses 19 kWh. This is possibly because to a high degree, smartphones companies, are already competing on improving smartphone energy efficiency as this performance metric is one that consumers rate as very important.

[244] https://www.komplett.dk/product/1141964/pc-tablets/tablets-e-bogslaesere/e-bogslaesere/onyx-boox-note-pro-103-64gb?gclid=EAIaIQobChMIysvgsf2U5wIVyuJ3Ch0qhw5LEAQYCyABEgKbwvD_BwE&gclsrc=aw.ds#
[245] https://www.komplett.dk/product/1137443/pc-tablets/tablets-e-bogslaesere/e-bogslaesere/pocketbook-inkpad3-pro-metalgraa?gclid=EAIaIQobChMIysvgsf2U5wIVyuJ3Ch0qhw5LEAQYDCABEgIK0_D_BwE&gclsrc=aw.ds#productinfo

6.4.4 Home/Office fixed phones

No data on BAT energy consumption for home/office fixed phones have been identified and a BAT level cannot be reported.

6.5 Summary

Table 75 .Energy consumption EU27 of personal IT equipment 2010-2025

	2010	2015	2020	2025
Standard notebooks	4.96	6.54	5.19	5.56
Gaming notebooks	1.06	1.40	1.35	2.52
Standard desktops	16.61	11.11	6.40	6.15
Gaming desktops	6.43	4.30	2.23	1.90
Integrated desktop	1.10	0.74	0.69	0.67
Thin clients	0.59	0.38	0.33	0.32
Workstations	1.20	1.26	1.34	1.49
Tablets/Slate	0.10	2.58	1.87	1.34
E-book readers	0.00	0.01	0.01	0.01
Smartphone	0.45	1.58	1.65	1.75
Home/Office fixed phones	4.15	4.42	4.48	4.13
Total personal IT equipment	**36.66**	**34.30**	**25.54**	**25.84**

7 Group VI. – Imaging equipment

7.1 Definition

The product group of imaging equipment is described as:

- office equipment (domestic/tertiary, including photocopiers, printers and multifunctional devices)
- 3D printers.

In the table below, the product group is expanded to reflect the categorisation used in the review study related to the imaging equipment voluntary agreement (hereafter called "the review study") with the addition of 3D printers, which were not part of the review study. The study team assessed separately the 3D printers in order to determine sales, stock, energy consumption and BAT, see Annex A.

Table 76. Product descriptions

Product type/category	Product description[1]
Monochrome laser MFD (Multi-Functional Printer)	A multi-functional printer, that can copy, scan and print, that use laser marking technology (sometime referred to as electro-photographic) to print in one colour only.
Colour laser MFD	A multi-functional printer, that can copy, scan and print, that use laser marking technology (sometime referred to as electro-photographic) to print in multiple colours.
Monochrome laser printer	A printer that use laser marking technology (sometime referred to as electro-photographic) to print in one colour only.
Colour laser printer	A printer that use laser marking technology (sometime referred to as electro-photographic) to print in multiple colours.
Colour inkjet MFD	A multi-functional printer, that can copy, scan and print, that use Inkjet marking technology to print in several colours.
Colour inkjet printer	A printer that use inkjet marking technology to print in multiple colours.
Professional printer and MFD	A professional printer or MFD that supports a basis weight greater than 141g/m2; A3 capable; if it only prints monochrome the IPM is equal or greater than 86; if it prints in colour the IPM is equal or greater than 50; print resolution of 600x600 dpi or greater; weight of the base model greater than 180 kg and several other features such as hole punch and ring binding.
Scanner	A product whose primary function is to convert paper originals into electronic images that can be stored, edited converted or transmitted.
Copier	A commercially-available imaging product whose sole function is the production of hard copy duplicates from graphic hard copy originals.
Facsimile (fax) machine	A commercially available imaging product whose primary functions are scanning hard copy originals for electronic transmission to remote units and receiving similar electronic transmissions to produce hard copy output.
3D Printers	An imaging product turning CAD (Computer Aided Design) files into physical objects[246].

All the product types except the 3D printers can be further divided into sub-categories according to speed ranges i.e. IPM (Images Per Minute) processed (printed, scanned, copied and/or faxed).

7.2 Market

Sales of imaging equipment, excluding 3D printers, have been derived from the review study. The method for finding the numbers is explained in the study – Task 2 page 8-14. The sales represented in this report are based on internal modelling files from the review

[246] The study team's own definition. See details in Annex A.

study and use actual numbers as well as forecasts to represent the period from 2010-2030. For years before 2010, data from the Ecodesign impact accounting 2018 have been used.

No previous Ecodesign studies exist for sales of 3D printers. An assessment of these printers has therefore been carried out for this task. The assessment, which explains the method that supports the sales data for 3D printers, can be found in Annex A. All data are presented in the table below.

Table 77. Sales of imaging equipment (EU28)

Product type	Sales (000 units)									
	1990	1995	2000	2005	2010	2015	2018	2020	2025	2030
Mono laser MFD	0	0	523	1047	1570	2093	2031	1991	1893	1801
Colour laser MFD	0	0	522	1045	1567	2089	2027	1987	1889	1797
Mono laser printer	3552	3601	3650	3700	3364	2310	1950	1748	1377	1106
Colour laser printer	0	0	217	759	1300	1514	1761	1889	2082	2182
Mono laser copier	2349	2010	1671	1332	943	232	51	0	0	0
Colour laser copier	0	0	61	138	189	338	177	0	0	0
Inkjet MFD	4999	6487	8117	10158	12464	14818	14378	14092	13401	12744
Inkjet printer	6099	7914	9903	12392	9704	956	928	909	865	822
Professional printer / MFD	0	0	59	119	178	238	231	226	215	205
Scanner	0	0	39	126	232	461	681	883	883	883
Facsimile (fax) machine	0	8500	6683	4171	804	402	161	0	0	0
3D printer	0	0	0	0	13	45	86	134	384	1102
Total	**17000**	**28512**	**31447**	**34985**	**32328**	**25496**	**24461**	**23858**	**22989**	**22642**

The stock development for imaging equipment is presented in Table 80. The stock for the years 2010-2030, excluding 3D printers, comes from the a review study and has been calculated using annual sales and a normal distribution for lifetime, assuming a typical lifetime (see Table 79) as the mean and a standard deviation of 1. For the years before 2010, data from the ecodesign impact accounting report has been used.

Table 78. Estimated typical lifetime of imaging equipment excl. 3D printers based on data from the review study

Product type	Lifetime
Inkjet printers & MFDs	5
Laser printers & MFDs	6
Scanners	6
Copiers	6
Facsimile (fax) machine	6

Table 79. Stock data imaging equipment (EU28)

Product type	Stock (000 units)									
	1990	1995	2000	2005	2010	2015	2018	2020	2025	2030
Mono laser MFD	0	0	1570	4710	7851	10991	12122	12251	11651	11080
Colour laser MFD	0	0	1567	4700	7834	10967	12096	12225	11626	11056
Mono laser printer	14149	14345	14542	14741	13859	12061	10526	9787	7682	6104
Colour laser printer	0	0	325	2384	4552	7123	8875	10281	11852	12757
Mono laser copier	9803	8447	7091	5735	4303	2557	1201	556	0	0
Colour laser copier	0	0	153	459	677	1785	1716	1154	0	0
Inkjet MFD	18213	24163	30396	38035	47031	62915	69867	71897	68373	65022
Inkjet printer	22219	29478	37081	46401	42349	18228	5924	4638	4411	4195
Professional printer / MFD	0	0	178	554	940	1327	1473	1500	1438	1368
Scanner	0	0	61	531	1124	2078	3143	4103	5644	5736
Facsimile (fax) machine	0	8500	44004	36493	16908	4164	2523	1479	71	0
3D printer	0	0	0	0	28	134	270	433	1292	3729
Total	**64383**	**84933**	**136967**	**154743**	**147455**	**134330**	**129737**	**130304**	**124039**	**121047**

7.3 Performance and energy use

7.3.1 Performance metric

The performance metric is suggested to be IPM (Images Per Minute) for the product combined with the categorisations (colour, monochrome, laser, inkjet, professional etc.). Both are used in the Voluntary Agreement for Imaging Equipment[247] and the review study and both are relevant for the purchase and usage parameters for end-users.
An approximate average utilisation is given by the usage pattern provided by the imaging equipment test method[248] in terms of jobs per day and images per job for each product speed (1-100 IPM).

7.3.2 Energy efficiency metric

The recognised energy efficiency metrics and test methods used for setting requirements in the Voluntary Agreement for Imaging Equipment[3] and in Energy Star are as follows:

- TEC - Typical Energy Consumption: this a value of how many kWh an imaging equipment device typically uses per week across all power modes while in normal operation based on a usage profile included in the test method. The weekly consumption can be converted to annual consumption by multiplying by number of weeks in a year, i.e. 52. TEC is used for standard and professional printers and MFDs using electro-photography, high performance inkjet and similar marking technologies;
- OM - Operational Mode: this provides values for power levels in sleep- and off-mode power consumption covering products, where TEC is less relevant such as inkjet devices, large format devices, fax machines and scanners.

No recognised energy efficiency metric and test methods are available for 3D printers.

7.3.2.1 Energy consumption

Average technology

The annual energy consumption for the representative technology has been calculated as follows for years 2010-2030:

- TEC products (laser and professional printers and MFDs):the TEC value is multiplied by 52 to give annual energy consumption. The TEC values are based on the modelling scenarios from the imaging equipment review study;
- OM products: Annual energy consumption data comes from the review study (Table 44). These have been calculated by assuming a use pattern (hours in active, ready, sleep and off modes) and power levels in the same modes;
- Scanners: the annual energy consumption for scanners is based on a German report about ICT related energy demand[249];
- Copiers and fax machines: annual energy consumption data comes from the review study (2018) and from the Ecodesign impact accounting 2018 report;

[247] Industry voluntary agreement to improve the environmental performance of imaging equipment placed on the European market. VA v.5.2. April 2015

[248] ENERGY STAR® Program Requirements Product Specification for Imaging Equipment. Test Method for Determining Imaging Equipment Energy Use. Rev. Dec-2018

[249] Development of ICT-related electricity demand in Germany - Study commissioned by the Federal Ministry for Economic Affairs and Energy Project no. 29/14

- 3D printers: the annual energy consumption for 3D printers has been estimated as detailed in Annex A. The data for annual energy consumption is only provided for 2018, because it has not been possible to find enough data to create a historic overview of the development.

For the years before 2010, data from the 2018 ecodesign impact accounting report have been used. Table 80 shows the historic development of the annual electricity consumption per unit. Table 82 provides the total electricity consumption of the EU28 stock.

Table 80. – Annual electricity consumption per device

Product type	Average Annual Electricity Consumption per device (kWh/unit/year)									
	1990	1995	2000	2005	2010	2015	2018	2020	2025	2030
Mono laser MFD	1069	1069	782	305	170	113	79	79	79	79
Colour laser MFD	1261	1261	924	360	255	153	92	92	92	92
Mono laser printer	666	666	488	190	137	96	71	71	71	71
Colour laser printer	1040	1040	761	297	247	161	110	110	110	110
Mono laser copier	1069	1069	782	305	170	113	79	79	79	79
Colour laser copier	1261	1261	924	360	255	153	92	92	92	92
Inkjet MFD	77	77	56	22	12	8	6	6	6	6
Inkjet printer	51	51	37	15	8	4	2	2	2	2
Professional printer / MFD	664	664	664	664	664	664	664	664	664	664
Scanner					24	19	19	10	10	
Facsimile (fax) machine							0.5			
3D printer							666			

For the major product groups studied in more detail in the review study, annual electricity consumption data are also provided for the individual speed ranges, see Table 81.

Table 81. Annual energy consumption per device with representative technology for each type of imaging equipment and speed range

Product	Annual energy consumption (kWh/year)	Product	Annual energy consumption (kWh/year)
Mono Laser MFD	**79**	**Mono Laser printer**	**73**
s ≤ 20	42	s ≤ 20	31
20 < s ≤ 40	79	20 < s ≤ 40	73
40 < s ≤ 60	140	40 < s ≤ 60	135
60 < s ≤ 66	234	60 < s ≤ 66	187
66 < s ≤ 80	307	66 < s ≤ 135	707
s > 80	863	s > 135	2995
Colour Laser MFD	**94**	**Colour Laser Printer**	**109**
s ≤ 20	47	s ≤ 20	52
20 < s ≤ 40	94	20 < s ≤ 40	109
40 < s ≤ 60	156	40 < s ≤ 51	224
60 < s ≤ 66	198	51 < s ≤ 60	177
66 < s ≤ 80	400	s > 60	931
s > 80	640		

Table 82. – Annual electricity consumption of the EU28 stock

Product type	Annual Electricity Consumption of the Stock (TWh/year)									
	1990	1995	2000	2005	2010	2015	2018	2020	2025	2030
Mono laser MFD	0.00	0.00	1.42	2.39	1.71	1.54	1.30	1.11	0.92	0.87
Colour laser MFD	0.00	0.00	1.67	2.81	2.37	2.20	1.72	1.38	1.07	1.02
Mono laser printer	9.43	9.56	8.39	4.12	2.09	1.32	0.89	0.75	0.55	0.43
Colour laser printer	0.00	0.00	0.26	0.99	1.22	1.39	1.27	1.29	1.30	1.40
Mono laser copier	10.48	9.03	6.59	2.60	0.84	0.36	0.13	0.06	0.00	0.00
Colour laser copier	0.00	0.00	0.16	0.23	0.19	0.34	0.24	0.14	0.00	0.00
Inkjet MFD	1.40	1.85	2.01	1.21	0.65	0.59	0.50	0.46	0.40	0.38
Inkjet printer	1.14	1.51	1.63	0.98	0.39	0.10	0.02	0.01	0.01	0.01
Professional printer / MFD	0.00	0.00	0.12	0.36	0.59	0.83	0.91	0.92	0.88	0.84
Scanner					0.03	0.04	0.06	0.04	0.06	
Facsimile (fax) machine							0.00			
3D printer							0.18			
Total	**22**	**22**	**22**	**16**	**10**	**9**	**7**	**6**	**5**	**5**

7.4 Energy efficiency improvement

Best Available Technology (BAT)

Annual energy consumption data for imaging equipment using Best Available Technology (BAT) are reported in Table 83 based on data and calculation models from the review study supplemented with other assessments.

The annual energy consumption for the representative technology has been calculated as follows:

- For TEC products (laser and professional printers and MFDsfor) each product in the full dataset a percentage saving is assessed by comparing the product with the BAT product for the same speed (e.g. 22 IPM). All the BAT saving percentages within each speed range are averaged and the resulting average BAT saving percentage is reported in the table. The BAT annual energy consumption is calculated by applying the saving percentage on the average energy consumption for representative technology;
- OM products: BAT savings have only been reported for the OM modes, i.e. sleep and off modes (about 11%), but not for the annual consumption. Instead, 10% savings have been assumed for the annual consumption based on the savings for the OM modes and the BAT savings for TEC products;
- Scanners: BAT savings have not been assessed in the review study. 10% savings have been assumed;
- Copiers and fax machines: Data come from the review study.

Table 83 – Savings in annual energy consumption per device for Best Available Technology (BAT); BAT annual energy consumption compared to annual energy consumption for representative technology.

Product type	BAT	Annual energy consumption	
Speed range	% savings	BAT	Representative technology
		(kWh/year)	(kWh/year)
Mono laser MFD	**25%**	**59**	**79**
s ≤ 20	16%	35	42
20 < s ≤ 40	25%	59	79
40 < s ≤ 60	20%	112	140
60 < s ≤ 66	26%	174	234
66 < s ≤ 80	31%	212	307
s > 80	15%	737	863
Colour laser MFD	**26%**	**70**	**94**
s ≤ 20	18%	39	47
20 < s ≤ 40	26%	70	94
40 < s ≤ 60	23%	120	156
60 < s ≤ 66	29%	141	198
66 < s ≤ 80	33%	269	400
s > 80	22%	499	640
Mono laser printer	**14%**	**63**	**73**
s ≤ 20	12%	28	31
20 < s ≤ 40	14%	63	73
40 < s ≤ 60	17%	112	135
60 < s ≤ 66	11%	167	187
66 < s ≤ 135	6%	668	707
s > 135	2%	2949	2995
Colour laser Printer	**26%**	**81**	**109**
s ≤ 20	20%	42	52
20 < s ≤ 40	26%	81	109
40 < s ≤ 51	43%	128	224
51 < s ≤ 60	15%	150	177
s > 60	6%	874	931
Colour inkjet MFD	**10%**	**5**	**5.9**
Colour inkjet Printer	**10%**	**2**	**1.7**
Professional printer and MFD	**25%**	**498**	**664**
Scanner	**10%**	**17**	**19**
Copier	**8%**	**1.1**	**1.2**
Facsimile (fax) machine	**0%**	**0.5**	**0.5**
3D printers	**25%**	**500**	**666**

3D printers

The BAT savings have been estimated and the method for the estimation can be seen in Annex A.

8 Group VII. – Home / office equipment

8.1 Definition

The product group of home and office equipment is defined as is shown in Table 65.

Table 84 - Product groups in the home and office equipment category.

VII. Home and Office equipment
Home gateway / IoT access devices
Home routers/gateways, integrated access devices
Base stations
Home network equipment
Office network equipment (servers, routers, switches)
Home NAS

The product group has been reorganised to reflect data collection categories used in Ecodesign impact accounting[250]. The boxes, indicated in blue in Figure 50, show the categories that are covered in this document. Base stations are covered under the category telecommunication networks while larger office network equipment is covered under the data centres category. The product groups in scope of this section are described in Table 85.

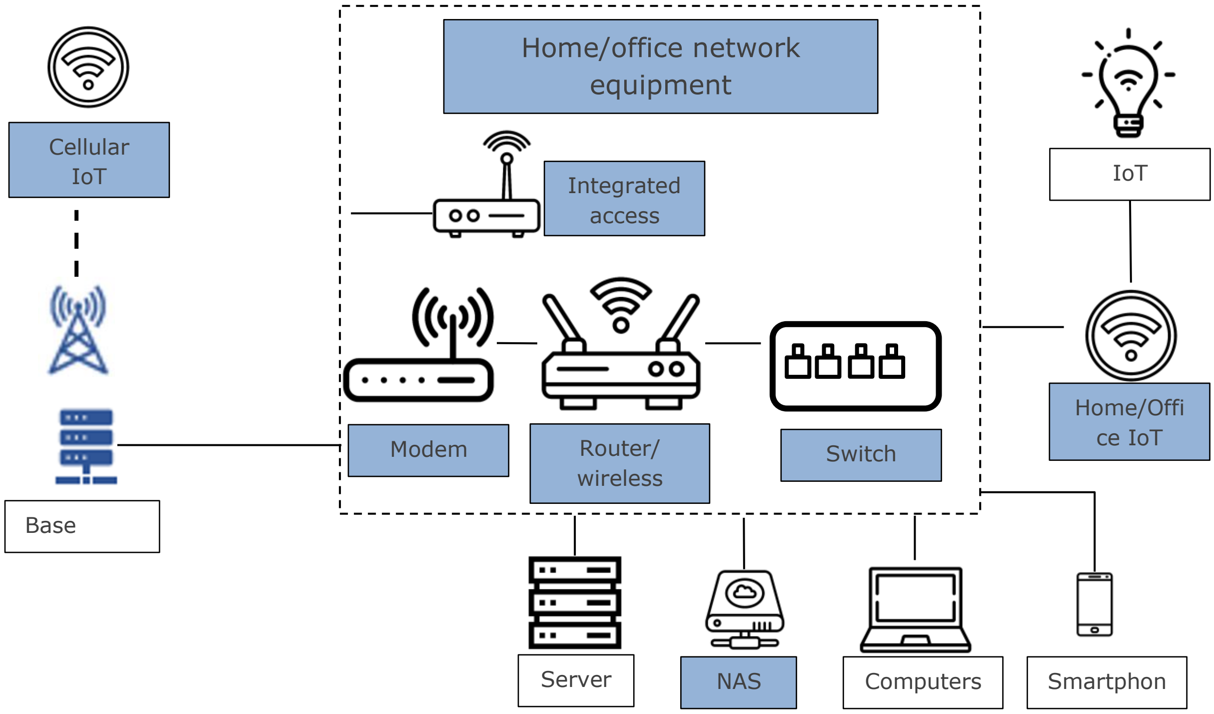


Figure 50 - Illustration of home and office equipment. The blue marked boxes are in scope of the assessments in this section.

[250] https://ec.europa.eu/energy/en/studies/ecodesign-impact-accounting-0

Table 85 - Product description home and office equipment

Product	Description
Home Network-attached storage equipment (NAS)[251]	One or more dedicated storage devices that are connected to a network and provide file access services to remote computer systems.
Home/Office Network Equipment[252]	A device whose primary function is to pass Internet Protocol (IP) traffic among various network interfaces / ports intended for use in residential and small business settings. The equipment provides a Local Area Network (LAN) where devices such as computers can connect to a Wide Area Network (WAN) such as the internet.
	Modem: A device that transmits and receives digitally–modulated analogue signals over a wired or optical network as its primary function.
	Router/wireless router: A network device that determines the optimal path along which network traffic should be forwarded as its primary function. Routers forward packets from one network to another based on network layer information. Devices fitting this definition may provide both Router functionality and wireless network capability.
	Switch: A network device that filters, forwards, and floods frames based on the destination address of each frame as its primary function. The switch operates at the data link layer of the OSI model.
	Integrated access device (IAD): A network device with a modem and one or more of the following functions: wired network routing, multi–port Ethernet switching and/or access point functionality.
IoT Cellular Gateway[253]	An IoT cellular gateway is a data communication device that provides a remote network with connectivity to a host network. The IoT Cellular Gateway is connected to the host network through the mobile network also known as Radio Access Network (RAN).
IoT home/office Gateway	An IoT home/office gateway is a data communication device that provides a remote network with connectivity to a host network. The IoT home/office Gateway is connected to a Local Area Network through the Home/Office Network Equipment. Several wireless protocols are used such as Zigbee and Z-Wave.
Internet of Things (IoT) (not in scope)	Is defined as computing devices embedded in everyday objects that can access the internet. E.g. a smart-light bulb, washing machine, speaker or IoT equipment used for industrial purposes or Smart city solutions. IoT is illustrated in the figure to show what the IoT gateways are connected to, but is not a part of scope.

8.2 Market

8.2.1 Sales

Sales for home Network-Attached Storage equipment (NAS) and home/office network equipment[254] have been derived from the ecodesign impact accounting(EIA) status report[255].

As for sales of IoT gateways, very limited sources of reported data have been identified and it has therefore been necessary to make some rough estimations based on the limited available data.

[251] Definition taken from Energy Star: https://www.energystar.gov/ia/partners/product_specs/program_reqs/StorageV1.0_Program_Requirements.pdf?cb43-b421

[252] Definitions taken from Energy Star: https://www.energystar.gov/products/office_equipment/small_network_equipment/key_product_criteria

[253]Definition from Techopedia: https://www.techopedia.com/definition/5358/gateway

[254] Referred to as SB Home Gateway in ECO design impact accounting report, but is named home/office equipment here, so it is not mistaken with the IoT gateway categories.

[255] https://ec.europa.eu/energy/sites/ener/files/documents/eia_status_report_2017_-_v20171222.pdf

Annual shipments worldwide of 3.2 million cellular IoT gateways was reported in 2017 by Berg Insights and shipments are forecasted to grow at a CAGR of 18.2 %[256] until 2023. Berg Insight also estimates that Europe accounts for one third of the market[256]. The reported sales of IoT cellular gateways in 2020 are forecasted from the reported sales in 2018 and estimated based on the reported European market share.

The sales for IoT home/office gateways is based on a forecast value reported by ABI Research who estimate that the shipments of IoT home/office gateways will grow to exceed 64 million units in 2021 worldwide[257]. It has been estimated that the European market share for IoT home/office gateways will also account for one third of the market. Furthermore, it has been assumed that the growth (CAGR 18.2%) in shipments of IoT home/office gateways has been similar to the growth in shipments of IoT cellular gateways. There is limited information on ABI Research definitions of IoT gateways, so there is a risk that the cellular IoT gateways are represented twice.

See sales for all the categories in Table 86.

Table 86 - Sales of all categories home and office equipment

Product	Sales (000's)				
	2010	2015	2020	2025	2030
Home Network-attached storage equipment (NAS)	2 814	4 824	6 834	8 844	10 854
Home/office network equipment	30 914	39 858	48 803	57 747	66 692
IoT Cellular Gateway	n.a.	n.a.	5 284	n.a.	n.a.
IoT Home/Office Gateway	n.a.	n.a.	17 276	n.a.	n.a.
Total			**78 198**		

8.2.2 Stock

Stock for NAS and home/office network equipment is based on reported data from an EIA study. Stock shown in the EIA study is that of products sold in that particular year as well as for those products sold in previous years and that have not yet reached their end-of-life. Reported typical lifetime for home/office network equipment and NAS is 5 years.

Stock of IoT cellular and home/office gateways is based on sales determined above. Stock is calculated by the products sold in 2020 and of the products sold in previous years that have not yet reached their end of life. The typical lifetime of IoT cellular and home/office gateways (5 years) is assumed to be equal to the lifetime of home/office network equipment. The stock is only provided for 2020, because there is limited data on the historic sales of IoT gateways. Stock for all categories is presented in Table 87.

Table 87 – Stock home and office equipment

[256] https://www.i-scoop.eu/internet-of-things-guide/cellular-iot-gateway-market-2023/

[257] https://www.telecomstechnews.com/news/2016/oct/31/iot-gateway-shipments-to-reach-64m-units-by-2021/

Product	Stock (000's)				
	2010	2015	2020	2025	2030
Home Network-attached storage equipment (NAS)	10 050	20 100	30 150	40 200	50 250
Home/office network equipment	136 580	181 403	226 125	270 848	315 570
IoT Cellular Gateway	n.a.	n.a.	19 355	n.a.	n.a.
IoT Home/Office Gateway	n.a.	n.a.	60 159	n.a.	n.a.
Total			**335 789**		

To verify the rather rough estimate of sales and stock, further research based on earlier studies has been made. A study conducted by EDNA in 2016[258] shows that they estimate a stock of approximately 263 million[259] installed gateways worldwide in 2020. If it is assumed that the EU will account for one third of that market (assumption based on market share estimate of cellular IoT gateways made by Berg Insights[256]) then the EU market share of all IoT gateways will be approximately 88 million units. Adding stock of both cellular IoT gateways and home/office gateways adds up to approximately 80 million units. Having two rough estimates that point towards the same value provides more certainty but it is still a rather rough estimate.

8.3 Performance and energy use

8.3.1 NAS

Energy Star provides information about the performance of NAS units but only have a limited number of products in their database[260]. The NAS units listed on Energy Star high performance business units and the performance metric stated by Energy Star might not represent the home market. However, given the lack of better data for these, , it is assumed that home market NAS units have similar performance characteristics. A NAS unit can be optimised from the point of view of transaction, streaming or capacity. Depending on the configuration, the manufacturer can also make changes in order optimise the performance metric [261]. See Table 88 for the amount of data points, performance metric and average values on each configuration.

[258] https://www.iea-4e.org/document/384/energy-efficiency-of-the-internet-of-things-technology-and-energy-assessment-report

[259] Based on reading of graphs in EDNA report, measurement errors might occur.

[260] https://www.energystar.gov/productfinder/product/certified-data-center-storage/results?formId=fcfc2996-cf57-4df6-915c-611fee23047a&scrollTo=1300&search_text=&snia_online_taxonomy_category_filter=&brand_name_isopen=0&storage_model_connectivity_filter=Block+I%2FO+and+Network+Attached+Storage+%28NAS%29&zip_code_filter=&product_types=Select+a+Product+Category&sort_by=brand_name&sort_direction=asc&currentZipCode=5750&page_number=0&lastpage=0 – Download excel sheet to get values

[261] https://www.energystar.gov/ia/partners/product_specs/program_reqs/StorageV1.0_Program_Requirements.pdf?cb43-b421

Table 88 - Performance metric of different configurations of NAS

NAS configuration	Data points	Performance metric	Value (average)
Transaction	2	IOPS/W[262]	4.74
Streaming	24	MiB/s[263]	0.9
Capacity	1	GB/W[264]	786

The performance metric ready idle (W) is provided for all three configurations, but it is only the capacity configuration that is optimised for it, which is why the performance of T this is much higher than the other configurations. However, ready idle for all configurations is reported here to provide an overall average of the performance for NAS units, see Table 89. Ready Idle (GB/W) is the total storage capacity divided by the power in ready idle state.

Table 89 - Performance metric GB/W for all NAS configurations

NAS configuration	Data points	Performance metric	Value (average)
Transaction	2	GB/W	43.2
Streaming	24	GB/W	59.2
Capacity	1	GB/W	786
Total average[265]		GB/W	296

8.3.2 Home/office network equipment

A relevant metric for home/office network equipment is Mbps, mega-bits per second. For this version of the report, no relevant data source has been identified.

8.3.3 IoT gateways

Throughput, measured as (Mbit/s), is considered as an important performance metric for IoT gateways. The throughput highly depends upon the communication technology, the energy use and the range. Figure 51 provides an overview of the performance of different communication technologies that is used for IoT equipment. Table 90 provides values that can be used to translate the colour coded values in Figure 51 for the average power consumption of an edge device. E.g. smart light bulb communicating with ZigBee to IoT gateway (considered edge device) or IoT gateway connected with Ethernet to router (considered edge device).

[262] Hot band test IOPS/W Tests the number of small data requests that can be performed per second from frequently accessed data per Watt

[263] Sequential read/write (MiBps /W) is how many million Bytes of data that can be read/written continuously per second per Watt

[264] Ready Idle (GB/W) is the total storage capacity divided by the power in ready idle state.

[265] It is assumed that each NAS configuration represent one third of the market.

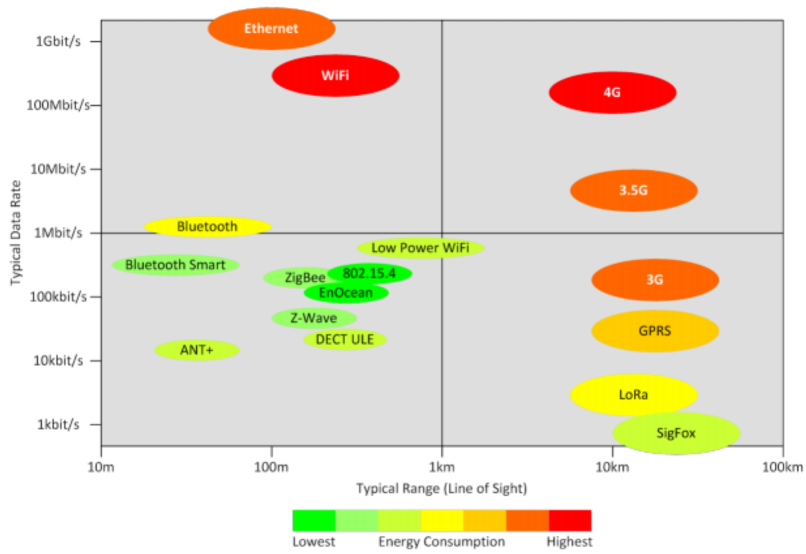


Figure 51 - Performance of communication technologies for IoT applications
Source: EDNA report 2016266

Table 90 - Numeric power consumption values gateways

Very low	<1mW
Low	1 – 10mW
Medium	10-100mW
High	100mW-1W
Very high	>1W

8.3.4 Energy consumption representative technology

The energy consumption of NAS and home/office network equipment is based upon data from the EIA status report. In the EIA report the power use (W) is divided into three power states: on-power, standby-power and idle-power. NAS and home/office equipment power states are reported in 5-year intervals between 2010 to 2050[267]. The load is also reported in the EIA report and divided into time spent in on-mode, standby-mode and idle-mode[267]. The power use in each state has been multiplied by the load mode to determine energy consumption per day which in turn has been multiplied with days in a year to determine the annual energy consumption (see Table 91).
It has not been possible to find any larger studies that calculate an average annual energy consumption for IoT cellular gateways and IoT home/office gateways.
The average standby power of Home/Office IoT gateways have been tested by EDNA[268] (Electronic Devices and Networks Annex - IEA 4E). EDNA has tested gateways used for smart lightning and home automation. They have tested gateways that communicate with Wi-Fi and Ethernet. The average standby power of the test is 1.6 Watts. The EDNA report is from 2016, therefore additional research of the energy consumption has been conducted to see if the value still holds.

[266]https://www.iea-4e.org/document/384/energy-efficiency-of-the-internet-of-things-technology-and-energy-assessment-report
[267] https://ec.europa.eu/energy/sites/ener/files/documents/eia_status_report_2017_-_v20171222.pdf see EFSBAU and LOADBAU Annex A.
[268]https://www.iea-4e.org/document/384/energy-efficiency-of-the-internet-of-things-technology-and-energy-assessment-report

Online research of popular IoT home/office gateways such as TRÅDFRI (sold by IKEA[269]), Phillips hue bridge[270] and Develco standard model[271], have been conducted. The informed power draw varies from 0.1-2.5 Watts. A simple test, with a watt meter, of TRÅDFRI and Phillips hue bridge show that the power draw is about 1-1.7 Watts.
Furthermore, the US EPA running the Energy Star programme has been contacted for information since they are working on a program for smart home management systems. At the moment they only have limited data available, however they have found similar results. It is assumed that the gateways are running at 24/7 all year around. Based on the above research a power draw of 1.5 W is estimated and used to calculate the annual energy consumption, see the result in Table 91.
It was not possible to find an overall value for the energy consumption of IoT cellular gateways either. The estimated energy consumption of the IoT cellular gateway have therefore been assumed to be the same as for the IoT home/office gateway.

Table 91 – Annual energy consumption

Product	Energy consumption [kWh/year]			
	2015	2020	2025	2030
Home Network-attached storage equipment (NAS)	56.9	54	43.4	40.5
Home/office network equipment	73.1	72.6	63.9	55.1
IoT Cellular Gateway	-	13.1	-	-
IoT Home/Office Gateway	-	13.1	-	-

8.4 Energy efficiency improvement

Different applications require different solutions and some communication technologies are therefore better suited to connect IoT gateways than others. See Figure 52 to determine the best available technology to connect different applications.

[269]https://www.ikea.com/dk/da/p/tradfri-gateway-hvid-40337806/?gclid=EAIaIQobChMIxdScmcPs5wIVBud3Ch0ypwlfEAQYAyABEgIw9vD_BwE&gclsrc=aw.ds

[270] https://www2.meethue.com/en-us/p/hue-bridge/046677458478

[271]https://www.develcoproducts.com/products/gateways/squidlink-gateway/#SquidlinkGatewayTechnicalSpecifications

Appl. Area	Application	Edge Device	ANT+	Bluetooth	Bluetooth Smart	DECT ULE	Z-Wave	ZigBee	802.15.4-2011-based	EnOcean	WiFi	Low Power WiFi	Ethernet	GPRS	3G (UMTS)	3.5G (HSPA)	4G (LTE)	LoRa	Sigfox
Smart Home	Smart Lighting	smart LED bulb	y	n	b	y	y	y	y	y	n	y	x	x	x	x	x	x	x
		gateway	x	x	x	x	x	x	x	x	y	b	y	y	n	n	n	x	x
	Home Automation	sensors	y	n	y	y	y	y	b	b	n	y	n	x	x	x	x	x	x
		actuators	y	n	y	y	y	y	b	b	n	y	n	x	x	x	x	x	x
		camera	x	x	x	x	x	x	x	x	y	x	b	x	y	y	y	x	x
		gateway	x	x	x	x	x	x	x	x	y	x	b	x	y	y	y	x	x
	Smart Appliances	smart appliance	y	n	b	y	y	y	b	b	n	y	n	x	x	x	x	x	x
		gateway	x	x	x	x	x	x	x	x	y	b	y	y	n	n	n	x	x
Smart Mobility	Smart Roads	roadside unit	x	x	x	x	x	x	x	x	b	x	x	x	x	x	x	x	x
	Smart Street Lighting	street light luminaires	x	x	x	x	x	x	x	x	x	x	x	y	n	n	n	b	b

b Best Available Technology

y Possible Technology

n Not Recommended Technology

x Not Appr. Technology

Figure 52 - Overview of best fitting technologies for investigated IoT applications.

9 GROUP VIII. – ICT IN PUBLIC SPACES

9.1 ATMs

9.1.1 Definition

An ATM (Automated Teller Machine) is a machine that dispenses cash, takes cash deposits and/or performs other banking services without intervention of bank personnel. It can be freestanding or built into the wall. It is usually located in and/or just outside a bank office, but it can also be found in large airports, train stations, hospitals, super-markets and hotel-lobbies. In warmer climates(e.g. Southern Europe) and tourist areas especially, ATMS can also be found in dedicated outdoor glass cubicles with their own lighting and air conditioning.

ITEM SPECIFICATION
Display
15" XGA colour consumer display screen (options)
• Touch screen
• Sunlight viewable
• Privacy filter
• Function key

System Platform
Microsoft® Windows® 7 Professional

Safe
• UL 291 Level 1
• CEN I
• CEN III GAS
• CEN IV GAS

Card Reader
EMV-ready card reader (options)
• ActivEdge
• MCR
• Dip

Cash Dispenser
MEDIA TECHNOLOGY
Advanced Function Dispenser (AFD) 2.0
• Bundle presenter up to 50 notes
• Banknote reject and bundle retract capable
Banknote Storage
• Up to four media cassettes
• 340 mm stacking space per cassette
• Money low sensor
• Divert/reject open bin, cassette or partioned cassette

Receipt Printer
80 mm enhanced graphical receipt printer

Encrypted PIN Pad
PCI-approved encrypting PIN pad with signature- and certificate-based
RKL support

Figure 53. ATM with specifications (source: Cennox.com[272])

The user interface has sections for identification (magnetic card slot, PIN-pad or keyboard), instructions (touch screen and/or display plus side-buttons), note-dispenser (and/or note-intake fordeposits) and proof of the transaction (receipt printer). In addition to this and , inside the ATM there is a computer-board (e.g. ATOM, Celeron, i3 with integrated GPU, internet modem, various USB and other slots), a storage unit (for e.g. 5,000 to 10,000 notes), various safety features e.g. to stain banknotes in case of a gas attack or similar

[272] https://www.cennox.com/uk/financial-services/self-service-banking-terminals/automated-teller-machines/the-diebold-5500

and a UPS[273]. The casing is usually robust (steel) and customised for the bank operating the device. There are weather-proof ATMs, but most ATMs can be found in air-conditioned and well-lit spaces.

9.1.2 History and Market

ATMs started out in the EU in the 1970s to replace the human teller behind the counter of a bank office. It took a while for bank clients to get used to the phenomenon, but for many account holders the ATMs are now, besides home banking on their PC and smartphone, the only physical interface with their banks.

Due to the steady increase in non-cash payments, the number of visits to the ATM is decreasing and thus most banks are also decreasing the number of bank offices but also the number of ATMs.

Technical innovations in ATMs have focussed on preventing fraud and physical attacks with gas explosions or ramming into the ATM with a car. In 2014 there were about 1000 physical attacks on ATMs in Europe, according to the sector association EAST (European Association for Secure Transactions) [274].

There are investigations into introducing biometric solutions in Europe, e.g. replacing the PIN-code with a fingerprint scan, which is a well-established practice in Japan. In a 2019 survey from EAST, 21% of respondents said they would not use such a technology and this figure increased to 50% in 2010 with respondents citing as reasons concerns of personal data privacy.

Table 92. Energy consumption of ATMs 1999 (source Roth 2002) and 2018 (VHK, misc.sources)

year		**1999**	**2014**	**2018**
parameter	*unit*			
stock	#	300.000	409.000	390.000
active h	h/d	3.4	3.4	3.4
active power	W	390	190	105
active unit energy/yr	kWh/yr	484	310	130
active EU energy/yr	*GWh/yr*	*145*	*96*	*51*
idle h	h/d	21.6	21.6	21.6
idle power	W	313	120	67
idle unit energy/yr	kWh/yr	2471	1577	528
idle EU energy/yr	*GWh/yr*	*741*	*387*	*206*
Total unit energy/yr	**kWh/yr**	**2955**	**1887**	**658**
Total EU (365 d)	**TWh/yr**	**0.88**	**0.48**	**0.26**

[273] Uninterruptable Power Supply, i.e. mainly a battery (e.g. 1-5 kVA) to protect the ATM from power surges and blackouts. It can also be used in conjunction with solar power where appropriate.

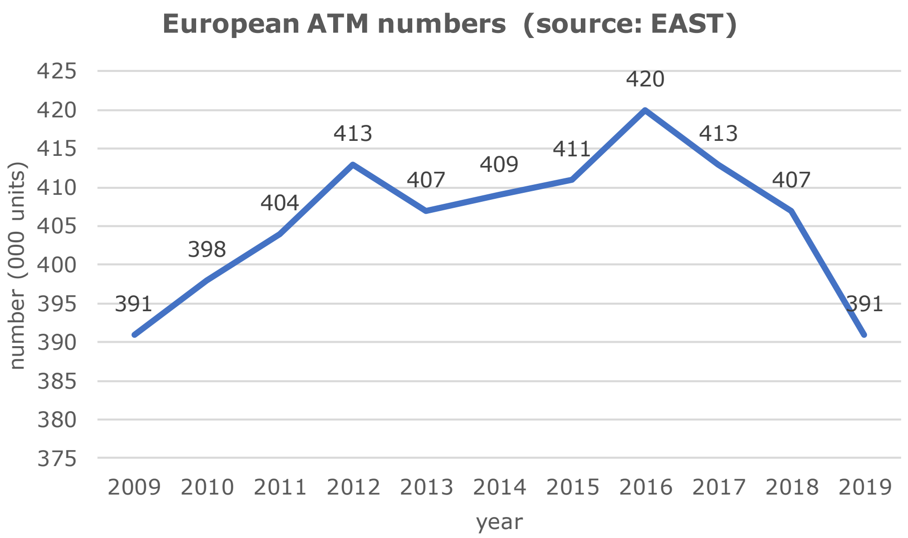
[274] https://www.association-secure-transactions.eu

9.1.3 Sales and Stock

The sector association EAST retrieves the statistics for the number of ATMs installed. This is given in the figure below for the period over the last 10 years.[275]

EAST estimates that there are 391,434 ATMs in Europe, a 3% decrease from the 2018 total. Overall numbers are declining in many countries. There are 200,000 ATMs in Russia, 166,845 in Brazil, 108,092 in Indonesia, 70,000 in Canada, 53,262 in Mexico, 52,466 in Turkey, 36,446 in Ukraine, 30,000 in South Africa, and 2,867 in Serbia which are not shown in these totals.

The product life of ATMs is estimated at 6 years, which suggests sales of 60-70,000 units per year. The freestanding standard versions, not so common in the EU but e.g. found in hotel lobbies, can cost as little as €2,500-€3,000, but the more common wall-mounted, bespoke bank versions are estimated –between cash dispensers and all-in-on versions—at double that amount. This suggests a B2B market in Europe of approximately €330 million in end-user prices.



275 https://www.association-secure-transactions.eu/industry-information/atm-numbers-europe/

Figure 54: European ATMs installed in stock 2009-H1 2019 (source: EAST, 2019)

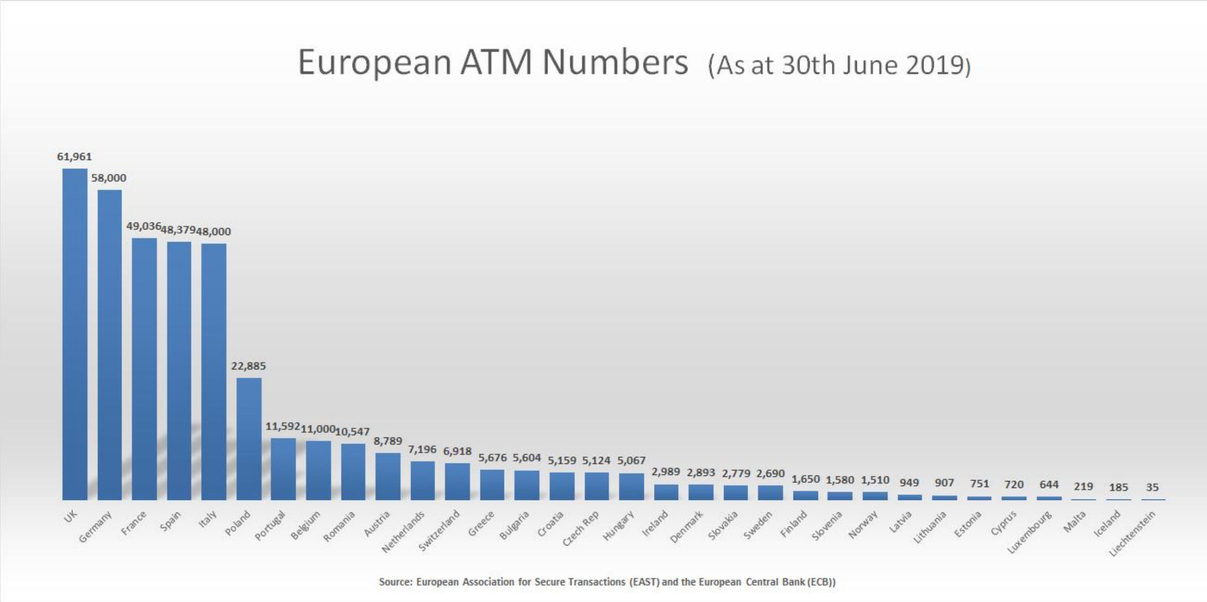


Figure 55: European ATM numbers per country (source: EAST, 2019)

In many European countries, ATM numbers are falling as non-cash payments increase and cash payments decline.

9.1.4 Energy

Investigations of ATM energy use are rare. The earliest source found is a study by Roth 2002 [276] for the US government. The data indicate an energy consumption of 0.84 TWh/yr for a stock of 300,000 units installed in the US in 1999. This will also be the number installed in the EU at that time.

In 2014 Diebold introduced an ATM with a 70W standby[277], which it claimed to be a 40% reduction with respect to the existing power use (120W). In 2018, other ATMs and brands also showed a similar power use. The data for 2018 in the next table stems from the Diebold 5500 Quad manual presumed to be representative of the latest generation of ATMs. In literature, "ATMs" are often also referred to as the whole glass cubicle with ATM, air-conditioning and lighting. The air conditioning (room air conditioner) takes up a large part, roughly half, of the energy consumption. For that reason, in India there are cost-effective proposals to properly insulate the walls of the cubicle. It is recommended to use solar photovoltaic panels to drive the ATM machines inside. [278]

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[276] Roth, K.W. et al, Energy Consumption by Office and Telecommunications Equipment in Commercial Buildings, Volume I: Energy Consumption Baseline, A.D.Little for the Office of Building Equipment (DOE), Jan. 2002.

[277] https://www.prnewswire.com/news-releases/diebold-innovation-leads-to-worlds-greenest-most-power-efficient-atm-250600621.html

[278] Singh, H.K., Pra-kash, R. and Shukla, K.K. (2016) Energy and Emission Reduction Potential for Bank ATM Units in India. Open Journal of Energy Efficiency, 5, 107-120. http://dx.doi.org/10.4236/ojee.2016.54010

9.2 Cash registers and POS Terminals

9.2.1 Definition

A Point-of-Sales (POS) system includes the hardware and software needed to process and complete purchase transactions on the spot in retail, hospitality, cultural and other sectors. A *cash register* is a computer --operated by a barcode-scanner and/or keyboard and/or touchscreen-- that totals, displays, and records the cost of purchased items. It is usually combined with an integrated or separate physical *money-drawer* for processing cash payments. A *POS terminal* processes card-payments using a magnetic card reader, a PIN-pad and a gateway to the financial institution approving the transaction. The POS system usually includes a *printer* for receipts and –in a retail environment—*a barcode-scanner* to identify the barcode of items purchased. In a hospitality environment, i.e. a bar or restaurant, there are often *mobile order-terminals* that feed into the POS system. A *POS system* not only includes (a selection of) all of the above, but also is linked to an information system for managing stock, tracking orders, recording customer details, logging hours and numerous other activities that enhance customer service, boost employee performance and meet tax obligations.

9.2.2 History & Market

The mechanical cash register was invented at the end of the 19th century, primarily to keep the cash safe, the employees honest and to register the purchases. The machines improved by adding a mechanism for individual sales (the first cash registers only recorded total amounts received); printed receipts; machines with several drawers, one for each clerk in a store, etc. In the 1960s electronic cash registers became available and from the 1970s onwards dominated the market. In the early 1970s, laser-scanners and universal barcodes were introduced. Computer performance increased and computing costs decreased. Detailed management of stock became a reality. Various forms of discounts could be more easily managed. The latest policy 'trend' is the use of the POS system for closer monitoring by the national fiscal system. Poland[279], Norway[280], Belgium[281], Germany[282] and others[283] introduced national regulations to this effect. The latest development in POS-payments is to pay with your smartphone in stores and restaurants.

EAST estimates that, as of 30 June 2019, there were 14,7 million POS Terminals deployed in Europe. In 2018 EAST began collecting data for POS Terminal numbers in Europe for the first time. POS terminals are the most widely deployed terminal type. Nevertheless, there will be an unknown number of retail outlets and restaurants that only have a cash register

[279] Polish regulation on cash registers, Communication from the Commission - TRIS/(2018) 00135, Directive (EU) 2015/1535, Notification: 2018/0023/PL

[280] Norwegian Cash Register Act.
http://www.eftasurv.int/media/notification-of-dtr/notifikasjon-skjema-cash-register-9007.pdf

[281] https://www.geregistreerdkassasysteem.be/nl (GKS)

[282] Kassensicherungsverordnung (KassenSichV). Published 2017. Implemented Jan. 2020. The Kassensicherungsverordnung (KassenSichV) regulates the technical requirements for electronic recording and security systems, such as computerized cash register systems and cash registers. The regulation is designed to protect against manipulation of companies' basic digital records.

[283] E.g. in Austria since 2017

and accept no cards. For the moment, a conservative number of 15 million installed cash registers is assumed. The European breakdown by country is given below. [284]

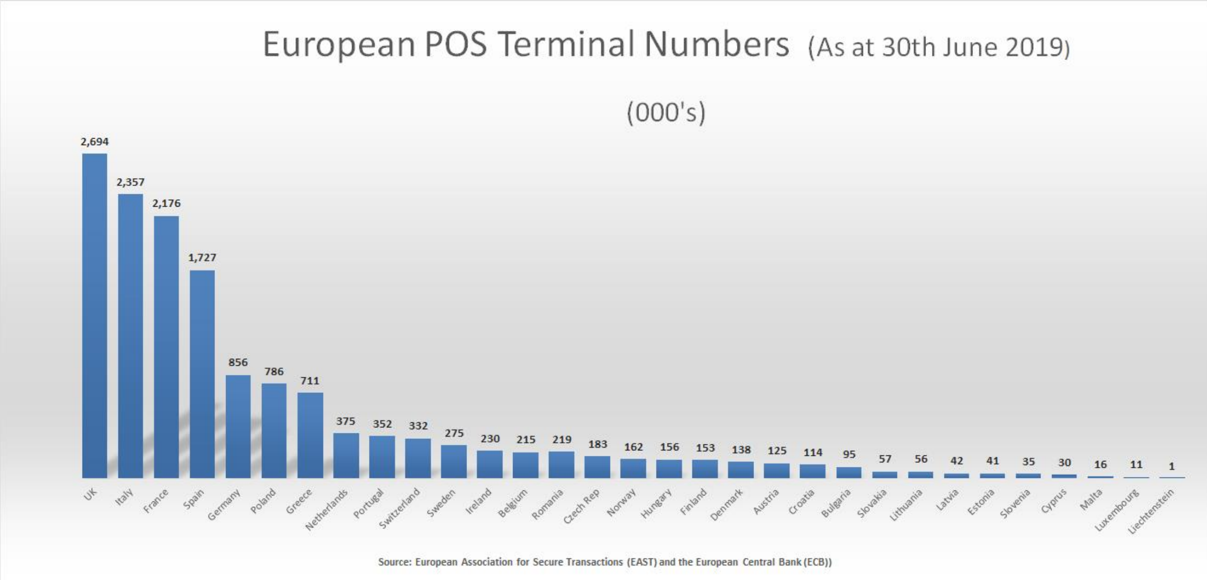


Figure 56. European POS Terminal Numbers as of 30.6.2019 (source: EAST 2020)

MEErP Part 2[285] reports 3.5 million retail stores (of which 0.9 supermarkets and department stores), 1.7 million hotels/ restaurants/ bars, 0.8 million personal services (hairdressers, etc.), 0.76 million trade and repair of motor vehicles enterprises and less than 0.1 million museums, cinemas, theatres, etc.. This comes down to around 7 million sites with one or more cash registers with POS terminals. Assuming that the average supermarket or department store may have 8 or 10 POS-terminals and cash registers then the numbers add up.[286]
Product life of cash registers and peripherals is estimated at 5 years. This suggests an EU market of 3 million units per year. Between cash register (€400), printer (€130-150), scanner (€200), POS card-payment terminal (€100) and installation costs, an average POS system costs at least around €1000,-/unit. [287]

In 2017, 43 retail payment systems existed within the EU as a whole. During the year, about 57 billion transactions were processed by those systems with totalling an amount of €44.0 trillion.[288]

Note that the above EU figures apply to the EU28. Projections for the EU27, i.e. without the UK, will be about 13% lower.

[284] EAST data do not include the number of UPTs (unattended payment terminals) in Europe.This is proving to be a challenge and no data is yet available.
[285] Kemna, R.B.J., MEErP 2011 – Methodology Report – Part 2, VHK for the EC, 28.11.2011.
[286] Note that MEErP-figures only intend to give a ballpark estimate whether the EAST figures are plausible. For some areas like retail stores there has been a downward trend in recent years and numbers are now 2,8 million retail stores in the EU28 (of which 0,294 million in the UK) Source: Eurostat, Number of retail stores (NACE Rev.2, G47) [dt_oth_n47_r2]
[287] Component prices estimated by VHK from internet offers, Feb. 2020.
[288] https://www.ecb.europa.eu/press/pr/stats/paysec/html/ecb.pis2017.en.html

9.2.3 Energy

Cash registers or POS systems have never been a priority in energy efficiency policies in the US, EU or anywhere else. Older data could only be found in Roth 2002. For the year 2000 it was found that, both in active mode (35h/week) and in idle mode (49h) the power drawn by a POS terminal was 50W. This comes down to 210 kWh/yr. At a US stock of 6,875 million (from totalling 4 years of sales 1996-2000), Roth reaches a US energy consumption of 1.5 TWh/year.
The report also contains some older data for active mode power in 1993 (70W with 10W in standby) and even 1985 (130W, also 130W in idle).
As regards the latest POS systems, there are only manufacturers' data available with very few of them boasting energy efficiency as a selling point. One exception is Toshiba that is presenting its WILLPOS B20 POS terminals with a CPU power consumption of 27W, reportedly a 49% reduction versus its previous 53W model. Assuming that an average model will use 30W during an 11 h day and 310 business days per year, the annual energy consumption is a little over 100 kWh/year. The previous model would then have used 180 kWh/year.

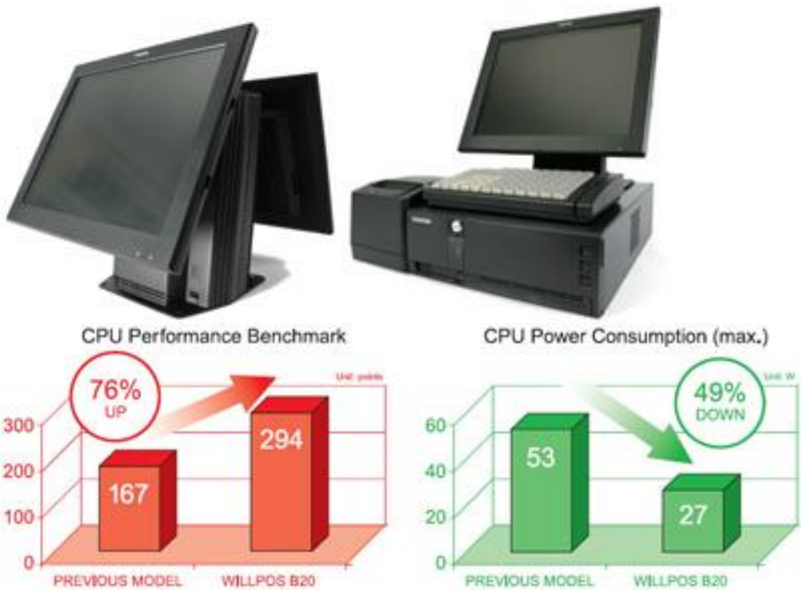


Figure 57. Toshiba Terminals WILLPOS A20 (top left) and B20(top right)

As regards POS receipt printers, Epson makes a point of its printers being paper-saving and energy-efficient.[289] Their TM-T88V printer consumes 2.4W (0.1A, 24V) in standby and 43W while printing (1.8A, 24V).[290] At 1h active and 10h standby mode per business day and assuming an 87% efficient AC-DC power supply, this will come down to about 24 kWh/year. Similar specifications were also found from other manufacturers.[291] A battery-powered (portable) model, the TM-P20[292], can operate on a 1240mA Li-ion (3.7V) battery on WiFI for 9h and on Bluetooth for 26h.If used for 310 business days each consisting of

[289] https://www.epson.eu/verticals/business-solutions-for-retail/eco-point-of-sale-printers
[290] https://www.epson.eu/products/sd/pos-printer/epson-tm-t88v-series#specifications
[291] https://www.bypos.be/thermische-bonprinters/star-tsp100eco-tsp143eco-bonprinter-kassalade-bypos-1774
[292] https://www.epson.eu/products/sd/pos-printer/tm-p20-series#specifications

11 hours per day then this results in only 10-15 kWh/year, but it is slower than the TM-T88V model (100mm/s versus 350 mm/s). Assuming a rounded value in between the two models, a 20 kWh/year energy consumption for a POS printer is assumed.
A handheld scanner will use less than 1 W (0.2 Ah, 5V) in active mode and 0.4 W in idle. Presuming that an on-counter scanner will use a bit more, 5 kWh/year is assumed.
A POS-terminal for card-payments in a mobile version, typically uses the same battery as the portable printer mentioned above and an electricity use of 10 kWh/year is assumed.
In total, an up-to-date new cash register (100), printer (20), POS card terminal (10), scanner (5) is assumed to be using 135 kWh per year. An older model—with a 4-5 year product life-- is estimated to use 230 kWh/year (180+30+15+5). The average installed model in 2020 will thus use 180 kWh/year. With 15 million units installed (see next paragraph) this comes down to an electricity use of 2.7 TWh/year.
With an up-to-date technology of 135 kWh/yr this will become 2 TWh/year in 3 years.
As regards the Best Available Technology (BAT), using a 10 kWh/yr tablet[293] at a mechanical cash drawer, an 8 kWh/yr Bluetooth printer and a 7 kWh/yr POs terminal and a 5 kWh/yr scanner will result in a 30 kWh/yr set-up and thus 0.45 TWh/year. For data-storage there are several blogs recommending use of solid-state drives (SSDs) instead of the hard-disk drives (HDDs).[294]

9.3 Ticket machines

9.3.1 Definition

A ticket machine is a self-service POS machine that, after payment, gives out one or more tickets or charges a magnetic card. Optionally it also prints a receipt.
The tickets or charged cards, properly validated at entry (and for cards also at the exit), give access to means of transport, places of culture, sports and other venues of entertainment or the time-limited use of parking spaces

[293] https://www.apple.com/environment/pdf/products/ipad/iPadPro_11-inch_PER_oct2018.pdf : 2.23 W in display on-idle mode, 0.23W
294 https://blog.constellation.com/2019/12/16/energy-efficiency-of-different-pos-systems/

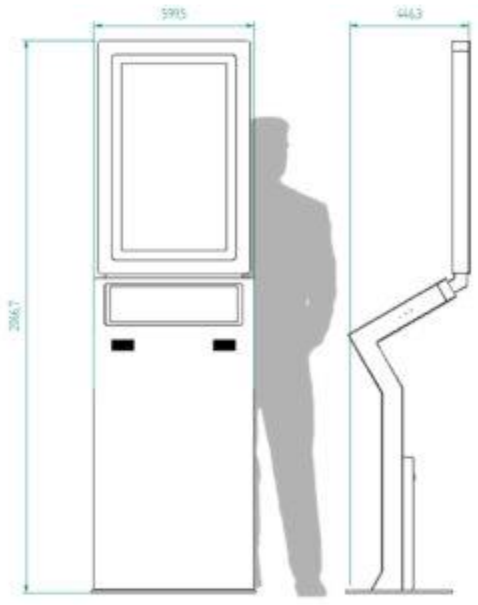
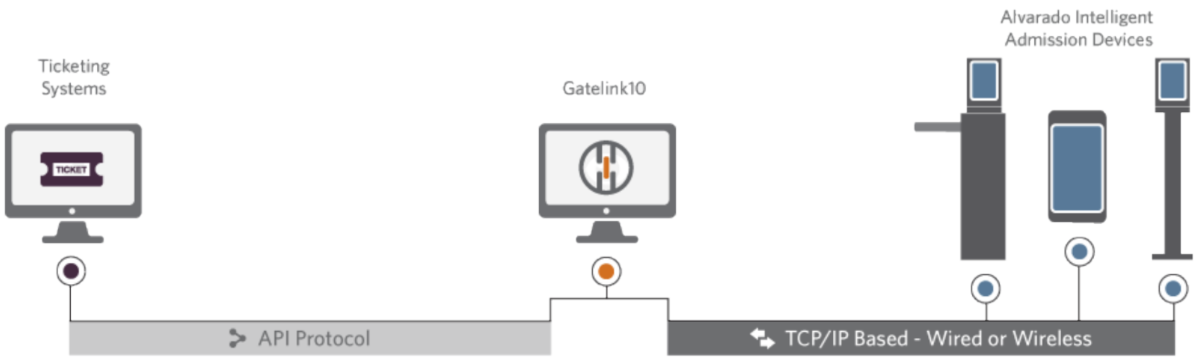


Figure 58. Ticket machine

9.3.2 History and market

The ticket machines were invented to supplement, and sometimes to completely replace ticket sales by staff in stations or at venues, as well as reducing sales of tickets by drivers of buses or conductors in trains. Ticket machines are efficient but have not overall eliminated the need for personnel selling tickets e.g. for special travel-requests or for people not understanding how to operate the ticket machine.
In recent years ticket machine are being used less because travellers/visitors tend to buy their tickets over the internet and then use the home-printed ticket or a digital (barcode) version on their smartphones to gain access especially to train-tickets and boarding passes for air-travel. Instead of ticket-machines for street-parking the payment can also be done via smartphones either through an app or by sending an sms[295].

The information technology behind a ticketing system can be quite sophisticated, as is shown in the figure below.



295 https://parking.brussels/fr/smart/stationner-en-voirie-mobile

Figure 59. 'Smart' ticketing system (source: Alvarado[296])

There are no sales data available, but the next paragraph gives an estimate of the numbers installed.

9.3.3 Energy

In principle, a ticket machine has the same components as a POS system, except for a coin slot mechanism and sometimes a banknote-reader/stacker[297] on the input side as well as a ticket storage/dispenser unit and/or a magnet card reader/writer on the output side. The coin-slot mechanism hardly uses any power[298]. A typical banknote-reader/stacker has an energy use of 6W in standby and 14W in normal operation.[299] Assuming 1h/d active mode and 23h/d in standby for 365 days this results in 55 kWh/year for this component. The ticket dispenser normally uses the same printer as for the receipts and thus represents no significant extra energy consumption compared to a POS system.
Magnetic card reader/writers are available and also powered by USB and thus consume a maximum 2.5W in on-mode and probably 0.5W in standby. This amounts to 5 kWh/yr at 1h active mode.
All in all, given energy consumption of 135 kWh/yr for an up-to-date POS system, an up-to-date ticket machine ('kiosk') will consume 195 kWh/yr. An older model will use 290 kWh/yr. The average installed model in 2020 will thus use 180 kWh/year. To this, the energy use of the validation scanner (or date-printer in older models) has to be added, which is estimated at 5 kWh/year (varies between 3kWh for small scanners in a bus/tram and over 50 kWh for an entry gate at a metro or an airport).
Note that the above consumption values do NOT apply to parking meters. Parking meters do not use touchscreens or even backlit monitors. They typically use low-power TFT displays (LCD with segments) and the most efficient types use E-ink (almost zero standby) screens. They have coin slot mechanisms and magnetic card readers but no banknote readers. The later versions all use solar panels (with battery) as a supplementary or–for the most efficient versions without printer—only power source. The printer, if present[300], will be the most power-hungry component. Given the many different versions of street parking meters it is difficult to make an estimate of the energy consumption. Based on the data for the latest models, the peak capacity of the typical solar panel (15W peak for a 30x30cm panel), an annual unit energy consumption of 30 kWh/year (grid-electricity, average 3.5W between active and standby) is estimated.

9.3.4 Stock and energy

The table below gives an estimate of the installed stock of ticket machines and check-in points. In total there are 113,500 ticket machines (180 kWh/yr), over 1 million street parking meters (30 kWh/yr) and over 0.5 million check-in points and gates to validate the tickets (5 kWh/yr) in the EU.

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[296] https://www.alvaradomfg.com/mobile-ticket-validation-pocketgate/

[297] Examples at https://www.payprint.it/en/payment-systems/banknote-reader-with-stacker.html

[298] The coins provoke an eddy current which is measured by a sensor and then compared to the known eddy current values by the CPU

[299] in 24 V DC, converted from 230V at assumed 87.5% efficiency https://www.payprint.it/images/pdf/lettore-banconote-ict-lx7-datasheet.pdf

[300] Giving in the plate number of the car or –better-- the number of the parking space is more efficient.

Table 93. Number of ticket machine and check-in point venues and 2020 EU energy use

venues	no. of venues	machines / venue	check-ins/ venue	machines	check-ins	GWh/yr
train stations	10,000	4	4	40,000	40,000	7,4
larger commercial airports	300	10	20	3,000	6,000	0,57
subways stations	2,500	2	10	5,000	25,000	1,025
regulated off-street parking spaces	26,200,000	(1/400)		65,500		11,79
regulated on-street parking spaces	14,700,000		(1/14)		*1,029,000*	30,87
trams	40,000		2		80,000	0,4
busses in public transport	170,000		2		340,000	1,7
TOTAL				**113,500**	**1,520,000**	**53,8**

*180 kWh/machine, 5 kWh/check-in point. *=except on-street parking meters 30 kWh*

sources: VHK on the basis of MEErP 2011, misc. public transportation statistics, EPA 2019[301]

The table below gives a further split-up of the regulated parking spaces in Europe.

[301] Scope of parking in Europe, data collection by the European Parking Association (EPA), 2019. www. europeanparking.eu

Table 94. Regulated parking spaces in Europe (source: EPA, 2019)

Off-street, of which	**26,175,123**
In structure	8,811,780
Surface level	3,774,824
Park&Ride (dissuasion)	1,110,190
In sport, cultural and leisure facilities	2,612,497
In shopping centres and markets	6,408,210
Hospitals, universities	2,398,378
Airports	1,059,243
On-street, of which	**14,712,574**
Regulated for general public use	8,665,046
Residents only	3,646,849
Loading and unloading	591,400
Motorbike spaces	955,334
Other reserved spaces (handicapped, police, etc.)	853,946
Total	**40,887,697**

9.4 Public WLAN hotspots

9.4.1 Definition

Public WLAN (Wireless Local Area Network) hotspots are public areas, like train-stations, airports, retail outlets, bars, etc., where a wireless internet connection is made available, usually for free as a customer-service. The hardware is typically a wireless hotspot access point that connects to the LAN network.

9.4.2 History and market

Public WLAN hotspots are a follow-up of internet cafés and commercial hotspot providers of the 1990s. Today, also due to the flat rates, the service is usually free for customers or, it is an initiative of the authorities for the good of the general public, e.g. in the Wifi4EU project.[302] The worldwide growth of these hotspots is exponential, from around 50 million in 2016 to 362 million in 2019. The latest projections predict 454 million hotspots in 2020 growing to 628 million in 2023 worldwide. [303]

Older Cisco reports show that in 2016 Western Europe, with a lead for France, had 35% or around 18 million of the global hotspots. Adding 6% for the Eastern European Member States minus UK[304] this amounts to 19 million EU hotspots in 2016. In 2020, 23% of the projected 454 million hotspots (=104 million) are expected to be in Western Europe. Adding 6%, this means 110 million hotspots.

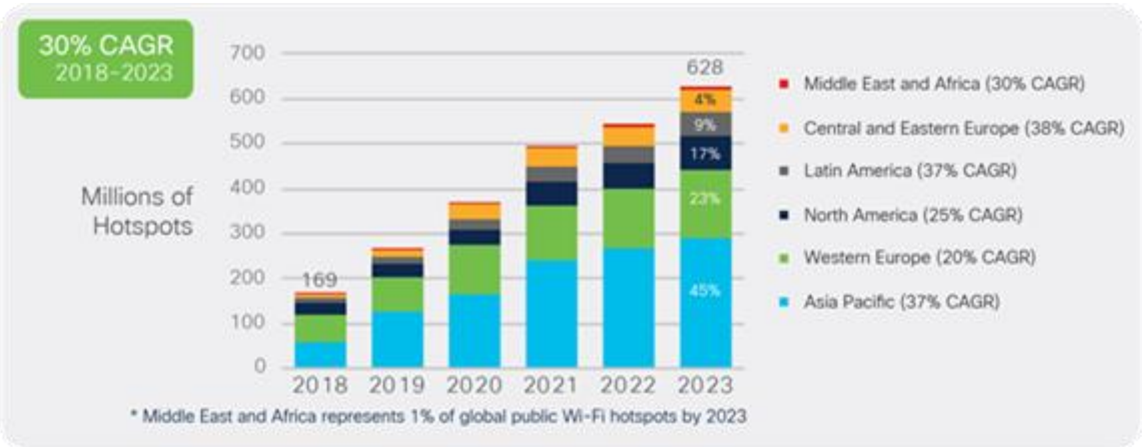

Figure 60. Millions of hotspots installed globally 2018-2023 (Source Cisco, 2020).

Worth mentioning is also the use of 'hotspots' from private households that make their own WiFi available to a public meshed hotspot network like FON (www.fon.com).

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[302] The European Commission proposes an investment of €120 million to promote access to wireless connectivity in public places. Free Wi-Fi would then be available in parks, squares, libraries, public buildings to benefit citizens and institutions with a public mission.B5-Wifi4EU_Factsheet_2020_ENpdf.pdf

[303] https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html

[304] The 12 NMS added 26% to population but hotspot-penetration was lower. On the other hand, without the UK the EU28 population lost 13% of a country with ubiquitous hotspots. Overall the Cisco 'Western Europe' population must be multiplied with 1.06 to find EU27 figures

9.4.3 Energy

Around 10 years ago, the power draw of the WiFi hotspot was found to be in the range of 6 to 9 W in active mode and a few Watts less in idle mode. The Energy Star 2013 criteria for Small Network Equipment, which include access points and routers, started from a base limit of 2W and 3.1 W respectively, adding 0.7W for WiFi in general and an adder of 1.3W for 802.11at 5GHz radio per stream[305]. Assuming two 5GHz radios this would then result in 5.3W and 6.4W respectively. The power supply for an access point is usually with PoE (Power over Ethernet). With the PoE 802.3af this means a maximum of 15.4W and with PoE 802.3at, the maximum wattage is in the range of 44-55W.

WiFi6 (802.11ax) typically uses PoE 802.3at. A Cisco access point for WiFi6 (8702.11ax) with 2.4GHz and 5GHz radios, USB activated, would use 28W. With USB switched off, this becomes 25W and with only half the radio antennae active, the power draw is 15W. Despite these considerable power usage figures, it is claimed that WiFi6 will use 3 to 4 times less energy than its predecessor because of clever power management called TWT, Target Wake Time.[306] Basically, this is a certain form of power management at a 100 micro-second scale that saves power especially for the access point clients.

One of the problems of establishing an energy efficiency metric with hotspot wireless access points and routers is that there is no defined duty cycle to establish the Typical Energy Consumption. For the moment, we will assume the 6W average for the whole period from 2008 to 2019. This comes down to 50 kWh/yr.

9.4.4 Summary

Based on the above, the EU energy consumption for hotspots in 2016 is 19x50= 950 GWh = 0.95 TWh/yr. In 2020 an energy consumption of 110x50=5500 GWh/yr= 5.5 TWh/yr can be expected.

9.5 Toll-related ICT

According to AISCAT[307] and ASECAP[308] statistics, there was a total of 15,557 toll lanes pertaining to 1,815 toll stations in the EU27[309] in 2018. The energy use per toll lane is assumed to be similar to that of a ticket machine (see that section), i.e. 180 kWh/unit/year. For the whole of the EU this gives an electricity use of 2.8 GWh/yr or 0.0028 TWh/yr.

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305 https://www.energystar.gov/sites/default/files/specs//private/SmallNetworkEquipment_V1_ENERGYSTAR_ProgramRequirements_Nov2013_0.pdf

306 http://www.turn-keytechnologies.com/blog/network-solutions/what-is-target-wake-time

307 Associazione Italiana Societá Concenssionarie Autostrade e Trafori http://www.aiscat.it/pubblicazioni/downloads/aiscat-in-cifre-2018.pdf

308 Association Européenne des Concessionaires d'Autoroute et d'Ouvrages a Péage http://ASECAPKeyFigures2019RevisedEdition%20(1).pdf

309 ASECAP members minus Morocco, Turkey, Russia, Serbia, UK.

Furthermore, there are 11,892 electronic toll collection (ECT) lanes for 36.7 million subscribers having a transponder. The transponder is usually a passive RFID (Radio Frequency Identification Device), i.e. giving an identification signal when passing the electromagnetic field generated by the ECT-lane transceiver. The signal is then registered for billing. Energy consumption of the transceiver for a population of 1000 tags is measured in micro Joules, i.e. negligible.[310] Assuming average power draw of 2W (off/idle/active) the energy consumption will round up the total energy use of conventional toll and ECT lanes to 3 GWh/yr or 0.003 TWh/yr.

Finally, in Germany there are 1.2 million owners of On-Board-Units (OBUs) paying tolls through a Global Navigation Satellite Systems GNNS[311] with 143,660 sections. Exact energy consumption is unknown, but OBU chipsets consume very little[312].

9.6 Security cameras

9.6.1 Definition

Security cameras are cameras used for

- remote surveillance of properties against breaking and entering,
- safety of citizens against crime,
- inspection of critical industrial processes.

In the first case in particular, they are networked cameras, activated by movement, often with storage in the internet (the 'cloud') and read-out in smartphone or tablet by very often private users or surveillance companies for hire. In the second case, the cameras are operated by police (city surveillance) or security staff. Cameras are analogue or increasingly HD CCTV (closed-circuit television). The third category are used by industrial operators for overseeing remote and/or high-risk processes. HD cameras are the most likely choice here.

9.6.2 History and market

Security cameras have become less costly and, through smart-recording, cloud-storage and smartphone-usage, are better manageable also for private customers who have a 2nd home or are often awayIn the EU at least, this would explain the rapid increase in networked cameras. With regard to law enforcement and security, the cameras are a safe

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310 https://www.researchgate.net/publication/264438998_Energy_consumption_evaluation_framework_for_passive_RFID_tag_anti-collision_algorithms

311 https://www.researchgate.net/publication/244994628_Global_Navigation_Satellite_System_based_tolling_State-of-the-art

312 For instance: IoT chipset for GNNS in 2016 works on 1.75-1.85V with 28uA/56mA/39mA in hibernate/acquisition/tracking mode. (source: https://www.gsa.europa.eu/system/files/reports/gnss_user_technology_report_webb.pdf). At 250h acquisition mode (car driving) and 8510h hibernate mode this gives 25 Wh energy consumption. For 1.2 million OBUs this is 30 MWh.

and efficient way to increase surveillance efforts. The same arguments play a role in industrial surveillance.

The most cited source regarding the market for surveillance cameras is HIS Markit. Total stock of security cameras went from 157 million in 2012 to 350 million in 2016.[313] In 2018 it was 656 million units and the projections for 2021 are over a billion. Two-thirds of the cameras are installed in Asia. The share of EMEA (Europe, Middle East, Africa) is 13%. Within EMEA, the EU will make up two-thirds of the market, i.e. 8-9%.[314] This means 75 million in 2020, 25 million in 2015 and 13 million in 2012.

Of the 2016 stock, 33% were network cameras, 60% analogue cameras and 7% HD CCTV[315] cameras.

For 2017 HIS projected sales of 98 million network cameras and 29 million HD CCTV cameras through professional sales channels. A new niche market is body-worn cameras for law-enforcement officers to record their activities mainly for legal purposes.

Figure 61. Video surveillance cameras, global sales 2017 (Source: IHS, 2018 [316]).

9.6.3 Energy

Network (IP) cameras do not use much power, i.e. around 6W and possibly 2-4 W more with extra functionality such as IR (InfraRed) lighting or pan-tilt mechanisms.[317] Power is often supplied as PoE (Power over Ethernet).

In energy terms this means a range of 52 to 88 (average 70) kWh/yr per unit. Storage can be more power-hungry, especially if there is no smart motion-detection. A NVR (Network Video Recorder), DVR (Digital Video Recorder) or NAS (Network Attached Storage) may use some 40-60W in active mode.[318] Assuming a 1W sleep mode and 1h active recording,

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313 https://www.sdmmag.com/articles/92407-rise-of-surveillance-camera-installed-base-slows

314 https://www.theverge.com/2019/12/9/21002515/surveillance-cameras-globally-us-china-amount-citizens

315 closed-circuit television

316 https://ihsmarkit.com/research-analysis/tape-and-disk-storage-present-viable-long-term-video-surveillance-storage.html

317 https://security.panasonic.com/training_support/support/technical_information/power_consumption_info/

318 https://reolink.com/cctv-ip-security-camera-power-consumption/

the NVR or NAS will use 30 kWh/yr[319]. In total, the energy use for camera plus storage is estimated at 100 kWh/yr.

9.6.4 Summary

Based on the above, the EU energy use of 75 million security cameras is estimated at 7.5 TWh/yr in 2020. In 2012, assuming the camera and storage to be 50% more power hungry, the energy use is estimated at 2 TWh/yr.

9.7 Summary public ICT

Table 95. Electricity consumption of public ICT devices

	2010	2015	2020	2025
Automated Teller Machines (ATM)	0.51	0.37	0.17	0.17
Point-of-Sales equipment	3.00	2.68	2.35	2.02
Ticket machines	0.04	0.04	0.04	0.04
Hot spots	0.26	0.78	4.79	6.96
Toll-related	0.03	0.03	0.03	0.03
Video-cameras	1.13	3.53	6.53	8.61
Total Public ICT	**4.97**	**7.43**	**13.90**	**17.84**

319 23Wh standby +60Wh active =83Wh/day; 83Wh/day x 365days/year= 30 kWh/year

10 Task 1 Summary

The figure below gives the estimated EU27 electricity consumption for the 8 main ICT categories investigated in Task 1.

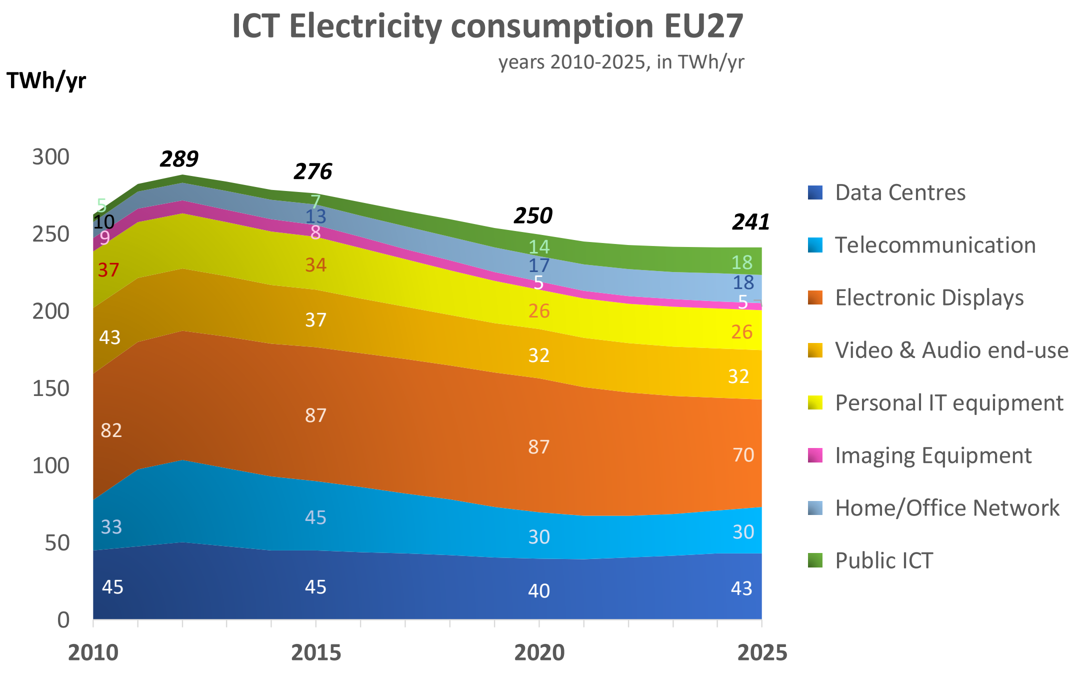

Figure 62. ICT Electricity consumption EU27 by category, 2010-2025

On the demand-side, video is the most important service rendered by ICT in terms of data traffic and bandwidth. Video on demand, movies, social media clips and game streaming take up close to 85% of the bandwidth of the data centres. Electronic displays (TVs, monitors, signage displays) are by far the largest end-use devices. The ever increasing display resolution, now 4K and perhaps 8K in the future is the main driver for the fast increasing data-traffic. Video-conferencing –currently not a significant contributor, could become a new driver for more bandwidth.

Audio-equipment, so far unregulated, could be a candidate for energy policy measures, especially in combination with video. Public ICT is the only category where energy consumption is clearly rising, especially due to hotspots and security cameras.

The category with the largest uncertainty as regards energy consumption is probably the personal IT equipment, e.g. desktop PCs, notebooks, tablets, etc.. Reliable, unbiassed databases and surveys on the subject are scarce.

Each main category covers 3 to 10 product groups. The EU27 electricity consumption 2010-2025, in TWh/yr, is specified in the detailed table hereafter.

Table 96. Summary ICT Electricity Use EU27, Task 1

ICT Electricity Use EU27 *(in TWh/year)*	**2010**	**2015**	**2020**	**2025**
Servers	18.66	18.66	22.05	27.24
Storage	1.80	1.80	4.35	4.45
Networks	0.53	0.53	0.74	1.06
Cooling etc.	23.74	23.74	12.40	10.07
Total Data Centres	**44.73**	**44.73**	**39.54**	**42.82**
Fixed Area Network (FAN)	13.49	18.40	17.70	17.90
Radio Area Network (RAN)	17.60	24.00	10.50	11.00
Satellite & terrestrial TV	1.91	2.60	1.80	1.20
Total Telecommunication	**33.00**	**45.00**	**30.00**	**30.10**
Television sets	66.99	71.34	64.38	43.50
Monitors	13.05	6.96	2.61	2.61
Signage Display	0.87	8.70	20.01	23.49
Total Electronic Displays	**80.91**	**87.00**	**87.00**	**69.60**
DVD/Video player	1.91	2.35	0.61	0.00
Video-projector	1.83	1.57	0.96	0.44
Game consoles	6.79	6.26	5.66	5.13
Interactive whiteboards	0.01	0.15	0.22	0.30
Video-conferencing	0.09	0.17	0.27	0.44
MP3-player	0.09	0.06	0.04	0.02
Home audio	18.79	13.35	10.09	10.09
Connected audio	0.00	0.00	0.00	0.01
CSTB	13.05	13.05	13.05	13.05
Digital TV services	0.00	0.00	0.74	2.70
Total video & audio end-use	**42.56**	**36.97**	**31.64**	**32.16**
Standard notebooks	4.96	6.54	5.19	5.56
Gaming notebooks	1.06	1.40	1.35	2.52
Standard desktop PCs	16.61	11.11	6.40	6.15
Gaming desktop PCs	6.43	4.30	2.23	1.90
Integrated desktop	1.10	0.74	0.69	0.67
Thin clients	0.59	0.38	0.33	0.32
Workstations	1.20	1.26	1.34	1.49
Tablets /Slatesl	0.10	2.58	1.87	1.34
E-book readers	0.00	0.01	0.01	0.01
Smartphones	0.45	1.58	1.65	1.75
Home/Office fixed phones	4.15	4.42	4.48	4.13
Total personal IT equipment	**36.66**	**34.30**	**25.54**	**25.84**
Mono laser Multi-Functional (MFD)	1.49	1.34	0.97	0.80
Colour laser MFD	2.06	1.91	1.20	0.93
Mono laser printer	1.82	1.15	0.65	0.48
Colour laser printer	1.06	1.21	1.12	1.13
Mono laser copier	0.73	0.31	0.05	0.00
Colour laser copier	0.17	0.30	0.12	0.00
Inkjet MFD	0.57	0.51	0.40	0.35
Inkjet printer	0.34	0.09	0.01	0.01
Professional printer / MFD	0.51	0.72	0.80	0.77
Scanner	0.03	0.03	0.03	0.05
3D printer	0.00	0.00	0.16	0.16
Total Imaging Equipment	**8.77**	**7.58**	**5.52**	**4.67**
Home Network-attached storage equipment (NAS)	0.57	1.00	1.42	1.52
Home/office network equipment	8.79	11.54	14.28	15.06
IoT Cellular Gateway	0.22	0.22	0.22	0.52
IoT Home/Office Gateway	0.70	0.69	0.69	1.39
Total Home/Office Network	**10.28**	**13.44**	**16.61**	**18.49**
Automated Teller Machines (ATM)	0.51	0.37	0.17	0.17
Point-of-Sales equipment	3.00	2.68	2.35	2.02
Ticket machines	0.04	0.04	0.04	0.04
Hot spots	0.26	0.78	4.79	6.96
Toll-related	0.03	0.03	0.03	0.03
Video-cameras	1.13	3.53	6.53	8.61
Total Public ICT	**4.97**	**7.43**	**13.90**	**17.84**

11 TASK 2: CLUSTERS

11.1 Introduction

In Task 1 the study team has retrieved, analysed and aggregated to EU-level the results from Member State, EU- and worldwide studies on the ICT products in the last 5 years and before. This was discussed in the previous 9 chapters, for which over 270 information sources were retrieved, analysed and –where appropriate-- aggregated.
In consultation with the Commission policy officer it was thus decided to address the first part of Task 2, i.e. the re-clustering of the ICT products into

1. categories I, II and VIII (data centres, telecommunication, public ICT with the addition of signage displays from category III)[320] ;
2. "Workplace end-use devices" (with the appropriate products from categories III - VII);
3. "Household end-use devices" (with the appropriate products from categories III - VII);

on the basis of the results in the previous chapters. This will be done in this chapter.

The other parts of Task 2, i.e. the discussion of Building Automation and 'Other controls' will follow in separate chapters.

11.2 Household and workplace end-uses

Summation of categories I, II and VIII, with signage displays in category III, is straightforward.

It is proposed to establish the subdivision between household and workplace end-uses consistently with the relative shares in the preparatory and impact assessment Ecodesign studies for the various ICT studies. These shares are given in the Ecodesign Impact Accounting report (VHK, 2018) and summarised in Table 97.

[320] Note that categories I, II and VIII relate to the products discussed in Chapters 2, 3 and 9 respectively.

Table 97. ICT end-use product stock per sector (source: VHK, EIA 2018)

Lot	ICT Products	Residential	Tertiary	Industry	Other
5	DP TV total	90%	10%	0%	0%
5	DP Monitor total	49%	44%	6%	1%
5	DP Signage total	0%	90%	10%	0%
18	STB Set Top Boxes	90%	10%	0%	0%
E3	VIDEO DVD players/recorders	90%	9%	1%	0%
E3	VIDEO projectors	3%	93%	3%	1%
E3	VIDEO game consoles	100%	0%	0%	0%
E9	ES Enterprise Servers total	0%	86%	12%	2%
E9	DS Data Storage products total	0%	86%	12%	2%
3	PC Notebook & Desktop	66%	29%	4%	1%
3	PC Tablet/slate	90%	9%	1%	0%
3	PC Thin client & Workstation	0%	86%	12%	2%
4	EP-MFD colour & mono	4%	82%	12%	2%
4	EP-printer colour & mono	4%	82%	12%	2%
4	EP-copier colour & mono	5%	82%	11%	2%
4	Inkjet all types	94%	5%	1%	0%
6 /26	SB Home Gateway/Phones/NAS	100%	0%	0%	0%
6 /26	SB Office Phones (fixed)	0%	86%	12%	2%
7	EPS total	75%	25%	0%	0%
27	UPS average	2%	83%	10%	5%

Using these multipliers, the energy was partitioned between residential ('household') and non-residential ('workplace') end-use devices and non end-use devices. The latter include the categories I, II and VIII (plus signage displays) as 'Workplace non end-use devices'. The small category of 'household non-end use devices' includes home gateways and routers. Figure 63 and Table 98 present the final results.

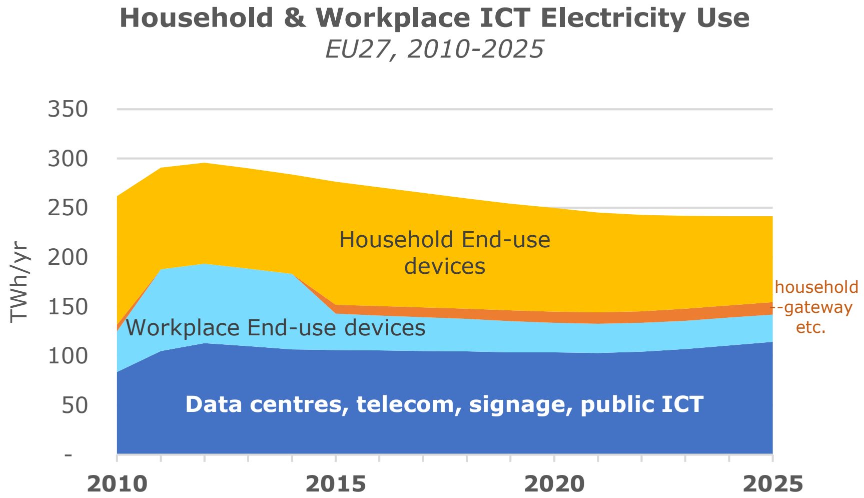

Figure 63. Household & Workplace ICT Electricity Use EU27, 2010-2025

Table 98. Electricity consumption ICT devices EU27, 2010-2025, Task 2

ICT Devices	Residential (TWh/yr)				Non-residential (TWh/yr)			
year	2010	2015	2020	2025	2010	2015	2020	2025
Servers	-	-	-	-	18.66	18.66	22.05	27.24
Storage	-	-	-	-	1.80	1.80	4.35	4.45
Networks	-	-	-	-	0.53	0.53	0.74	1.06
Cooling etc.	-	-	-	-	23.74	23.74	12.40	10.07
Total Data Centres	-	-	-	-	**44.73**	**44.73**	**39.54**	**42.82**
Fixed Area Network	-	-	-	-	13.49	18.40	17.70	17.90
Radio Area Network	-	-	-	-	17.60	24.00	10.50	11.00
Satellite & terrestrial TV	-	-	-	-	1.91	2.60	1.80	1.20
Total Telecommunication	-	-	-	-	**33.00**	**45.00**	**30.00**	**30.10**
Televisions	60.29	64.21	57.94	39.15	6.70	7.13	6.44	4.35
Monitors	6.39	3.41	1.28	1.28	6.66	3.55	1.33	1.33
Signage Display	-	-	-	-	0.87	8.70	20.01	23.49
Total Electronic Displays	**66.69**	**67.62**	**59.22**	**40.43**	**14.22**	**19.38**	**27.78**	**29.17**
DVD/Video player	1.72	2.11	0.55	-	0.19	0.23	0.06	-
Video-projector	0.05	0.05	0.03	0.01	1.77	1.52	0.93	0.42
Game consoles	6.79	6.26	5.66	5.13	-	-	-	-
Interactive whiteboards	-	-	-	-	0.01	0.15	0.22	0.30
Video-conferencing	0.01	0.02	0.03	0.04	0.08	0.16	0.25	0.39
MP3-player	0.08	0.05	0.04	0.02	0.01	0.01	0.00	0.00
Home audio	16.91	12.02	9.08	9.08	1.88	1.34	1.01	1.01
Connected audio	-	0.00	0.00	0.01	-	0.00	0.00	0.00
CSTB	11.75	11.75	11.75	11.75	1.31	1.31	1.31	1.31
Digital TV services	-	-	0.67	2.43	-	-	0.07	0.27
Total video & audio end-use	**37.31**	**32.26**	**27.80**	**28.47**	**5.25**	**4.71**	**3.85**	**3.70**
Standard notebooks (I1,I2,75%I3)	3.28	4.32	3.43	3.67	1.69	2.22	1.77	1.89
Gaming notebooks (D1, D2, 25%I3)	1.06	1.40	1.35	2.52	-	-	-	-
Standard desktops (I1,I2,I3+40%D1&D2)	10.96	7.33	4.22	4.06	5.65	3.78	2.18	2.09
Gaming desktops (60%D1&D2)	6.43	4.30	2.23	1.90	-	-	-	-
Integrated desktop - Total	0.73	0.49	0.46	0.44	0.38	0.25	0.24	0.23
Thin clients	-	-	-	-	0.59	0.38	0.33	0.32
Workstation	-	-	-	-	1.20	1.26	1.34	1.49
Tablet/Slate - Total	0.09	2.32	1.69	1.21	0.01	0.26	0.19	0.13
E-book readers	0.00	0.01	0.01	0.01	-	-	-	-
Smartphone	0.45	1.58	1.65	1.75	-	-	-	-
Home/Office fixed phones	2.08	2.21	2.24	2.06	2.08	2.21	2.24	2.06
Total personal IT equipment	**25.07**	**23.94**	**17.27**	**17.62**	**11.59**	**10.36**	**8.27**	**8.22**
Mono laser MFD	0.06	0.05	0.04	0.03	1.43	1.29	0.93	0.77
Colour laser MFD	0.08	0.08	0.05	0.04	1.98	1.84	1.15	0.89
Mono laser printer	0.07	0.05	0.03	0.02	1.75	1.10	0.63	0.46
Colour laser printer	0.04	0.05	0.04	0.05	1.02	1.16	1.08	1.09
Mono laser copier	0.04	0.02	0.00	-	0.69	0.30	0.05	-
Colour laser copier	0.01	0.01	0.01	-	0.16	0.28	0.12	-
Inkjet MFD	0.53	0.48	0.38	0.33	0.03	0.03	0.02	0.02
Inkjet printer	0.32	0.08	0.01	0.01	0.02	0.01	0.00	0.00
Professional printer / MFD	-	-	-	-	0.51	0.72	0.80	0.77
Scanner	0.01	0.02	0.02	0.03	0.01	0.02	0.02	0.02
3D printer	-	-	0.00	0.00	-	-	0.15	0.15
Total Imaging Equipment	**1.17**	**0.84**	**0.57**	**0.50**	**7.60**	**6.74**	**4.94**	**4.17**
Home Network-attached storage (NAS)	0.57	1.00	1.42	1.52	-	-	-	-
Home/office network equipment	5.80	7.61	9.43	9.94	2.99	3.92	4.86	5.12
IoT Cellular Gateway	0.08	0.08	0.08	0.19	0.14	0.14	0.14	0.33
IoT Home/Office Gateway	0.46	0.45	0.45	0.92	0.24	0.23	0.23	0.47
Total Home/Office Network	**6.92**	**9.14**	**11.38**	**12.57**	**3.36**	**4.29**	**5.23**	**5.92**
Automated Teller Machines (ATM)	-	-	-	-	0.51	0.37	0.17	0.17
Point-of-Sales equipment	-	-	-	-	3.00	2.68	2.35	2.02
Ticket machines	-	-	-	-	0.04	0.04	0.04	0.04
Hot spots	-	-	-	-	0.26	0.78	4.79	6.96
Toll	-	-	-	-	0.03	0.03	0.03	0.03
Video-cameras	-	-	-	-	1.13	3.53	6.53	8.61
Total Public ICT	**0.00**	**0.00**	**0.00**	**0.00**	**4.97**	**7.43**	**13.90**	**17.84**
TOTAL	**137**	**134**	**116**	**100**	**125**	**143**	**134**	**142**
Of which, Non end-use devices	***7***	***9***	***11***	***13***	***87***	***110***	***109***	***120***
Of which, end-use devices	***130***	***125***	***105***	***87***	***38***	***33***	***25***	***22***

The overall trend is that, especially since 2015, the energy consumption of most end-use devices is decreasing. Energy consumption for the non-residential ICT data centres and telecom, etc. is fairly stable and even declining since 2012 but may be increasing slightly in 2025. Home network equipment for households is still rising. Signage displays is a newcomer expected to be a major contributor to the increase of non-residential ICT energy. Another, but more modest contributor, are video security cameras.

Major energy savers are Electronic displays (excluding signage displays), video projectors, desktop computers (without significant increase for notebooks or other business computing) and imaging equipment.

12 Building Automation and Control Systems (BACS)

12.1 Introduction

The aim of Task 2 of this study is to retrieve, analyse and aggregate data from the EU28 and report on the results from Member States' and EU wide studies, which were performed over the last 5 years on the present and forecast energy consumption and energy improvement potential of ICT product categories relevant for a system-focus approach.

Building automation and control systems (BACS) fall under this category because they are both energy using systems due to their own energy consumption (self-consumption) and energy related products because they influence and control the energy consumption of the buildings they are installed in. Typically, the energy related consumption is many times higher than the BACS' own energy consumption. Additionally, there may also be non-energy related services such as security and fire safety.

The system-focus approach is relevant due to the potentially very many connections from the BACS to building components and the technical building system; to sensors inside and outside the building; and even to an external entity such as an electric grid aggregator[321], which may take over the control of some of the equipment within predefined limits for achieving a flexible demand.

Non-residential BACS were included in the Ecodesign Working Plan 2016-2019[322] as a product group with high energy saving potential for which a dedicated preparatory study would be launched. This study is currently ongoing and it followed a scoping study.[323] The study and draft reports have been used as input to the current study.

Other relevant studies and sources used include:

- "The scope for energy and CO2 savings in the EU through the use of building automation technology"[324]
- Ecodesign preparatory study on smart appliances[325]
- Review of ecodesign regulation for standby and networked standby[326]
- Study on smart readiness indicator for buildings[327]

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[321] An aggregator is an entity, which has entered into an agreement with an electricity customer on access to disposing of the electricity customer's flexible consumption and/or generation in the electricity market. The aggregator pools flexibility from customers and converts it into electricity market services, for example for use by the TSO (Transmission System Operator), DSO (Distribution System Operator) and/or BRP (Balance Responsible Party).

[322] Communication from the Commission. Ecodesign Working Plan 2016-2019. COM(2016) 773 final.

[323] www.ecodesignbacs.eu

[324] "The scope for energy and CO2 savings in the EU through the use of building automation technology". Waide Strategic Efficiency Limited with ABS Consulting (UK) Limited, Birling Consulting Ltd and William Bordass Associates prepared for the European Copper Institute. Second edition, 13 June 2014.

[325] https://eco-smartappliances.eu/en

[326] https://www.ecostandbyreview.eu/

[327] https://smartreadinessindicator.eu/

- "The impact of the revision of the EPBD on energy savings from the use of building automation and controls". Study performed for eu.bac by Waide Strategic Efficiency Limited.[328]
- "Guidelines for the transposition of the new Energy Performance Buildings Directive (EU) 2018/844 in Member States." eu.bac. European Building Automation Controls Association. June 2019.[329]
- Energy Performance of Buildings Directive[330], which addresses BACS and especially the amendment of May 2018[331]

12.2 Definition

12.2.1 Scope

Building automation and control systems (BACS) are systems used in buildings for management, monitoring, metering, automating, , communicating and controlling of

- heating, ventilation (including window openings) and air conditioning (HVAC);
- domestic hot water (DHW);
- solar shades;
- lighting;
- electrical power distribution;
- access control & security;
- fire safety;
- etc.

All buildings may use BACS, whether they be commercial, residential, multi-storey buildings or one family homes. More advanced BACS are usually found in multi-storey buildings and are often more advanced in commercial and office buildings compared to residential ones.

BACS are found in both existing buildings and new-build. They are sold as standalone components, as components embedded in other products (and particularly within the technical building system (TBS), and as overarching management systems sitting above and coordinating numerous TBS within a building.

There is a significant on-going deployment across the entire building stock. This is partly related to the digitalization of the economy, the further deployment of automated intelligence in all areas of human activity, the spread of broadband and building renovation activities.

The main aims of the BACS are to provide services for the benefit of the building occupants such as good indoor climate and safety, for reducing the consumption of energy and other

[328] "The impact of the revision of the EPBD on energy savings from the use of building automation and controls". Study performed for eu.bac by Waide Strategic Efficiency Limited. www.eubac.org/cms/upload/downloads/position_papers/EPBD_impacts_from_building_automation_controls.pdf

[329] www.eubac.org/cms/upload/eu.bac_guidelines_on_revised_EPBD_June_2019.pdf

[330] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02010L0031-20181224 (consolidated)

[331] Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency

resources and for ensuring a sound building. BACS substitute or supplement manual control of desired conditions, such as indoor temperature or access control, and typically, automatic regulation and control is much more accurate than that done manually.

Additionally, BACS can also play a role in a smart grid system, where energy supply and demand side are controlled together in an optimised way. This can take place e.g. by reducing heating or cooling services for a limited period of time in order to reduce a peak load of the energy supply system or to better integrate renewable energy supplies – also called demand flexibility. The aims here are cost reductions and environmental improvement. In this case, BACS are connected to an external controller, typically an aggregator, which is allowed to control certain parameters of the building components within allowed bands of flexibility (e.g. allowing the indoor temperature in a heating situation to decrease maximum 1 ºC during 1 hour).

Hence, systems can cover both a wide and limited range of services. Simple stand-alone systems with one controller for one controlled component e.g. a remotely controlled motorised window blinds, a radiator thermostat, and a sensor controlled light source are not considered to be in the scope of this study. Some of these are defined as local building controls, which have been included in the review study of ecodesign of standby and network standby (Commission Regulation (EC) 1275/2008).

In the following, definitions of BACS from two main sources are provided:

The Energy Performance of Buildings Directive (EPBD)[332] defines BACS as: "`building automation and control system' means a system comprising all products, software and engineering services that can support energy efficient, economical and safe operation of technical building systems through automatic controls and by facilitating the manual management of those technical building systems;" The definition is supplemented with this definition: "'technical building system' means technical equipment for space heating, space cooling, ventilation, domestic hot water, built-in lighting, building automation and control, on-site electricity generation, or a combination thereof, including those systems using energy from renewable sources, of a building or building unit;". I.e. the technical building system comprises the energy consuming equipment that provides the energy services for maintaining the desired indoor climate, light level, safety etc.

In EN ISO 16484-2[333], BACS refers to "Building Automation and Control Systems comprising all products and engineering services for automatic controls (including interlocks), monitoring, optimization for operation, human intervention and management to achieve energy–efficient, economical and safe operation of building services. Controls herein do also refer to processing of data and information". Interlock is a functionality used to avoid simultaneous heating and cooling.

An illustrative overview of a BACS is provided in Figure 64 below.

[332] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast) (consolidated version)
[333] Building automation and control systems (BACS) — Part 2: Hardware

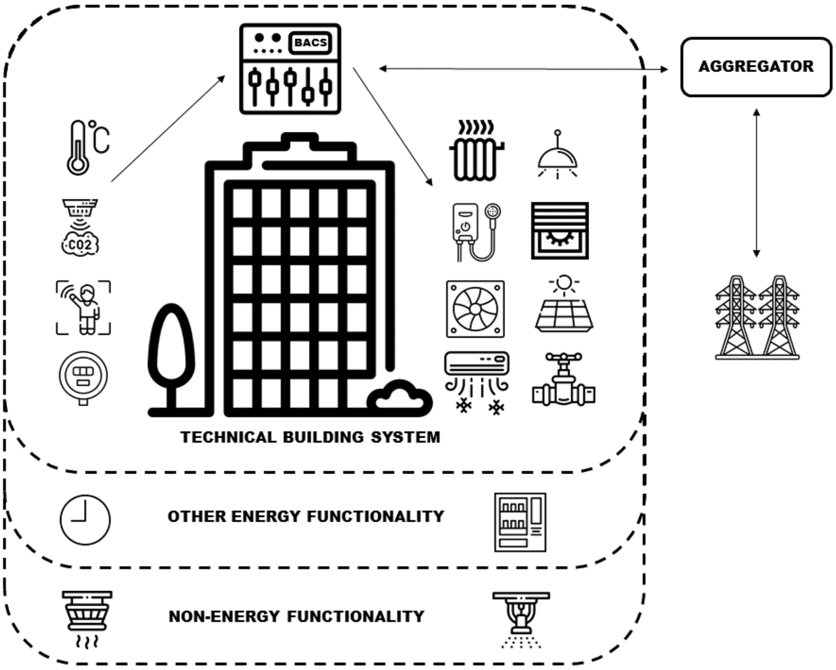


Figure 64: Illustrative overview of a BACS.

The BACS receives data from sensors and meters such as for temperature, CO2 presence, energy etc. and sends control signals to equipment in the technical building system such as space heaters, water heaters, ventilation units, air conditioners, lighting, blinds, photovoltaics and valves. Smart grid functionality can be achieved through a connection to an external aggregator, which aggregates flexibility demand from many end-users and provides it to the supply grid. Other energy and non-energy functionalities may also be part of a BACS, such as a time controlled vending machine or a fire alarm activating a sprinkler system.

12.2.2 BACS functionalities

The main aim of the BACS is to ensure that the technical building system (TBS) delivers services to cover the needs specified for the building in an optimised way by controlling the TBS operation in relation to the desired internal conditions, the actual occupancy of the building, the climatic conditions, the performance characteristics of the TBS etc. and ensuring energy and other resources is only used where it is needed, when it is needed and in the amounts required.

The BACS will be better in controlling the TBS compared to manual control or individual controls e.g. thermostats on radiators because BACS can take many more parameters into account at the same time and react immediately to changed conditions and may also anticipate future needs. Therefore, the saving potential will typically be higher for BACS than for other simpler regulation systems.

BACS is based on input parameters, the control system and control signals sent to the technical building system. Input parameters come from sensors and meters and user interface for desired service level.

Typically, BACS are installed in the building, but it may also be located on an external server or a cloud system connecting to sensors, meters and the TBS via the internet.

For the following, main functionalities related to the technical building system followed by other energy and non-energy functionalities are detailed.

Indoor climatic conditions
A basic functionality of BACS is to regulate the indoor temperature and air quality through space heating, cooling and/or ventilation system (HVAC). It may also include humidity control although this is more rare.

Input parameters may come from sensors and meters for indoor and outdoor temperature, solar radiation, wind speeds, indoor air CO2 content, pressure in ventilation channels and humidity.

Control of building components
Often BACS also include control of building components such as blinds, solar shadings, skylights, windows and doors as part of securing indoor climatic conditions, creating shade for office work and for access control and safety.

Input parameters may come from sensors for registration of openings, rain and solar radiation.

Lighting
Lighting can also be part of BACS, especially for larger buildings with much lighting in common areas such as offices and shopping centres. The control ensures the right illumination level when needed and regulated in relation to the solar radiation.

Input parameters may come from light and solar radiation meters and time control systems.

Domestic hot water (DHW)
Domestic hot water may be part of BACS when there is a high DHW consumption. The control secures DHW at the right temperature at the water tapping points after a maximum period of time as required in the local building regulation and complying with the DHW hygienic requirements.

Input parameters may come from water meters, temperature sensors and time control systems.

Electrical power distribution, generation and storage
For larger buildings or building complexes, the electrical power distribution may also be controlled by the BACS to ensure no overloads and fast reaction in case of breakdowns and short circuits. Furthermore, if a local power generation system is installed for emergency purposes or for generation of green electricity from PV systems, BACS may also control these power generators and a possible battery storage system.

Input parameters may come from power meters and sensors.

Smart grid system
As mentioned previously, BACS and the technical building system may be part of a smart grid system, where the equipment is not only regulated for optimisation of the building

itself, but for the building together with the energy supply system to provide demand flexibility. This will allow a better integration of a higher proportion of intermittent renewable energy and reduce peak loads at times, when the energy supply is expensive and more polluting. The effect in decarbonising energy networks would be important.

Input parameters would additionally be control signals from the supply grid, typically through an aggregator.

Other energy functionalities
Other energy functionalities not included in the technical building system include control of appliances that are permanently connected such as vending machines and kitchen appliances.

Non-energy functionalities
Non-energy functionalities include access control to ensure only permitted access to specific areas depending on time of day, week etc. Other functionalities are security and fire safety. Input parameters may come from presence detector sensors, cameras and fire alarms.

12.2.3 Automation and control components

BACS use a wide range of components, which provide data input to the computing system such as:

- Temperature sensors
- CO2 sensors
- Humidity sensors
- Presence detectors
- Solar radiation sensors
- Outdoor wind speed meter
- Light meter
- Domestic cold and hot water meters
- Electricity meters
- Heat and other energy meters
- Door and window opening sensors
- Smoke and fire detectors
- Access control detectors
- User setting for desired indoor quality level, scheduling etc.

BACS use components such as valves, actuators and motors for direct control of building components and of the technical building system. Some parts of the TBS only need control signals from the BACS to deliver the required amount of heating, cooling etc. to the building.

12.2.4 Interconnectivity and interoperability

Because BACS is not a single product but a system, which connects to a broad range of components and type of equipment in the technical building system, interconnectivity and interoperability between the system components are highly relevant. Wired and wireless network connections included over the internet and the communication protocols used are important aspects in this relationship.

Previously, BACS used often proprietary communication protocols combined with simple analogue signals to the TBS equipment. Nowadays, several non-proprietary protocols are common, such as BACnet, LonWorks®, Konnex (KNX), S-Mode (instabus EIB), M-bus, Modbus, OPC, oBix, etc., of which some are mainly used for connection of third-party devices and systems.

Recently, wireless components using generic communications protocols are coming into the market such as Bluetooth Low Energy, Z-Wave, Zigbee, etc., all being very energy efficient. See further details in Section 12.3.3.

12.2.5 Standards and norms

A central European Standard is EN 15232, which specifies:

- a structured list of control, building automation and technical building management functions which contribute to the energy performance of buildings; functions have been categorized and structured according to building disciplines and so called Building automation and control (BAC);
- a method to define minimum requirements or any specification regarding the control, building automation and technical building management functions contributing to energy efficiency of a building to be implemented in building of different complexities;
- a factor based method to get a first estimation of the effect of these functions on typical buildings types and use profiles;
- detailed methods to assess the effect of these functions on a given building.

EN 15232 refers to separate standards that are used to derive the energy performance impact of each building system sub-element, e.g.:

- Heating, EN 15316-1 and EN 15316-4
- Domestic hot water, EN 15316-3
- Cooling, EN 15243
- Ventilation, EN 15241
- Lighting, EN 15193
- Technical building management, EN 16947

12.3 Market

12.3.1 Current sales and stock

BACS are available on the market in many configurations and sizes and with different functionalities from plug-and-play systems that individuals and building owners can install to complex systems requiring specialised staff for configuring, installing and commissioning.

BACS therefore differ from many other products assessed in ecodesign preparatory studies as most of them are not produced or imported as one product and they do not appear as BACS in the Eurostat Prodcom statistics. Data are available in Prodcom for some of the BACS components such as light sources and controls, control gears and luminaires, but these components are not only used for BACS and cannot be used for assessing a product volume. All in all, Prodcom is not a reliable source for market data.

The ongoing preparatory study on BACS Task 2 on markets[334] has still not reported final market data, but the study reports data that can be used as an indication of the economic market size. The study uses data from BSRIA market research reports[335], eu.bac (European Building Automation and Controls Association representing the European manufacturers for Home and Building Automation and Energy Service Companies)[336] and VDMA (The Mechanical Engineering Industry Association, representing member companies in the SME-dominated mechanical and systems engineering industry in Germany and Europe)[337].

The reported total market size in EU-27 for 2018 (i.e. without UK) for BACS in residential and non-residential including non-energy functionality for the complete supply chain is estimated at 3.7-3.8 billion EUR. The residential sector is assumed to cover about 56% of the market value and the non-residential 44%. A break-down estimate on the value chain was provided:

- BACS product: 42%
- Engineering, installation, wiring etc.: 27%
- Additional 3rd party services: 31%

See the BACS Task 2 reports for more details on the assumptions behind these figures.

Based on this overall figure and to get an overall idea of how many buildings are equipped with BACS, the ICT Study team has assessed the market size in units based on an average empirical price per square metre for a BACS combined with EU-27 building floor area data.

As for the empirical price for a full BACS installed in a building, several sources have been reported: The Working Plan study related to the current Working Plan 2016-2019 reports between 29 EUR/m² and 50 EUR/m² for non-residential buildings. An analysis report for use of BACS in EU[338] reports about 29 EUR/m² for service buildings and 12 EUR/m² for residential buildings include costs to procure, install and commission the system. Other sources from USA report the cost in the range of 2.30-2.50 USD per square foot (2016-2017 figures) (22-24 EUR/m²). For the following assessments, 29 EUR/m² and 12 EUR/m² have been used for non-residential and residential buildings, respectively.

With the total economic market size, the distribution on residential (56%) and non-residential buildings (44%), and with an average price per square meter, the additional

[334] Ecodesign preparatory study for Building Automation and Control Systems (BACS) implementing the Ecodesign Working Plan 2016 -2019. Initial draft Task 2 report on Markets. VITO & Waide Strategic Efficiency) for the European Commission.

[335] https://www.bsria.com/uk/market-intelligence/market-reports/building_controls/

[336] www.eubac.org

[337] www.vdma.org/en/

[338] "The scope for energy and CO2 savings in the EU through the use of building automation technology". Waide Strategic Efficiency Limited with ABS Consulting (UK) Limited, Birling Consulting Ltd and William Bordass Associates prepared for the European Copper Institute. Second edition, 13 June 2014.

amount of floor area covered through the annual sales can be derived. Furthermore, as an example of a calculation , the number of units sold has been included assuming an average building size of 2000 m², see Table 99.

Table 99: Calculation of BACS sales for EU-27, 2017.

The number of units sold is based on an average building size of 2,000 m², which should be seen as an example of a calculation. .

BACS market	Sales		
	Total value Billion EUR/year	BACS floor area covered Million m²/year	Units sold
Total BACS market	3.75	232	115948
Residential market	2.10	175	87500
Non-residential market	1.65	57	28448

12.3.2 Stock

An assessment of the stock and penetration rate of BACS is given in Table 101. It has been calculated from the number of units sold (Table 99), the percentage of buildings equipped with BACS using the total building floor area presented in Table 100 and an assumed a lifetime of 30 years[339]. The table also shows the penetration rate, i.e. the percentage of buildings equipped with BACS using the total building floor area presented in Table 100. Uncertainties with this simplified stock calculation are considerable, but the end result, i.e. stock figures from the assumed lifetime and sales, match those of other sources, as indicated in the following.

Table 100: Building floor area for EU-27, 2017.[340]

Building type	Floor area Million m²
Residential multi-family	6,669
Residential single-family	10,809
Non-residential	11,250
Total	28,728

[339] Ecodesign preparatory study for Building Automation and Control Systems (BACS) implementing the Ecodesign Working Plan 2016 -2019. Task 5 report: Environment & Economics. VITO et al. for the European Commission. January 2020.

[340] Renewable Space Heating under the Revised Renewable Energy Directive. First interim report. TU WIEN et al. for the European Commission. Internal report. May 2020.

Table 101: BACS stock for EU-27, 2017.

Based on 30 years lifetime, and penetration rate based on Table 100 building floor area.

BACS market	Stock		
	Units installed	BACS floor area covered Million m²	Penetration rate
Total BACS market	3,478,448	6957	24%
Residential market	2,625,000	5250	30%
Non-residential market	853,448	1707	15%

The calculated building penetration rate can be compared to sources reporting on the 25% penetration rate for non-residential buildings.[341],[342],[343]. The lower penetration rate calculated above may be due to the fact that either the distribution of market value on residential and non-residential data do not reflect the situation in the EU or that there are there are a large number of non-residential building types rarely having BACS installed such as industrial and educational buildings.

12.3.3 Market developments

Technological development

BACS have traditionally focused on controlling the technical building system and mainly the HVAC and lighting system with an onsite control box and a number of sensors connected through cables using proprietary or open communication protocols.

New trends include increased use of wireless sensors, the use of open protocols, especially energy efficient wireless protocols (Bluetooth Low Energy, Z-Wave, Zigbee, etc.) as interconnecting systems between the BACS, sensors and the technical building system, the use of internet connected systems including cloud BACS, IoT (Internet of Things) devices and sensors and mobile app controllers. This development is partly due to new players on the market especially for the smart home area such as Amazon, Google and Samsung and for devices such as Nest, SmartThings, Philips and IKEA, partly due to increased interoperability between systems and components from different brands reducing the costs of the systems.

Sales development

The preparatory study for BACS states that market projections of annual average growth value reported in the trade press are between 2.6% and up to 7%. Additionally, the study

[341] Preparatory Study to establish the Ecodesign Working Plan 2015-2017 implementing Directive 2009/125/EC. Task 3 Final Report.

[342] http://bpie.eu/wp-content/uploads/2016/02/Deep-dive-4-Building-automation.pdf

[343] "The scope for energy and CO2 savings in the EU through the use of building automation technology". Waide Strategic Efficiency Limited with ABS Consulting (UK) Limited, Birling Consulting Ltd and William Bordass Associates prepared for the European Copper Institute. Second edition, 13 June 2014.

reports a BACS deployment rate under a business as usual scenario (without impacts of the 2018 revisions in the EPBD) of about 1.2% per year.

The 2018 EPBD revisions included a requirement for the Member States – within certain limits – to ensure that non-residential buildings should be equipped with BACS by 2025 and that residential buildings have electronic monitoring of the efficiency and effective control functionalities for optimum generation, distribution, storage and use of energy. This is expected to increase the BACS deployment rate substantially.

Other drivers are:

- General economic growth
- Increase of building renovation and new build rates
- Stricter requirements for indoor environment regarding air and light quality, temperature, draught, etc.
- Increased need for air conditioning including control of it due to climate change impact
- Established targets on building energy efficiency, CO2 footprint etc. by the building owner or other organisations, schemes etc.
- Upcoming schemes for flexible demands via e.g. aggregators providing economic and other benefits for the building owner or users
- An increased focus on data driven solutions for energy efficient buildings

These requirements are expected to increase the sales to the above mentioned annual sales growth figures to around 3%-7%. The ongoing preparatory study on BACS is expected to detail the sales projections in the next version of their Task 2 report and therefore further assessment of projected sales have not been provided in this report.

12.4 Performance and energy use

12.4.1 Performance parameters

The main performance parameter for BACS is the capability of being an automation and control system for a technical building system within the required main functionality in terms of maintaining the indoor environmental requirements for thermal comfort, sanitary hot water, indoor air quality, lighting, etc. The BACS acts as an energy-related product because it controls the energy consumption of the building they are installed in. As described previously, BACS may have other functionalities related to energy (e.g. control of appliances) and non-energy use (e.g. safety), however the focus in this section is performance related to the technical building system as defined in the EPBD and the standard EN 15232.

The EN 15232 standard defines a number of individual BACS control functions relevant for the TBM (Technical Building Management), see these below, and the performance of a specific BACS is assessed by setting an energy performance class for each control function in the BACS ranging from D (less efficient) to A (more efficient) based on the degree of sophistication that the BACS control function provides. E.g. a BACS control function for a heat generator based on combustion or district heating will be in class D if it only has a constant temperature control, while in class B and A if it has a variable temperature control depending on outdoor temperature and the load.

These individual control function scorings are combined into a performance class for the complete BACS:

- Class A: High energy performance BACS and TBM functions
- Class B: Advanced BACS with some TBM functions
- Class C: Standard BACS
- Class D: Non-energy efficient BACS

EN 15232 only includes energy-related functions for the technical building system in the context of EPBD. Other functions not included in EN 15232 may still be energy-related such as control of other types of appliances. BACS may also include non-energy related functions such as security and safety.

The BACS control functions in EN 15232 are provided in the following[344]:

For heating control, typical BACS control functions are:

- "emission control", e.g. individual room temperature control with BACS including schedulers and presence detection which can lower the general heat demand
- "control of distribution pumps in networks", e.g. switching off circulation pumps when not required or modulating the flow to meet the system needs
- "heat generator control for combustion and district heating", e.g. reducing the return temperature based on load forecasting to increase boiler efficiency by condensation
- "heat generator control for heat pump", e.g. controlling the exit temperature based on load forecasting
- "heat pump control system", e.g. inverter-driven variable frequency compressor depending on the load
- other functions are "sequencing of different heat generators", "Thermal Energy Storage (TES)" or "control of Thermo Active Building Systems (TABS)".

For domestic hot water (DHW) supply:

- reduce standby losses in hot water storage tank (if any) with automatic on/off control based on forecasted demand
- control of DHW pump (if any).

For cooling control:

- many similar functions to heating
- "interlock between heating and cooling" to avoid simultaneous heating and cooling.

For air supply or ventilation (if any):

- demand driver variable outside air supply

[344] Ecodesign preparatory study for Building Automation and Control Systems (BACS) implementing the Ecodesign Working Plan 2016 -2019. Task report on scoping. VITO and Waide Strategic Efficiency for European Commission Directorate-General for Energy. July 2018.

- heat recovery unit, icing protection
- free air night time cooling mechanical by automatic opening windows and/or operating the ventilation unit
- humidity controls (if any)

For lighting controls:

- control the use of artificial lighting, e.g. based on presence detection and/or monitoring indoor luminosity by natural light
- indirectly, reducing the lighting energy demand by proper control can decrease the building cooling demand or increase the heating demand.

For blind control (if any):

- prevent overheating
- reduce glare
- controls can be combined with HVAC and lighting.

For the 'Technical Building Management' (TBM) function group:

- set point management, e.g. web interface to heating/cooling temperature set points (20°C/26°C) with frequent resetting to default values where relevant
- run time management, e.g. predefined schedule (e.g. a night time set back temperature) with variable preconditions (e.g. no presence in the room)
- manage local renewable sources or CHP (Combined Heat and Power plants) to optimize own consumption and use of renewables
- control of Thermal Energy Storage of heat recovery (if available)
- smart grid integration
- detect faults in the Technical Building System (TBS), for example:
    - read out alarms (error codes) from the TBS (e.g. heat pump, gas boiler, etc.) and provision of comprehensible feedback to occupants and alarm(error codes) logging
    - continuous monitoring of SCOP (Seasonal Coefficient of Performance) or SEER (Seasonal Energy Efficiency Ratio) of a heat pump to verify maintenance needs (e.g. clogged heat exchanger, cooling fluid leakage, etc.)
    - regular checking sequence to verify the maximum power output of a heat pump or gas boiler to establish maintenance needs (e.g. contaminated gas burner, dirt on heat exchanger, valve errors, damage on pipe insulation, installation errors such as reverse connection of heat exchangers, correct control logic and set point of circulation pumps, etc.)
    - checking the power consumption of an Air Handling Unit (e.g. increased power consumption due to clogged filter or air inlet/outlet, leakages in or clogged ventilation duct work, broken air dampers/fans, etc.).
- Reporting energy consumption relative to indoor conditions:
    - displaying the current values and logged trends
    - calculation of performance parameters, e.g. it is possible to format data according to EN ISO 52003-1 & -2 that describes possible EPBD Indicators and therefore allows to track performance and eventually report any performance gaps. Therefore it could help to identify problems in the construction and commissioning of the building and its TBSs.

12.4.2 BACS energy use

BACS consume energy, also called self-consumption, for the functionality of the BACS controller box, which may include consumption of components that control part of the technical building system such as actuators for opening and closing of windows and doors and sensors for temperature, humidity, pressure, CO2, light level, presence etc. Only little information is available on the self-consumption, because often the focus has been on the impact on the building energy consumption, which is many times higher than the self-consumption.
The BACS scoping study[344] refers to a Swiss research project[345], which is used in the following for estimating the BACS self-consumption.

The Swiss project has analysed several highly automated non-residential buildings with respect to their electricity consumption. The analyses were made for six constructed buildings (five office buildings and one school) and one fictional office building with four variations, each implemented with different designs of the building automation system and connected products.

The resulting annual electricity consumption was 2-5 kWh/m² for the room automation part of the BACS and 3-6 kWh/m² for the entire BACS (including control of the central HVAC system). These figures included all components involved in the automation and control of the technical building system such as control of fans, light actuator, standby power for electronic ballasts and all related power supplies. The BACS preparatory study – also citing the Swiss source – proposes that the boundaries of the BACS self-consumption should be redrawn to exclude components that are essential aspects of the technical building system. Assuming a resulting self-consumption in the lower end of the above interval, e.g. 4 kWh/m²/year for the entire BACS, the average building size of 2000 m² used as an example in a previous section would have an annual electricity consumption of 8000 kWh for the BACS.

Residential buildings were not studied in the Swiss project. However, those would typically be less automated having a lower BACS self-consumption. Based on the average installation costs, see Section 12.3.1, which is 57% lower for residential than for non-residential buildings, a rough estimation is that BACS for residential buildings have the same percentage of lower energy consumption, i.e. 2.3 kWh/m²/year. For an average EU dwelling of 80 m², the annual consumption is thereby 184 kWh/year, which is about 5% of the average total annual electricity consumption for a dwelling (2017, 3,713 kWh/year[346]). Due to lack of data and the approximation used, this figure is used for both multi-family and single-family buildings.

See estimated BACS total energy consumption for the 2017 sales and stock in Table 102.

[345] Electricity consumption of building automation, P. Kräuchi et al. Energy Procedia 122 (2017) 295–300
[346] https://www.odyssee-mure.eu/publications/efficiency-by-sector/households/electricity-consumption-dwelling.html

Table 102: Estimated BACS total energy consumption for sales and stock, EU-27, 2017

based on 4.0 kWh/m²/year for non-residential buildings and 2.3 kWh/m²/year for residential buildings.

BACS market	BACS floor area covered Million m²		Electricity consumption GWh/year	
	Sales	Stock	Sales	Stock
Total BACS market	232	6957	630	18903
Residential market	175	5250	403	12075
Non-residential market	57	1707	228	6828

12.5 Energy efficiency improvement

12.5.1 Building energy savings

The largest saving potential related to the use of BACS is due to the automation and control of the technical building system. Energy savings are achieved by installing a BACS in a building without a BACS or upgrading or replacing a less efficient BACS (Class C or D) with a BAT (Best Available Technology) BACS (Class A). The Best Available Technology (BAT) is a BACS that meets the Class A requirements of EN 15232-1.

Approximate efficiency levels provided in the literature are provided in the following.

One source[347] reports the efficiency gains for service buildings and residential buildings presented in Table 103 and Table 104.

Table 103: Assumptions of energy saving potentials for service sector buildings.

Reference scenario is representing current practice, while optimal assumes an optimal level of installation and operation of the BACS from a user cost-effectiveness perspective.

Building services	Energy savings	
	Reference scenario	Optimal scenario
Space heating	10 %	37 %
Water heating	10 %	37 %
Cooling / ventilation	10 %	37 %
Lighting	10 %	25 %

[347] "The scope for energy and CO2 savings in the EU through the use of building automation technology". Waide Strategic Efficiency Limited with ABS Consulting (UK) Limited, Birling Consulting Ltd and William Bordass Associates prepared for the European Copper Institute. Second edition, 13 June 2014.

Table 104: Assumptions of energy saving potentials for residential sector buildings.

Reference scenario is representing current practice, while optimal assumes an optimal level of installation and operation of the BACS from a user cost-effectiveness perspective. na: non-available in the source.

Building services	**Energy savings**	
	Reference scenario	**Optimal scenario**
Space heating	na	25 %
Water heating	na	25 %
Cooling / ventilation	na	na

An overall conclusion from these two tables is that about 15%-27% of savings can be achieved additionally by having Class A BACS in all EU buildings. Other sources report 15%-22% savings. Assuming a potential of 20% and 15% of the total building final energy consumption for non-residential and residential sectors, respectively, the total potential energy savings by full implementation of optimised Class A BACS in all buildings amount to about 1,000 TWh/year. Total energy consumption in buildings is approximately 6000 TWh/year (2017).

These figures can be compared to energy savings due to the BACS measures in the EPBD analysed in a recent report[348]. The total savings are reported to be about 400 TWh/year. The EPBD BACS measures are seen as providing only part of the full BACS energy saving potential due to reduced scope and fewer measures and it is seen to correlate with the total saving potential of about 1,000 TWh/year.

Due to uncertainties about sales and stock figures and how fast the BACS deployment rate will increase, the saving potential is provided as a figure that can be reached over a number of years depending upon the policy instruments and measures in place. The current BACS study is expected to assess the saving potentials in more details. It will be finalised by the end of 2020.

12.5.2 BACS energy use

The Swiss research project referenced above also analysed the variations in self-consumptions between the buildings analysed and provided the following opportunities for reducing consumption:

- improve the efficiency of BACS power supplies which accounted for between 15% and 65% of electricity consumption claiming that these are often oversized
- select components and actuators to maximise use of no power consumption modes across the duty cycle for example: the controls for a normally open valve should be in no power consumption mode when the value is open
- use bi-stable or latching relays for electromechanical switches in preference to traditional relays that need permanent power to maintain the opposite mode to their default mode (i.e. normally open or normally closed)

[348] "The impact of the revision of the EPBD on energy savings from the use of building automation and controls". Waide Strategic Efficiency Limited for eu.bac. 2019.

- shut down the complete lighting control gear and circuits when the building is unoccupied to reduce their standby power consumption
- use energy harvesting technologies (e.g. solar cells and piezo actuators) as power supplies thereby reducing the demand on BACS power supplies
- reduce the number of servers, gateways or vendor specific solutions.

The BACS preparatory study estimates that it should be possible to reduce the self-consumption of BACS by an average of at least 1 kWh/m²/year in non-residential buildings corresponding to 25% of the assumed self-consumption of 4 kWh/m²/year. A similar percentage of reduction is assumed for residential buildings, i.e. 25% of 2.3 kWh/m²/year, corresponding to approximately 0.6 kWh/m²/year.

See resulting figures in Table 105.

Table 105: Estimated BACS total energy savings in self-consumption for current BACS sales and stock, EU-27, 2017.

Based on 1 kWh/m²/year for non-residential buildings and 0.575 kWh/m²/year for residential buildings.

BACS market	BACS floor area covered Million m²		Electricity savings GWh/year	
	Sales	Stock	Sales	Stock
Total BACS market	232	6957	158	4726
Residential market	175	5250	101	3019
Non-residential market	57	1707	57	1707

Table 105 shows that if all current BACS sales were efficiency optimised, an annual energy savings potential for the self-consumption of about 158 GWh/year would be achieved and if all currently installed BACS were replaced with efficiency optimised versions, the saving potential would be about 5 TWh/year. The results are based on the situation in 2017 regarding BACS penetration rates.

12.5.3 BACS simple payback period

At high aggregation levels the monetary savings potential of BACS can only be an overall estimate, with large deviations in specific situations.

At current prices and sales acquisition rates, costs are 3.75bn/yr for 115,948 systems (Table 99), which is 0.8% of the total EU potential market. The total EU saving potential at 100% penetration was estimated at 1000 TWh/yr (final energy) and thus the annual savings of this 0.8% is 8 TWh in primary energy. Assuming an average €0.086/kWh primary energy, the 8 TWh gives an annual savings of €0.69bn/year. The simple payback period (SPP) is then 5.4 years.

13 INDUSTRIAL SENSORS

13.1 Definition

13.1.1 Scope

Smart industrial sensors are electronic packages added to new and existing electrical motors, fans, pumps and compressors to lower running costs (energy, auxiliaries), optimise maintenance (lower costs and down-time), increase product life and integrate systems across platforms.[349,350] They consist of at least three, and often four components:

- analogue transducers that convert physical input (temperature, vibrations, acceleration, acoustics, etc. [351]) into electrical output signals;
- a computing unit that processes the electrical signals into intelligible information. It can have expanded capabilities, such as data filtering, combining output from multiple (types of) transducers, self-calibration, data pre-processing to reduce data load on gateways, etc.
- a communication interface that sends the information via a WiFi, Bluetooth or other network to local or distant (cloud) storage for analysis by an operator.
- its own power supply (battery or energy harvester EH) if it is an add-on device.

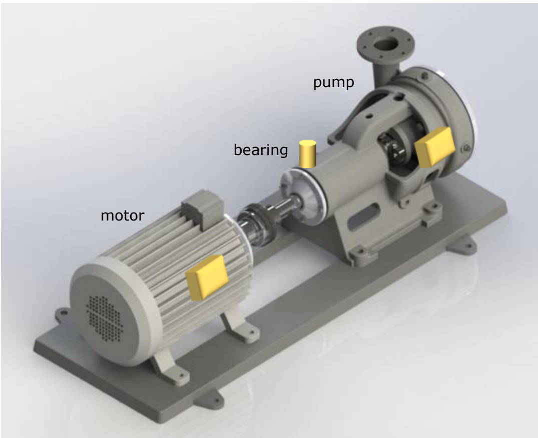


Figure 66: Smart sensors (yellow) on motor, bearings and pump (source: VHK 2020).

Figure 66: *Triaxial vibration sensors (yellow) on fan* (source: EBM-Papst, 2018)

[349] Tyler Wojciechowicz, Smart Sensor vs Base Sensor - What's the Difference? Semiconductorstore, Sep 18, 2018. https://www.semiconductorstore.com/blog/2018/Smart-Sensor-vs-Base-Sensor-Whats-the-Difference-Symmetry-Blog/3538/

[350] Gary W. Hunter, Joseph R. Stetter, Peter J. Hesketh, Chung-Chiun Liu - Smart sensor systems, Article in NATO Science for Peace and Security Series B: Physics and Biophysics · January 2012 https://www.researchgate.net/publication/258734399_Smart_Sensor_Systems

[351] The IEEE 1451 family of standards (with the most recent addition of 1451.7 in 2010) provides a digital communication interface standard for transducers and network-capable processors.

The communication protocol for transmitting information to external devices is either wired (usually Modbus or LAN protocols) but more often than not wireless: 2.4 GHz radio frequency band for Bluetooth Low Energy (BLE), IEEE 802.11gn, Zigbee (IEEE 802.15.4). Besides transmitting information the sensors may also receive information for remote updating.

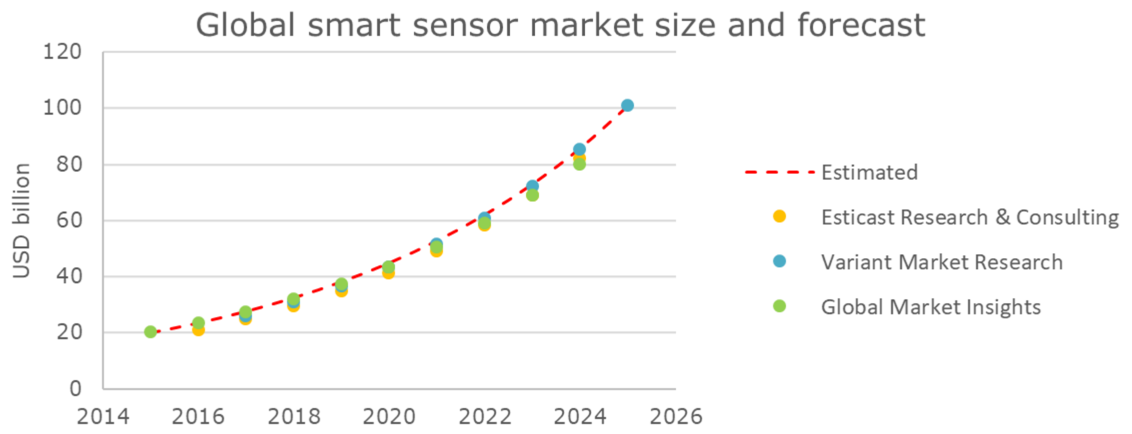
Energy consumption for smart industrial sensors is very low: a button- or coin-cell battery for an add-on sensor will last a lifetime (5 to 10 years). Energy harvesters, i.e. taking the power from the ambient (sunlight, vibrations, etc.) are starting to be used in some industrial sensors.

The most important reason why smart industrial sensors could be eligible for Ecodesign and Energy Labelling Working Plan is because of their energy (and other resources) saving potential across a wide range of new and existing industrial machinery with motors, fans, pumps and compressors.

13.2 Market

13.2.1 Sales

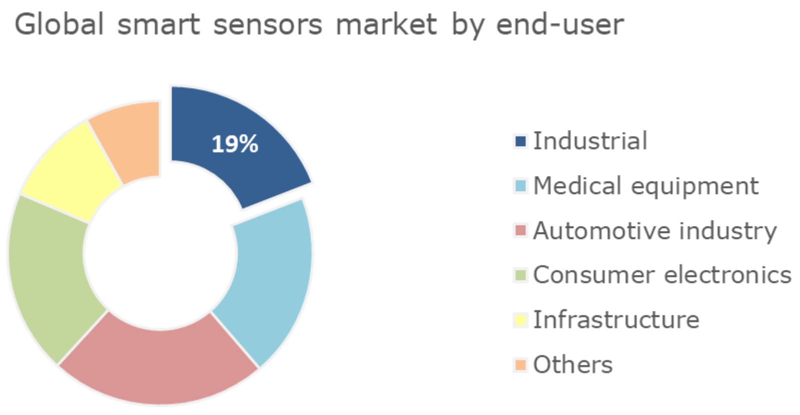
Global market size 2015[352,353] estimated at USD 20 billion and a CAGR (Compound Annual Growth Rate) of 17.6%[354] over 2016-2025 period gives USD 45 billion in 2020 and USD 101 billion in 2025[355].



Sources: Esticast Research & Consulting, Variant Market Research, Global Market Insights

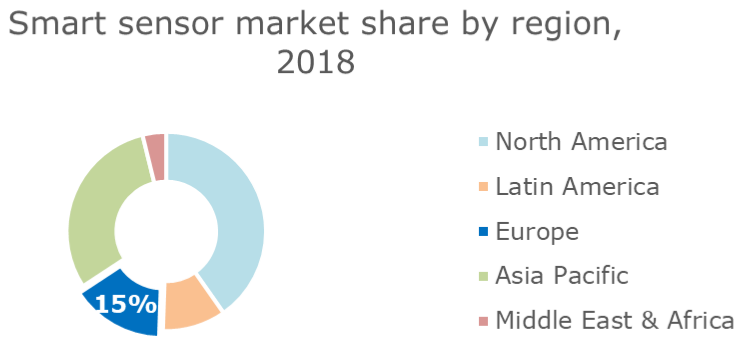
Figure 67: Global smart sensor market size and forecast

[352] Global Market Insights, Report on Smart Sensors: https://www.gminsights.com/industry-analysis/smart-sensor-market
[353] https://www.slideshare.net/Abhishekjha244/smart-sensor-market-forecast-and-industry-analysis-report-2016-2024
[354] Based on global sales figures of several market reports (Global Market Insights, Variant Market Research and Esticast Research and Consulting) for 2016-2024. CAGR of 17.83% by Verified Market Research for 2018-2025 comes close.
[355] https://www.variantmarketresearch.com/press-release/global-smart-sensors-market-is-estimated-to-reach-101-billion-by-2025-says-variant-market-research



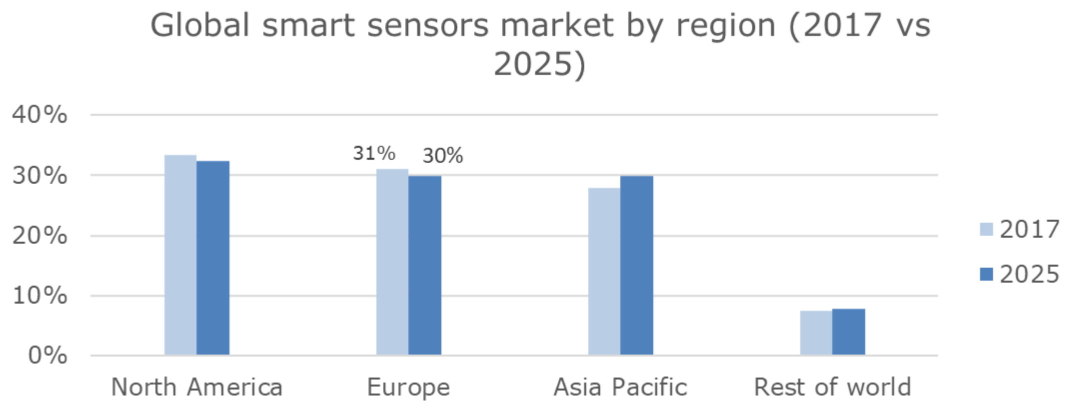
Source: https://www.alliedmarketresearch.com/smart-sensors-market

Figure 68: Global smart sensor market by end-user



Source: https://www.researchnester.com/reports/smart-sensor-market/1072

Figure 69: Smart sensor market by geographical share in 2018



Source: Variant Market Research

Figure 70: Smart sensor market by geographical share 2017 vs 2025

The graphs indicate a share of 19% for industrial/commercial smart sensors (Figure 68) which means USD 8.2 billion in 2020. The European Union market takes an average of 25.3%[356] of the global sales for 2020 resulting in a USD 2.16 billion (€1.92bn) sales for the EU. The list prices for smart motor sensors measuring vibrations and temperature for

[356] Average from 31% (2017), 30% (2025) and 15% (2018) from Variant Market Research and Research Nester.

induction or synchronous industrial AC motors, fixed speed or variable speed, new or existing, frame-sizes IEC 56-450 kW, the list prices are in the range of €100 - €450 [357]. At an end-user price of €220 /unit this results in a unit sales of around 8.6 million units at an end-user cost of € in 2020 in the EU. See also Table 106.

Table 106. EU market figures for 2020

global sales	40	billion Euro[358]
industrial sector	19	%
EU share of global sales	25.3	%
sales EU industrial sector	1.92	billion Euro
price/unit	220	Euro
units sold in EU industrial sector	8.7	million
CAGR global	17.6	%

The actual product life is unknown, but considering that the battery is non-replaceable, it is fair to assume an average product life of 5 years.

13.2.2 EU stock

Taking the data from Table 106 and the product life of 5 years, the sales and stock data were calculated (see Figure 71). For 2020 the sales are estimated at 8.7 million units and the stock 53.4 million units. In 2025 it is calculated that the numbers will more than double.

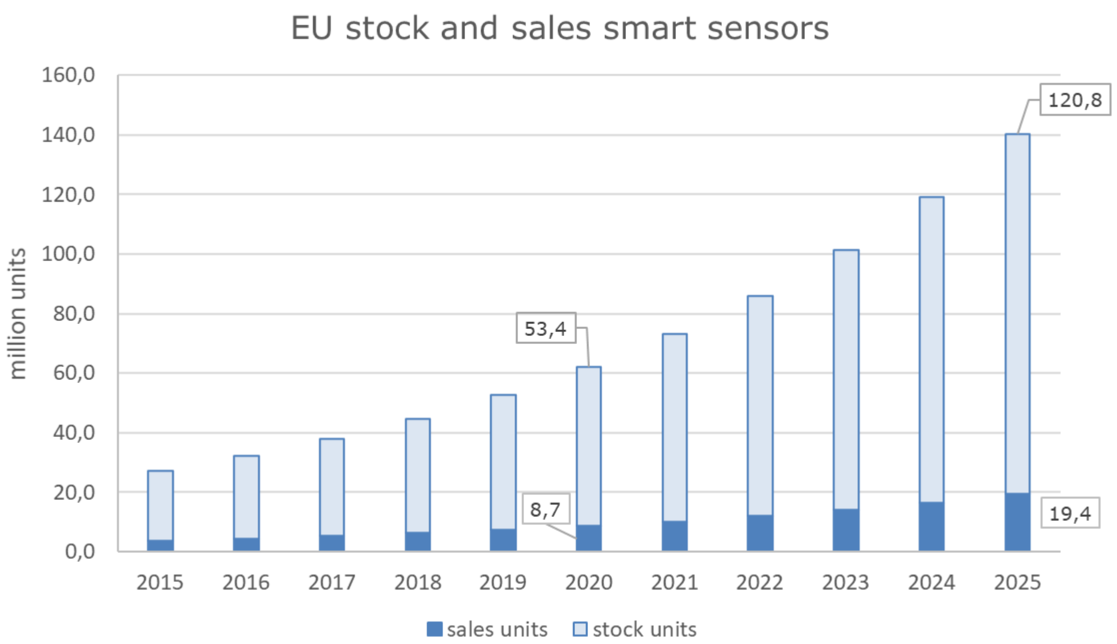


Figure 71: EU stock and sales smart sensors (VHK estimate 2020)

[357] https://www.techniekwebshop.nl; https://ncd.io/; https://www.technischeunie.nl/product/prd1894719575; https://www.conrad.de/de/p/bosch-connected-devices-and-solutions-multi-sensor-modul-connected-industrial-sensor-solution-i-ciss-2148499.html

[358] Conversion

13.2.3 Energy harvesters

The use of energy harvesters as a power supply for industrial sensors is still in its infancy, but developing. Currently, energy harvesting technologies typically still deliver (too) small power outputs to work without some storage device, i.e. a battery.

Table 107: Typical energy harvesting power outputs
(source:IDTechEx report, January 2014)

Thermal	Vibration	PV	RF
0.5 - 10 mW	1 µW – 20 mW	10 µW - 15 mW	0.01 – 0.1 µW

For 2020, market reports for energy harvesting systems[359] describe a global sales of USD 488 million (base: 2017 USD 358 million, CAGR 10.85%)[360]. As with smart sensors, Europe is assumed to account for about 25%, meaning USD 122 million. With an 18%[361] share for industrial use, this comes down to a sales of USD 22.2 million (€19.8 million). Assuming a price of USD 4 per module in 2020[362], this amounts to 5.6 million units sold in the EU in 2020. [363] EH use technologies for harvesting energy from ambient sources, such as sunlight, vibrations, radio and thermal waves, and store the energy in a battery or (super)capacitor. EH are used in smart sensors either as a complement to their standard power source or as the only power source. As EH modules are also used in other industrial/commercial products (e.g. smart switches, building automation), the number of EH modules in smart sensors used with the products in scope is currently unknown.

13.3 Usage

Smart sensors are available for motors in sizes from 0.12 to over 1000 kW (IEC framesizes 56 to 450), i.e. the full range of the Ecodesign motor regulation. They can also be applied to or used in bearings, fans, pumps and compressors.

Smart sensors are typically used to achieve:

1. Energy saving— Detect if, how much and how long the motor/fan/pump/compressor is operating at suboptimal conditions (stall conditions, frequent on/off switching cavitation, vibrations etc.) and suggest –at the analysis phase—suitable remedies through system optimisation (adjusting process control, motor cooling, etc.), install variable speed drive, substitute worn parts causing the vibrations, proper lubrication, etc.

[359] https://www.marketreportsworld.com/global-energy-harvesting-systems-market-12344294

[360] Conservative estimate, other sources present higher figures:
https://www.powerelectronics.com/technologies/energy-harvesting/article/21851975/whos-harvesting-energy
https://www.slideshare.net/sherrythomas13/energy-harvesting-market-by-source-system-application-forecast-20172024

[361] https://www.slideshare.net/spansion/spansion-energy-harvesting-pmics

[362] https://www.slideshare.net/Funk98/energy-harvesting-for-iot - mentions a price in 2014 of < 1 USD per integrated micro energy harvester. On internet, prices can be found between USD 0.10 to USD 10. IDTechEx Energy Harvesting report (2017) mentions an EH-price of USD 3.50 for non-mesh sensors, and USD 10 for wireless mess sensors.

[363] Note that energy harvesters are also used in other applications such as switches: Energy harvesters worden echter ook in andere producten gebruikt zoals schakelaars. [https://switches-sensors.zf.com/us/energy-harvesting-technology/]

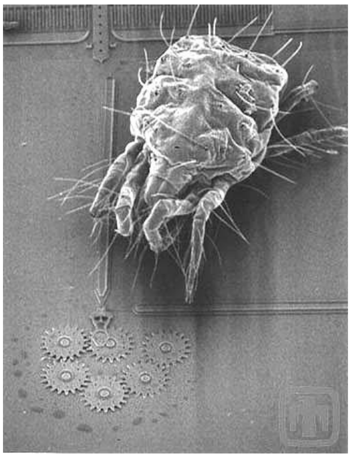
2. Optimal Condition-Based Maintenance (CBM) — Unlike time-based maintenance (TBM) or run-to-failure maintenance (RTF), CBM is based on the actual measured condition of the equipment as indicated by the industrial sensors. This leads to savings in maintenance costs, because actions are only performed when necessary, and significantly less down-time, because parts are performing in optimal conditions and they are replaced/repaired in time, i.e. before the process of which they are part breaks down. [364]
3. Enhanced product life — Smart sensors can extend the life of the motor by up to 30%. For instance, temperatures exceeding the rated operating temperature of the windings by as little as 10 °C can shorten the life of a three-phase induction motor by half [365]. Vibrations from misalignment, wear of bearings, cavitation, etc. can cause mechanical damage (and noise).
4. Integrate systems throughout plants, allowing multiple pieces of machinery to be networked together. This empowers operators to monitor the system as a whole.

A critical factor is the software application used to analyse asset health from the measured variables and to provide timely, meaningful information. Machine Learning (ML), a.k.a. Artificial Intelligence (AI), plays an important part in that. CBM uses continuous (real-time) measurements on the assets, statistical models and historic failure data to predict failures before they happen, to reduce the risks of unexpected breakdowns, reduce maintenance costs (only when needed), improve product-life, enhance energy-efficiency and performance.

13.4 Technologies

13.4.1 Transducers

More and more, MEMS (Micro Electro Mechanical Systems) and NEMS (Nano Electro Mechanical Systems) are becoming the basis for the new generation of industrials sensors. They are small embedded systems combining electrical, mechanical and/or chemical components, varying in size from micro- or nanometres to a few millimetres.



A particular system may contain a few or millions of MEMS. Production techniques are often similar to those used in computer chip production: CVD (Chemical Vapour Deposition), PVD (Physical Vapour Deposition), optical lithography, etching and micro-machining of silicon wafers, etc.. Currently, they are used in pressure sensors, acceleration meters, acoustic sensors, magnetic sensors, gyroscopes, etc.. MEMS sensors also find their applications in whole classes of new devices like fitness trackers, smart watches and virtual reality glasses.

Figure 72: A spider mite next to a MEMS gear train.

[364] An enhanced variation of CBM is predictive maintenance (PdM) which uses sensor measurements with predictive algorithms (prognostics) to predict failure of an asset with the aim of eliminating unplanned downtime.

[365] https://www.efficientplantmag.com/2004/07/temperature-monitoring-is-key-to-motor-reliability/

13.4.2 Power supply

Smart sensors that are wireless (WSNs) must have their own power supply to operate. Several developments are described here that are aimed at improving a WSN's reliability and lifecycle.

Lowering power consumption

The US DARPA has a programme aimed at extending battery life on IoT devices (for military purposes)[366]. The goal is to consume less than 10 nW during sleep, a 1000-fold improvement over current state-of-the-art sensors. The 10 nW threshold was chosen since the battery passively loses 10 nW of power on its own, also known as passive self-discharge. DARPA intends to make this technology available for commercial use, e.g. in detecting damage to critical infrastructure, automobiles, industrial control systems, medical devices, and climate monitoring systems.

The latest generation commercial energy harvesting wireless sensors requires standby currents of only 100 nanoamperes (nA) or less.[367]

Energy harvesters

While energy harvesters are intended to make WSNs maintenance-free with regards to energy supply, the source (vibrations, light, etc.) for generating the energy may not always be available or reliable. Systems using energy harvesters therefore almost always include a rechargeable battery or (super)capacitor for storing the harvested energy to bridge periods when the energy source is not available.

Most consumer electronics devices today have a standby current of a few milliamperes (mA), whereas power-optimised embedded designs typically achieve standby currents of a few microamperes (µA), an improvement of factor 1000. The latest generation of energy harvesting wireless sensors requires even lower standby currents of 100 nanoamperes (nA) or less, an improvement of more than factor 10000.[368]

MEMS are one of the most promising solutions for use in energy harvesters (EH)[369]. They transform energy from vibrations using a piezoelectric material placed onto a mechanical resonator[370]. A forecast on energy harvesting efficiency improvements is shown in the table below. It shows thermoelectric, photovoltaic (PV) and vibration sources. Among PV-technologies, dye-sensitized solar cells (DSC) are relatively new, and have made the most progress in recent years[371]. In 2020 commercial DSC have reached efficiencies of up to 19%.[372]

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[366] https://www.iotforall.com/darpas-take-iot-battery-problem-n-zero/

[367] https://www.enocean.com/en/technology/energy-harvesting-wireless/

[368] https://www.enocean.com/fileadmin/redaktion/pdf/white_paper/White_Paper_Internet_of_Things_EnOcean.pdf

[369] https://www.electronicdesign.com/power-management/article/21796369/energy-harvesting-and-wireless-sensor-networks-drive-industrial-applications (2013)

[370] Optimization Method for Designing Multimodal Piezoelectric MEMS Energy Harvesters, Conference: SPIE 9517, Smart Sensors, Actuators, and MEMS VII; and Cyber Physical Systems, Barcelona, Spain, Volume: 9517 (https://www.researchgate.net/publication/277138101_Optimization_Method_for_Designing_Multimodal_Piezoelectric_MEMS_Energy_Harvesters)

[371] https://www.nrel.gov/pv/cell-efficiency.html

[372] https://www.3gsolar.com/technology

Table 108: Energy harvesting efficiency forecast

Energy Harvesting type	2020	2024
Thermoelectric	1 mW/K² *MEM technologies: material-modulation doping, devices-surface micromachining, polymer substrate, heat path optimization, BITe film technology*	4.5 mW/K² *MEM technologies: TEG enhancement by nanostructured materials (superlattice or high density nanowires), advanced radiator materials & designs, hybridization with PV cells*
Photovoltaic	PCE > 15% *PV technologies: Hight quality organic molecules, NW, QD, multi-junctions, junctions with low interface recombination, integration in 3D flexible electronic chip*	Indoor: > 20% Outdoor: > 40% *PV technologies: Breakthrough in DSSC/NW/QD based cells, tandem, hybrid & integrated solar cell*
Vibration	1.5 mW/cm² *MEM technologies: Hybrid generators, non-linear characteristics, new piezo materials*	10 mW/cm² *MEM technologies: Heterostructured piezo nanostructures, near-field characterization, integrates nano-magnets, increased NW density into devices, new integration techniques*

Source: https://www.slideshare.net/Funk98/energy-harvesting-for-iot (2015)

Batteries

Although Lithium-ion (LI-ion) batteries mark a significant performance improvement over other types. Industrial grade Lithium-ion batteries can operate for up to 20 years and 5000 full recharge cycles, with an temperature range of -40°C to 85°C, and the ability to deliver high pulses for two-way wireless communications.

As an alternative, for long lasting low-power operation often non-rechargeable lithium batteries with very low self-discharge rates are chosen. Most notably, lithium thionyl chloride ($LiSOCl_2$) is able to deliver a 40-year service, because of its high specific energy, high energy density, wide temperature range (–80°C to 125°C), and very low self-discharge rate (<1% per year)[373].

Solid-state batteries are an upcoming type of battery that compared to lithium-based batteries, are potentially safer with a higher energy density[374]. Due to these qualities much research is done to develop solid-state batteries for electric vehicles, focused on extending battery lifetime and lowering production cost. They are also being used in pacemakers, RFID and wearable devices, at high cost.

When energy harvesters are used, the harvested energy needs to be stored in rechargeable batteries or supercapacitors. The latter is often cheaper, but not preferable due to its bulky size and high self-discharge rate and thus Li-ion batteries are usually employed.

[373] https://www.embedded-computing.com/guest-blogs/low-battery-self-discharge-the-key-to-long-life-remote-wireless-sensors

[374] https://en.wikipedia.org/wiki/Solid-state_battery

13.4.3 Computing

All smart sensor measurement information needs to be interpreted to become usable knowledge about the monitored asset. Data science is often of key importance for successfully determining problems and predictions, to improve operations, energy efficiency, and minimize maintenance disruption and costs.

With the rise of data centres and cloud computing in the past years, there has been considerable development in collecting and handling massive quantities of continuous data. Almost every major technology company and a number of product manufacturers (in scope) are developing artificial intelligence (AI) technologies to automate tasks of turning information to knowledge. As this knowledge is valuable for purposes of CBM prognostics and process optimisation, these technologies are being offered as services by such companies to clients.

Machine learning (ML) is an application of AI to discover information from large datasets, and automatically learn from experience. Whereas ML requires large datasets to learn, research is lately also being done on learning models that are able to learn from scratch[375] or only few training samples ("few-shot learning")[376]. In the future these developments could lead to less dependence on massive amounts of measurements for deriving usable knowledge, less dependence on large scale computing resources (data centres) making CBM cheaper and easier to implement, and improved CBM prognostics.

13.4.4 Configurations

One way of introducing smart sensor technology to products is to integrate or embed the it into the product as a default feature.
Ebm-papst is outfitting all of their GreenTech EC fans and blowers with a communication interface for remote monitoring and control[377,378]. This makes it possible to add (external) smart sensors to the fans for local and remote smart control.

Another way is providing universal add-on smart sensors for assets that need to be managed, which has the considerable advantage of using them with existing equipment. Several global manufacturers (e.g. ABB, Bosch, Schaeffler) have taken on this strategy.

Advancements in miniaturisation already make complete coin-sized EH WSNs possible, that include sensors, solar cells, energy harvesting unit, power storage, a wireless communication transceiver and a microprocessing unit. Lower costs of smart sensors can make them more ubiquitous in use (commoditisation), further improving asset management.
EH WSNs are now primarily used in locations that are difficult to reach that would make battery replacements very costly. However, they can also be a viable alternative to battery-driven WSNs.

[375] https://deepmind.com/blog/article/alphago-zero-starting-scratch

[376] https://towardsdatascience.com/advances-in-few-shot-learning-a-guided-tour-36bc10a68b77?gi=616c6c1779dc; https://arxiv.org/abs/1904.05046

[377] https://www.ebmpapst.com/media/content/info-center/downloads_10/brochures/ebm-papst_GreenTech-EC-Technology_en.pdf

[378] https://hte.ebmpapst.com/content/dam/ebm-papst/corporate/downloads/catalogues/products/en/Brennwerttechnik_2017-03_EN.pdf

13.4.5 Using smart sensors with products in scope

As mentioned, the main reason why smart industrial sensors might be eligible for Ecodesign or Energy Label measures is in its saving potential for industrial motors, pumps, fans and compressors.

Below is a summary of the most occurring problems the products in scope may experience, and which smart sensors may be used for monitoring and how they can save on operational costs.
Smart sensors may also be used to improve or optimise production or logistics process-related aspects only, and not monitor the asset specifically. E.g. monitor a specific gas mixture, humidity in a space, etc. However, as this usage is highly dependent on specific processes, it is not possible to assemble general cost-benefit figures.

Motors
The best way to measure the temperature of motor windings is through embedded temperature sensors in the motor. However, these are not always available. External smart sensors can measure only the skin temperature of the motor, so in such cases algorithms are necessary to approximate the actual motor temperature.

Vibration in motors can be caused by e.g. imbalance, misaligned couplings, failing foundation or metal frame. Vibration directly affects the bearings, and leads to damage to the motor and/or connected parts.
Vibration specifically originating from the bearings is usually caused by electric discharge machining (EDM) [379], which causes bearing noise and also grease degradation.
As most mechanical forces come together at the bearings, mechanical vibrations are usually measured on the motor bearings.

Power parameters like current and harmonic distortion can reveal how the motor (or machine) is performing. If the electrical condition of motors specifically needs to be monitored, then e.g. high potential sensors and power signal analysis may be employed to identify changes in the system properties (such as resistance, conductivity, dielectric strength and potential) caused by electrical insulation deterioration, broken motor rotor bars and shorted motor, stator lamination etc.

Various field studies have often found vibration and temperature measurement to be sufficient in providing very reliable indications of motor condition.

Since motors form the basis for the other products in scope, the same sensors can be used for the other products to monitor or predict the problems mentioned for motors.

[379] When voltage accumulates on a motor shaft, it often finds the path of least resistance to ground via the motor bearings. This causes pitting on the bearing surfaces and ultimately leads to a grooved pattern (fluting) in the bearing raceways. When noise occurs, the damage is usually already substantial enough that failure is imminent.

Pumps
As with motors, pump vibration can be caused by imbalance, a failing foundation or metal frame, shaft misalignment, but also by impeller damage, pump bearing wear, and/or coupling wear and cavitation.
Besides equipment failure, vibration also causes a loss of (energy) efficiency.

Cavitation[380] in the impeller may develop during operation of a pump or be caused by e.g. poor piping design. Often, cavitation is not discovered until acoustic or vibration anomalies are noticed. By that time, substantial damage has occurred to the pump and often also to connected equipment such as the motor driving the pump and piping. Pump cavitation is therefore a prime reason that warrants early warning.

Vibration sensors can be used to deduce imminent cavitation, but will need to rely on machine-learned knowledge of the pump (offered as a service by some pump manufacturers). Alternatively, high-sensitivity differential pressure sensors can be specifically used to measure minute pressure fluctuations which are often a precursor of cavitation.

Power sensors can determine how often a submersible or hydraulic pump is cycling on/off to maintain flow or pressures, which contribute to knowledge about the pump's performance.

Cost savings
Pumps account for an estimated 7% of maintenance costs of a plant or refinery, and pump failures are responsible for 0.2% of lost production [381].

Fans
Besides the potential problems with motors, fans can additionally experience stall[382], surge and instability issues.

Stall or rotating stall[383] can cause mechanical damage for fans, as it generates (usually random) vibrations, and vibration-related noise (hammering). Continuously operating in stall can cause structural metal fatigue. However, even without damage, fans operating in stall have a suboptimal efficiency.

Surges are violent instabilities of the complete fan and ducting system during which the airflow may reverse and recover at an oscillating frequency (a few Hz). In a system in surge the air alternates between high velocity in the duct compressing the air in the plenum[384].

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[380] Pump cavitation is the result of a drop in the liquid pressure below its vapour pressure at the pump suction. This causes bubbles to form, which collapse at the impeller and other interior surfaces. The hydraulic impacts caused by the collapsing bubbles are strong enough to cause areas of fatigue on the metal impeller surfaces.

[381] Niki Bishop, Improve reliability with essential asset monitoring, InTech, 2012

[382] Stall is a reduction in the lift generated by a foil as the angle of attack increases. In stall the air no longer follows the foil surface uniformly.

[383] Rotating stall occurs when a disturbance causes the fl ow to separate from one of the blades, which results in blocking of the fl ow through the corresponding blade cell. This in turn affects the fl ow angles in the blade cells either side to change, so that the following blade then tends to stall whilst the preceding blade becomes more stable. The stall cell eventually moves to the next passage and then the one after that, rotating around the impeller in the opposite direction to that of the rotation. (Eurovent 1-11, FANS and SYSTEM STALL: PROBLEMS and SOLUTIONS, Eurovent WG 1, 2007)

[384] Engineering Data 600, Twin City Fan Companies, Ltd., 1999

Fan instability[385] occurs where the fan has more than one working conditions (i.e. having more than one fan curve), on which the fan can operate due to external causes (temperature, pressure, etc.), leading to a flow fluctuation between its fan curves. This should not be confused with "instability", as the resulting duty, although unexpected and unacceptable for many reasons, may well be perfectly stable.

In all cases the volume flowrate and thus the efficiency decreases.
These problems can be measured through vibration, flow, pressure (e.g. using a Petermann probe) and also acoustic frequency sensors. The measurements will need to rely on algorithms to determine the probable cause(s).

Compressors
Rotating stall is the most prevalent type of stall phenomenon[386] with compressors, and it can cause vibration stress which can result in blade failure[387]. Modern compressors are carefully designed and controlled to avoid or limit stall within an engine's operating range[388].

Compressor fouling are defined as particulate fouling and/or corrosion fouling. Particulate fouling mostly reduces the efficiency due to distorted airflow. In corrosion fouling deposits cause pitting corrosion on the blades, which may ultimately (partially) break. The resulting imbalance in the impeller causes vibration and fatigue damage, and finally compressor failure[389].

For compressors, mainly vibration can be measured. Usually conductivity resistance sensors are used to determine particulate fouling.

Cost savings
Particulate fouling can cause energy efficiency losses of about 1%[390]. For turbo-machinery that can use up to 70 megawatts of power, an energy efficiency loss of 1% due to particulate fouling translates into annual losses of USD 300 000.
Compressors account for an estimated 8% of maintenance costs of a plant or refinery, and compressor failures are responsible for 0.6% of lost production.

13.5 Energy, emissions and costs

13.5.1 Self-consumption of smart sensors

Power for smart sensors is typically delivered by a button- or coin-cell (battery), with voltages from 1 to 3.3V and capacities from 120 mAh to 1 Ah. This means it can deliver

[385] It is most commonly found where the fan delivers into a large plenum chamber, or an extensive duct system having a large cubic capacity. (Eurovent 1-11, FANS and SYSTEM STALL: PROBLEMS and SOLUTIONS, Eurovent WG 1, 2007)

[386] M.P. Boyce, in Combined Cycle Systems for Near-Zero Emission Power Generation, 2012

[387] Flow-Induced Vibrations, editors Shigehiko Kaneko, Tomomichi Nakamura, Fumio Inada et al., 2014 (https://www.sciencedirect.com/book/9780080983479/flow-induced-vibrations)

[388] https://en.wikipedia.org/wiki/Compressor_stall

[389] https://www.turbomachinerymag.com/compressor-rotor-failure-due-to-fouling/

[390] https://www.emerson.com/documents/automation/cracked-gas-compressor-white-paper-en-41052.pdf

3.3 Wh over its lifetime. The (usually) non-replaceable battery is dimensioned to last the lifetime of the smart sensor, i.e. at least 5 to 10 years in worst conditions. So, in the worst case, up to the point that the meaningful data are transmitted to the cloud or to other remote storage (cell phone, tablet or PC) for further data analysis, the annual energy use is typically no more than 0.6 Wh/yr (0.0006 kWh/yr) per sensor.
Wired power sources for smart sensors include DC, power over USB, or power over Ethernet (PoE), usually also at 3.3V or 5V.

Table 109: Comparison of wireless technologies

	Experimental results using 3.3 V supply		
	BLE	ZigBee	ANT
Time of one connection ±SD*	1150 ms ±260ms	250 ms ±9.1 ms	930 ms ±230 ms
Sleep current	0.78 μA	4.18 μA	3.1 μA
Awake current	4.5 mA	9.3 mA	2.9 mA

**SD: standard deviation*

Artem Dementyev, Steve Hodges, Stuart Taylor, Joshua R. Smith - Power consumption analysis of Bluetooth Low Energy, ZigBee and ANT sensor nodes in a cyclic sleep scenario, Wireless Symposium (IWS), 2013 IEEE International, April 2013, DOI: 10.1109/IEEE-IWS.2013.6616827[391] [392]

There is a large difference in energy use between sleep mode and active mode. Taking the BLE (Bluetooth Low Energy) as a reference, the power use during the 1150 ms (~1s) transmission is 14.85 mW and the energy is thus 0.005 mWh per hour or 0.043 Wh per year (1 yr =8760 hours). Then, assuming that 1 data transmission (1 sample) per hour is enough[393], the other 3599 seconds/hour the sensor is using 2.57 μW of power, in energy this is 0.00256 mWh of energy per hour or 0.022 Wh per year. In total, the sensor is using 0.065 Wh/year. The coin-type battery in the smart sensor has a capacity of 3 Wh (3V*1Ah), so more than enough for the declared product-life of 5 years even at the state-of-the-art 2013. This does not take into account possible extra computing power but on the other hand it also does not take into account that the state-of-the art 2020 is over 7 times more energy efficient than that of 2013 that we used in the calculation.

Note that Wi-Fi takes up much more energy than BLE and the annual energy consumption is then much closer to the 5 year battery capacity.
requirement
For storage on a remote location, messages from the sensors are usually less than a few hundred bytes. Assuming that the sensor sends 8760 messages per year this comes down 8760 write actions. This results in an energy consumption of 0.0007 Wh (SSD drive) up to 0.08 Wh (HDD), i.e. on average 0.0042 Wh. Note that this not the energy use of the sensor but of the storage device.

Subsequently, the data is analysed by software on a computer that alerts an operator if maintenance action required. The annual energy use for the data analysis and interface of the computer is estimated at (less than) 1 Wh/yr.

[391] https://semiwiki.com/wp-content/uploads/2016/08/IWS20201320wireless20power20consumption.pdf
[392] Data are from 2013. Current state-of-the-art energy consumption for Bluetooth in active mode (4.5mA*3.3V□14.8 mW) is over a factor 7 less (2 mW).
[393] [https://journals.sagepub.com/doi/full/10.1155/2014/782710]

The total energy use per smart sensor would then be 0.36 Wh/yr (sensor and electronics) + 0.006 Wh/yr (sensor communication) + 0.24 Wh/yr (gateway communication to remote storage) + 0.042 Wh/yr (writing data on remote storage) + 1 Wh/yr (data analysis and interface)[394] = 1.65 Wh/yr. This is illustrated below.

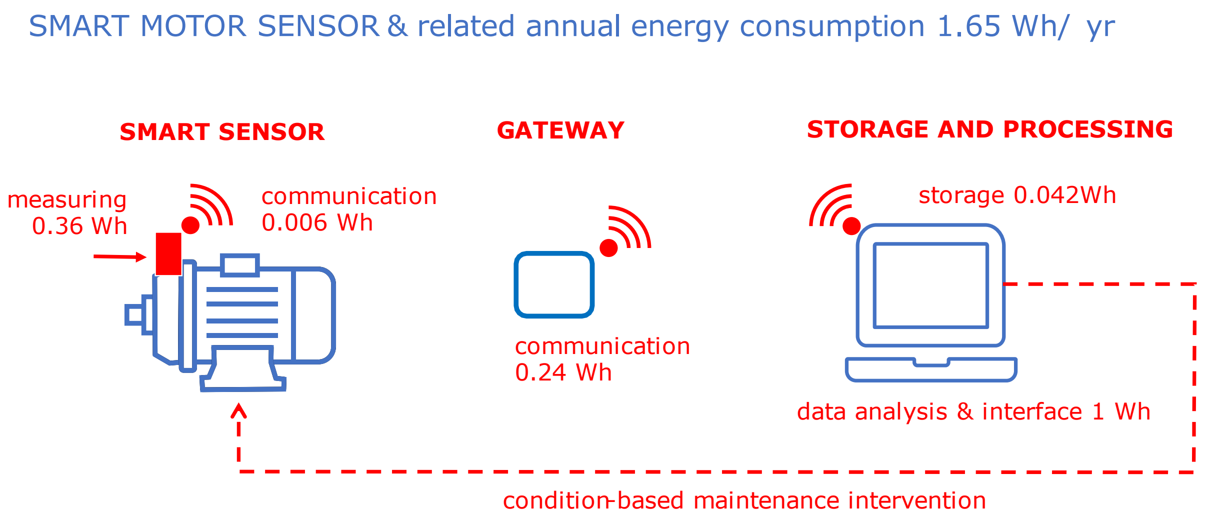

Figure 73: Energy consumption components in smart monitoring

The EU stock in 2020 of around 53.4 million units will then use around 88 MWh/yr. This equals roughly the average electricity use of 25 EU households in 2020 and is insignificant.

13.5.2 Energy saving in other products

As mentioned, the reason why industrial sensors could be eligible for Ecodesign measures lies in their energy and resources saving potential in motors (>0.12 kW) and motor applications. The table below gives an overview of the installed stock of motors as well as their annual electricity use in 2020 and 2030. The differences between 2020 and 2030 are not large, as this is a mature market.

In total, there are 420-444 million motors installed in the EU. If we assume that industrial sensors will not be placed on small (below 1 hp) and special motors, there are around 100 million motors in the EU. If we assume that also for fans, water pumps and standard air compressors it would only be interesting for 25% of the installed stock to place an (additional) sensor, some 70 million would be added. For bearing-sensors we might add an extra 30 million and thus we arrive at an EU market of 200 million sensors.

As calculated, the current stock is at the most 50 million sensors and thus there is still a potential of placing 150 million sensors.
The energy use of the industrial motor stock, without small and special types, is 1294 TWh/yr in 2030. Even at a conservative estimate of 5-10% saving from sensors, this comes

[394] The analysis is done once per hour (8760 times/year) and involves setting up reference values for 'normal behaviour' especially in the beginning and then a relatively simple floating point operations in a stochastics context. This should be possible within 1 Wh/year (approx.. 0.4 Ws per operation).Probably the most energy-intensive part, which the study team does not consider part of the strict sensor functionality, is the graphics user interface (GUI) for managing a few hundred sensors.

down to a potential of 65-130 TWh electricity saving. Even if already 25% of this (50 million sensors) is realised, this still leaves a potential electricity saving of 50-100 TWh.
An advantage is that the measure could be applied to all motors, new and existing. In other words, the impact of measures would not be slowed down by the stock replacement dynamics.

Table 110. Motors installed and electricity use EU (source: VHK, EIA 2018 update)

	Life (yrs)	Installed (000 units)		Electricity Use (TWh/yr)	
		2020	2030	2020	2030
Small & special*	8-16	322 540	339 582	183	187
Medium (S) 0.75-7.5 kW (3 ph)	9	81 829	87 369	160	157
Medium (M) 7.5-75 kW (3 ph)	11	13 635	14 656	265	262
Medium (L) 75-375 kW (3 ph)	16	1 593	1 751	574	574
Large LV 375-1000 kW (3 ph)	18	176	194	286	301
Total electric motors		***419 773***	***443 551***	***1 468***	***1 481***
Total without small & special		**97 233**	**103 970**	**1 286**	**1 294**
FAN Industrial Fans >125W	15	241 065	272 904	153	159
WP Water pumps	11	19 830	22 884	134	153
CP Standard Air Compressors	9-12	1 141	1 229	56	58
Total other industry components		**262 036**	**297 017**	**343**	**371**

**=<0.75kW, 1-phase>0.75 kW, Brake, Explosion, 8-pole*

13.5.3 Monetary savings

Apart from the monetary saving on electricity costs as indicated above, there is the saving on maintenance costs and the gain from less process down-time.

A source using internal studies estimates that a properly functioning CBM programme can provide savings of 8-12% over the traditional PM schemes[395].
Furthermore, CBM programmes can deliver the following benefits [396] [397] [398]:

- Maintenance costs: 14-30% reduction
- Downtime: 20-45% reduction[399]
- Breakdowns: 70-75% reduction
- Production: 15-25% improvement

On average, repair cost for a failed asset is typically 50% higher than if the problem had been addressed prior to failure.
Additionally, for compressors, Fusheng reports the following improvements:

- Mean time to repair (MTTR[400]): up to 15% less due to timely repairs.
- First-time fix rate: up to 20% more repairs adequately fixing a problem (consequently less repairs were needed to solve a specific problem).

[395] Gopalakrishna Palem, Condition-Based Maintenance using Sensor Arrays and Telematics, International Journal of Mobile Network Communications & Telematics (IJMNCT) Vol. 3, No.3, June 2013. DOI: 10.5121/ijmnct.2013.3303

[396] Gulati, Ramesh (2012-08-17). Maintenance Best Practices. Industrial Press, Inc.

[397] Niki Bishop, Improve reliability with essential asset monitoring, InTech, 2012

[398] Intel IoT Industrial Automation – Solution Brief – Improving Downtime and Energy Efficicency with IoT-Connected Air Compressors (https://cdrdv2.intel.com/v1/dl/getcontent/333853)

[399] For motors, ABB estimates a 70% reduction in unplanned downtime using smart sensors.

[400] MTTR is the total corrective maintenance time for failures divided by the total number of corrective maintenance actions for failures during a given period of time.

A plant-wide benchmark[401] for maintenance costs is:

maintenance costs / estimated plant replacement costs

Maintenance costs include direct labour, materials, labour by contractors, salaries and overhead. Estimated plant replacement costs are the total indexed value of plant and equipment. As a reference, a world-class performing company on reliability has typical maintenance costs between 1 - 2.5% of estimated plant replacement asset value.

13.6 Saving potential

The report in the previous sections suggest a significant environmental and economic impact as well as a very significant saving potential. Ecodesign measures could play a role as an accelerator of reaching the full market potential.

A challenge will be the fact that the smart industrial sensor is not an energy-using product, i.e. where the self-consumption should be regulated, but it is an energy-related product that improves the energy and resources efficiency of other products. On the other hand, many of the products that will benefit from the smart industrial sensors are already regulated under Ecodesign (motors, fans, pumps, compressors) and thus could be addressed horizontally from that angle.

[401] https://www.efficientplantmag.com/2000/09/comparing-maintenance-costs/;
Reducing operations and maintenance costs, Emerson Process Management, 2003
(https://www.emerson.com/documents/automation/product-data-sheet-reducing-operations-maintenance-costs-en-41038.pdf)

14 UNINTERRUPTIBLE POWER SUPPLIES (UPS)[402]

14.1 Scope, Policy Measures and Standards

14.1.1 Scope

A UPS is defined as *'a combination of electronic power converters, switches and energy storage devices (such as batteries) constituting a power system for maintaining the continuity of power to a load in the case of input power failure'* in the 2014 Ecodesign preparatory study prepared by Ricardo-AEA Ltd[403] and test standard IEC 62040-3:2011[404]. The Ecodesign preparatory study followed the recommendation in the EcoDesign Working Plan 2009-2010, which identified UPS as an indicative product group for potential environmental improvement and possible future Ecodesign measures[405].

Apart from 'maintaining the continuity of the load in case of input power failure' ('black-outs') the UPS takes care of power surges and spikes. Typically, UPS batteries work long enough to overcome a short black-out and/or give enough time for computer files to be saved and/or in the case of larger systems e.g. hospitals—give enough time for the back-up (diesel) generator set to start up.

14.1.2 Policy measures

The 2014 Ecodesign preparatory study illustrated that a significant energy saving of 11 TWh/year in 2025 could be made and this is mainly based on the smaller size UPS products which act as a back-up power for desktop PCs.

However, at the Ecodesign Consultation Forum of 20 December 2017, the decision to develop Ecodesign and/or Energy Label measures was postponed. One reason was doubts voiced on the projected energy savings as the market for UPS as back-up for office PCs was moving away from desktops towards notebooks (these don't need a UPS as the battery is incorporated in them). Due to the rapid replacement of desktop PCs by notebook PCs therefore, this UPS market was decreasing rapidly. Another reason was that under the US-EU Agreement on the Energy Efficient Labelling of Office Equipment at the time[406],

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[402] Contribution by Daniela Kemna with René Kemna (VHK)

[403] Stephanie Boulos, Chris Nuttall, Bob Harrison, Pedro Moura & Christoph Jehle, *ErP Lot 27 – Uninterruptible Power Supplies; Preparatory Study – Final Report* (2014), Ricardo-AEA/R/ED56828, Issue no. 1.

[404] As also defined in IEC 62040-3:2011.3.1.1.

[405] The Commission, *Establishment of the working plan for 2009-2011 under the Ecodesign Directive,* COM(2008) 660 final, p.5 and Annex I. Following Martijn van Elburg et al. , Study on Amended Working Plan under the Ecodesign Directive, VHK for the EC DG ENTR (now DG GROW), July 2011.

[406] Agreement between the Government of the United States of America and the European Community on the coordination of energy-efficient labelling programs for office equipment - Exchange of diplomatic Notes OJ L 172, 26.6.2001, p. 3–32

there was also an EU Energy Star label for UPS products.[407] Finally, in 2016 JRC Ispra started a (voluntary) Code of Conduct for UPS (CoC UPS)[408], with 10 signatories.
Today, the market for UPS products is growing especially for servers of all sizes, i.e. from the single file back-up server in a small office to the UPS for large server farms in data centres. Edge Computing, which brings data as close as possible to the end-user to lower the latency, is creating a whole new market for UPSs as a power back-up for e.g. base stations. The EU Energy Star label for UPS ended when the aforementioned US-EU Agreement expired on 20 February 2018 under the Trump administration. Additionally, judging from its website, the CoC for UPS does not seem to have been very active since its outset in 2016.
Apart from the voluntary US Energy Star label, the USA's DoE has presently increased its efforts by introducing new mandatory (minimum) Energy Conservation Standards for Uninterruptible Power Supplies through the (amended) Energy Policy and Conservation Act 1975. These minimum energy efficiency standards were published on the 10th of January 2020, with compliance starting January 10, 2022.
The above developments indicate that there is now a good reason to revisit the UPS as a possible topic for the Ecodesign Working Plan 2020-2024.

To complete the overview of legislation, it should be mentioned that there are generic European legislations relevant to UPS and these include the Low Voltage Directive (LVD) 2014/35/EU[409], the Electromagnetic Compatibility Directive (EMC) 2014/30/EC[410], the Directive on Batteries and accumulators and waste batteries and accumulators 2006/66/EC[411], the WEEE Directive[412] and RoHS[413].
Voluntary measures include, for instance, the German Blue Angel label for UPS.

Regarding the circular economy, it is appropriate to mention that the UPS was taken up by the Product Environmental Footprint Category Rules (PEFCR) in 2019.[414] This project was a collaboration between industry and other experts and was mainly based on inputs (Bill-of-Materials, Energy, Sales, etc.) of the Ecodesign Lot 27 preparatory study.

14.1.3 Standards

The main standard relevant to UPS is the European Standard series EN IEC 62040. Firstly, these standards prescribe general and safety requirements for handling and using UPS[415].

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[407] Qualified under Uninterruptible Power Supplies specification 1.0. See https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-products/energy-star_en

[408] https://ec.europa.eu/jrc/en/energy-efficiency/code-conduct/ups and https://e3p.jrc.ec.europa.eu//communities/ict-code-conduct-ac-uninterruptible-power-systems

[409] Directive 2014/35/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of electrical equipment designed for use within certain voltage limits, OJ L 96, 29.3.2014, p. 357–374

[410] Directive 2014/30/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to electromagnetic compatibility (recast), OJ L 96, 29.3.2014, p. 79–106

[411] Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC, OJ L 266, 26.9.2006, p. 1–14 (latest status: https://ec.europa.eu/environment/waste/batteries/)

[412] Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment Text with EEA relevance OJ L 174, 1.7.2011, p. 88–110 electronic equipment (WEEE) OJ L 197, 24.7.2012, p. 38–71

[413] Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment OJ L 174, 1.7.2011, p. 88–110

[414] https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_UPS.pdf

[415] EN IEC 62040-1:2019. Uninterruptible power systems (UPS). Safety requirements

Secondly, they provide a conformity assessment which ensures that UPS placed on the market have an appropriate level of electromagnetic compatibility (EMC)[416]. Thirdly, they establish a method to specify performance and test requirements of UPS as a whole[417]. Finally, these standards set out harmonized requirements declaring the environmental aspects relating to UPS with the aim of promoting a reduction of adverse environmental effects during the entire UPS life cycle. These environmental requirements reflect other horizontal environmental standards and are related to UPS in particular[418]. In addition to these specific UPS standards, other International and European Standards exist that are relevant to the UPS' components or to their installation[419].

The Product Environmental Profile (PEP) for smaller UPSs in particular, appears to be popular. The PEP (Product Environmental Profile) registered under the PEP ecopassport® Program is a type III environmental declaration according to the ISO 14025 standard. It is dedicated to electric, electronic and HVAC-R products.[420] PEPs are available for UPSs from APC/Schneider Electric, Legrand and others.

14.2 Market

UPS market data for the EU are available by size-class (in kVA or Watt, see Figure 74 and Table 111) and topology:

- VFD with Voltage and Frequency of the AC output are dependent on those of the input (a.k.a. 'Standby' topology);
- VI with the output's Voltage Independent of the input voltage (a.k.a. 'Line Interactive')
- VFI with the output's Voltage and Frequency being Independent of the input voltage and frequency (a.k.a. 'Double Conversion').

The EU unit shipments in the following table are taken from the UPS Business-as-Usual scenario in the 2018 Ecodesign Impact Accounting[421], which is a harmonised version of the data from the 2014 preparatory study.

Table 111. Market data UPS (source: EIA 2018)

UPS	**main**	**Sales (000 units)**				**Stock (000 units)**				**Load**	**Life**
size-class	**topology**	***2010***	***2015***	***2020***	***2030***	***2010***	***2015***	***2020***	***2030***	**kVA**	**years**
<1.5 kVA	VFD	1000	1041	1265	1915	4027	4065	4791	6575	0.32	4
1.5-5 kVA	VI	402	419	509	687	2994	3242	3599	5002	1.93	8
5.1-10 kVA	VFI	26	27	32	44	230	258	281	388	4.33	10
10.1-200 kVA	VFI	13	14	17	23	140	155	170	233	43.79	12

[416] EN IEC 62040-2:2018. Uninterruptible power systems (UPS). Electromagnetic compatibility (EMC) requirements

[417] EN IEC 62040-3:2011. Uninterruptible power systems (UPS). Method of specifying the performance and test requirements

[418] EN IEC 62040-4:2013. Uninterruptible power systems (UPS). Environmental aspects. Requirements and reporting

[419] E.g. IEC 60146 *Semiconductor Electronic Converters*; EN 50171 *Central power supply systems*; EN IEC 60439 *Low voltage switchgear and control gear assemblies*; EN 50272-2 *Safety requirements for secondary batteries and battery installations, stationary batteries*; etc.

[420] http://www.pep-ecopassport.org/create-a-pep/.

[421] Wierda, L. and Kemna, R., Ecodesign Impact Accounting, VHK for the EC, 2018.

The Load in the table refers to the average wattage (kVA) applied to a UPS of a certain size-class. The 'Life' relates to the average service life in years, which is a parameter needed in calculating the average stock.

Figure 74. Examples of Current Available UPS on the Market for each size-class

Currently there are many UPS models that exceed the 200 kVA limit of the fourth Category, however - as the PEFCR study explains – these often consist of several smaller models combined.

14.3 Usage

UPS units are commonly found in server rooms and data centers, but also in other environments with time- and/or process-critical operations like base-stations for radio networks, hospitals, financial institutions (e.g. payments), certain manufacturing, security, military, etc..

They play a significant role in maximising the availability of systems. UPS modules are often operated in parallel to the connected equipment in order to increase the availability and to provide extra security of the electrical supply. One or more additional modules are included to maintain capacity in the event of a failure. This is known as operating in 'redundant configuration'. Under these circumstances, each UPS shares the supply but operates at a reduced power level. Alternatively, some modules operate at high capacity and others are inactive until needed.

For non-IT environments, the UPS are the first-line emergency devices in a micro-grid. They provide power before other back-up devices (such as diesel generators or fuel cells), become operational.
Generally, UPS of Category 1-3 – i.e. up to 10kVA – are considered to be a server back-up. For base-stations 10-20 kVA is a typical UPS size. Large UPSs in the range of 50 and 200 kVA are used in larger data centers and server rooms, as well as providing back-up for non-IT applications.
The UPS market is dominated by a dozen manufacturers, including ABB, Schneider Electric/APC, Eaton Corporation, Emerson Network Power Inc., Mitsubishi Electric.[422] The hardware is often sold through service providers who also take care of the maintenance and monitoring of the UPS. Specialist data center designers are often the specifiers for the UPS. The data center owners pay the hardware (capex) and the operating costs (opex). In cloud cent, these costs (capex write-off and opex) are paid by server operators.

14.4 Technologies

There are two major developments in UPS technology. One is the transition for larger capacities such as those found in data centers and range from Valve Regulated Lead Acid VRLA ('Lead') batteries to Litium-ion ('Li-ion') batteries. The other development, is that electronics with batteries are getting smarter.

Batteries
Figure 75 below shows the trend of the annual data center Li-ion UPS penetration in North America and Europe over the period 2016-25, in GWh, according to Bloomberg New Energy Finance[423].

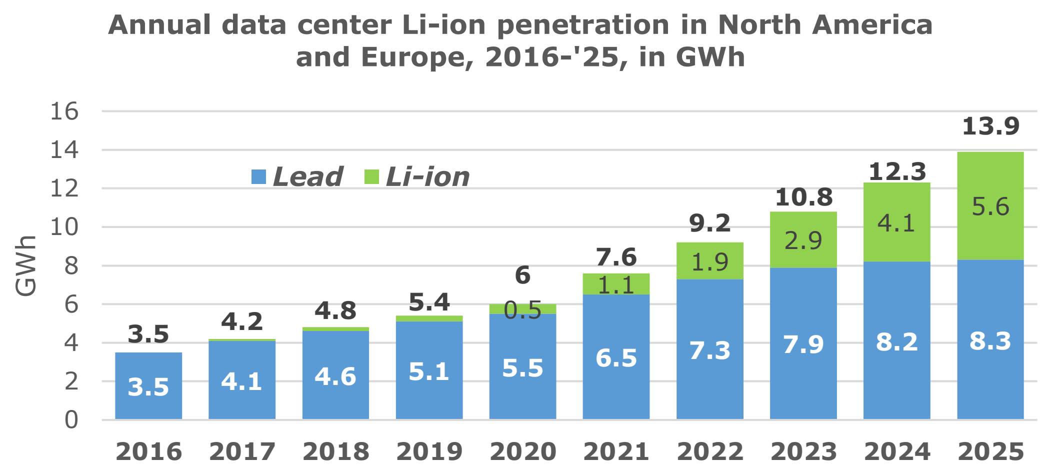


Figure 75. Data center Li-ion penetration in North America and Europe, 2016-'25, in GWh.[423]

[422] https://www.mordorintelligence.com/industry-reports/global-data-center-ups-market-industry
[423] https://www.datacenterknowledge.com/business/report-lithium-ion-gain-one-third-data-center-ups-market-2025

The advantages of Lithium-ion over Valve Regulated Lead Acid VRLA ('Lead') batteries according to Schneider Electric are[424]:

- about three times less weight for the same amount of energy
- up to ten times more discharge cycles depending on chemistry, technology, temperature, and depth of discharge
- about four times less self-discharge (i.e. slow discharge of a battery while not in use)
- four or more times faster charging, key in multiple outage scenarios

However, compared to VRLA, the li-ion batteries are about 1.2 to 2 times more capex for the same amount of energy due to higher manufacturing costs and cost of required battery management systems (see section 5 hereafter) as well as stricter transportation regulations.

In the longer term, the Li-ion technology itself offers of course still ample room for improvement.[425] [426]

Smarter controls

Especially in the context of 5G base stations, manufacturers suggest using the UPS battery capacity also for intelligent peak shaving, e.g. for grids with solar PV panels to use the battery capacity when supply is low (at night) and charge when supply is high (during daytime). [427]

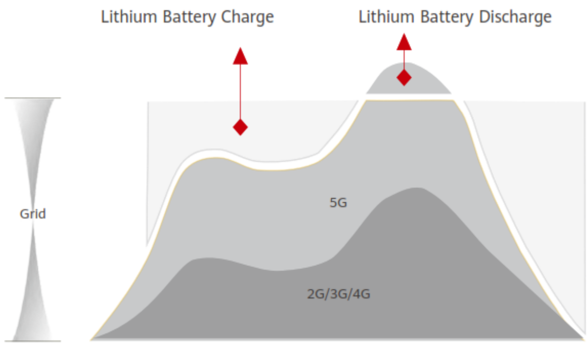


Figure 76. Intelligent peak shaving (source: Huawei[428])

[424] Whitepaper https://download.schneider-electric.com/files?p_Doc_Ref=SPD_VAVR-A5AJXY_EN
[425] https://www.renewableenergyworld.com/2019/04/03/why-lithiumion-technology-is-poised-to-dominate-the-energy-storage-future/#gref
[426] https://ec.europa.eu/energy/sites/ener/files/technology_analysis_-ongoing_projects_on_battery_based_energy_storage.pdf
[427] https://carrier.huawei.com/~/media/CNBGV2/download/products/network-energy/5G-Telecom-Energy-Target-Network-White-Paper.pdf
[428] Ibid.

14.5 Energy, Environment and Costs

14.5.1 Energy

As mentioned, the 2014 preparatory study concluded that an electricity saving of more than 10 TWh/year was possible by 2025. Table 112 gives an overview of the projected scenarios from that study with and without policy measures.

Table 112. Electricity scenarios for UPS, 2010-2030, without (BAU) and with policy measures

TWh electricity	Business-as-Usual (BAU)					with Ecodesign and Energy Label				
	2010	*2015*	*2020*	*2025*	*2030*	*2010*	*2015*	*2020*	*2025*	*2030*
UPS below 1.5 kVA	1.5	1.5	1.8	2.2	2.5	1.5	1.5	0.5	0.2	0.2
UPS 1.5 to 5 kVA	5.8	6.3	6.9	8.3	9.7	5.8	6.3	4.3	1.3	1.1
UPS 5 to 10 kVA	0.7	0.8	0.9	1.0	1.2	0.7	0.8	0.8	0.7	0.8
UPS 10 to 200 kVA	4.2	4.6	4.6	5.0	5.8	4.2	4.6	4.2	3.7	3.7
Total UPS	**12.3**	**13.2**	**14.2**	**16.4**	**19.2**	**12.3**	**13.2**	**9.8**	**6.0**	**5.8**
					Savings versus BAU	*-*	*-*	***4.4***	***10.5***	***13.4***

This assessment was based on a policy scenario with an Energy Label and ultimately an Ecodesign minimum efficiency requirement starting with a first tier in 2015-2016 and then a second tier in 2019 at an Ecodesign level equal to the best available technology (BAT) in 2013.

Note that these projections are all based on lead-acid (VRLA) batteries and did **not** take into account the technology switch from VRLA to Lithium-ion batteries. It also did not take into account improved 'smart grid' control options.

14.5.2 Environment

Greenhouse gases

The Greenhouse gas reduction from the 13.4 TWh electricity saving in 2030 is 4.6 Mt CO2 equivalent, using a conversion of 0.34 kg CO2 equivalent per kWh electricity.

Material efficiency

Figure 77 gives the material's composition of a small (<1.5kVA) UPS with a lead-acid battery from a Product Environmental Profile (PEP) by Schneider Electric. The representative product used for the analysis is the SUA1500I: 980 Watts / 1500 VA, Input 230V / Output 230V, Interface Port DB-9 RS-232, SmartSlot, USB, 27 kg. This model uses 2 batteries of 12V, 17 Ah.

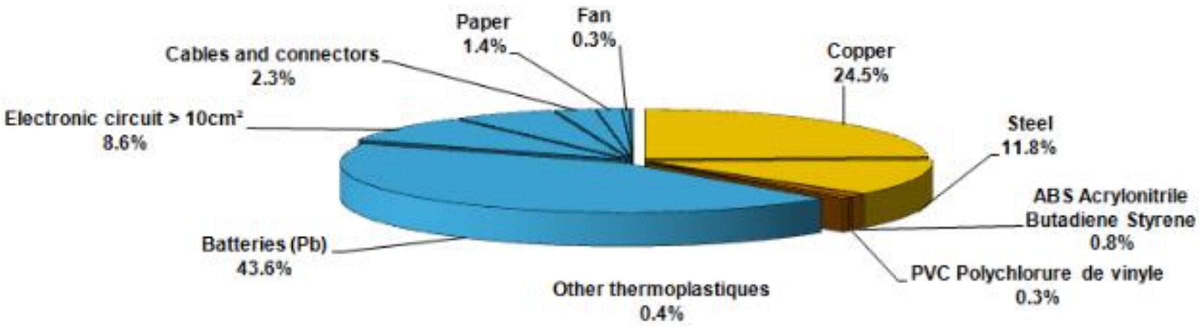


Figure 77. UPS <1.5 kVA Constituent Materials (source: Schneider[429])

The largest materials fraction, even for this small UPS, are lead-acid batteries (44%), followed by Copper (25%), steel (12%) and electronics (9%). For larger UPSs the batteries fraction will be larger (up to 70%).
Given that the Li-ion batteries are almost half as small, there is a considerable saving potential.

14.5.3 Monetary costs

Table 3 shows the annual expenditure in the EU with and without policy measures according to the 2014 preparatory study. The measures would render a saving of €2.6bn in 2030 with respect to the BAU scenario.

Table 113. Expenditure scenarios for UPS, 2010-2030, without (BAU) and with policy measures

Expenditure in bn euros/year	**Business-as-Usual (BAU)**					**with Ecodesign and Energy Label**				
	2010	***2015***	***2020***	***2025***	***2030***	***2010***	***2015***	***2020***	***2025***	***2030***
UPS below 1.5 kVA	0.4	0.5	0.6	0.7	0.8	0.4	0.5	0.3	0.3	0.4
UPS 1.5 to 5 kVA	1.4	1.6	1.8	2.3	2.7	1.4	1.6	1.4	1.0	1.1
UPS 5 to 10 kVA	0.3	0.3	0.3	0.4	0.5	0.3	0.3	0.3	0.3	0.4
UPS 10 to 200 kVA	1.7	1.9	2.0	2.3	2.8	1.7	1.9	1.9	2.1	2.4
Total UPS	**3.8**	**4.3**	**4.7**	**5.7**	**6.8**	**3.8**	**4.3**	**4.0**	**3.8**	**4.2**
					Savings versus BAU	*-*	*-*	***0.8***	***1.9***	***2.6***

These policy measures did not take into account the substitution of lead-acid by Li-ion batteries for example.

Additionally, Schneider Electric provides a 10-year total cost of ownership (TCO) analysis showing that the TCO of Li-ion is 39% less than that of VRLA despite the 82% capital cost premium. The Li-ion operating expenses are 76% lower , because of 70% lower maintenance costs, 48% lower space lease costs because the Li-ion footprint is half that of the VRLA, 50% lower energy costs because of fewer energy losses and lower cooling costs. In addition, there is no need for battery replacement over the 10 year period because the product life of Li-ion is 3 times longer (12 years versus 4 years) (See Table 114).

Table 114. Total Cost of Ownership (TCO) of 1 MW UPS over 10 years with VRLA and Li-ion batteries

Capital expenditure	**VRLA**	**Li-ion**
UPS material costs	$ 60 000	$ 120 000
Installation costs	$ 12 000	$ 12 000
Transportation costs	$ 549	$ 366
Subtotal CAPEX	**$ 72 549**	**$ 132 366**
Operating expenditure over 10 years	**VRLA**	**Li-ion**
UPS maintenance	$ 46 330	$ 13 899
Space lease costs	$ 54 597	$ 28 368
Energy costs	$ 26 989	$ 13 495
Battery refresh	$ 108 790	$ -
Subtotal OPEX	**$ 236 706**	**$ 55 762**

429 https://download.schneider-electric.com/files?p_enDocType=Product+environmental&p_File_Name=GWOG-8WPL63_R0_EN.pdf&p_Doc_Ref=SPD_GWOG-8WPL63_EN

CAPEX	$ 72 549	$ 132 366
OPEX	$ 236 706	$ 55 762
Total TCO	**$ 309 255**	**$ 188 128**

14.6 Saving Potential

From the data in the previous sections it can be concluded that there is a significant and growing UPS market with a new saving potential due to the technology not considered at the time of the 2014 preparatory study. In that sense, the electricity saving potential of 10 TWh electricity, the 5 Mt CO2 equivalent carbon saving and the €2.6 bn projected monetary saving by 2030 as set out in the 2014 study are probably even an under-estimation.

15 HOME AUDIO EQUIPMENT[430]

15.1 Scope, policy measures and test standards

15.1.1 Scope

The product-group of home audio equipment was part of the ICT-study for the European Commission that ran in parallel to the study on the Ecodesign and Energy Label Working Plan (EELWP). As such, in Task 1 of the ICT-study (Chapter 5, par. 5.7 and 5.8) the product group was identified as a possible candidate for the further investigation in the context of both the Task 3 of the ICT study and of the EELWP.

Home audio equipment

Home audio equipment is comprised of consumer electronic products with the specific function to play music or emit sound from physical content carriers to content broadcast or streamed over air, cable or a network, and have mains power connection.
Home audio products include loudspeakers and Hi-Fi equipment with or without the function to receive and play radio or content over the network. Also considered are separate sound systems for televisions (soundbars or dedicated speaker systems).
As an essential part of home audio equipment, loudspeakers are included, especially since they are increasingly becoming energy-using products[431].
Network connected audio products (NCAP) are not HiNA products, but have HiNA functionality and are covered by Ecodesign[432].

Excluded from scope in general is audio equipment that typically operate without mains power, e.g. headsets, portable speakers and portable audio players.

Below are descriptions of home audio products.

Product type	NCAP*
Loudspeakers or speakers are cabinets with sound drivers with the sole function of transmitting soundwaves into the air. They do not have network connectivity, and receive electric analog audio signals. Loudspeakers that do not require a dedicated power supply, but are powered instead by the electric analog audio signal itself are called passive loudspeakers. Active loudspeakers require their own dedicated power supply, and are included in this definition.	No
Radios are devices for the purpose of receiving public or commercial radio broadcasting stations through radio frequencies. They are mains powered, but also include models that can also run on battery. Clock radios are also included.	No
Players/recorders refer to devices that play or record audio on their respective media (e.g. audio cassette, CD, DAT, MD, DCC, SACD, vinyl records, etc.), and are not network-connected. They may also have the ability to play a combination of media, e.g. a "CD/cassette player with USB".	No

430 Contribution by William Li (VHK)

431 Self-powered "active" loudspeakers, active subwoofers and network connected loudspeakers require mains power to operate.

432 COMMISSION REGULATION (EC) No 1275/2008 of 17 December 2008 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for standby and off mode electric power consumption of electrical and electronic household and office equipment OJ, L339, 18.12.2008, p. 45 (audio equipment is included, as stated in Annex I)

Amplifiers are devices that are fed audio signals and increase the power of these signals for multiple loudspeakers. Depending on the amplifier design, audio signal input may come from various sources and may be in analog or digital format. The purpose of the amplifier is to process and control the audio signal(s) and the sound power level coming out of the loudspeakers. If the amplifier has network capabilities to connect to a home network for playing music files or stream audio, it is an NCAP.	Possible
Receivers are amplifiers with built-in radio tuners. Most receivers can also relay video signals, and are also called AV receivers (AV = Audio Video). If the receiver has network capabilities to connect to a home network for playing music files or stream audio, it is an NCAP.	Possible
Tuners are radios in the form of rack component decks, that rely on an amplifier with loudspeakers for the output of sound.	No
Microsets are relatively small sets of a device with integrated radio and media players, and loudspeakers that may be integrated as well, detachable or separate. They may also play audio from USB media. If they can be network-connected to stream music, such microsets are classified as an NCAP. In the market microsets are also referred to as mini sets, micro audio sets, micro systems etc.	Possible
Wireless speakers are loudspeakers that are connected to a home network (usually through Wi-Fi) to play streaming audio from network sources on the same home network. Wireless speakers require their own power supply for their network functionality. Wireless BT speakers for the home (mains connected) are included. Some wireless speakers have wireless mesh network capabilities. They can often be controlled through an app on a smartphone. Portable wireless speakers with (rechargeable) batteries and only offering Bluetooth network connection are excluded from scope and definition.	Possible
Smart speakers are a type of wireless speaker that offers voice command control through a voice assistant, which is activated using "hot words"[433]. Smart speakers support Ethernet and (multiple) wireless networks standards, mostly Wi-Fi and Bluetooth, and may have wireless mesh network capabilities. Smart speakers require their own power supply for their HiNA functionality. The usage of smart speakers can be extended beyond audio playback, such as to control home automation devices. Some smart speakers may feature some control buttons, status lights or a display to show a visual response or status. The first smart speaker was introduced in 2014. Smart displays are smart speakers with a large touchscreen[434] [435] [436], and are considered as a single product type. Smart displays can be used to play streaming audio but also for video or other visual oriented information.	Yes
Soundbars are loudspeakers designed to play audio from TVs, with a wide and low form factor to fit underneath or in front of TVs. If the soundbar has network capabilities to connect to a home network for playing music files or stream audio or to connect to a wireless mesh, it is an NCAP. Soundbars may also be "smart", in which case they have all the capabilities of smart speakers.	Possible
Network audio players are devices used to play streaming audio mostly as their main or sole function. They require connection to a home network to access audio files or audio streams from network sources. Their form factor ranges from Hi-Fi component decks to microsets. They can be standalone players, or multi-room capable. Network audio players are controlled using an interface on the device itself, or using an app on a smartphone or tablet connected to the same home network.	Yes

* 'Possible' means depending on whether the product has network capabilities or not.

[433] https://en.wikipedia.org/wiki/Smart_speaker

[434] *Brown, Rich. "Echo Show, Nest Hub, Facebook Portal and more: How to pick the best smart display in 2019". CNET. Retrieved 2019-06-19.*

[435] *Faulkner, Cameron (9 October 2018). "How Google's new Home Hub compares to the Echo Show and Facebook Portal". The Verge. Retrieved 2019-06-19.*

[436] *Lacoma, Tyler (October 26, 2018). "What is a smart display?". Digital Trends.*

15.1.2 Policy measures and test standards

As listed in Annex I of Commission Regulation (EC) No 1275/2008, home audio equipment is covered under 'Consumer equipment'. 1275/2008 is amended in Regulation (EU) No 801/2013 to include networked connected audio products in the scope of the Ecodesign regulations on (networked) standby.

The current standby regulations give 0.5/1/1W power limits for off-mode/standby/standby + status display. For HiNA networked standby the limit is 8W and for other networked standbys it is 2W. Draft proposals of the Commission for a revision aim of 0.3W in off-mode and 2W in other-than-HiNA limits.

IEC 62087 provides test methods for audio equipment in parts 1, 2 and 5. EN IEC 62087 was adopted by CLC/TC 100X 'Audio, video and multimedia systems and equipment and related sub-systems'[437], whose Secretariat is held by CEB-BEC, the Belgian Electrotechnical Committee.

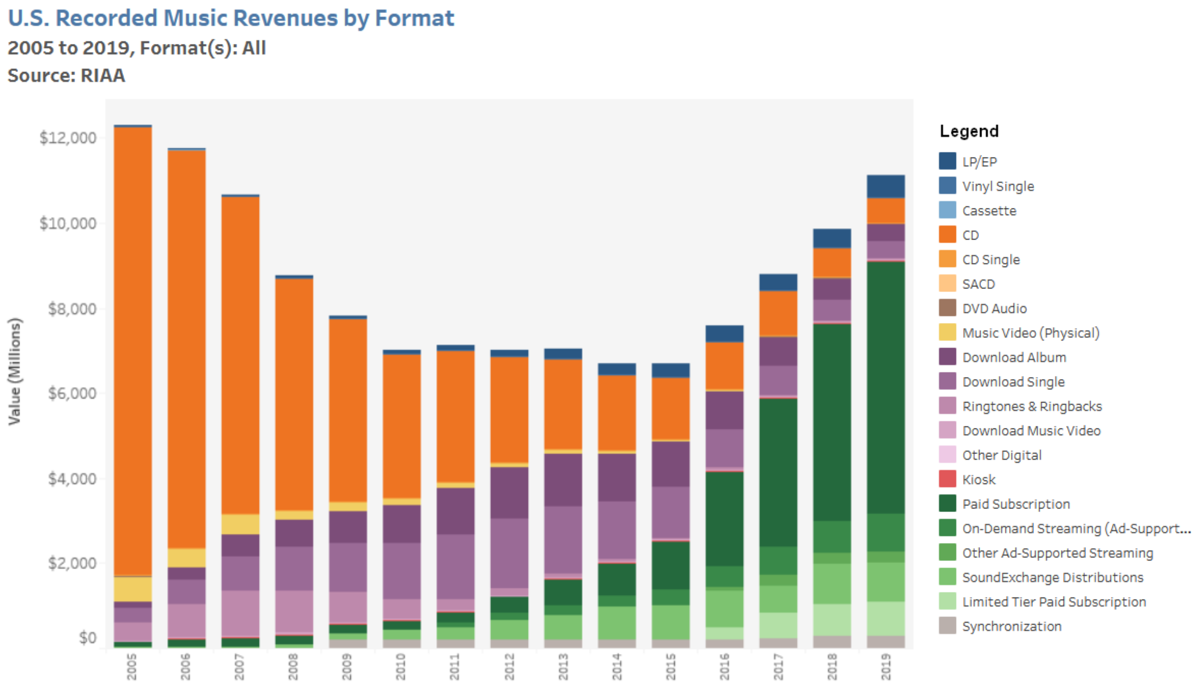
15.2 Market

The worldwide home audio hardware market grew by 20% in 2018, with a further 19% growth projected in 2019[438]. The home audio market is growing with a CAGR of 14.6% during 2020-2027[439].
Estimates of the stock of individual audio products is given in combination with the energy use in the next paragraph.

15.2.1 Shift to streaming media

Over the past few years a clear shift towards digital media can be observed is seen in the revenue sources from the RIAA[440]. Already by 2012, downloaded music (singles and albums) has overtaken CD sales and (online) music streaming has become the main mode by which consumers listen to music. This also means that there is a sales shift from audio products that play physical media to NCAPs that play digital media[441]. GfK reports that devices that stream audio contents via Bluetooth or Wi-Fi are the standard today: in 2018 already, 71 percent of the global sales value originated from such products[442].

[437] https://www.cenelec.eu/dyn/www/f?p=104:7:176303021958201::::FSP_ORG_ID:1258737
[438] Worldwide Home Audio Market Report, Futuresource Consulting, 2018
[439] https://www.researchandmarkets.com/research/p88ftf/global_home_audio
[440] https://www.riaa.com/u-s-sales-database/
[441] https://www.euromonitor.com/home-audio-and-cinema
[442] https://www.gfk.com/press/audio-devices-become-smarter-and-sound-better



(Source: Recording Industry Association of America RIAA, 2019 [443])

Figure 78. U.S. Recorded Music Revenues by Format 2005-2019

15.2.2 Loudspeakers

Futuresource Consulting[444] reports that the sales of passive loudspeakers are in decline with worldwide sales of 50 million in 2017 falling to 45 million units in 2018. Statista also shows a decline in revenues from USD 2.55 billion in 2015 to USD 2.05 billion in 2017. These figures indicate a global average price of USD 45 per unit.

The decline does not mean that consumers demand fewer loudspeakers. Instead, the decline of these loudspeakers is made up by the introduction of wireless and smart speakers, and is basically a shift within types of speakers.

15.2.3 Wireless speakers

Wireless speakers have a significant global revenue CAGR of 21% for the period 2015-2017. The global sales amount to USD 4.45 billion in 2015 to USD 6.5 billion in 2017.

A web survey on wireless speakers available in the Netherlands gave an average unit price of 275 euro[445].

Assuming Europe has a 20% market share and a product life of 8-10 years, these figures result in a sales on 5.86 million units and a stock of 24.8 million units in 2020.

15.2.4 Soundbars

According to GfK more than 11 million soundbars were sold globally in 2014 (64% more than in 2013). For 2015, GfK estimates that more than 14 million soundbars were sold.

[443] https://www.riaa.com/u-s-sales-database/ (permission to copy is granted as long as due credit is given)

[444] https://futuresource-consulting.com/press-release/consumer-electronics-press/worldwide-loudspeaker-market-under-pressure-but-with-pockets-of-growth/

[445] Tweakers.net on 23 June 2020: 77 mono wireless speakers without voice assistants and no (rechargeable) battery.

Statista reports a global sales revenue of soundbars of USD 2.3 billion or EUR 1.9 billion (rate of 1 January 2015), resulting in an average unit price of 135 euros. Statista also reports a CAGR of 10.4% for the period 2015-2017.
Based on these values, sales in EU27 is estimated to be 4.3 million units in 2020. With an 8-10 year lifespan the estimated installed base is about 28 million soundbars in 2020. With 194 million EU27 households[446], this means 1 in every 7 households has a soundbar.
The average consumer price of network connected soundbars on the Dutch market in 2018-2020 period is €550. For standard soundbars it is about €360.

15.2.5 Smart speakers

In 2018, 34% of smart speaker owners in the USA had multiple smart speakers (2 to 10+), rising to over 40% ownership in 2019. The number of households with smart speakers has risen from an average of 1.8 units in 2018 to an average of 2 units in 2019 [447]. We assume 1.8 units to be applicable in Europe in 2020.
European sales in 2019 are estimated[448] to be 9 million units for smart speakers with an installed base of 20 million units in 2020. An average of 1.8 units per household means 11 million households having smart speakers in EU27.
The Statista figures give a CAGR between 2020 to 2025 of about 26.4%. Allied Market Research[449] projects a global CAGR for smart speakers of 23.4% between 2018 and 2025. Following this more conservative CAGR, 32 million units will be sold in 2025 in Europe. With a product life of 5 years, this means an installed base in 2025 of 118 million units in Europe. Assuming an average of 2 units per household with a smart speaker, this results in 59 million EU27 households.
Smart displays have an estimated global sales rate of 16.9 million units[450] in 2019 and 18 million units in 2020 and are expected to reach 24 million units in 2025 worldwide. Estimating the EU market share to be similar to smart speakers (20%), this results in 3.6 million units in 2020 and 4.8 million units in 2025. With a product life of 5 years, the EU stock is 8.7 million units in 2020 and 26 million in 2025.
The total stocks of these devices in 2020 is 28.7 million units and 144 million in 2025.

Besides being used for audio entertainment and home automation, Deloitte Global foresees visually impaired people (over 250 million people in the world), and illiterate people (about 700 million adults in the world) to be potential consumer growth markets. These use cases show utility-driven market potential for smart speakers.

15.2.6 Receivers, amplifiers, players and microsets

Market figures for separate product types were not found. In the period from 2015-2017 the global sales of receivers, HTiB (home theatre in a box) and Hi-Fi systems combined are experiencing a decline in CAGR revenue of -12.4%, from USD 3.65 billion in 2015 to USD 2.8 billion in 2017[451]. The term "Hi-Fi systems" usually refers to audio systems

[446] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=proj_19np&lang=en
[447] Voicebot Smart Speaker Consumer Adoption Report, January 2019
[448] https://www.statista.com/outlook/15010500/102/speakers/europe
[449] https://www.alliedmarketresearch.com/smart-speaker-market
[450] https://www.strategyanalytics.com/access-services/devices/connected-home/smart-speakers-and-screens/market-data/report-detail/global-smart-display-forecast-by-region-2014-2023; https://advanced-television.com/2019/01/08/smart-display-sales-12-of-smart-speaker-market-in-2019/
[451] https://www.statista.com/statistics/801522/global-home-audio-market-size-by-category/

consisting of separate components, but also includes micro systems that have separate or integrated loudspeakers.
Tuner and tape audio separates can be considered to be practically non-existent in the market and are not taken into account, as many manufacturers have discontinued such products in the past 10 years. CD-players and the relatively new network audio players mostly remain as Hi-Fi audio components that require an amplifier.
Following the saturation figures of the LBNL study[452] we arrive at stock values for 2020 of 90 million Hi-Fi systems (including micro sets) and 141 million receivers and amplifiers.

A price web survey[453] on receivers and amplifiers available in the Netherlands considering only the first half of most watched models, shows that the average price is 675 euros. Likewise the HTiB has an average price of 527 euros, Hi-Fi systems 216 euros, and Hi-Fi component separates (CD-players) 363 euros.

15.2.7 Radios

Following the European Electronic Communications Code (Directive 2018/1972) in 2018, the EU is currently in a process of transitioning towards public access to digital radio broadcasting (DAB, DAB+). E.g., Italy and France have made DAB+ reception mandatory for all radios sold from 2020[454]. This transition ultimately means that in certain countries the stock of analog radios will no longer function, and (a certain percentage of)) owners will buy a digital replacement.
We use the saturation of clock- and net-connected radios in the LBNL study for all radios in the EU, at 126%, meaning 84% of the households having at least 1 radio, and 1.5 radios per households. Assuming this has not significantly changed in 2020, this gives a stock of 244 million units in 2020. The listening time is extended from 0.36 hr/day (clock radios) to 2 hr/day (all radios).

A web survey[455] on FM clock radios gave an average unit price of 32 euros, while DAB radios cost twice as much at an average of 72 euros.

15.3 Usage

Audio equipment for home entertainment, in the form of radios, started 100 years ago. In the 1960s home audio provided consumers with the possibility to buy and listen to media of their own choice in the form of vinyl records and tapes. Not long after, consumers were also able to record audio on tape and audio cassettes.
In the 1970s, Hi-Fi stereo component systems with separate loudspeakers became popular, integrated or stacked as 'towers' of component decks. CD-players, being the first medium for digital music were introduced in the 1980s. Many physical recordable digital alternatives for the analog compact audio cassette followed (e.g. DAT, MD), but all ultimately disappeared due to consumer preference for recordable CDs and digital music files (mp3) in the mid-1990s.

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[452] Karen B. Rosen and Alan K. Meier, Energy Use of Home Audio Products in the U.S., LBNL, December 1999
[453] Tweakers.net on 24 June 2020: 364 receivers and amplifiers, 20 HTiB, 233 Hi-Fi systems, 34 Hi-Fi CD-player components.
[454] https://www.worlddab.org/public_document/file/1283/WorldDAB_Infographic_Q2_2019_A4_with_sources_FINAL_ONLINE_ENGLISH_23_03_2020.pdf
[455] Tweakers.net, Fnac.fr, Mediamarkt.de on 25 June 2020: 307 FM clock radios and 56 DAB clock radios.

In the 1990s, sound systems specifically for TVs entered the market, e.g. offering ‘surround sound’ with multiple speakers in the room and in 1998 the first soundbar for consumers was introduced.

Nowadays, consumption of digital audio files such as mp3 files has evolved into streaming audio, requiring (wireless) networks and internet connected devices (computers, smartphones, etc.) or network connected audio products (NCAP). Due to the high availability and popularity of streaming services, home audio equipment of all types are including network capabilities. Streaming-only home audio products are also available on the market for some years now. Since 2018, over 70% of all home audio revenues are from devices that can wirelessly stream audio.
Audio cassette players have almost disappeared, but still do exist and are now considered a niche market. Vinyl record players have started a comeback and vinyl records are outselling CDs since 2019, although still dwarfed by digital/streaming music revenues.

Wireless connected audio products are on the rise, as they provide flexibility to consumers in terms of room placement, connections and an easy increase in the number of units, while all can be controlled wirelessly using smartphones, tablets or computers. This flexibility enables multi-room audio solutions, where wireless connected speakers can be added and placed in every room and audio can be played simultaneously, or each speaker can play from a different audio source.

Radios and clock radios are also transitioning to digital radio signals, either from a broadcast or from the internet. These products are starting to offer wireless music streaming as well.

For televisions and home theatre use, developments in soundbars have made them a serious and affordable alternative to home theatre systems with separate loudspeakers, with less cable clutter and commanding much less space. Soundbars are also offered with a wireless connected subwoofer, making room placement more flexible. Some can be connected to separate wireless speakers for a more immersive surround sound while watching television, or as part of a multi-room audio system.

Furthering the wireless integration of home audio products are smart speakers, that were launched in 2016. Consumers can use their voice to control their audio entertainment, to ask information, or to control other equipment (e.g. for home automation). Soundbars are now also being equipped with smart technology for the same function as smart speakers.

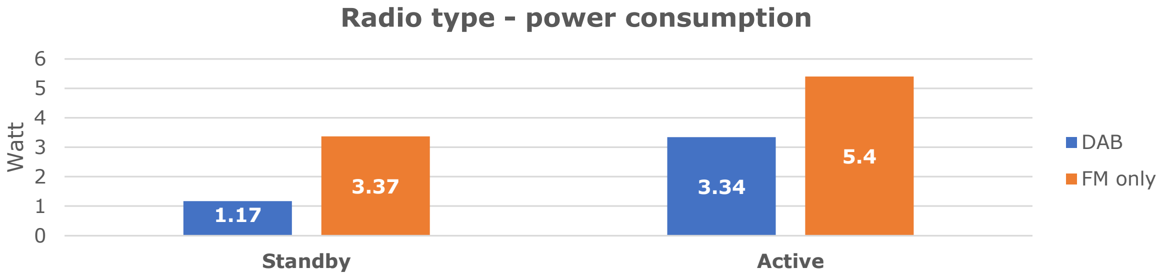
15.4 Technologies

15.4.1 Radio

Currently most radios receive the analog FM radio signal. The transition to digital radio is, among other reasons, necessary for a more efficient use of the available radio spectrum. Fewer frequencies are required for the same number of radio broadcast channels. Digital radio also offers a lower power consumption. Intertek[456] performed a study on the power

[456] Intertek Technical Report 101092233MKS-001b, 2013

consumption of home audio equipment that feature digital radio. While the results vary according to product type, it shows that for 29 table top radios, DAB can use up to 39% less power than FM.



(source Intertek, 2013)

Figure 79. Radio standby and active power consumption per type

15.4.2 Wireless home networks

As more devices are outfitted with wireless networking capabilities (e.g. for smart device operations), their power consumption can increase due to their intended use on the network. Products with HiNA functionality especially, that keep their (mesh) network alive to instantly respond to the user will have higher power consumption during their networked standby.

A sampling of wireless connected audio products using Wi-Fi shows a relatively large spread of networked standby power consumption, while all of them offer the same functionality.

Bluetooth is also available as a wireless connection technology and consumes much less energy than Wi-Fi based networks. Only Bluetooth Basic Rate/Enhanced Data Rate (BR/EDR), is designed for continuous wireless connections and optimised for audio streaming. As an adhoc paired connection, it is not being used for HiNA-functionality products, and the standby power consumption of Bluetooth products is similar to products that have no network capability (<1 W). However, Bluetooth is being used for wireless connections between some soundbars and their subwoofers with the requirement that they must be within a proximity of 10 metres. The soundbar uses a Bluetooth connection to stream the sound signal to the subwoofer.
There exists a Bluetooth Mesh standard, but this is designed for short-burst wireless connections only. The Bluetooth mesh networking specification is only available for Bluetooth LE and does not support audio streaming[457].

15.4.3 Smart speakers

Smart speakers have an average power consumption of 2.2 W in standby and 3.9 W in use (e.g. playing music at moderate volume). Since smart speakers are always "listening", leading manufacturers (e.g. Amazon, Google) have started implementing very energy

[457] https://www.bluetooth.com/learn-about-bluetooth/bluetooth-technology/topology-options/le-mesh/mesh-faq/

efficient microphones that use MEMS technology over about the past two years. These piezoelectric MEMS microphones in themselves use virtually no energy until activated [458].
The use of smart speakers to control other smart devices can, however, have a significant effect on the standby power consumption of other network-connected products, as reported by NRDC[459]. Their study also shows that network standby consumption of connected products (smart TVs) can be drastically lowered, and network-standby consumption drops from around 20 W to below 1 W and these have been demonstrated just by software updates alone.

15.4.4 Sound amplification

Sound amplification electronics are used in stereo amplifiers, receivers, micro sets, and all speaker devices that require mains power to function. In consumer audio these amplifier electronics are described in Class A, A/B, D, G, and H (listed in increasing energy efficiencies). Class D amplifiers represent the top of amplifier efficiency, with rates in excess of 90% being achieved in the real world[460]. Also, Class D designs are lightweight, which offers other advantages.
Currently, Class A/B amplifiers are the most prevalent in the market, because they perform very well, are relatively cheap, and their efficiency is perfectly adequate for low powered applications.

Table 115. Amplifier efficiency by type

Amplifier Class	Typical Efficiency
A	~15-35%
B	~70%
A/B	~50-70%
G & H	~50-70%
D	>90%

(source: Audioholics, 2018)

15.4.5 Sound production

The drivers of loudspeakers convert only about 1% of the electrical energy sent by an amplifier to acoustic energy[461]. Designs with better driver sensitivity require less power to produce a certain sound level, leading to lower heat generation and a longer driver life. E.g., certain horn-loaded speakers can have a sensitivity of 110 dB. This is a hundred times the output of a loudspeaker rated at 90 dB sensitivity, which would be excellent for a traditional radiating cone type.

[458] https://www.smart2zero.com/news/always-mems-mic-uses-sound-energy-wake-system
[459] The energy impacts of smart speakers and video streaming devices, Natural Resources Defense Council, 2019 https://www.nrdc.org/sites/default/files/gadget_report_r_19-07-b_13_locked.pdf
[460] https://www.audioholics.com/audio-amplifier/amplifier-classes
[461] https://www.klipsch.com/education/speaker-sensitivity

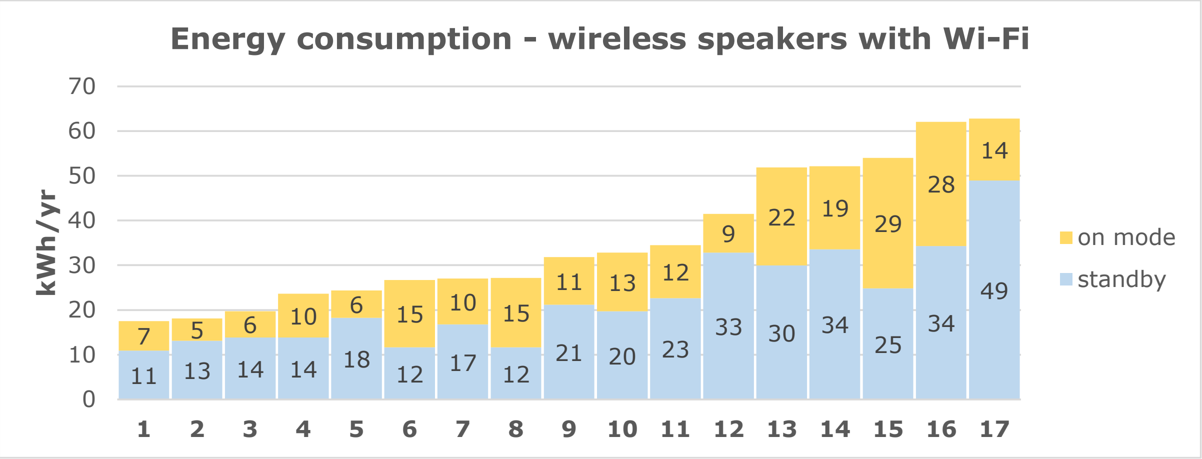
15.5 Energy

European investigations of the on-mode energy consumption of audio equipment are rare. They are not specifically investigated in the DG GROW Lot3 study on sound and imaging equipment. The most comprehensive study carried out in the US is from 1999 by Rosen and Meier of LBNL[462].

For the EU27 we estimate fewer hours of television usage (4h/day instead of 6.5 in the US) and the outcome per household is multiplied by EU27 (i.e. excl. UK) total households.

15.5.1 Wireless speakers

Wireless speakers are estimated to be used for 4 hr/day. Test measurements from the Dutch consumer organisation Consumentenbond show a range of 18 to 62 kWh/year in calculated energy consumption. Note these 17 models are WiFi (and Bluetooth) enabled and have an average standby power of 3W and active mode power (50% volume) of 9.2W. The Consumentenbond also tested 6 models that are only Bluetooth enabled. For these models the power is 0.4 and 3.7W in standby and active mode respectively.



(source VHK based on Consumentenbond tests of 17 models[463])

Figure 80. Annual energy consumption wireless speakers

15.5.2 Soundbars

Soundbars are used in conjunction with TVs to enhance the TV audio, but also for listening to music only. TV use in the EU is estimated at 4 hr/day and music listening to 2 hr/day, resulting in a daily use of 6 hours. The average standby power was 3 W (range 1.2-10.5 W) and 9.25 W for on-mode power (range 9-24W).

Twenty-eight tested models show a difference in energy consumption ranging from 32 to 104 kWh/yr.

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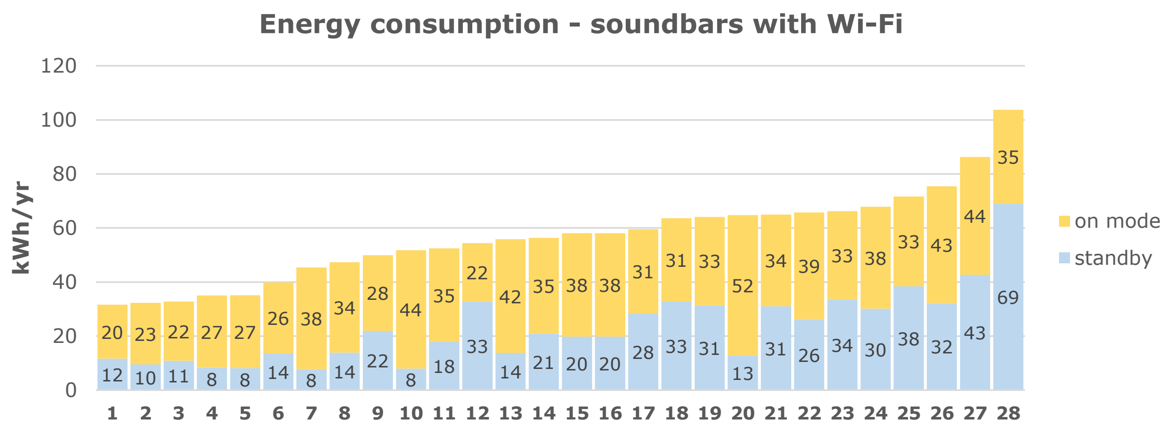
[462] Karen B. Rosen and Alan K. Meier, Energy Use of Home Audio Products in the U.S., LBNL, December 1999

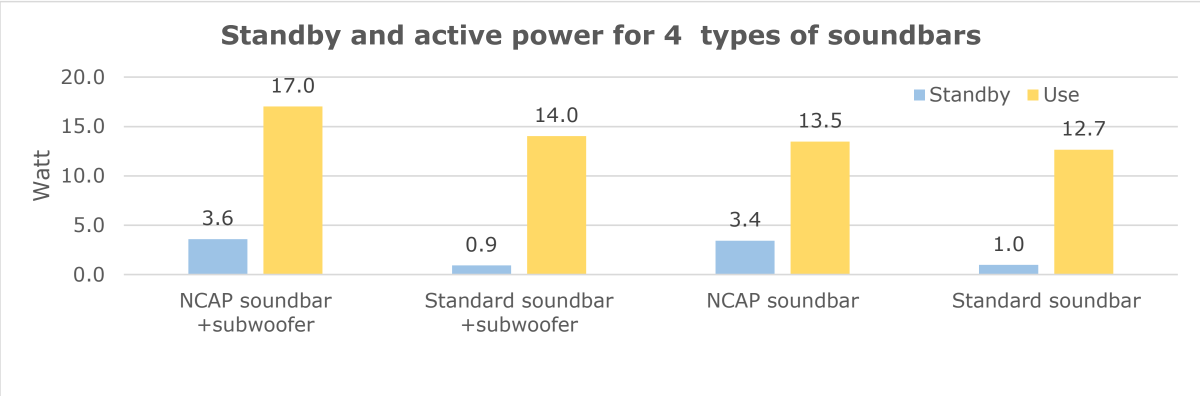
[463] https://www.consumentenbond.nl/wifi-speakers/producten



(source VHK based on Consumentenbond test 2020 of 28 models [464])

Figure 81. Annual energy consumption soundbars

Figure 82 below shows average power in active and standby mode for 4 soundbar types from a database of 64 recently tested models by the Dutch consumer organisation Consumentenbond. Being network connected (NCAP) makes a difference of 2.4-2.5 W in standby mode overall. For the active mode there is a 3W difference in active mode for the types with subwoofer and only 0.8W difference for standard soundbars. Note that among the soundbars without subwoofers there are many upmarket brands (Bose, Sonos, etc.).



(source VHK based on Consumentenbond tests 2018-2020, covering 64 models[465] [466] [467])

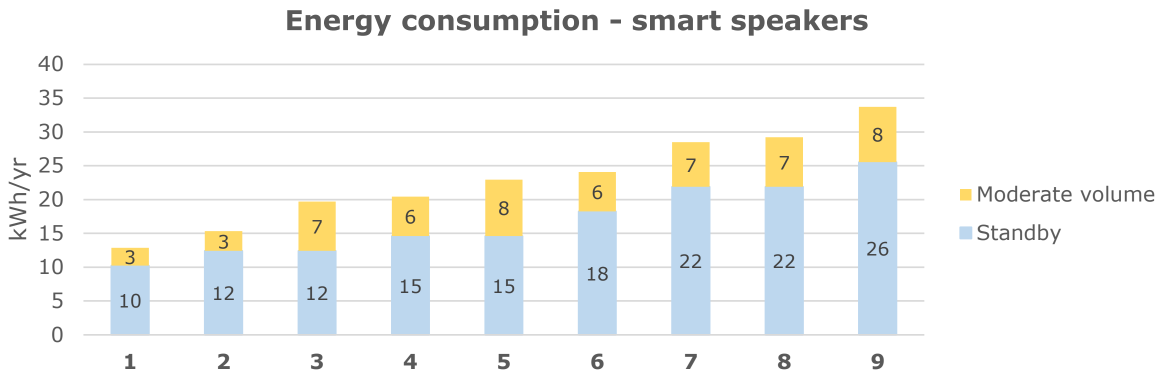
Figure 82. Power consumption soundbars in standby and active mode, by type

15.5.3 Smart speakers

Energy consumption of smart speakers, including smart displays, are estimated with a 4 hr/day active use. The power consumption difference between smart speakers and smart displays is very small. The average standby power is 2.3 W and 4.2 W for on-mode with moderate audio volume playing.

Below are consumptions of 9 market leading models (Amazon, Google, Apple) available in Europe.

[464] Stefan Vrijdag, Consumentengids, January 2020, p.52
[465] Stefan Vrijdag, Consumentengids, January 2019, p.50
[466] Stefan Vrijdag, Consumentengids, January 2018, p.26
[467] Stefan Vrijdag, Consumentengids, January 2015, p.60



(source VHK based on manufacturer information[468 469 470])

Figure 83. Annual energy consumption smart speakers

15.5.4 Receivers and amplifiers

We adhere to the power consumption values found in the LBNL study for receivers and amplifiers, i.e. an average of 1.45 W for standby, and 31.5 W for on-mode. A small sample review of current offerings on the market does not show a considerable change in these values.

Receivers can be used for both music listening and/or TV watching, while amplifiers are mostly used for music only. Active usage for both is estimated at an average of 2 hr/day.

15.5.5 Microsets and players

The available data of the Dutch NGO HIER[471] from 2016 has been extended with 24 microsets from 2020 by VHK. This gives an average standby power of 0.35 W and an on-mode power of 38 W.

The standby power consumption of 1.8 W for CD-players from the LBNL study seem high compared to current offerings. A sample[472] of 7 current CD-players shows a standby power of 0.32 W and on-mode power of 14.8 W.

For network audio players we consider a networked standby power of 1.9 W and on-mode power of 20 W. Averaging these three product types results in a standby power of 0.86 W and an on-mode power of 24 W.

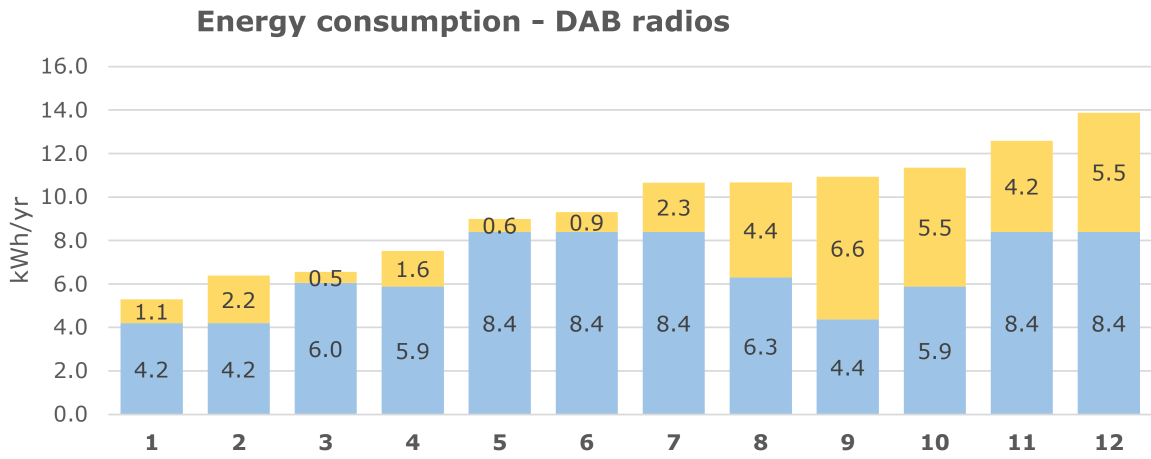
As these products are used purely for music listening, the average usage time is estimated at 2 h/day.

15.5.6 Radios

In 2017, according to the Eurobarometer, 75% of Europeans listened to the radio at least once a week, of which 50% listen everyday. Specific activity studies in the Netherlands and Belgium indicate average inhabitants listening to the radio 2 hours a day, for a large part combined with other activities in the home.

Adjusting the 2013 Intertek study on 29 table-top radios (see Figure 77) with an additional sample of 12 current digital audio broadcast DAB radios, based on manufacturer information, gives an average standby power of 1.8 W and 4.8 W for on-mode power.

[468] https://www.androidpit.com/smart-home-consumption-costs#home
[469] https://bigtechquestion.com/2019/07/22/smarthome/amazonalexa/echo-show-5-electricity/
[470] https://www.the-ambient.com/features/power-smart-home-tech-yearly-cost-374
[471] HIER Klimaatbureau, Een vernieuwde analyse van huishoudelijke apparaten, 2016
[472] VHK, 2020



(source VHK based on manufacturer information, 2020)

Figure 84. Annual energy consumption of digital audio broadcast (DAB) enabled

15.5.7 EU27 Energy consumption in 2020

In the table below, the abovementioned values are used to calculate the energy consumption for EU27 in 2020.

Table 116. EU27 energy consumption in 2020

	on-mode	standby	installed units	standby		on-mode		total
	h/d	h/d	mln.	W	TWh/yr	W	TWh/yr	TWh/yr
Smart speakers (5)	4	20	28.7	2.3	0.48	4.2	0.18	0.66
Wireless speakers (4)	4	20	24.8	3	0.54	9.25	0.33	0.88
Soundbars (6)	6	18	28	2.05	0.38	14.29	0.88	1.25
Microsets / players (2)(4)	2	22	90	0.86	0.62	24	1.58	2.20
Radios	2	22	244	1.8	3.53	4.8	0.85	4.38
Receivers / amplifiers (3)	2	22	141	1.45	1.64	31.5	3.24	4.88
Totals					**7.19**		**7.06**	**14.25**

(1) power values from study Fraunhofer IZM, 2007

(2) standby power from study Fraunhofer IZM, 2007; saturation from LBNL study, equal to 'compact stereo sets'

(3) usage time estimated to be half of tv watching (4 h/d)

(4) usage time estimated to be equal to listening on receivers/amplifiers

(5) usage time estimated

(6) daily usage time estimated to be equal to 4 hr tv watching + 2 hr listening to music

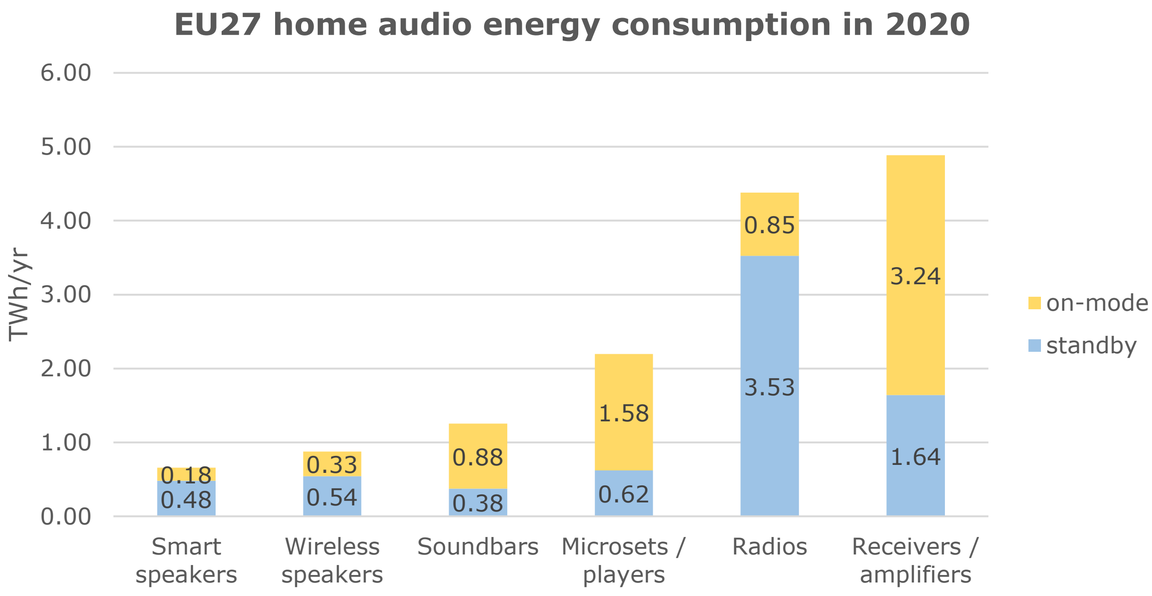


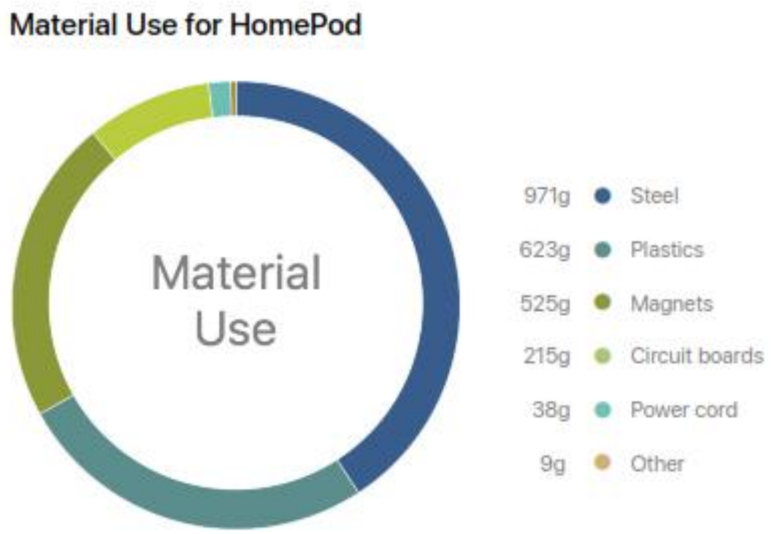
Figure 85. EU27 Energy consumption home audio products 2020

15.5.8 Material efficiency and environment

Figure 13 shows the materials composition of the Apple HomePod, which was one of the very few Bills-of-Materials the study team could retrieve in the given time. Nonetheless, as this product contains all components of a typical audio product (recording, processing, speakers) it is helpful in showing that, apart from the metals and plastics for the frame and apart from the circuit boards covered by the WEEE directive, the magnets are an important part of the typical audio product.

As far as magnets go, there are two types: The standard ferrite type that is the default for all speakers where space is not an issue and the Neodymium type, 20 times stronger but more expensive, that is used where there is not much space, such as headphones and small speakers.

Neodymium is a Rare Earth Metal and as such it also features on the Commission's Critical Materials list. If audio products are selected for the Working Plan, this seems to be a suitable topic for investigation.



(source: Apple HomePod, Environmental Report [473])

Figure 86. Material use in the Apple HomePod

15.6 Saving potential

The past few decades have seen drastic changes in home audio equipment: from analogue to digital, from physical media to streaming, etc. As a possible sector for energy- or material efficiency it has never been addressed by policy makers, the reason being that comprehensive energy and environmental data on audio equipment is scarce. The greater part of this chapter is therefore based on generic market studies, energy data from consumer tests, manufacturer specifications and some legacy US material. In other words, there is considerable uncertainty regarding the accuracy of the data.

Having said that, there are strong indications that energy and material efficiency has increased over the past two decades. The 14 TWh electricity consumption that are now assessed is less than half the energy use estimated for EU audio equipment in the year 2000 (31 TWh/yr).

The sector is economically significant and, apart from the greenhouse gas emissions, there are also new environmental impact aspects like magnets that could be interesting. The tests by consumer associations show that there is a wide disparity in energy consumption. This might lead to 20-30% savings in on-mode (2-3TWh/yr) and if the standby energy-consumption is regulated on a product-specific basis then those standby power limits might be more ambitious.

[473] https://www.apple.com/environment/pdf/products/homepod/HomePod_PER_feb2018.pdf

16 ICT CONSUMER BEHAVIOUR[474]

16.1 Introduction

16.1.1 Scope

For Task 3 of the ICT-study, the Commission, at the request of the JRC IPTS, was asked to take a closer look at consumer behaviour. As was established in Task 1, video viewing has by far the most data-intensive content for ICT, taking up over 80% of the bandwidth and,consequently, most of the energy use for data centers, telecommunication and end-use equipment.

As an illustration, Cisco gives an overview of the near and longer term future bandwidth requirements for the various video technologies (see Figure 87).

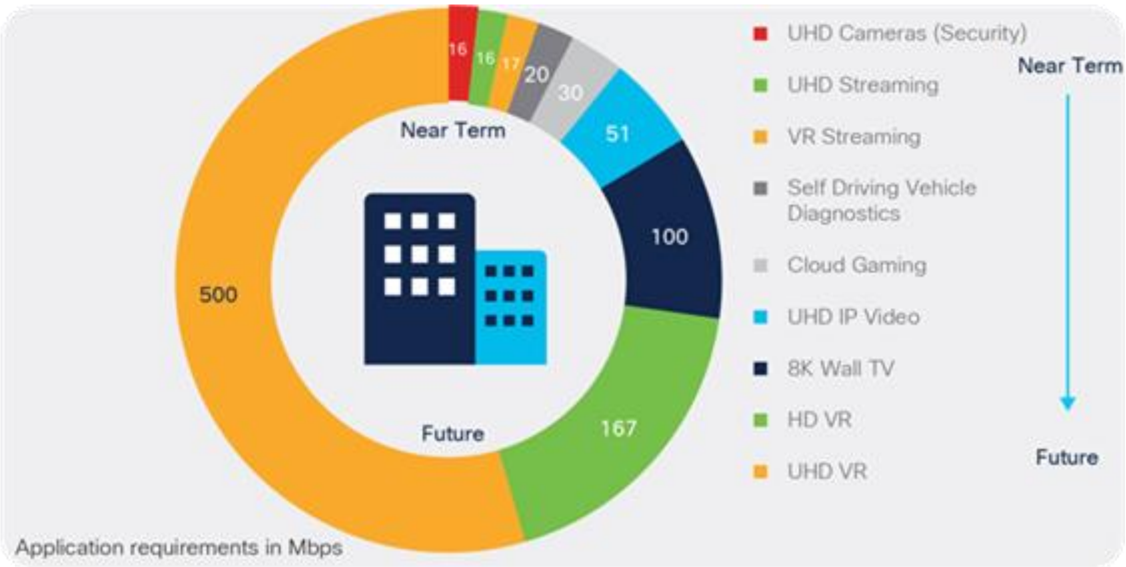


Figure 87. Demand for bandwidth and video in the connected home of the future (source: Cisco Internet Report 2018-2023 [475])

The EU target of having 100% broadband (of which 50% with >30 Mbps bandwidth) in 2020 will probably be met. The same goes for the 2025 target of 100% >100 Mbps bandwidth. But what are EU-citizens going to do with that?

The question is not whether manufacturers will want to sell 8K and other high-bandwidth video applications –they will-- but whether the consumers will want to buy these devices with a resolution-improvement that is not visible to the human eye. [476]

[474] Contribution by William Li with René Kemna (VHK)

[475] https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html

[476] As mentioned in Chapter 3, even with UHD resolution you need a very large screen to even notice the difference with normal HD. Most consumer-oriented magazines and consumer associations tell consumers that the added value of UHD over HD is very small (if any) unless you have a very large screen. Even more so this is the case for 8K television (https://www.cnet.com/news/8k-tv-what-you-need-to-know/ , 3 Jan. 2020)

For business-use of the internet the quality and capacity of video conferencing is an important issue, especially given the rather disappointing experiences during the recent corona-crisis.

In Chapter 3, in particular paragraphs 3.1.4 (Services) and 3.2 (Market) statistics are shown illustrating Internet use and in this chapter we try to expand on them.

16.1.2 Methodology

Investigating consumer viewing, listening and digital communication behaviour, with the goal of energy saving and promoting circular economy principles is not straightforward. The obvious parameters are time expenditure and activity (as a proxy for bandwidth), but the interpretation of data needs careful consideration.

Time usage per individual, activity or device
Calculating the time consumers spend in front of a screen or a device is problematic in that those who never watch television are incorporated in the statistics by defualt.
For instance, a study by the German statistics office Destatis mentions that the average individual television viewing-time (D. *Sehdauer*) per capita (>3yr of age) is 221 minutes (3h41m) per day[477]. This is the outcome of a survey that asks each individual how long they watch TV and then determines the average hours per day. This includes a considerable proportion of the population that does not watch TV ever. It also does not take into account that people may watch TV together. For that reason, Destatis proposes that the average time that a TV is on with people that watch television (D. *Verweildauer*) is a more relevant parameter. This parameter is 319 minutes (5h20m) per day.

A similar example is from Spain with an average viewing time of 206 minutes (3h26m) per inhabitant with a population of 45 million inhabitants >4 yr). However for the group of 31 million declared TV-viewers, the average viewing time in 2019 was 308 minutes (5h06m)[478].

For end-use devices, the usage time calculated not per individual or activity, but per device (TV, PC, etc.) is relevant. This is not a typical parameter that is included in social behavior studies and it requires additional information on the size and composition of the household and its park of media devices.

Peak time
Another relevant parameter is the time of day when the internet usage peaks. As indicated in Chapter 3, this determines the desired capacity/bandwidth needed for a smooth connection. In principle, in most countries where viewing and listening habits are being monitored, this parameter is not a problem. But to actually use this knowledge in e.g. smart grid management will require some detailed modelling that is outside the scope of this ICT study.

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477 Destatis, Spartenbericht Film, Fernsehen, Hörfunk, Statistisches Bundesamt, 2017. https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Bildung-Forschung-Kultur/Kultur/Publikationen/Downloads-Kultur/spartenbericht-film-fernsehen-hoerfunk-5216207199004.pdf?__blob=publicationFile

478 https://www.abc.es/play/television/noticias/abci-television-tradicional-marca-datos-consumo-hace-17-anos-202001070857_noticia.html?ref=https:%2F%2Fwww.google.com%2F

16.1.3 Data sources

There are many sources dealing with the usage of internet and traditional media (TV, radio), but many of these sources have a vested interest in 'hyping' up the internet dimension as a new market for advertising and their own market research. In other words, accuracy and reliability may leave a lot to be desired.

For that reason, the study team has focused on 'neutral' official sources that deal with the information society and agencies that are responsible for viewing or listening behaviour statistics.

EU-wide statistics on consumer behaviour in the digital age are available from Eurostat, EC DG COMM and EC DG CNECT. For a number of years now, Eurostat seems to be the main EU data source for the information society (isoc database). DG COMM, through its Eurobarometer (the last one in 2018) investigated the usage of media with a focus mainly on how to optimise communication on EU policies. DG CNECT has contracted studies dealing with the technical side of media-use in view of the targets for the EU Digital Agenda (see Chapter 3).

National monitoring of viewing and listening hours/preferences is usually in the hands of neutral agencies. In the Netherlands there is the Audiomonitor for radio and Stichting KijkOnderzoek (SKO)[479] for television. In Germany there is the AGAM for audio/radio[480] and AGF Videoforschung[481] for TV. In Italy, there is the Autorita' per le garanzie nelle comunicazioni (AGCOM)[482], which sometimes engages in media research.[483]

Time-expenditure studies by national statistics offices are another reliable source, where media use is a part of the survey. These surveys are budget-intensive and not held every year. For instance, in the Netherlands the government Sociaal and Cultureel Planbureau performs such a study every 3-4 years[484]. In Sweden, the last time-expenditure study was held in 2011[485] and in Germany in 2012-2013.[486]

Where, within the short timeframe for the ICT study, none of the above neutral sources could be retrieved, the study team resorted to commercial sources that are deemed sufficiently reliable. As such, the recent study of IP for Belgium was used[487], as well as recent data from Médiamétrie for France.[488] For Spain, the article was based on data that

[479] https://kijkonderzoek.nl/

[480] Arbeitsgemeinschaft Media-Analyse e. V. (agma) https://www.agma-mmc.de/

[481] https://www.agf.de/

[482] https://www.agcom.it/

[483] Agcom, Rapporto sul consumo di informazione, Autorita'per Le Garanzie Nelle Comunicazioni, servizio economico-statistico, Feb. 2018.
https://d110erj175o600.cloudfront.net/wp-content/uploads/2018/02/Agcom-Consumo-di-informazione.pdf

[484] https://digitaal.scp.nl/trends-in-mediatijd/assets/pdf/trends-in-mediatijd.pdf

[485] LEVNADSFÖRHÅLLANDEN RAPPORT 123, Nu för tiden, I denna rapport ges en bred statistisk belysning av svenska folkets tidsanvändning år 2010/11. www.scb.se (Sweden Statistics office)

[486] Destatis, Zeitverwendungserhebung - Aktivitäten in Stunden und Minuten für ausgewählte Personengruppen - 2012/2013, published 2015.
https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Einkommen-Konsum-Lebensbedingungen/Zeitverwendung/Publikationen/Downloads-Zeitverwendung/zeitverwendung-5639102139004.pdf;jsessionid=80E66340948F1B6AAF5CE19F68888B28.internet8722?__blob=publicationFile

[487] https://www.ipb.be/nl/cross-media/content/articles/de-tijdsbesteding-van-de-belgen-onder-de-loep

[488] https://www.mediametrie.fr/fr/laudience-de-la-television-au-mois-de-mai-2020

were originally from Kantar.[489] For Eastern Europe the Statista.com data was used.[490] Aggregated data were used for Nordic countries[491].

Finally, to cover the time spent on social media, there is an overview from the Hootsuite site, based on globalwebindex.com data for selected countries.

16.2 European Union

Since 2018 Eurostat provides most statistics on the *information society* (isoc), *communication and information* (ic) databases. Data are country-specific, but for some aspects there is not much to differentiation between Members States. Note that the acronyms are the names of the Eurostat databases. Internet search with a database name and 'Eurostat' finds the full interactive database[492]. Only the highlights are given below.

For households in the EU27 (EU28 excl. UK) in 2019:

- isoc_ci_in_h and isoc_ci_it_h show that 90% of households in EU27_2019 have internet access, almost all with broadband. Lowest ownership is in Bulgaria (75%); the highest is in Scandinavia and in the Netherlands (98%);

- isoc_ci_cm_h shows that 83% of households have at least one computer with internet access.

For individuals in the EU27 in 2019:

- isoc_cicci_use says that 32% of individuals in EU27 2019 use cloud services for storing pictures, files, etc. Usage is highest in Denmark, Ireland (≥50%); lowest in Greece (<10%). Overall usage is growing fast (usage was 24% in 2018);

- isoc_ci_stv_i mentions that only 9% use a smart TV for internet activities (VOD or internet);

- isoc_ec_ifi suggests that 15% of EU-citizens handled investment services, insurances and/or loans through the internet with large differences between countries, from 4% in Bulgaria to 50% in Estonia and Sweden.

For enterprises in the EU27 in 2019:
- isoc_cicce_use 24% cloud computing with the highest usage in Scandinavia (50-65%) enterprises>10 employees;

- 4% of enterprises use 3D printing (2018) highest NL & BE 6%.

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[489] https://www.kantarmedia.com/

[490] https://www.statista.com/statistics/1037609/poland-linear-tv-viewing-time/

[491] https://www.nordicom.gu.se/sites/default/files/mediefakta-dokument/Nyhetsbrev_Norden/nordicom_mediatrends_nordic_1-2014.pdf

[492] Also, a full overview of the over 30 isco databases is given at https://ec.europa.eu/eurostat/web/digital-economy-and-society/data/database

Table 117 gives an overview of the percentage of individuals privately engaged in internet activities and the percentage using internet daily. In 2019, 77% of EU citizens used the internet daily (up from 51% in 2010). About half of EU citizens used them for phone/video calls, social networks, banking, listening to music and online purchases in the last 3 months. Nordic countries and the Benelux are most active on the internet, Italy and France less active and the least active are most Eastern European Member States.

Table 117. Internet activities 2019 and frequency of use 2010-19 all individuals (Eurostat isoc_ci_ac_i & isoc_ec_ibuy & isoc_ci_ifp_fu)

All numbers in %	Internet use: telephoning or video calls	Internet use: participating in social networks (creating user profile, posting messages or other contributions to facebook, twitter, etc.)	Internet use: Internet banking	Internet use: seeking health information	Internet use: listening to music (e.g. web radio, music streaming)	Online purchases in the last 3 months	Online purchases in the last 12 months	Frequency of daily internet use (percentage of individuals in various years)			
2019→								2010	2015	2018	2019
EU27 (from 2020)	52	54	55	53	51	49	60	51	65	74	77
Belgium	58	76	71	49	48	55	66	59	73	82	85
Bulgaria	58	53	9	30	30	14	22	33	46	55	60
Czechia	45	59	68	56	51	43	64	38	63	75	76
Denmark	56	81	91	67	71	74	84	76	87	92	92
Germany	55	53	61	66	51	71	79	60	75	84	85
Estonia	53	65	81	60	65	56	68	57	77	82	83
Ireland	46	64	67	57	58	59	67	47	67	74	83
Greece	51	57	31	50	55	32	39	31	55	61	65
Spain	55	59	55	60	63	47	58	44	64	72	78
France	48	42	66	50	50	58	70	60	68	75	77
Croatia	48	58	46	63	50	35	45	40	60	66	71
Italy	49	42	36	35	44	28	38	46	62	71	73
Cyprus	72	72	41	69	55	31	39	40	63	77	79
Latvia	57	65	72	48	44	34	47	49	66	73	75
Lithuania	61	61	65	61	47	38	48	45	56	68	73
Luxembourg	53	63	71	58	61	63	72	74	92	86	87
Hungary	61	69	47	60	59	35	49	48	63	69	75
Malta	55	71	54	62	62	50	58	49	70	77	82
Netherlands	61	67	91	74	62	70	81	76	85	90	92
Austria	41	56	63	53	53	54	62	53	68	76	80
Poland	49	53	47	47	49	41	54	42	52	64	68
Portugal	40	60	42	49	52	28	39	38	55	64	65
Romania	49	60	8	31	31	15	23	21	37	53	57
Slovenia	42	52	47	48	51	45	56	54	61	71	74
Slovakia	55	59	55	53	46	47	60	58	60	68	76
Finland	65	67	91	76	76	55	73	72	84	88	90
Sweden	63	72	84	62	:	70	82	76	82	88	91
Norway	64	86	95	69	78	67	82	81	89	93	95
Switzerland	69	53	73	67	58	75	80	:	:	:	89

Table 118 covers internet use of individuals in enterprises in EU27 Member States in 2018. About 40% of individuals used ICT in any form, 10% in the form of computerized equipment or production machinery and 38% only in the form of PCs, laptops, smartphones, tablets or other portable devices.

Table 118. Individuals in enterprises doing ICT tasks and fraction working from home 2018 (source: Eurostat isoc_iw_ap & isoc_iw_hem extract 28.6.2020)

	% individuals using ict at work									% individuals working from home						
All numbers In %	used computers, laptops, smartphones, tablets or other portable devices at work	used other computerized equipment or machinery such as those used in production	used computers, laptops, smartphones, tablets, other portable devices or other computerized equipment or machinery such as those used in production lines, transportation or other services at work	exchanged emails or entered data in databases in their work	created or edited electronic documents in their work	used social media for their work	used applications to receive tasks or instructions in their work	used occupational specific software in their work	developed or maintained IT systems or software in their work	every day or almost every day	at least once a week (but not every day)	less than once a week	at least once a week	at least once	never	used the internet for the job when working from home
EU27	38	10	40	33	25	9	11	21	4	4	5	6	9	15	25	14
Belgium	42	18	44	38	24	9	15	23	4	5	5	8	10	18	23	17
Bulgaria	21	4	21	15	12	4	5	8	1	2	2	2	4	6	15	5
Czechia	36	18	43	34	30	8	13	23	3	:	:	:	:	:	:	:
Denmark	51	18	52	43	32	14	11	21	8	6	7	16	14	30	22	28
Germany	51	13	54	45	36	10	8	32	5	5	5	7	10	17	37	15
Estonia	47	19	48	43	36	15	26	26	5	6	7	9	13	22	26	22
Ireland	32	12	34	26	19	7	13	13	4	5	3	3	8	11	23	11
Greece	23	11	24	19	18	7	6	11	3	4	3	2	7	9	14	8
Spain	33	8	36	27	21	10	14	20	4	4	5	6	10	15	21	14
France	41	9	43	33	24	7	14	23	4	6	6	5	12	17	25	16
Croatia	28	1	30	26	21	5	1	14	2	3	2	3	5	8	22	8
Italy	32	3	33	26	19	9	8	12	4	3	4	4	7	11	22	9
Cyprus	35	1	36	29	27	10	7	14	3	2	1	2	4	6	30	5
Latvia	36	16	39	29	20	10	12	19	3	5	4	6	10	16	23	15
Lithuania	35	10	37	29	19	11	9	18	2	3	4	5	7	12	25	12
Luxembourg	46	14	47	40	34	11	15	23	6	8	6	9	13	22	25	19
Hungary	29	8	30	25	21	8	15	16	4	4	3	4	8	12	18	11
Malta	47	12	48	41	29	18	21	26	7	8	5	7	13	20	28	20
Netherlands	59	21	61	52	44	20	23	31	8	7	13	12	20	32	28	31
Austria	46	11	49	43	31	11	11	34	7	4	6	6	10	17	32	16
Poland	31	7	32	25	20	7	9	13	3	4	4	5	7	12	20	11
Portugal	35	8	37	32	19	10	16	23	5	4	4	4	8	12	25	11
Romania	17	4	18	14	9	6	5	7	1	1	2	2	3	4	14	4
Slovenia	38	15	40	32	27	8	12	19	7	6	5	4	11	15	25	15
Slovakia	31	4	35	27	18	7	10	10	1	4	5	5	9	13	22	13
Finland	49	15	50	45	32	14	22	30	8	8	8	10	16	26	23	25
Sweden	45	:	:	41	31	13	12	22	7	:	:	:	:	:	:	:

Norway	65	15	66	60	49	25	37	50	11	11	13	14	24	38	:	37

About 33% of professional users employed ICT devices for e-mail exchange and inserting data in a work-database, 25% for editing electronic documents, 9% for social media, 11% for applications to receive work-tasks/instructions. About 21% used specific work-software and 4% are ICT-specialists developing or maintaining IT systems or work-related software. Table 118 also reveals that in 2018 about 9% worked from home at least once a week, including 4% working from home (almost) every day. Then there is 6% that occasionally –but less than once a week—worked from home. Almost all individuals working from home (14%) used the internet for their work.

Before 2018, EU data on media use were gathered by the European Commission DG COMM[493] in a context of trying to improve communication policy. Data were gathered by TNS with over 30,000 respondents aged 15+ for 28 Member State plus 5 candidate countries (see Annex D).

Figure 88 gives a comparison of media use in their most recent study in autumn 2017 and the previous study in autumn 2016.

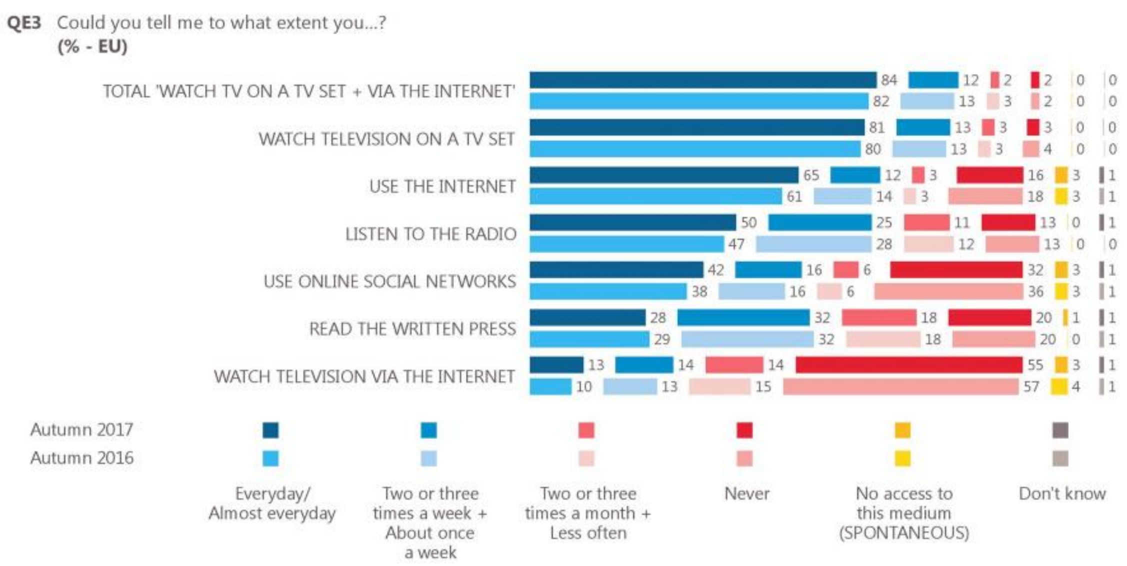


Figure 88. Media use in the EU autumn 2016 and 2017 (source: EC DG COMM, 2018)

Television (94% pf which was watched on a television set) remains the medium most commonly used by European citizens: 84% watch it every day or almost every day, which represents an increase of two percentage points since the Standard Eurobarometer survey of autumn 2016 (EB86). The proportion of Europeans watching television on the Internet continues to rise: 27% watched it this way at least once a week in the autumn of 2017.

The trend chart 2010-2017 (Figure 89) shows that traditional TV-viewers slightly decrease from 97 to 94%, which is actually not that much. Likewise, listening to the radio has decreased but relatively little, i.e. from 79 to 75% over the 2010-2017 period. People (occasionally) watching TV on the internet increased from 16 to 27%, but only 2% watch TV only through the internet.

[493] EC DG COMM, 2018) , Eurobarometer 88 "Media use in the European Union", Field: November 2017, 2018. https://ec.europa.eu/commfrontoffice/publicopinion/index.cfm/ResultDoc/download/DocumentKy/82871

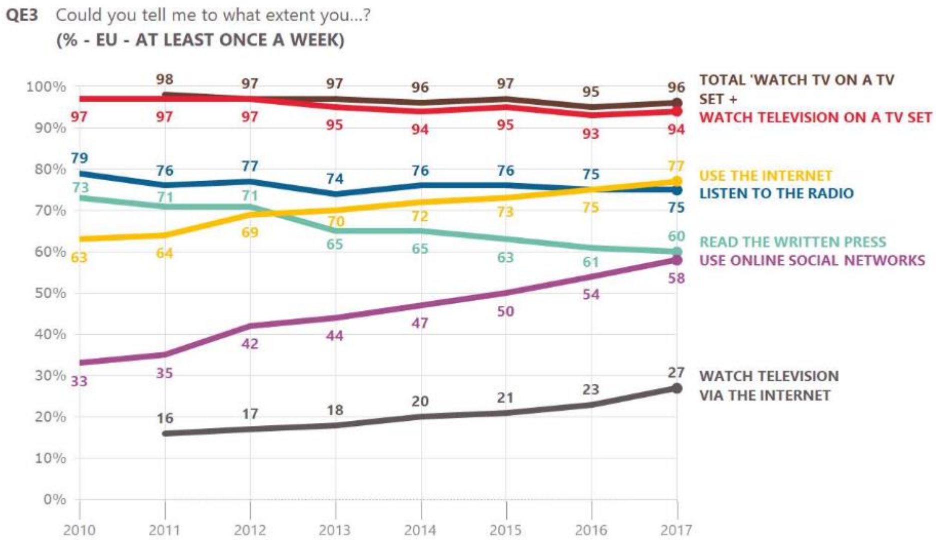


Figure 89. Trends in media use in the EU 2010-2017 (source: EC DG COMM, 2018)

Figure 90 shows which countries had the most avid TV viewers on a TV set in the autumn of 2017. In Bulgaria, Romania, Portugal and Italy 90% or more of individual respondents watched TV every day, whereas in Finland, Luxembourg and Sweden 70% or less watched TV on a daily basis according to this source.

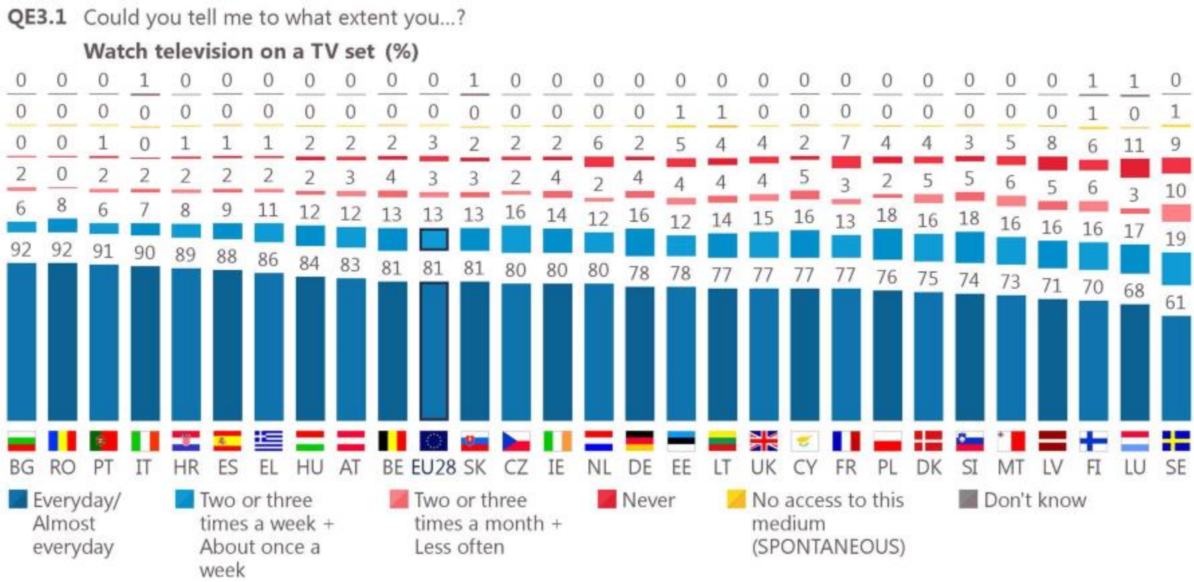


Figure 90. Viewing TV on a TV-set by country (source: EC DG COMM, 2018)

To some extent, Figure 91 shows the inverse scenario whereby individuals watch TV on the internet: 20% or more of Maltese, Swedes, Irish, British, Luxembourgers and Austrians watched TV on the internet (almost) everyday, whereas only 6% of Bulgarians and Greek did so in 2017.

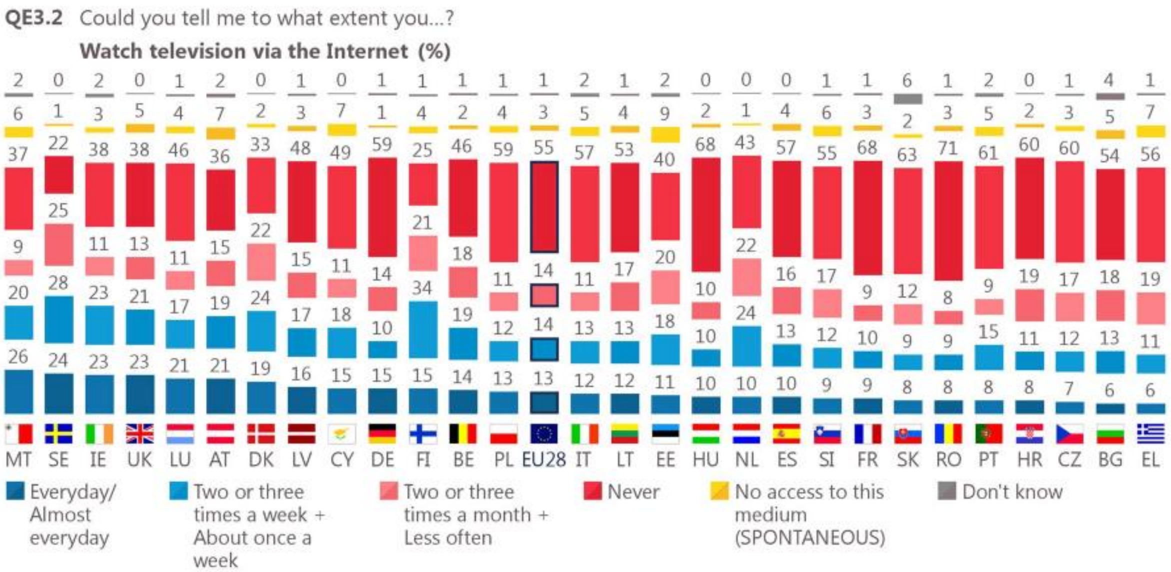


Figure 91. Viewing TV via the internet (source: EC DG COMM, 2018)

About 50% of EU-citizens listened to the radio every day and 25% at least two or three times a week. Germany and Austria have the most radio-listeners, at 71 and 67% respectively every day, whereas only 29% of Bulgarians and 24% of Romanians listened to the radio every day in the autumn of 2017.

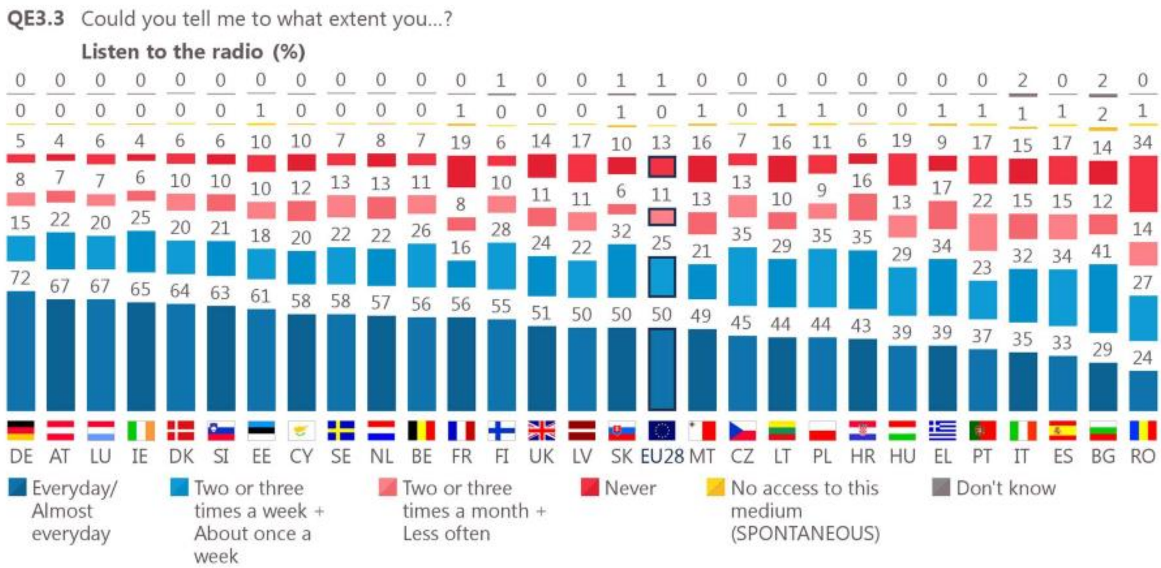


Figure 92. Listening to the radio (source: EC DG COMM, 2018)

Regarding the use of the internet in autumn 2017, the Dutch were number 1 with 91% using it every day, followed by the Scandinavians (88% Sweden, 87% Denmark, 76% Finland). Romania is reported to have the lowest daily internet use by this source, at 42% of respondents.

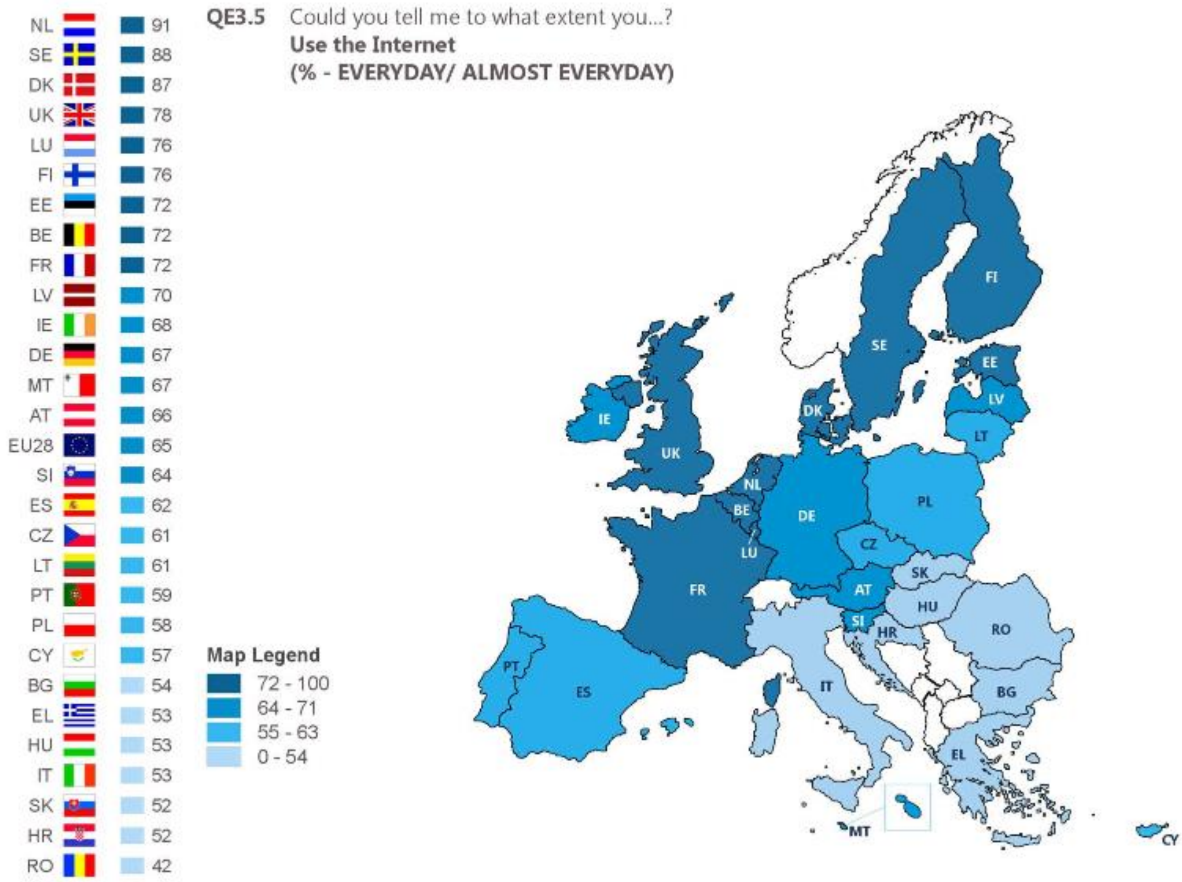


Figure 93. Use of the internet in the EU, autumn 2017 (source: EC DG COMM, 2018)

16.3 Netherlands

The most recent aggregation of time spent on viewing, listening and communicating using media is from the SCP in 2019.

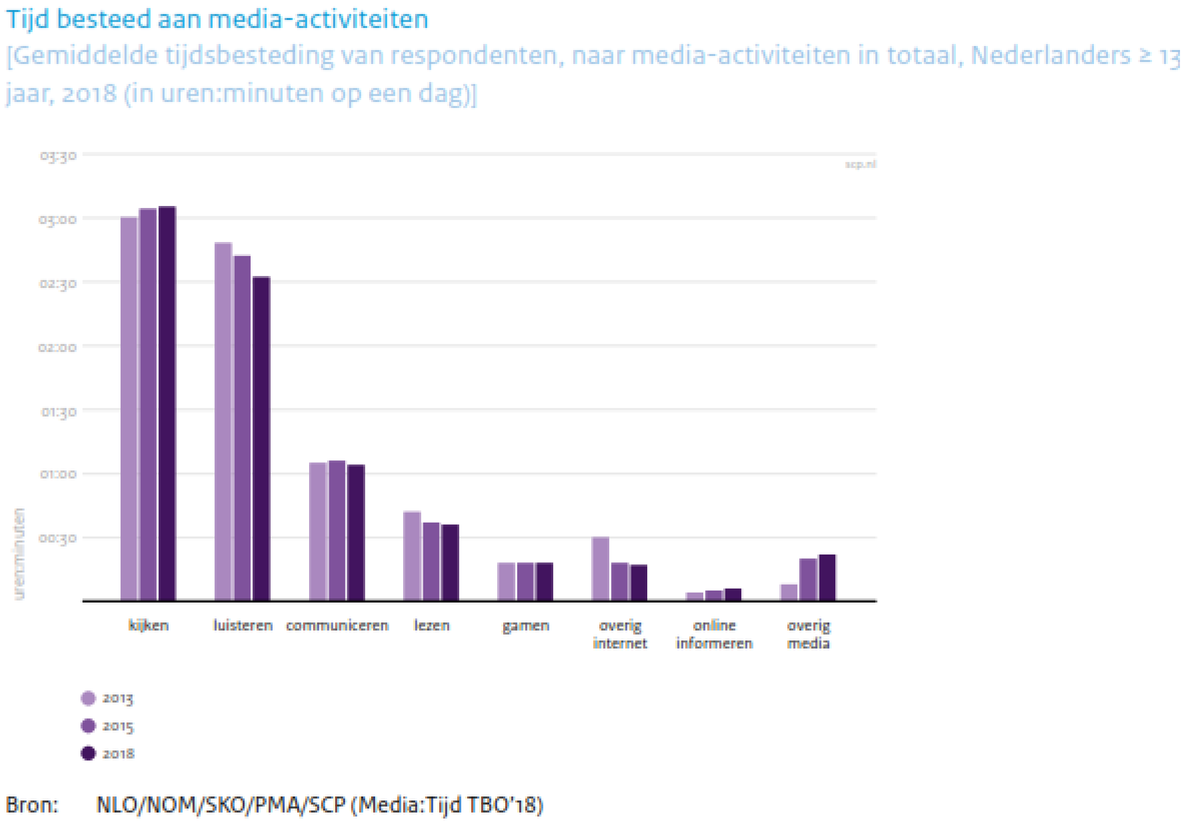


Figure 94. Use of media, Netherlands, 2013-2015-2018 (source: SCP, 2019)
(kijken= viewing, luisteren=listening, communiceren=communicate, lezen=reading, gaming=gaming, overig internet=other internet, online informeren=inform online, overige media=other media)

Overall, the time people spend on media has not changed significantly: In 2015 it was 8h33m and in 2018 it was 8h23m. Viewing and listening are the most important activities. Viewing was fairly constant at a total of 3h04m per day (2h30m linear TV, 25m atch-up TV, 10m streaming TV, 4m online clips). The viewing times according to SKO are slightly longer (total 202 minutes, i.e. 3h22m) Listening went down from 2h48m in 2013 to 2h32m in 2018, while streaming went from 5 to 19 minutes over the same period. This is according to the SCP, but, probably due to a different definition, the organisation permanently monitoring radio- and music, found considerably higher listening times, i.e. up to 202 minutes (3h22m).
Internet use, i.e. information search, online shopping and banking, etc. as part of 'communication', stayed the same over the years. Time spent reading dropped from 42 to 36 minutes between 2013 and 2015 but did not further decrease in 2018.

Table 119. Listening behaviour, Netherlands, 2018 (source: Audiomonitor 2019)

Device use	**% of time**
smart speaker	1%
tablet	2%
car radio	13%
clock radio	3%
mediaplayer (iPad MP3)	1%
smartphone	14%
notebook	6%
PC	8%
portable radio	8%
TV/settop box	8%
radio/stereo set	32%

Sample size = 5289

Media use	**minutes**	**%**
Live radio	145	61%
Music streaming	34	21%
Youtube	10	9%
Own CD/MP3	9	7%
Podcast	3	2%
TV music channel	2	1%
Audio TOTAL	**202**	**minutes**

Figure 95. Listening behaviour, Netherlands, 2018 (source: Audiomonitor 2019)

Not surprisingly, the young spent more time on the internet and the old more time on TV and radio. See figure below.

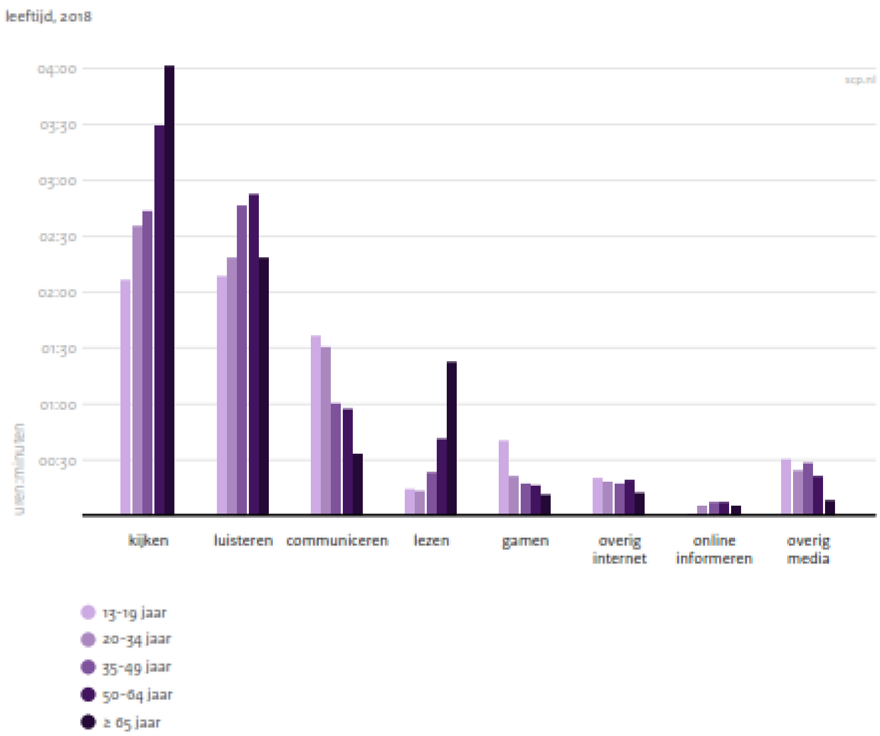


Figure 96. Use of media by age group, Netherlands, 2018 (source: SCP, 2019)

Most time is spent on media in the evenings. Peak times are at 21h20, with 53% of the Dutch population viewing at this time during the week and 59% on Sundays. Listening and communicating are the media mostly used for multitasking, combining with study or manual labour, while viewing and reading are more single task activities.

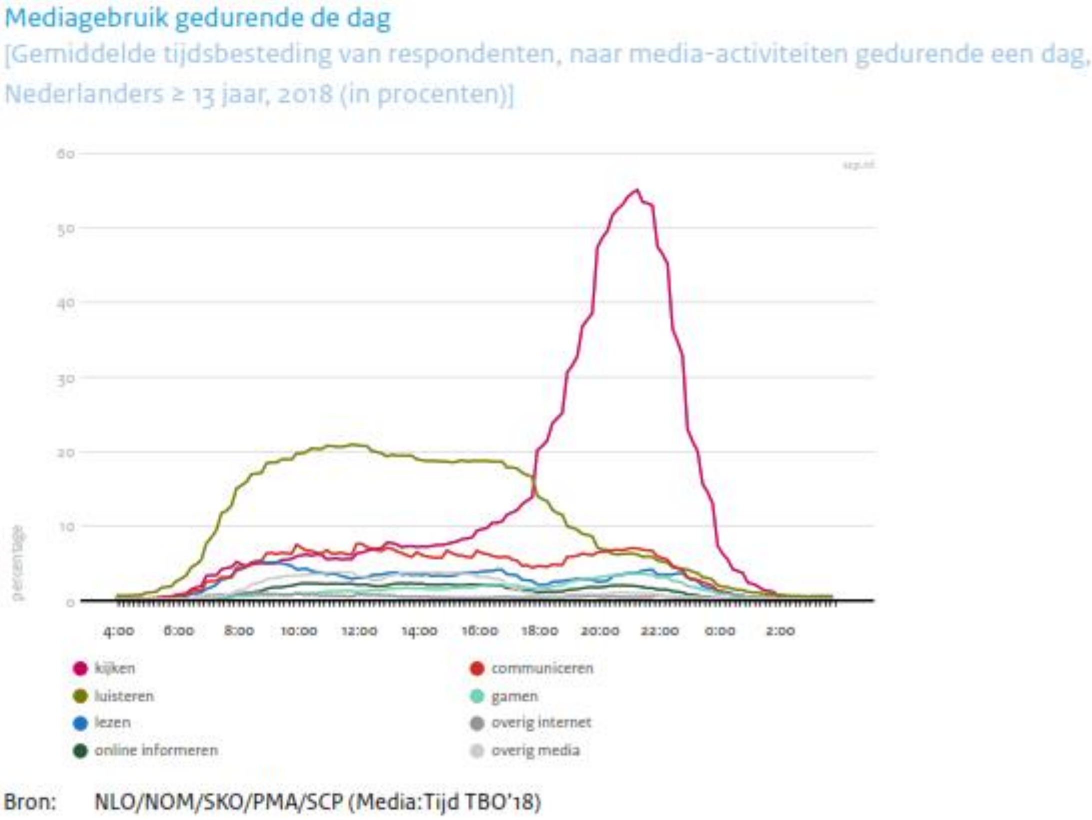


Figure 97. Timing of media usage, Netherlands, 2018 (source: SCP, 2019)

16.4 Belgium

Advertising agency IPB performs its Life Observer studies to monitor time spent on the daily activities of the 18-64 year age group of Belgians. . (See Belgium section in Annex D)

Figure 98 gives a general overview of the timeline and activities for the average Belgian in 2018.

Figure 99 singles out the media-activities, with a peak showing at around 21:00h for TV and Internet, while listening to the radio is most popular during working hours from 7:00h to 17:00h.

On weekdays the Belgians use the radio for 194 minutes per day. Of this, 90% (174 minutes) of listening to the radio is combined with other activities (see Figure 100). The young (18-24 years) listen to the radio for 101 minutes a day, the middle aged (35-44) for about 206 minutes and the elderly for (55-64) 239 minutes.

Of the 190 minutes spent watching TV, about 60 minutes of those are spent on carrying out other tasks simultaneously (e.g. eating, cooking, napping, playing with kids, etc.). Over 30% of Belgians eat in front of the TV and about 22 minutes of the average TV-viewing time is spent on surfing the internet. The young (18-24 years) watch TV for 110 minutes a day, the middle aged (35-44) for about 198 minutes and the elderly (55-64) for 251 minutes (4h11m).

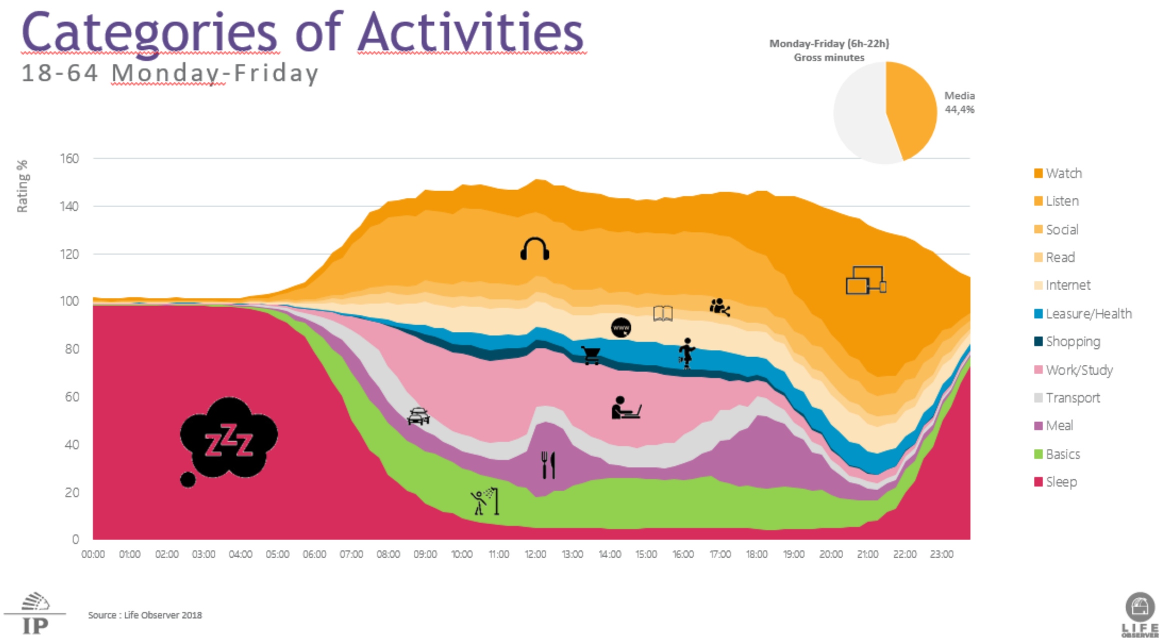


Figure 98. Timing of activities during the day of average Belgians 2018 (source: IP)

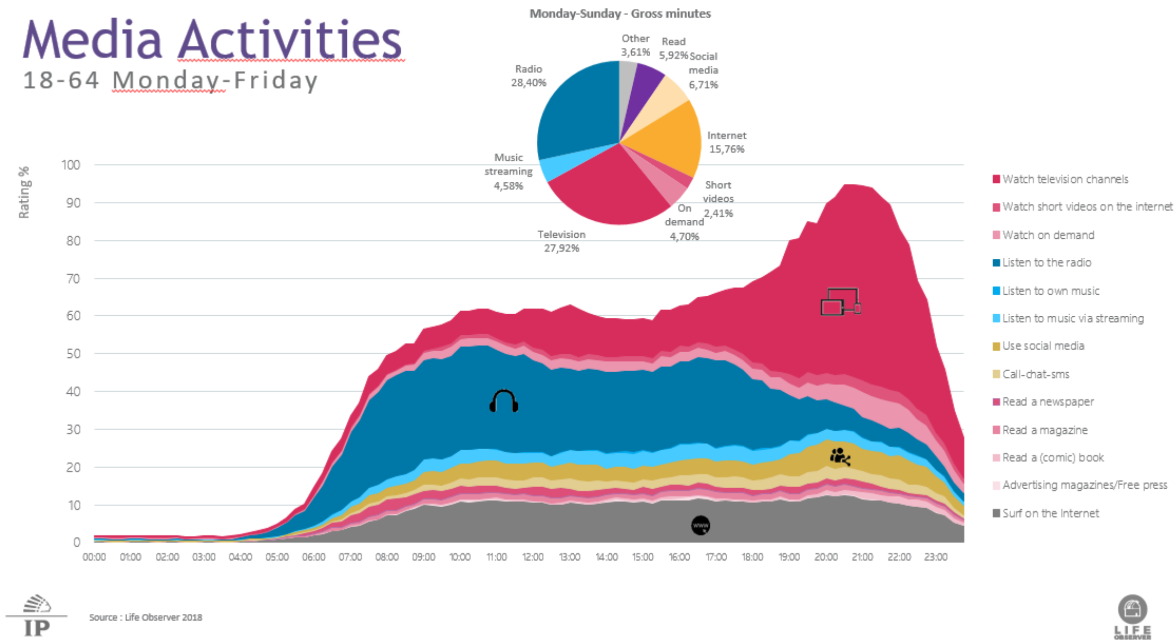


Figure 99. Timing of media activities during the day of average Belgians 2018 (source: IP)

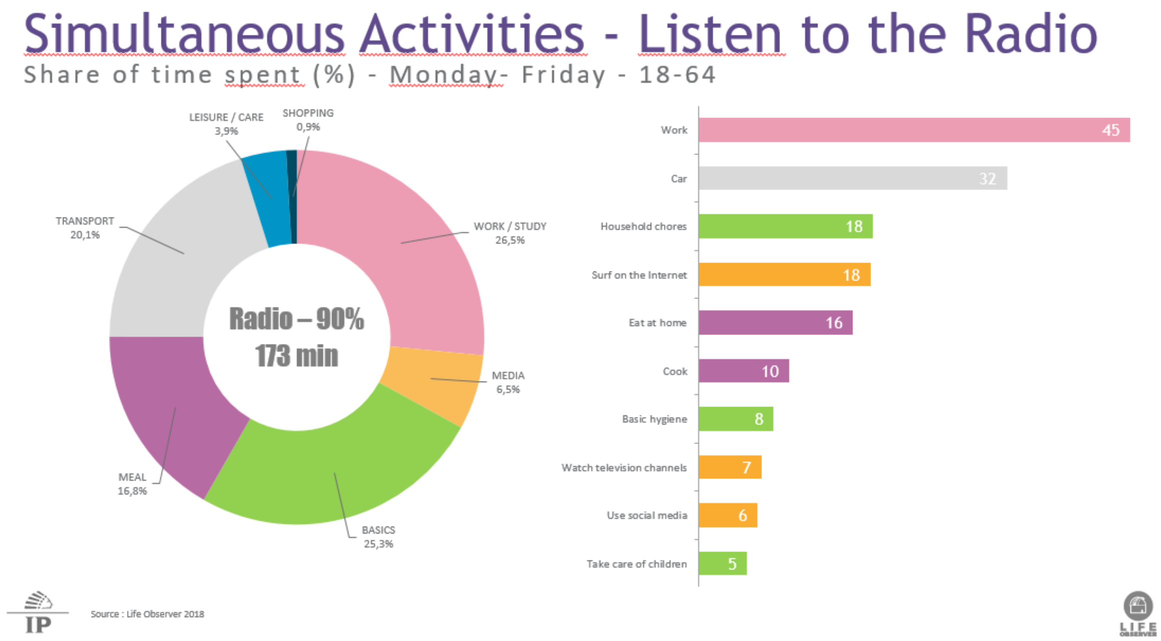


Figure 100. Radio multitasking, Belgium 2018 (source: IP)

Figure 101 gives differences in media use between age groups in Belgium. Amongst others, the young (18-24 years) surf the internet for 120 minutes a day, the middle aged (35-44) for about 105 minutes and the elderly (55-64) for 107 minutes.

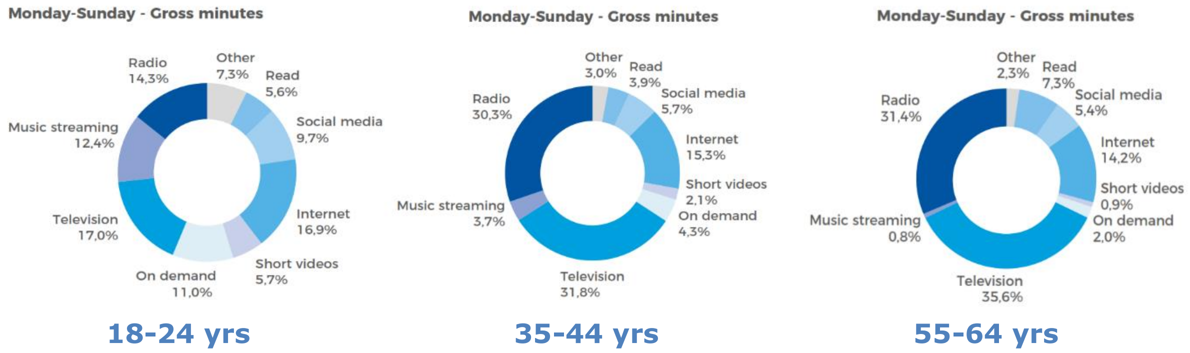
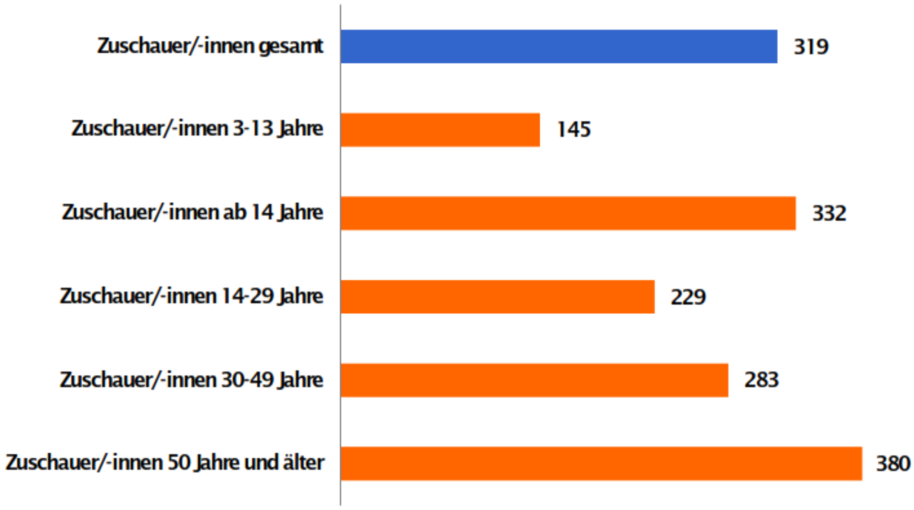


Figure 101. Timing activities by age group, Belgium 2018 (source: IP)

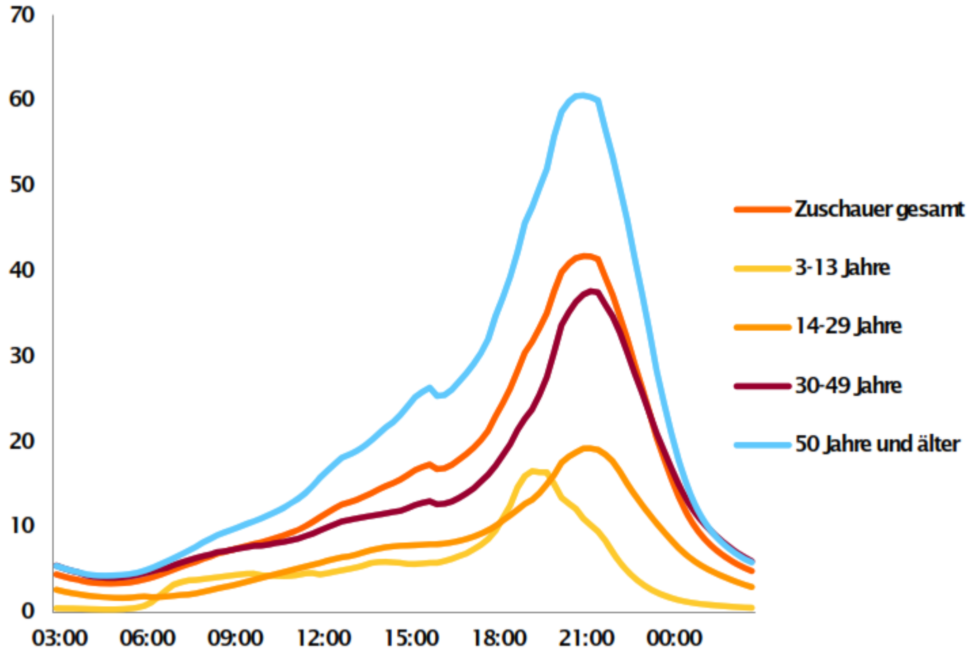
16.5 Germany

According to the German statistics office Destatis, the average German watches TV for 319 minutes per day (D. Verweildauer 5h19m), with considerable differences between the young and the old (see Figure 102)



Quelle: AGF Videoforschung in Zusammenarbeit mit GfK; videoSCOPE 1.1, 01.01.2017 bis 31.12.2017, Erwachsene ab 14 Jahren, alle Sender, Montag bis Sonntag, 3:00h bis 3:00h
Stand: 12.07.2018, eigene Darstellung

Figure 102. TV viewing, Germany 2017 (source: AGF in Destatis, 2018)



Montag bis Sonntag 3:00 bis 3:00 Uhr, Personen ab 3 Jahren.

Quelle: AGF in Zusammenarbeit GfK; TV Scope 6.1, 01.01.2017 bis 31.12.2017, Stand: 12.07.2018, eigene Darstellung

Figure 103. Timing of TV viewing during the day, Germany 2017 (source: AGF in Destatis, 2018)

The average watching time (*D. Sehdauer*), including those that do not watch TV, is 221 minutes in 2017, according to the same source. Peak TV viewing is between 20:00h and 21:00h, depending on age.

The average listening time (Verweildauer) per radio-listener, as well as the percentage of listeners per age group is given in Figure 104.

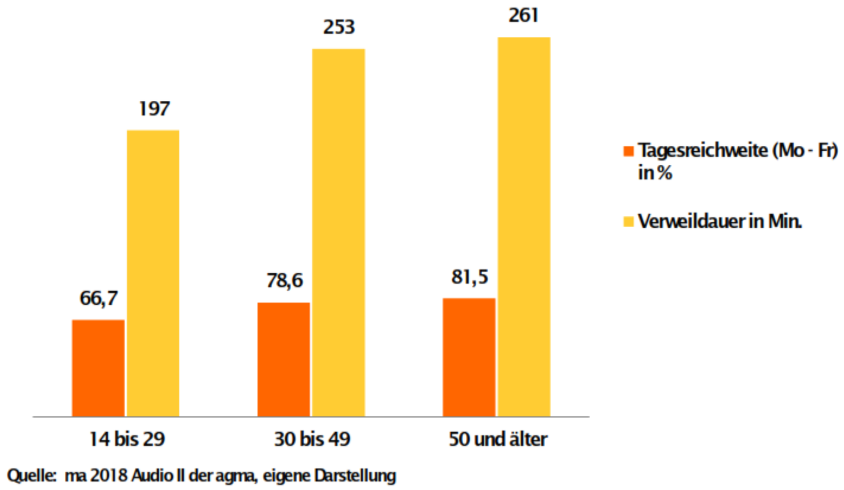


Figure 104. Average listening time per radio-listener, as well as the percentage of listeners per age group (source: AGF in Destatis, 2018)

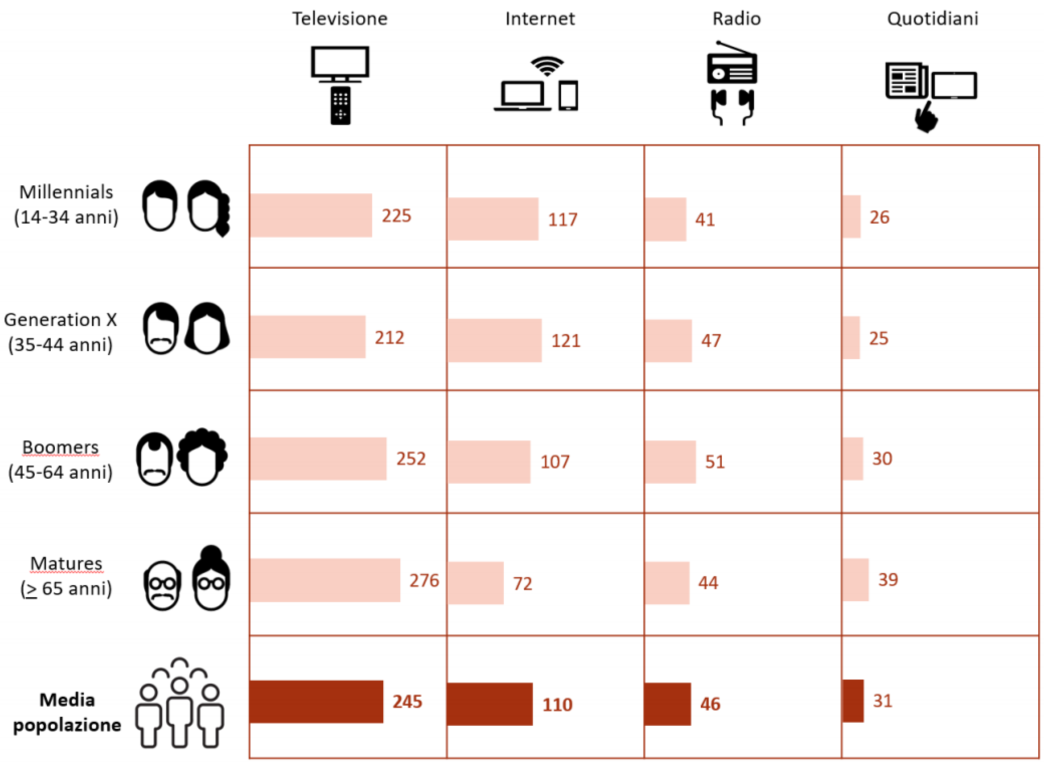
In Germany, the most recent time expenditure study (Zeitverwendungserhebung) relates to 2012-2013. [494]

16.6 Italy

In Italy, the Agcom government agency contracted GfK to carry out a consumer survey on communication amongst 14,000 respondents from the age of 14+, at both national and regional level. Figure 105 shows that for the average Italian, there were 245 minutes of TV viewing time (4h05m), 110 minutes of internet use (1h50m), 46 minutes listening to the radio and 31 minutes reading the newspaper. It is remarkable that the differences between the age groups for TV and radio are relatively small. For internet, the young (14-34) use it over 60% more than the elderly (>65). For newspapers it is the other way around.

Figure 106 shows that the peak time for watching TV is 21:00-22:00h in the evening. For radio it is 9:00-10:00h in the morning. This usage pattern is not very different from e.g. Belgium and the Netherlands.

[494] Statistisches Bundesamt, Zeitverwendungserhebung - Aktivitäten in Stunden und Minuten für ausgewählte Personengruppen 2012/2013, Wiesbaden, Germany 2015.



Quotidiani=Newspapers

Figure 105. Media use in Italy per age group, in minutes (source: AGCOM, 2018)

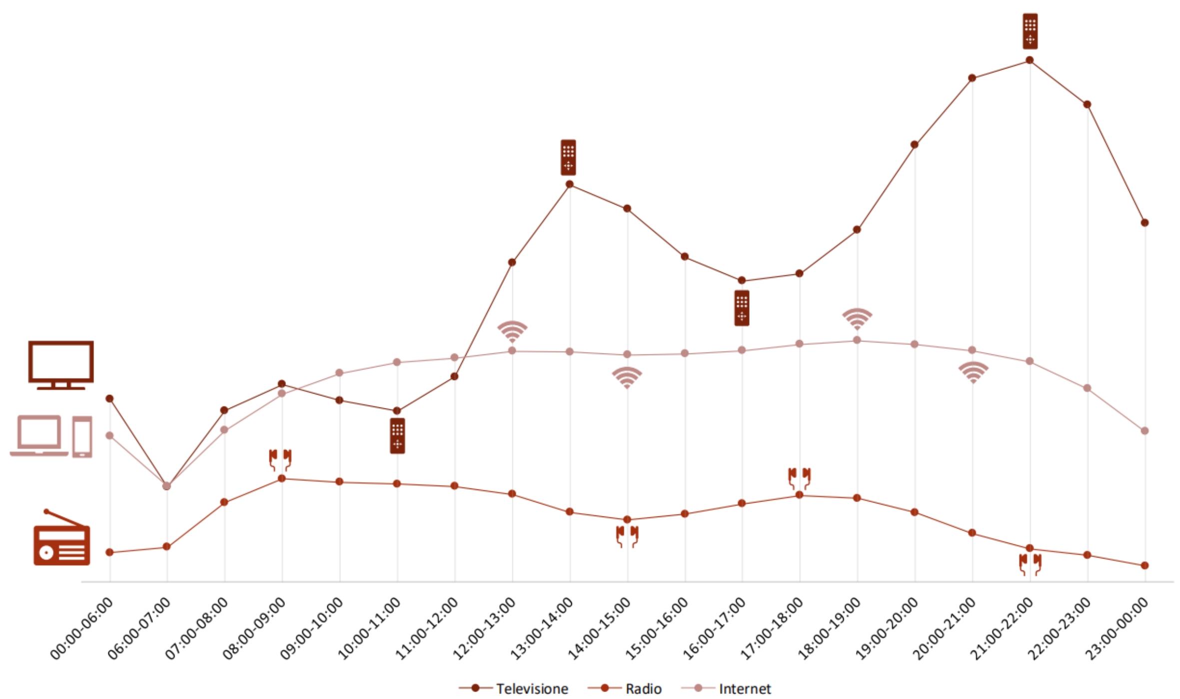


Figure 106. Exposure to media over the day, Italy (source: AGCOM, 2018)

Italian radio listening surveys for 2019 show a population of 34.8 million daily listeners (age group>14 years) with an average listening time of 205 minutes per day.[495]

16.7 Spain

As mentioned in paragraph 1, the average TV-viewing time per Spanish citizen and per average Spanish viewer are very different (see Figure 107).

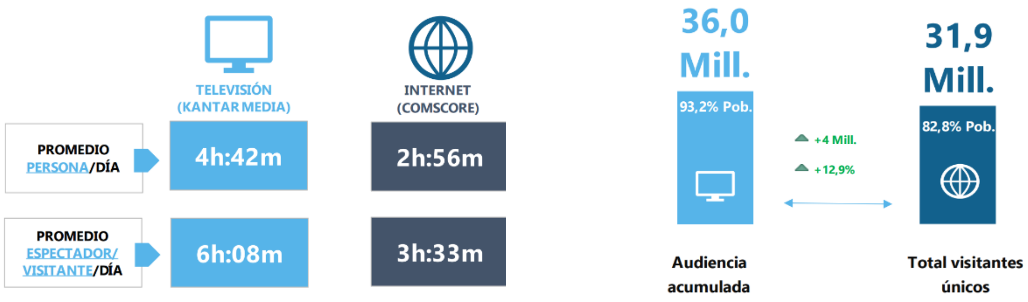


Figure 107. TV and internet usage per citizen and per active user. Spain 2019.[496]

16.8 France

The latest time expenditure study by the French national statistics office INSEE stems from 2010/2011. It shows amongst others the TV viewing behaviour of age 11+against a background of the household composition, occupation and whether the respondent is an active TV viewer ('practitioner'). The overall average was 125 minutes for the whole population and 164 minutes per practitioner. Individuals who were employed or were studying watched up to 24% less on average. Those who were not working or studying watched almost 40% more.

[495] https://www.primaonline.it/2020/01/28/300556/radio-ecco-i-nuovi-dati-di-ascolto-anno-e-2-semestre-2019-deejay-recupera-la-terza-posizione-boom-radiofreccia-virgin-rmc-e-m2o/

[496] https://www.abc.es/play/television/noticias/abci-television-tradicional-marca-datos-consumo-hace-17-anos-202001070857_noticia.html?ref=https:%2F%2Fwww.google.com%2F

Table 120. TV viewing time, average (minutes) for all and practitioners, % of practitioners (source Insee, 2010[497])

EMPLOYMENT	All			Employed or student			Not employed or not student		
	Average time	Average time per practitioner	number of practitioners	Average time	Average time per practitioner	number of practitioners	Average time	Average time per practitioner	number of practitioners
Type			%			%			%
All	125	164	76	95	135	70	171	201	85
Person alone	146	191	76	96	147	65	189	219	86
Single-parent family	118	163	72	98	144	68	172	207	83
Couple without children	147	178	83	106	139	76	173	199	87
Couple with 1 child	112	147	76	96	131	74	154	188	82
Couple with 2 children	95	133	72	88	126	70	137	171	80
Couple with 3 or more children	102	146	70	90	136	66	148	179	83
Complex household	125	169	74	86	127	68	168	208	81

Champ : individus de 11 ans et plus en France métropolitaine et dans 3 DOM (la Martinique, la Guadeloupe et la Réunion).

Médiametrie, the agency that monitors French TV-viewing daily, mentions an average of 4h03m of TV watching per individual in the month of May 2020[498] (May 2019: 3h38m). Individuals below 50 watched 2h51m per day (May 2019: 2h32m) and those aged 50 and older watched 5h54m per person per day on average (May 2019: 4h55m).[499]

16.9 Greece

As an input to the Eurostat figures, the Greek statistics office monitors internet use. Table 121 shows the latest figures for the period 2015-2019.

[497] Insee, enquête Emploi du temps 2009-2010. https://www.insee.fr/fr/statistiques/1280984#consulter
[498] When France was still in complete Corona-virus lockdown
[499] https://www.mediametrie.fr/fr/laudience-de-la-television-au-mois-de-mai-2020

Table 121. Percentage of Greek population using the internet by type of activity 2015-2019
(source: Greece Statistics, 2020[500])

Activity	2015	2016	2017	2018	2019
Communication					
Sending/receiving e-mails	77.1	74.7	75.2	75.3	77.9
Phoning over the internet	44.0	46.5	47.9	61.1	66.8
Social networking	65.7	67.5	71.5	73.4	74.9
Information search/online services					
Finding information about goods and services	80.4	81.9	82.1	89.4	88.3
Reading/downloading newspapers and magazines	85.4	85.3	87.1	...	87.7
Using services related to travel and accomodation	31.2	39.9	40.2	...	...
Finding information or using health related services	55.7	58.8	67.6	65.2	65.9
Training/ education					
Using services related to training/education	47.7	...	...	...	...
Playing/ downloading games and music	...	57.6	...	74.7	...
Other online services					
Internet banking	20.8	27.7	35.9	37.8	40.3
e-government					
Obtaining information from public authorities	62.2	63.6	64.2	64.5	64.6
Downloading official forms	36.0	38.4	39.7	39.7	39.9
Sending filled in forms	37.1	37.5	34.5	33.3	36.5

According to Nielsen Media Research 2010, the average Greek watched 4 hours and 26 minutes of TV per day. Elderly people (65+ years) even watched 414 minutes per day (6h54m).

16.10 Nordic countries

In the Nordic countries, TV viewing time is the lowest in Europe, as illustrated in the table below.

[500] https://www.statistics.gr/documents/20181/1515741/GreeceInFigures_2020Q1_EN.pdf/4ab68b3f-bd6c-d77d-8bf9-cfcbf91aa937

Table 122. TV-viewing time in Nordic countries 2003-2013 (minutes/day) [501]

year	Denmark	Finland	Iceland	Norway	Sweden
	(Age 3+)	*(Age 10+)*	*Age 12-80)*	*(Age 12+)*	*(Age 3+)*
2003	157	173	153	164	150
2004	162	167	151	166	151
2005	152	169	147	164	146
2006	150	169	149	156	154
2007	148	166	126	154	157
2008	167	177	183	174	160
2009	189	176	158	184	166
2010	201	178	141	183	166
2011	198	178	136	178	162
2012	195	183	128	175	164
2013	180	182	118	168	159

Note: TV-meter-data, except for Iceland in 2003-2007 (diary surveys). Yearly averages, except for Iceland (data for one week during autumn). Sources: TNUS Gallup Danmark, Finnpanel, Capacent, TNS Gallup Norge, MMS

Although the number of TV-viewers has decreased, approximately seven out of ten Nordic people still watch television on a daily basis, from 66 per cent in Norway to 73 per cent in Finland.

16.11 Eastern Europe

According to Statista:

- Polish linear TV watching time in 2019 is set at 4,16h (250 minutes)[502];
- On average Hungarians watched TV for 280 minutes (4h40m); the young (4-17 years) spent 175 minutes in front of the TV, the middleaged (18-49 years) 209 minutes and older people (50+years) 393 minutes (6h33m) in 2019;
- Romanian audiences spent an average of 330 minutes (5h30m) per day watching television.

16.12 Social media

Many providers are interested in showing the growth of the internet in the media-landscape. Although the accuracy of such data may be limited because of vested interests, we have decided to put forward data from the most cited source, Hootsuite, in the table below.

[501] https://www.nordicom.gu.se/sites/default/files/mediefakta-dokument/Nyhetsbrev_Norden/nordicom_mediatrends_nordic_1-2014.pdf
[502] https://www.statista.com/statistics/1037609/poland-linear-tv-viewing-time/

Table 123. Internet, social media, TV, music streaming and gaming in selected countries 2019
(source: globalwebindex (Q3 2019) figures presented by Hootsuite)

	Internet use	Social media	Watch TV	Music streaming	Games console
Germany	4h 52m	1h 19m	3h 06m	0h 51m	0h 42m
Netherlands	4h 37m	1h 19m	3h 08m	0h 54m	0h 42m
Italy	6h 0m	1h 57m	3h 07	1h 01m	0h 49m
France	5h 08m	1h 42m	3h 19m	0h 58m	0h 56m
Spain	5h 41m	1h 51m	3h 11m	1h 01m	0h54
Poland	6h 26m	2h 00m	3h 18m	1h 13m	0h 43m

television time includes broadcasting (linear) television and content delivered via streaming and video-on-demand services. Use of different devices and consumption of different media may occur concurrently

ANNEX A: GLOSSARY

Source: https://cloudscene.com/glossary (except where grey font)

Big Data	Structured and unstructured data sets that are too large and complex for traditional processing methods to deal with. Challenges include the capture, storage, analysis, sharing and protection of such data. Cabinet: aA metal framed chassis that holds, secures and organizes a vertical stack of network and server hardware, including routers, switches, access points, storage devices and modems. Also known as a rack.
Carrier Hotel	A carrier hotel is a data centre where technology infrastructure connects to a range of telecoms and network service providers. Businesses rent floor space for their servers, storage devices and other IT hardware, while the carrier hotel provides the power, bandwidth, cooling and security. Also known as a colocation centre.
Carrier-Neutral Data Centre	A carrier-neutral data centre facilitates interconnection between numerous telecoms carriers and colocation providers, thus enabling customers to switch providers without physically moving to a new site. Also known as a network-neutral data centre.
Clean and Renewable Energy	Clean or renewable energy refers to power generated from sustainable and environmentally friendly sources such as solar, wind, water and geothermal, with minimum pollution or carbon footprint.
Cloud Computing	Cloud computing is the delivery of software, storage, and other computing services via the Internet (the cloud), rather than being deployed on local hardware. Cloud services are typically charged on a monthly usage basis.
Cloud computing [Cisco]	Cloud computing is[1] the on-demand availability of computer system resources, especially data storage and computing power, without direct active management by the user. The term is generally used to describe data centres available to many users over the Internet. Large clouds, predominant today, often have functions distributed over multiple locations from central servers. If the connection to the user is relatively close, it may be designated an edge server. Clouds may be limited to a single organization (enterprise clouds[1][2]), or be available to many organizations (public cloud). Cloud computing relies on sharing of resources to achieve coherence and economies of scale.
Cloud computing [Baliga 2010]	Can be summarised as "a model for enabling convenient on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction".
Cloud Hosting	In a cloud-hosted solution, customers rent virtual server space instead of physical servers. The virtual partitions draw resources from an array of underlying physical servers installed in a data centre. The physical server itself may be shared with other applications or customers. This is generally considered less secure than a colocation or a VPS.
Cloud On-Ramp	A private, direct connection to the cloud from within a data centre. The connections are usually to major cloud providers such as Amazon Web Services (AWS), Microsoft Azure, Google Cloud, IBM Softlayer, VMWare, Rackspace, Alibaba Cloud and Oracle Cloud. Find Cloud On-Ramps on Cloudscene
Cloud Server	A cloud server is a remote virtual server hosted by a cloud computing service. Cloud servers offer similar functionality to dedicated physical servers, but can be more reliable, scalable, flexible and cost-effective.
Cloud Service Provider	A cloud service provider is an organization that offers cloud-computing services such as IaaS, PaaS or SaaS. These services are typically offered to customers under an on-demand, pay-as-you-go model. Find Service Providers on Cloudscene
Cloud services [Cisco]	Other cloud services are: managed software as a service (MSaaS), mobile backend as a service (MBaaS), information technology management as a service (ITMaaS)
Colocation Centre	A colocation centre (colo) is a data centre where technology infrastructure connects to a range of telecoms and network service providers. Businesses rent floor space for their servers, storage devices and other IT hardware. Also known as a carrier hotel. Find Data Centres on Cloudscene
Cross-connect	A cross-connect is a hardware connection between separate racks/cabinets/infrastructure provided by a data centre. For example, a link between a network and an Internet service provider.
Dark Fibre	Dark fibre is unused optical fibre. Companies that lay cables can gain economies of scale by installing more than is immediately needed, with the excess fibre remaining dark (unlit) until purchased by future customers.

Data Centre	A data centre is a building that hosts servers, storage devices, network equipment and other IT infrastructure. These facilities typically include backup power supplies, redundant communications links, cooling systems, fire suppression and security protection. Find Data Centres on Cloudscene
Data Centre Operator	A data centre operator is a company that runs and manages a facility enabling interconnection between businesses and their customers, partners, networks and IT equipment. Find Data Centre Operators on Cloudscene
Data Centre Security	Data centre security refers to practices that protect data centres from a range of attacks and threats, both physical and digital. Security measures may include biometric authentication, mantraps, armed personnel, firewalls and anti-malware systems. Read about the world's most secure data centres
Dedicated Connectivity	Service Providers that can provide dedicated connectivity but are not direct partners with the Cloud Service Provider.
Dedicated Server	A dedicated server is a form of Internet hosting where the customer leases an entire server not shared with other customers. This gives the organization complete control over the server's operating system and hardware. Also known as a dedicated hosting service.
desktop as a service (DaaS) [Cisco]	Desktop as a service (DaaS) The DaaS provider typically takes full responsibility for hosting and maintaining the computer, storage, and access infrastructure, as well as applications and application software licenses needed to provide the desktop service in return for a fixed monthly fee[5].
Disaster Recovery (DR)	Disaster Recovery is a strategy that mitigates the impact of negative events (such as fire, flood or power failure) by enabling an organization to quickly resume operations following the event. Examples include switching mission-critical functions to a backup location.
Express Routing	Express Routing uses a private connection between a data centre and its customer's infrastructure, avoiding the public Internet and thereby offering higher reliability and lower latency than regular connections.
Geothermal Cooling	With geothermal cooling, a closed-loop coolant-filled piping system runs under the ground around the data centre, using the steady underground temperatures to help cool the facility.
Green Data Centre	A green data centre is one where the power, cooling, lighting, construction and maintenance are designed for maximum energy efficiency, minimum carbon footprint and reduced environmental impact. Read about modern data centres "going green"
Heating, Ventilation and Air Conditioning (HVAC)	HVAC refers to the industry standard technology that provides heating, cooling and air quality services to buildings and vehicles.
Hosted Partner	Service Providers that have direct partnership with the Cloud Service Provider and can provide a hosted connection.
Hybrid Cloud	Hybrid cloud combines and integrates on-premises, private cloud and public cloud services, giving businesses the flexibility to switch workloads to the most efficient platform as needed.
Infrastructure as a Service (IaaS)	IaaS is a cloud-computing model that delivers virtualized computing resources over the Internet, with the hardware (servers, storage, network devices etc.) being provided for and managed by an external service provider.
infrastructure as a service (IaaS) [Cisco]	Iinfrastructure as a service (IaaS) are online services that provide high-level APIs used to derefer various low-level details of underlying network infrastructure like physical computing resources, location, data partitioning, scaling, security, backup etc. [3]
Interconnection Data centre	Interconnection refers to the networking of multiple separate data centres and/or Internet service providers to achieve business or technology objectives. Interconnection allows facilities to share workloads for the most efficient use of resources.
International Business Exchange (IBX)	IBX is a registered trademark of Equinix, and refers to Equinix's network of colocation data centres designed to protect customers' mission-critical data, with high reliability, redundancy, power density and security. Find Equinix data centres on Cloudscene
Internet Exchange (IX)	An Internet exchange is a physical facility through which Internet service providers transfer traffic between their networks using a direct connection, rather than through a third party network. The advantages are reduced cost, lower latency and more efficient bandwidth utilization.
[Global Interconnection Index (GXI) Volume 3]	Internet exchanges were created as physical infrastructure meeting places to facilitate data traffic exchange. These exchanges were built and hosted inside carrier-neutral colocation data centre campuses. The voluntary exchange of traffic among providers became known as peering.

Internet of Things (IoT)	The IoT refers to the global network of smart devices, vehicles, buildings and other objects embedded with intelligent software and sensors that enable these items to communicate and collect data.
Internet Protocol Transit (IP Transit)	Internet Protocol Transit is a service that enables traffic to traverse an ISP's network and connect to the wider Internet.
Intra-Campus Cross-Connect	Intra-campus cross-connect uses fibre optic cables to interconnect clusters of nearby data centres, enabling high-speed data transfer between sites and allowing customers to leverage the combined power of the campus.
Latency Network	Latency is the delay that occurs in transmitting data over a network. High latency can adversely impact the function of many applications.
Managed Hosting	Managed hosting is a provisioning model whereby the hardware is owned by a service provider and leased to a single client, who also pays for ongoing management and maintenance of the infrastructure.
Meet-Me Room	A meet-me room is an area within a colocation data centre where telecoms companies can physically interconnect circuits and exchange data without incurring local loop charges.
Metro Ethernet	Metro Ethernet refers to an Ethernet network deployed across a metropolitan area and used to connect businesses to the Internet, to a larger network, or to other offices.
N+x Redundancy	N+x redundancy is a resiliency strategy that guarantees availability in the event of component failure. If a component, N, has at least one independent backup, then this is known as N+1 redundancy. Two backups would be N+2 and so forth.
Near-net	A near-net location is an area within close proximity to an on-net building. Cloud Pathfinder will display near-net providers that can deliver internet or cloud connectivity within 200 meters of an on-net location.
Network	A network is a group of computer systems linked together. Types of networks include Local Area Network (LAN), Wide Area Network (WAN), Wireless Local Area Network (WLAN), Storage Area Network (SAN) and Metro Area Network (MAN). Networks may be further categorized based on topology, protocol and architecture.
Network Fabric	A network of interconnected data centres enabling internet traffic exchange between networks for service providers, internet service provider (ISPs) and content delivery networks (CDNs).
Network Service Provider (NSP)	A network service provider is a business that offers direct Internet backbone access to ISPs. Examples of NSPs include telecoms companies, data carriers and wireless communications providers. Find Service Providers on Cloudscene
On-net	An on-net location is an enterprise building in which a network service provider can deliver services directly, such as internet or cloud connectivity.
Payment Card Industry Data Security Standards (PCI DSS)	A proprietary security standard for the handling of major branded credit cards, administered by the Payment Card Industry Security Standards Council, and designed to reduce fraud and improve the control of personal card data.
Peering [Global Interconnection Index (GXI) Volume 3]	Peering in carrier-neutral data centre campuses evolved to become IT traffic exchange points, where all types of business-to-business and machine-to-machine traffic integrated direct, private connections between each other with distributed, colocated IT components. These direct, private connections became known generally as interconnection, and are central to an Interconnection Oriented Architecture® (IOA®), in which the distance between users and producers is removed.
Physical Server	A physical server is a hardware-based computing device that provides data to other computers. The term is used to differentiate from software-based virtual servers.
Platform as a Service (PaaS)	PaaS is a cloud-computing model that delivers an environment that enables developers to build apps and services over the Internet, meaning the developers do not need to deploy local hardware and software.
platform as a service (PaaS) [Cisco]	platform as a service (PaaS) is a category of cloud computing services that provides a platform allowing customers to develop, run, and manage applications without the complexity of building and maintaining the infrastructure typically associated with developing and launching an app[4] Examples from Amazon and Google.
Point of Presence (PoP)	A PoP is an interface or demarcation point between communicating entities such as telecoms carriers or Internet service providers. In a colocation data centre, the PoPs will often be situated in a Meet-Me Room.

Power Redundancy	Power redundancy involves the duplication of critical power systems so that power will always remain available in the event of failure of one component. High availability power supplies are often configured as N+1, N+2 and 2N.
Power Usage Effectiveness (PUE)	PUE is an energy efficiency metric developed by a consortium known as 'The Green Grid'. It measures the ratio of total power consumed by a data centre relative to the power used to run its IT equipment. Read about modern data centres "going green".
Private Branch Exchange (PBX)	A PBX is a telephony (telephone or telephony?) system within an organization that switches internal calls between users and allows users to make and receive external calls over shared phone lines.
Private Cloud	A private cloud resides on an organization's intranet or hosted data centre where all hardware, management, maintenance, security and updates are the responsibility of the organization.
Public Cloud	A public cloud resides in a service provider's data centre and the provider is responsible for all management and maintenance. This reduces costs and improves scalability, however security may be less robust than a private cloud solution.
Rack	A metal framed chassis that holds, secures and organizes a vertical stack of network and server hardware, including routers, switches, access points, storage devices and modems. Also known as a cabinet.
Rack Unit	A standard unit of measure used to describe the height of a server mounted on a 19-inch or 23-inch rack. The height of one rack unit is 44.45mm. The common written form is expressed with a "U" eg. 1U = 1 rack unit.
Remote Hands	Remote hands is a service provided by colocation data centres that enables customers to outsource basic IT maintenance tasks to technicians employed by the data centre, thereby allowing customers to focus on their own core business. Remote hands' technicians assist with simple tasks like running cables, checking ports, observing indicators and rebooting servers.
Service Provider	Service providers offer a range of services to other businesses. Services may include networking, communications, legal advice, consulting, data storage, management, maintenance and more. Also refer to Cloud Service Provider. Find Service Providers on Cloudscene
Smart Hands	Smart hands is similar to a remote hands service but involves more complex tasks such as installing equipment, configuring firewalls, circuit testing and troubleshooting. While remote hands' services are often offered at no additional cost, smart hands services are normally billed by the hour.
Software as a Service (SaaS)	SaaS is a cloud-based software distribution model that enables customers to access applications hosted over the Internet (typically via a web browser) and licensed on a subscription basis.
Software as a service (Saas) [Cisco]	Software as a service (Saas) is a software licensing and delivery model in which software is licensed on a subscription basis and is centrally hosted[2].
Storage as a service [Baliga_2010]	Storage as a service (example: iCloud, Google Drive).
Subsea Cable	A subsea cable is a cable laid on the ocean floor between land-based stations and used to transmit telecommunication signals between the world's continents. Modern cables are around 25 mm in diameter with an optical fibre core. Read about Google's latest investment in an APAC subsea cable.
Suite	Data centres offer space options in various sizes, from small cabinets or racks, to multi-rack cages and private suites. A suite is designed for customers seeking a larger enclosed floor space with customer-specific security controls.
Uninterruptible Power Supply (UPS)	A UPS is a device that provides emergency power when the primary power source fails, allowing equipment to continue to operate for a limited time. It can also provide protection from power surges.
Uptime	Uptime is a measure of the time that a piece of equipment is active and operational. It is normally expressed as a percentage – for example, five nines reliability refers to a device that is operational 99.999% of the time.
Virtualization	Virtualization refers to the creation of a logical or virtual version of a computing resource, such as a server, network, operating system or storage device. Virtualization makes more efficient use of IT hardware, allowing for the provision of more flexible, scalable and lower cost services. Virtual Private Server (VPS) A VPS is a virtual machine that resides on a physical machine within a data centre. The VPS runs its own virtual operating system and is

	offered as a service to customers who may install almost any software that is compatible with the OS.
VPN & IP VPN	VPN = Virtual private network, still accessible from public gateways (risk of DDoS) IP VPN = Internet Protocol Virtual Private Network is a VPN that does not use a public gateway but a secure gateway (for instance a dongle).
Wide Area Network (WAN)	A WAN is a computer or telecommunications network in which the interconnected computers extend over a wide geographical distance spanning regions, countries or continents.
Workload and compute instance [CISCO_2016]	A server workload and compute instance is defined as a virtual or physical set of computer resources, including storage, that are assigned to run a specific application or provide computing services for one to many users. A workload and compute instance is a general measurement used to describe many different applications, from a small lightweight SaaS application to a large computational private cloud database application. For the purposes of quantification, we consider each workload and compute instance being equal to a virtual machine or a container.

ANNEX B: THE EVOLUTION OF THE DATA CENTRE

by Jack Woods [https://siliconangle.com/2014/03/05/the-evolution-of-the-data-center-timeline-from-the-mainframe-to-the-cloud-tc0114/]

As mentioned in Wikibon's "The Data Centre: Past, Present and Future" post, "Data centres are at the centre of modern software technology, serving a critical role in the expanding capabilities for enterprises." The concept of "data centres" has been around since the late 1950s when American Airlines and IBM partnered to create a passenger reservations system offered by Sabre, automating one of its key business areas. The idea of a data processing system that could create and manage airline seat reservations and instantly make that data available electronically to any agent at any location became a reality in 1960, opening the door to enterprise-scale data centres.

Since then, physical and technological changes in computing and data storage have led us down a winding road to where we are today. Let's take a brief look at the evolution of the data centre, from the mainframe of yesterday, to today's cloud-centric evolution, and some impacts they've had on IT decision-making.

1946

The Electronic Numerical Integrator and Computer (ENIAC) was built in 1946 for the U.S. Army to store artillery firing codes and was dubbed as the first general-purpose electronic digital computer.

Early 1960s

The first transistorized computer (TRADIC) was introduced in 1954 and was the first machine to use all transistors and diodes and no vacuum tubes. Serious commercial systems did not arrive until the 1960s, leading to mainframes like the IBM System series to develop a substantial jump in compute abilities.

1971

Intel introduced its 4004 processor, becoming the first general-purpose programmable processor on the market. It served as a "building block" that engineers could purchase and then customize with software to perform different functions in a wide variety of electronic devices.

1973

The Xerox Alto becomes the first desktop computer to use a graphical UI and included a bit-mapped high-resolution screen, large internal memory storage, and special software.

1977

ARCnet is introduced as the first LAN, being put into service at Chase Manhattan Bank. It supported data rates of 2.5 Mbps, and connected up to 255 computers across the network.

1978

SunGard develops and establishes the business of commercial disaster recovery.

Note: Prior to the introduction of PC servers, IT decisions revolving around the mainframe had to be made on an absolute enterprise scale for everything from operating system, hardware, and applications. All of these things ran within one device for the entire enterprise, offering limited flexibility and difficult IT decisions.

1980s

Personal computers (PCs) were introduced in 1981, leading to a boom in the microcomputer industry.

Sun Microsystems developed the network file system protocol, allowing a user on a client computer to access files over a network in a manner similar to how local storage is accessed.
Computers were being installed at a rapid rate everywhere we turned, but minimal attention was being given to environmental and operating requirements.

Early 1990s

Microcomputers began filling old mainframe computer rooms as "servers," and the rooms became known as data centres. Companies then began assembling these banks of servers within their own walls.

Mid 1990s

The ".com" surge caused companies to desire fast internet connectivity and nonstop operation. This resulted in enterprise construction of server rooms, leading to much larger facilities (hundreds and thousands of servers). The data centre as a service model became popular at this time.
Note: Thanks to PCs (servers), IT decisions started being made in two separate ways. Servers allowed for application-based decisions, while hardware (data centre) decisions remained at their own enterprise level.

1997

Apple created a program called Virtual PC and sold it through a company called Connectix. Virtual PC, like SoftPC allowed users to run a copy of windows on the Mac computer, in order to work around software incompatibilities.

1999

VMware began selling VMware Workstation, which was similar to Virtual PC. Initial versions only ran on Windows, but later added support for other operating systems.
Salesforce.com pioneered the concept of delivering enterprise applications via a simple website.

2001

VMware ESX is launched – bare-metal hypervisors that run directly on server hardware without requiring an additional underlying operating system.

2002

Amazon Web Services begins development of a suite of cloud-based services, which included storage, computation and some human intelligence through "Amazon Mechanical Turk."

2006

Amazon Web Services begins offering IT infrastructure services to businesses in the form of web services, now commonly known as cloud computing.

2007

Sun Microsystems introduces the modular data centre, transforming the fundamental economics of corporate computing.

2011

Facebook launches Open Compute Project, an industry-wide initiative to share specifications and best practices for creating the most energy efficient and economical data centres.
About 72 percent of organizations said their data centres were at least 25 percent virtual.

2012

Surveys indicated that 38 percent of businesses were already using the cloud, and 28 percent had plans to either initiate or expand their use of the cloud.

2013

Telcordia introduces generic requirements for telecommunications data centre equipment and spaces. The document presents minimal spatial and environmental requirements for data centre equipment and spaces.
Google invested a massive $7.35 billion in capital expenditures in its Internet infrastructure during 2013. The spending was driven by a massive expansion of Google's global data centre network, which represented perhaps the largest construction effort in the history of the data centre industry.

Today and Beyond

Today's datacentres are shifting from an infrastructure, hardware and software ownership model, toward a subscription and capacity on demand model.
In an effort to support application demands, especially through the cloud, today's data centre capabilities need to match those of the cloud. The entire data centre industry is now changing thanks to consolidation, cost control, and cloud support. Cloud computing paired with today's data centres allow IT decisions to be made on a "call by call" basis about how resources are accessed, but the data centres themselves remain completely their own entity.

ANNEX C: ASSESSMENT OF 3D PRINTERS

Introduction

3D printing, also referred to as Additive Manufacturing (AM), is a production technology that is gaining popularity in the market[503]. The fundamental production technique of AM is to put one thin layer on top of another until the desired 3D object is produced. There are many kinds of AM technologies that use this technique. In 2017 the revenue for all AM products and services worldwide was 7.34 billion USD[504]. The revenue is forecast at 15.8 billion USD in 2020 and 35.6 billion USD in 2024[505], which corresponds to an expected growth of 385% from 2017 to 2024.
AM has been known to designers since the 1980s and is mainly used to create rapid prototypes in 3D shapes. The price of 3D printers has decreased rapidly during the last decade and it is now possible to buy a 3D printer that prints prototypes for the price of about 230 EUR[506]. It is also possible to find cheaper printers for leisure use and there is a market for very expensive professional printers that are used in the space industry and in the medical industry, where prints are produced in high quality plastic or metal.

Product scope of 3D printers

In this report the most common 3D technologies will be shortly introduced. 3 main target groups for the 3D printers have been identified based on the classification used in the industry[507], see Table 124.

Table 124 - *Categorisation of 3D printers.*

Market type	Description	Price range USD[508,509]
Desktop 3D printers – leisure	Low price printers sold for hobby and leisure use	0-2,000
Desktop 3D printers – Professionals	Design studios, manufacturing companies that create prototypes, makerspaces, labs, workshops, schools and universities	500-5,000
Industrial printers	Large printers that use advanced technologies e.g. to print metal objects for the space industry. Printers that are used for large scale production	5,000+

503 https://www.forbes.com/sites/tjmccue/2019/03/27/wohlers-report-2019-forecasts-35-6-billion-in-3d-printing-industry-growth-by-2024/#62afce1c7d8a

504 https://www.forbes.com/sites/tjmccue/2019/03/27/wohlers-report-2019-forecasts-35-6-billion-in-3d-printing-industry-growth-by-2024/#62afce1c7d8a

505 https://www.forbes.com/sites/tjmccue/2019/03/27/wohlers-report-2019-forecasts-35-6-billion-in-3d-printing-industry-growth-by-2024/#3c9c3d557d8a

506 https://www.amazon.com/Comgrow-Creality-Printer-Upgrade-Certified/dp/B07GYRQVYV/ref=sr_1_3?keywords=3D+printer&qid=1578298073&sr=8-3

507 https://www.forbes.com/sites/tjmccue/2019/03/27/wohlers-report-2019-forecasts-35-6-billion-in-3d-printing-industry-growth-by-2024/#4ddbd92d7d8a

508 https://www.idtechex.com/de/research-article/who-buys-consumer-level-3d-printers/7519

509 https://www.forbes.com/sites/tjmccue/2019/03/27/wohlers-report-2019-forecasts-35-6-billion-in-3d-printing-industry-growth-by-2024/#4ddbd92d7d8a

The overall AM market continues to trend upward. However, this growth is mainly caused by the growth of industrial printers, as the desktop printers below 5,000 USD are declining in sales[510].

Nonethelss , the scope of the current study focuses on desktop printers for professional purposes and for leisure in a price range of 0 USD to 5,000 USD. Industrial printers are not included in the product scope of this project, because they are mainly used for advanced special-purpose printing e.g. printing components for the space industry, for medical application or for large scale production.

Product type and specific energy consumption

3D printers use a variety of technologies to create 3D objects, but common to all of them is the fact that objects are built layer by layer in a desired shape by heating up a material. This requires a heating device e.g. a heated nozzle or a laser beam to melt the material, motors for positioning the heating device, a roller device for adding material, fans for cooling and a computer unit that processes data. Below the components of a Fused Deposition Modelling (FDM) printer is illustrated, but bear in mind that the components and thus the energy use of other technologies are different e.g. Selective Laser Sintering (SLS) where a laser beam is used to melt material instead of a heated nozzle.

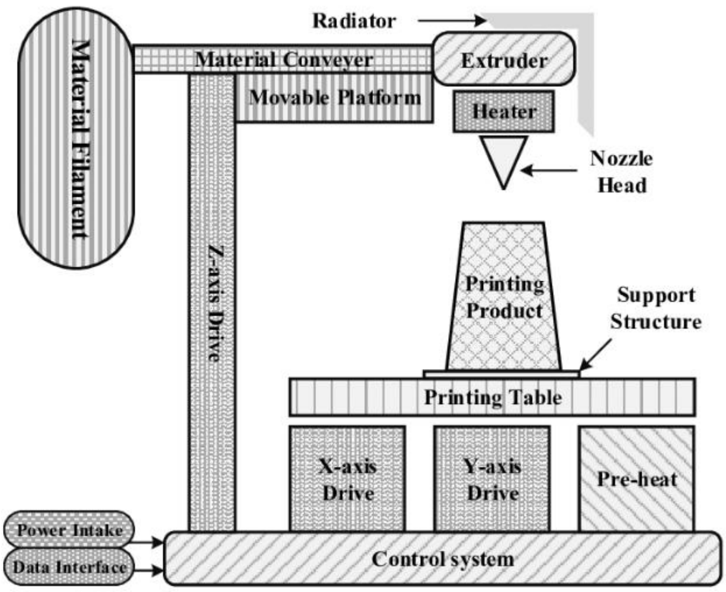


Figure 108 - *Schematic of an FDM printer[511].*

[510] https://www.forbes.com/sites/tjmccue/2019/03/27/wohlers-report-2019-forecasts-35-6-billion-in-3d-printing-industry-growth-by-2024/#4ddbd92d7d8a

[511] Peng, T. (2016). Analysis of Energy Utilization in 3D Printing Processes. Procedia CIRP.

In Table 125, the different AM process types are described and the Specific Energy Consumption (SEC) is represented in terms of consumption per kg of finished product. A variety of different technologies for 3D printing exist on the market, but since the industrial printers are excluded from the product scope, only the most common technologies used in desktop printers are presented here. The SEC data are from a study made by Yoon, H. et. al.[512] who compares studies from other researchers who have tested different 3D printing technologies. Some of the data therefore, go back to 2010, but the average of the data gives an indication of the energy consumption of the different 3D printer technologies. A more detailed introduction to 3D printer technologies can be found at ALL3DP.com[513].

Table 125 - *Description of technology and Specific Energy Consumption related to weight of finished product.*

Technology	Brief description	Printing materials	Specific Energy Consumption (SEC) (kWh/kg)
Fused Deposition Modelling (FDM)	Material is selectively dispensed through a nozzle or orifice	Polymers	23.08-163.69 346.4 148.89 48.1-61.4
Average			161
Selective laser sintering (SLS)	Thermal energy selectively fuses regions of a powder bed	Metals and polymers	29.83-40.09 36.04 14.5 29.72 56.75-66.02 26.3-39.8
Average			211
Stereolithography (SLA)	Liquid photopolymer in a vat is selectively cured by light-activated polymerisation	Photopolymers	20.70-41.38
		Average	31

Data in table is collected and adapted from reports on energy consumption of 3D printers by Verhoef, L. Et. Al.[514] (2018).

Sales and Stock

In 2018, 528,952 desktop printers (unit price less than 5,000 USD) were sold worldwide according to Wholers report of 2018[515]. The market size and year-by-year growth rate for the worldwide market is represented in USD in Table 126.

[512] Yoon, H. S., Lee, J. Y., Kim, H. S., Kim, M. S., Kim, E. S., Shin, Y. J., Chu, W. S., & Ahn, S. H. (2014). A comparison of energy consumption in bulk forming, subtractive, and additive processes: Review and case study. International Journal of Precision Engineering and Manufacturing - Green Technology.

[513] https://all3dp.com/1/types-of-3d-printers-3d-printing-technology/

[514] Verhoef, L. A., Budde, B. W., Chockalingam, C., García Nodar, B., & van Wijk, A. J. M. (2018). The effect of additive manufacturing on global energy demand: An assessment using a bottom-up approach. Energy Policy.

[515] https://www.forbes.com/sites/tjmccue/2018/06/04/wohlers-report-2018-3d-printer-industry-rises-21-percent-to-over-7-billion/#35c2b86d2d1a

It has not been possible to find sales numbers of 3D printers sold in Europe alone. Therefore, the worldwide economic output (GDP), has been used to estimate an EU market share (of sold 3D printers) that is equivalent to EU economic output (GDP). In 2018 the EU generated 16.3% of the total economic (GDP) output[516].
If the market share of sold 3D printers in the EU corresponds to the economic output, it can be assumed that 86,219 3D desktop printers were sold in the EU in 2018 (out of 528,852 Worldwide[517]) and 45,036 3D desktop printers in 2015 (out of 278,000 Worldwide[518]). There was no available data for sales of 3D desktop printers for the other years. Therefore, sales numbers for all other years have been estimated and forecast at a growth rate that corresponds to the year-by-year growth in total AM manufacturing. The year-by- year growth rate from 2021 to 2030 has been estimated by Wohler to grow at CAGR 23.5% from 2019 to 2023[519]. This growth rate has been estimated to continue until 2030.
In 2009, the FDM printing process patent expired, which drove down the cost of FDM printers and made 3D printing available for the mass market[520]. Before 2009 3D printing was only used by specialised industries and researchers; no data has therefore been provided for the years before 2008.

Table 126 - Worldwide market value development. Yellow is forecast- or estimated by author of the report. Green is actual numbers reported by other sources. Blue is forecasted by other source.

Market value development	2008	2010	2015	2020	2025	2030
Market size AM manufacturing worldwide /million USD)	987	1,540	5,200	15,800	45,393	130,415
Year on year growth	20%	20%	15%	22%	24%	24%

The historic stock development for 3D desktop printers can be seen in
Table 127. The stock numbers for 3D printers have been calculated using the annual sales also presented in the table and applying a normal distribution, assuming an estimated lifetime (see next section) as the mean, and the standard deviation of 1. The annual sales and the normal distribution based on the lifetime were used to establish the stock.

Table 127 - Sales and Stock. Yellow is for- or backcasted by author of the report. Green is actual numbers reported by other sources.

Sales and stock	2008	2010	2015	2020	2025	2030
Unit sales EU (units)	8,549	13,336	45,036	133,555	383,703	1,102,375
Stock (units)	8,549	28,244	134,268	433,426	1,291,628	3,729,152

516 https://www.thebalance.com/world-s-largest-economy-3306044
517 https://www.forbes.com/sites/tjmccue/2018/06/04/wohlers-report-2018-3d-printer-industry-rises-21-percent-to-over-7-billion/#35c2b86d2d1a
518 https://www.forbes.com/sites/tjmccue/2018/06/04/wohlers-report-2018-3d-printer-industry-rises-21-percent-to-over-7-billion/#35c2b86d2d1a
519 https://downloads.3dhubs.com/3D_Printing_Trends_Q1_2019.pdf?utm_campaign=Gated%20Content%20Downloads&utm_source=hs_automation&utm_medium=email&utm_content=79739036&_hsenc=p2ANqtz--BDChoHHvpKbJUKNKTT2y_ElYmSG15eBZF1C35fna-Paj9gmTxsXI3T3xp2ZAbfQKZ42saJbsrjogO0CkofO4wf7uKbg&_hsmi=79739036
520 https://www.fisherunitech.com/blog/history-of-3d-printing

Expected lifetime

It has not been possible to find data on expected lifetime for 3D printers. This is perhaps because most of the desktop printers have been produced and sold during the last 5-8 years. and have therefore been in use for too brief a period of time to allow for their average lifetime to be accurately measured.

Many of the printers have been developed by DIY companies e.g. Ultimaker and Makerbot[521], which means it is relatively easy to buy new spare parts and change them. However, some of them probably get replaced as new and better printers are developed. To obtain an estimated expected lifetime, 3D printers have been compared to regular printers, as regular printers have a long history of use and similar components, such as motors, bearings, a laser beam, a frame, software and hardware. The expected lifetime of a regular printer is approximately 6 years according to a review study. The same lifetime has been assumed for the 3D printers.

With an expected lifetime of 6 years the current stock on the European market is estimated to be about 433,000 printers in 2020.

Power consumption of 3D printers

In Table 128, the average power consumption of several 3D printers is provided. Data for most of the printers in the table comes from testing, where the power consumption has been measured over time, and calculating an average power consumption. However, it has not been possible to find data for average power consumption for all the printers and an estimation has therefore been made for some of the printers, based on the stated maximum power consumption and using the ratio for average to maximum power consumption of the other tests.

The printers have been selected based on: relevant studies of low-cost printers; relevant representation product types for the scope of the current study; high market share; popularity on online marketplaces such as Amazon and product tests reported by public and credible sources. An average of the average power consumption of the printers has been calculated and will be used to make further estimations of total energy consumption.

[521] https://3dsourced.com/3d-printers/history-of-3d-printing/

Table 128 – *Average power consumption of selected 3D printers.*

Printer	Technology	Average power consumption (W)	Source
Professional printers			
Creator Pro	FDM	250	https://3dprintingmentor.com/how-much-power-do-3d-printers-use-and-what-does-that-cost/
Lumen X (Cellink)	SLS	100	https://cellink.com/global/bioprinting/lumen-x/
Ultimaker S5	FDM	300[522]	https://ultimaker.com/3d-printers/ultimaker-s5
Replicator 2x – 2	FDM	120	Walls, S., Corney, J., & Vasantha, G. (2014).
Average professional 190			
Leisure use printers			
Makerbot Cupcake CNC	FDM	50	Walls, S., Corney, J., & Vasantha, G.[523]
Ender 3 Pro (Creality)	FDM	100	Study team's own test
Mars LCD (Elego)	SLS	40[524]	https://www.amazon.com/ELEGOO-Photocuring-Printer-Off-line-Printing/dp/B07K2ZHMRF/ref=sr_1_4?keywords=sls%2Bprinter&qid=1578477339&sr=8-4&th=1
i3 MK3	FDM	200	https://3dprintingmentor.com/how-much-power-do-3d-printers-use-and-what-does-that-cost/
MINI Delta	FDM	60	https://3dprintingmentor.com/how-much-power-do-3d-printers-use-and-what-does-that-cost/
Ultimaker Original	FDM	60	Walls, S., Corney, J., & Vasantha, G.[28]
Average leisure		90	

Usage of 3D printers and total energy consumption

Usage is based on the load time, defined as the total number of hours the 3D printers are running. The load time is determined by how often the printer is used and for how long it is running each time. It has not been possible to find numbers for load time of 3D printers. However, one study has been found, which shows that 83 % of the users[525] of low-cost desktop 3D printers used them several times a week. There are no statistics on what the users are printing and how long it takes. A print can take anywhere between 10 minutes and several days, depending on the printer, settings, size and geometry of the printed object etc. A few examples are therefore provided here, and an estimate of average approximate print time is based on that:

- 4 minutes for a 2x4 Lego piece;
- 20 minutes for cell phone case;
- 2 hours for a baseball; and
- between 1-5 hours to print a small toy[526].

Based on the examples above it is assumed, that the leisure user will make a print 2 times a week each with a duration of 3 hours. Load time is therefore equal to 6 hours a week and a total load time of 312 hours per year. With a load time of 312 hours, the printer is utilized 3.5% of the year. The energy consumption of a printer used for leisure is shown in Table 129.

[522] Maximum power consumption is 500 W, an estimate of average power consumption of 300 W has been made by the authors.

[523] Walls, S., Corney, J., & Vasantha, G. (2014). Relative Energy Consumption of Low-Cost 3D Printers. Pure.Strath.Ac.Uk.

[524] Maximum power consumption is 60 W, an estimate of average power consumption of 40 W has been made by the authors

[525] https://3dprintingindustry.com/news/personal-3d-printing-user-study-indicates-market-evolving-18122/

[526] https://3dprinterly.com/how-long-does-it-take-to-3d-print/

Professionals are also a large user group of 3D printers and it is assumed that professionals use the 3D printer for almost all working hours during the week. A case with a professional utilisation degree of 40% has therefore been calculated in Table 129.
In Table 129, a case with a utilisation of 100% has been calculated, the case assumes that the printers are used as much as possible e.g. if a printer is installed in an office space for shared use. The case also serves as a worst-case example because there are many uncertainties in the data.

Table 129 - *Total annual energy consumption*

Case	Leisure case	Professional case	100% utilisation
Average estimated power use [W]	90	190	190
Average estimated load time (hours/year)	312	3506	8760
Annual energy consumption (kWh/year/printer)	28	666	1665
Stock 2020 (units)	243,441[527]	243,441[528]	486,883
Total energy consumption of 3D printers 2020 (GWh)	7	162	810

The bigger perspective

Even though, the market for 3D printers is growing rapidly it still makes up a very small part of the European manufacturing market and this is also shown by the relatively low total energy consumption represented by 3D printers. The annual energy consumption of regular printers is estimated to be 7400 GWh[529], even if assuming a 100 % utilisation of all printers, 3D printing still only makes up 11 % of the energy that regular printers use.

Best Available Technology (BAT)

It has not been possible to find any major energy comparison studies for this task that can be used to determine the BAT. The energy consumption value provided in this document is based on an average between many different 3D printers and different 3D printing technologies. Taking the 3D printer with the lowest energy consumption and comparing it to the average is therefore not possible because the energy consumption is, to a high degree, dependent upon the quality of the print. A 3D printer that prints to a high standard will typically use more energy, because in order to attain high quality, a longer printing time is needed to add more infill and several thinner layers depending on the material used. Further studies of energy consumption and quality based on different 3D printers and 3D printing technology is thus needed to determine the actual energy consumption and BAT.
It is still possible to find the capacity for energy improvement of 3D printers. A huge part of the energy consumption comes from the heating of the print bed. Some printers come with an "ECO" setting[530] that will turn off the print bed after the first few layers are printed.This is because the print bed is mainly used to make the part stick and to prevent it from warping as this is the part that is more exposed during the putting down of the

[527] Half of the desktop printers are estimated to be sold to leisure users based on prediction from IDTechEx: https://www.idtechex.com/de/research-article/who-buys-consumer-level-3d-printers/7519
[528] Half of the desktop printers are estimated to be sold to professional users based on prediction from IDTechEx: https://www.idtechex.com/de/research-article/who-buys-consumer-level-3d-printers/7519
[529] https://www.review-imagingequipment.eu/documents
[530] https://whambamsystems.com/blog/f/turning-off-the-eco-setting-on-a-cr-10s

first layers. Other printers use an enclosure to prevent the heat going into the air which will cause less energy consumption to heat the nozzle and the print bed[531]. Some printers will only turn off the heating elements (the print bed and nozzle) when the print is complete , but the electronics that power the computer and cooling fans will still be running at full capacity until the printer is shut off by the user.

The development of 3D printing equipment is still relatively new, compared to e.g. the equipment used to print pages. In this document it is therefore assumed that 3D printing equipment can achieve some of the same energy savings as regular printers, just by providing smarter settings such as sleep mode, standby mode and only providing heat when needed. An estimated energy reduction of 25% is therefore suggested. This would correspond to the energy reduction requirements suggested by the review study of imaging equipment assuming it is possible to reach the same energy savings as for regular printers (14-26%). See the resulting consumption levels in Table 130.

Table 130. – *BAT energy consumption levels*

Imaging equipment type	Average (kWh/year/printer)	Estimated reduction	Estimated BAT (kWh/year/printer)
3D printer (professional case)	666	25%[532]	500

[531] https://pinshape.com/blog/guide-green-3d-printing/

ANNEX D: CHARACTERISTICS OF SURVEYS

EC DG COMM, Media Use in the European Union, Eurobarometer 88, 2018 (Field November 2017)

Population aged 15+

	COUNTRIES	INSTITUTES	N° INTERVIEWS	DATES FIELDWORK		POPULATION 15+	PROPORTION EU28
BE	Belgium	TNS Dimarso	1.005	05/11/2017	13/11/2017	9.693.779	2,25%
BG	Bulgaria	TNS BBSS	1.051	05/11/2017	12/11/2017	6.537.535	1,52%
CZ	Czech Rep.	TNS Aisa	1.021	05/11/2017	13/11/2017	9.238.431	2,14%
DK	Denmark	TNS Gallup DK	1.000	05/11/2017	14/11/2017	4.838.729	1,12%
DE	Germany	TNS Infratest	1.565	05/11/2017	12/11/2017	70.160.634	16,26%
EE	Estonia	TNS Emor	1.009	05/11/2017	13/11/2017	1.160.064	0,27%
IE	Ireland	Behaviour & Attitudes	1.001	05/11/2017	13/11/2017	3.592.162	0,83%
EL	Greece	TNS ICAP	1.008	05/11/2017	13/11/2017	9.937.810	2,30%
ES	Spain	TNS Spain	1.008	05/11/2017	13/11/2017	39.445.245	9,14%
FR	France	TNS Sofres	1.072	05/11/2017	12/11/2017	54.097.255	12,54%
HR	Croatia	HENDAL	1.094	05/11/2017	12/11/2017	3.796.476	0,88%
IT	Italy	TNS Italia	1.034	05/11/2017	12/11/2017	52.334.536	12,13%
CY	Rep. Of Cyprus	CYMAR	500	05/11/2017	12/11/2017	741.308	0,17%
LV	Latvia	TNS Latvia	1.018	05/11/2017	12/11/2017	1.707.082	0,40%
LT	Lithuania	TNS LT	1.013	05/11/2017	14/11/2017	2.513.384	0,58%
LU	Luxembourg	TNS ILReS	507	05/11/2017	13/11/2017	457.127	0,11%
HU	Hungary	TNS Hoffmann	1.039	05/11/2017	12/11/2017	8.781.161	2,04%
MT	Malta	MISCO	503	05/11/2017	12/11/2017	364.171	0,08%
NL	Netherlands	TNS NIPO	1.034	05/11/2017	13/11/2017	13.979.215	3,24%
AT	Austria	ipr Umfrageforschung	1.016	05/11/2017	13/11/2017	7.554.711	1,75%
PL	Poland	TNS Polska	1.014	05/11/2017	13/11/2017	33.444.171	7,75%
PT	Portugal	TNS Portugal	1.076	05/11/2017	12/11/2017	8.480.126	1,97%
RO	Romania	TNS CSOP	1.062	05/11/2017	12/11/2017	16.852.701	3,91%
SI	Slovenia	Mediana	1.009	05/11/2017	13/11/2017	1.760.032	0,41%
SK	Slovakia	TNS Slovakia	1.044	05/11/2017	13/11/2017	4.586.024	1,06%
FI	Finland	TNS Gallup Oy	1.016	05/11/2017	13/11/2017	4.747.810	1,10%
SE	Sweden	TNS Sifo	1.002	05/11/2017	14/11/2017	7.998.763	1,85%
UK	United Kingdom	TNS UK	1.334	05/11/2017	14/11/2017	52.651.777	12,20%
		TOTAL EU28	28.055	05/11/2017	14/11/2017	431.452.219	100%*

* It should be noted that the total percentage shown in this table may exceed 100% due to rounding

CY(tcc)	Turkish Cypriot Community	Lipa Consultancy	500	05/11/2017	12/11/2017	143.226
TR	Turkey	TNS Piar	1.005	05/11/2017	19/11/2017	56.770.205
MK	Former Yugoslav Republic of Macedonia	TNS BRIMA	1.040	05/11/2017	09/11/2017	1.721.528
ME	Montenegro	TNS Medium Gallup	532	05/11/2017	12/11/2017	501.030
RS	Serbia	TNS Medium Gallup	1.011	05/11/2017	13/11/2017	6.161.584
AL	Albania	TNS BBSS	1.050	05/11/2017	12/11/2017	2.221.572
		TOTAL	33.193	05/11/2017	19/11/2017	498.971.364

Survey results are estimations, the accuracy of which, everything being equal, rests upon the sample size and the observed percentage. With samples of about 1000 interviews, the real percentages vary within the following confidence limits.

Statistical Margins due to the sampling process
(at the 95% level of confidence)

various sample sizes are in rows *various observed results are in columns*

	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	
	95%	90%	85%	80%	75%	70%	65%	60%	55%	50%	
N=50	6.0	8.3	9.9	11.1	12.0	12.7	13.2	13.6	13.8	13.9	N=50
N=500	1.9	2.6	3.1	3.5	3.8	4.0	4.2	4.3	4.4	4.4	N=500
N=1000	**1.4**	**1.9**	**2.2**	**2.5**	**2.7**	**2.8**	**3.0**	**3.0**	**3.1**	**3.1**	**N=1000**

Netherlands

SKO kijkonderzoek.

https://www.gids.tv/artikel/1754/hoe-worden-de-kijkcijfers-gemeten
For monitoring of TV-viewing data SKO uses a consumer-panel of about 2800 persons divided over 1250 households to generate representative data through monitoring-boxes that register the programs being watched (on the main TV) and –through a remote control operated by the viewers— the persons in the households watching. Viewing behaviour on secondary TVs is not monitored.

The time-expenditure study Het Media:Tijd-onderzoek is a collaboration of the Sociaal en Cultureel Planbureau (http:// www.scp.nl) and research organisations in the field of media, i.e. the Nationaal Luister Onderzoek (NLO (http://www.nationaalluisteronderzoek.nl/)), Nationaal Onderzoek Multimedia (NOM (http://www.nommedia.nl/)) and Stichting KijkOnderzoek (SKO (http://www.kijkonderzoek.nl/)). Also in 2018 the Platform Media-adviesbureaus (PMA (http://pma-bureaus.nl/)) participated. The department of audience research (Publieksonderzoek) of the Nederlandse Publieke Omroep (NPO (https://over.npo.nl/)) also contributed. Market research organisation Gfk (https://www.gfk.com/nl/) was responsible for the measurements in the field, which took place between end of August and mid October 2018 with persons of 13 years and older in private households. The sample-size consisted of 2655 respondents, using either a diary or online means for registration of their time expenditure.

Belgium

IPB Life Observer 2018
https://www.ipb.be/sites/default/files/ip-book-lo-a5-nl-web.pdf
The study was performed in February 2018 in collaboration with GfK holding, an online survey amongst 4214 persons aged between 18 and 64 years. The sample, divided equally over 7 weekdays, was chosen to be representative of region, gender, age and education attainement levels. Respondents registered for 54 activity-types and how they had spent the previous day, registering start- and end-time. Single task media activities were considered primary and multi-task media activities as secondary.

Germany

The AGF TV-viewer panel (D. Fernsehpanel) consists of 5.400 households with a total of 11,000 people. Since 01.01.2016 the reference basis is a German population of 38.584 million households with 74.498 million persons of 4 years or older with at least one TV and a German-speaking head of household.

The 2012/2013 German time-expenditure study (D. Zeitverwendungserhebung ZVE), published in 2015, was performed in collaboration with the statistics offices of the regions (D. Länder) and –in order to avoid seasonal influences—spread over a year, from August 2012 till July 2013. The survey resulted in data from 5040 households with 11,371 persons older than 10 years of age. In total, the data from 33,842 diaries with 165 types of activity were aggregated to overall German statistics using the census data 2012 (D. Mikrozensus).

Italy

The AGCOM study is based on a GfK survey in 2017 amongst over 14,000 persons, representative of the Italian population at national and regional level of age 14 years and above .

France

The 2010 INSEE time-expenditure survey (F. emploi du temps), included for the first time children from age 11 to 14 years old. As such, 17 383 persons in the French metropolitan area participated in a diary survey of a full day (weekday and/or weekend day) between March 2010 and September 2010. A portion of the participants also indicated their satisfaction (scale -3 to +3) with their activities for time periods of 10 minutes. A distinction was made between primary activities and secondary activities (e.g. eating in front of the TV).

REFERENCES

Task 1 References

1 Introduction

1. https://ec.europa.eu/eurostat/help/faq/brexit
2. www.cisco.com
3. https://www.itu.int/online/mm/scripts/gensel29?_search_region=B&_languageid=1
4. http://istizada.com/list-of-emea-countries/

2 Group I. -Data centres

1. https://tweakers.net/nieuws/153918/totaal-vermogen-nederlandse-datacenters-stijgt-naar-1391mw.html
2. Commission Regulation (EU) 2019/424 of 15 March 2019 laying down ecodesign requirements for servers and data storage products pursuant to Directive 2009/125/EC of the European Parliament and of the Council and amending Commission Regulation (EU) No 617/2013
3. SNIA Emerald™ Power Efficiency Measurement Specification
4. ENERGY STAR® Program Requirements for Large Network Equipment
5. Carl Cottuli, Comparison of Static and Rotary UPS, Revision , by Schneider Electric
6. https://blog.se.com/datacenter/2011/09/15/for-data-center-energy-efficiency-hot-aisle-beats-cold-aisle-containment/
7. https://www.grcooling.com/iceraq
8. Cloudscene_2019: data extracted from website november 2019 [https://cloudscene.com/browse/data-centers]
9. https://cloudscene.com/datacenters-in-europe (accessed 26-11-2019)
10. Range International Information Group, Langfang, China. https://www.datacenters.com/news/and-the-title-of-the-largest-data-center-in-the-world-and-largest-data-center-in
11. GXIv3_2019: Global interconnection Index v3, 2019 by Equinex [https://www.equinix.com/gxi-report/]
12. Source: Data center growth in the United States: decoupling the demand for services from electricity use: Arman Shehabi et al 2018 Environ. Res. Lett. 13 124030
13. www.snia.org/sites/default/files/emerald/Training/EmeraldTraining_Feb-Mar2018/
14. AEmeraldTraining_Feb-Mar2018_Storage_Taxonomy_Emerald_3.0.1.pdf
15. https://ec.europa.eu/transparency/regdoc/rep/10102/2019/EN/SWD-2019-106-F1-EN-MAIN-PART-1.PDF
16. Bio by Deloitte with Fraunhofer IZM, Lot 9 -Ecodesign Preparatory Study on Enterprise Servers and Data Equipment, for the EC, July 2015. https://op.europa.eu/en/publication-detail/-/publication/6ec8bbe6-b8f7-11e5-8d3c-01aa75ed71a1
17. VHK, Ecodesign Impact Accounting 2018, for the EC, 2019.
18. OJ L 346, 20.12.2016, p. 1–50
19. Cisco, Annual internet report, 2016
20. Chen, Yiming Miao, Xin Jian, Xiaofei Wang, Iztok Humar, Cognitive-LPWAN: Towards Intelligent Wireless Services in Hybrid Low Power Wide Area Networks, 2018. https://arxiv.org/pdf/1810.00300.pdf
21. https://newsroom.cisco.com/press-release-content?type=webcontent&articleId=1955935
22. AGCoombs_2018: https://www.agcoombs.com.au/news-and-publications/advisory-notes/improving-data-centre-infrastructure-efficiencies-2/ (accessed Jan 2020)
23. https://www.google.com/about/datacenters/efficiency/
24. Japan Electronics and Information Technology Industries, www.jeita.or.jp
25. DPPE: Holistic Framework for Data Centre Energy Efficiency - KPIs for Infrastructure, IT Equipment, Operation (and Renewable Energy), Japan National Body/Green IT Promotion Council, August 2012
26. Eric Masanet, Arman Shehabi, Nuoa Lei, Sarah Smith, Jonathan Koomey, Recalibrating global data center energy-use estimates, Science 28 Feb 2020: Vol. 367, Issue 6481, pp. 984-986, DOI: 10.1126/science.aba3758
27. https://eta.lbl.gov/sites/all/files/publications/lbnl-1005775_v2.pdf
28. Data center growth in the United States: decoupling the demand for services from electricity use: Arman Shehabi et al 2018 Environ. Res. Lett. 13 124030
29. Environmental Engineering (EE): Energy Efficiency measurement methodology and metrics for servers, Draft ETSO EN 303 470 V1.0.0 (2018-06)

30. https://www.ams-ix.net/ams/documentation/colocation-traffic-ams
31. https://www.nextplatform.com/2019/03/20/how-to-benefit-from-facebooks-new-network-fabric/
32. Ricardo-AEA, ErP Lot 27 – Uninterruptible Power Supplies, Ecodesign preparatory study for the European Commission DG ENER, June 2014.
33. Commission Regulation (EU) 2019/424 of 15 March 2019 laying down ecodesign requirements for servers and data storage products pursuant to Directive 2009/125/EC of the European Parliament and of the Council and amending Commission Regulation (EU) No 617/2013
34. https://ec.europa.eu/jrc/en/news/eu-code-conduct-data-centres-10-years-improved-energy-efficiency
35. https://ec.europa.eu/jrc/en/news/eu-code-conduct-data-centres-10-years-improved-energy-efficiency
36. https://international.eco.de/topics/datacenter/white-paper-utilization-of-waste-heat-in-the-data-center/
37. https://cloudscene.com/news/2017/07/greendatacenters/ Published 26 July 2017
38. https://cloudscene.com/news/2019/03/data-center-giants-invest-in-renewable-energy/
39. https://sustainability.aboutamazon.com/pdfBuilderDownload?name=goals&name=sustainable-operations&name=sustainability-in-the-cloud
40. https://www.forbes.com/sites/energyinnovation/2018/04/12/google-and-apple-lead-the-corporate-charge-toward-100-renewable-energy/#20d38bb91b23
41. fd_2020: 'Ecomodus' op server moet Amsterdam forse stroombesparing opleveren, financieel dagblad (https://fd.nl/, accessed 21-2-2020)
42. SNIA (Storage Networking Industry Association) Emerald™ Program
43. Computing terminology differs from SI and distinguishes between Mi = 1,000,000 and M=1,048,576. It is also measuring in B = Bytes not b=bits. 8bits=1Byte.
44. Technical assistance study for the assessment of the feasibility of using "points system" methods in the implementation of Ecodesign Directive (2009/125/EC). Task 5. Extended Case study: Data Storage System. Final report. June 2017
45. Nokia 7950 Extensible Routing System
46. https://lafibre.info/images/datacenter/201703_Nokia_7950_XRS_R15.pdf
47. https://www.reportbuyer.com/product/5741687/data-center-ups-market-global-outlook-and-forecast-2019-2024.html
48. http://www.fchea.org/in-transition/2018/11/12/whs20dthibvg3pvhfjekribqhs0bbt
49. applied by Google's environmentally data centre in Hamina, Finland
50. Apparently used by Facebook
51. https://www.datacenterknowledge.com/facebook/facebook-s-new-data-center-cooling-design-means-it-can-build-more-places
52. https://adeptdc.com/
53. https://www.datacenterknowledge.com/design/robot-monitors-data-center-cooling-behind-closed-cabinet-doors

3 Group II.-Telecom Networks

1. https://www.itu.int/pub/R-REG-RR-2012
2. www.itu.int
3. standards.ieee.org
4. www.etsi.org
5. International Standards Organisation www.iso.org
6. International Electrotechnical Commission, www.iec.ch
7. Internet Engineering Task Force, www.ietf.org
8. https://ictfootprint.eu
9. https://www.ghgprotocol.org/sites/default/files/ghgp/GHGP-ICTSG%20-%20ALL%20Chapters.pdf
10. http://www.techteledata.com/how-submarine-cables-are-made-laid-operated-and-repaired/
11. https://peering.google.com/#/infrastructure
12. https://www.reddit.com/r/Stadia/comments/b58pmg/google_said_they_have_over_7000_edgenode_locations/
13. http://www.satsig.net/ or SES Annual report at https://www.ses.com/sites/default/files/SES_AR_2018_A4_0319_web_0.pdf
14. https://www.esa.int/Applications/Telecommunications_Integrated_Applications/Satellite_frequency_bands
15. In legacy Ecodesign regulation (EC) No 107/2009 of 4 February 2009 called a Simple Set Top Box SSTB
16. https://www.ftthcouncil.eu/documents/FTTH%20Council%20Europe%20-%20Panorama%20at%20September%202018.pdf
17. https://www.howtonetwork.org/design/ccda/chapter-1-network-fundamentals/network-fundamentals-the-osi-model/
18. http://esc.microsemi.com/cgi-bin/download_p.pl?res_id=350921&filename=2171507_Microsemi_META-DX1_Product_Brief_350301.pdf

19. https://www.lightreading.com/gigabit/wireless-satellite/onewebs-leo-satellites-clock-400-mbit-s-latency-of-32-ms-in-initial-tests/d/d-id/752812
20. https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20200127-1?inheritRedirect=true&redirect=%2Feurostat%2Fweb%2Fdigital-economy-and-society%2Fpublications
21. https://ec.europa.eu/eurostat/statistics-explained/index.php/Cloud_computing_-_statistics_on_the_use_by_enterprises#Use_of_cloud_computing:_highlights
22. https://ec.europa.eu/eurostat/statistics-explained/index.php/Cloud_computing_-_statistics_on_the_use_by_enterprises#Use_of_cloud_computing:_highlights
23. http://www.euro.who.int/en/health-topics/Health-systems/e-health/data-and-statistics
24. https://ec.europa.eu/health/ehealth/overview_en
25. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2018:233:FIN
26. https://ec.europa.eu/digital-single-market/en/node/81744
27. https://ec.europa.eu/digital-single-market/en/sitemap
28. https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2019.pdf
29. ITU, Measuring the Information Society Report 2018, Volumes 1 and 2, 2019.
30. https://data.consilium.europa.eu/doc/document/ST-10211-2019-ADD-1/en/pdf
31. https://www.itu.int/en/ITU-D/Statistics/Pages/definitions/pricemethodology.aspx
32. https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20191203-1
33. https://ec.europa.eu/digital-single-market/en/news/mobile-broadband-prices-europe-2019
34. https://www.idc.com/promo/global-ict-spending/regional-markets
35. https://ec.europa.eu/digital-single-market/en/policies/improving-connectivity-and-access
36. https://ec.europa.eu/digital-single-market/en/news/study-broadband-coverage-europe-2018
37. European Commission, SWD(2016) 20 final, Brussels 2.2.2016
38. Decision (EU) 2017/899 of the European Parliament and of the Council of 17 May 2017 on the use of the 470-790 MHz frequency band in the Union, OJ L 138, 25.5.2017, p. 131–137
39. Design Aspects of Low Latency Services with Time-Sensitive Networking. Available from: https://www.researchgate.net/publication/323696804_Design_Aspects_of_Low_Latency_Services_with_Time-Sensitive_Networking [accessed Mar 29 2020].Energy Efficiency Improvement Options
40. Öko Institut and TU Berlin, Study on the practical application of the new framework methodology for measuring the environmental impact of ICT – cost/benefit analysis, for the EC DG Connect (Digital Agenda), 2014.
41. dena-METASTUDIE, Analyse der mit erhöhtem IT-Einsatz verbundenen Energieverbräuche infolge zunehmenden Digitalisierung, Berlin, November 2017
42. Fraunhofer IZM, entwicklung-des-ikt-bedingten-strombedarfs-in-Deutschland, 18.11.2015
43. ADEME u. Capgemini Consulting (2015): Assessment of electricity consumption in the ICT layer in Smart Grids
44. Imperial College (2015): The impact of information technology on energy consumption and carbon emissions
45. EMPA (2014): The Energy Intensity of the Internet: Home and Access Networks
46. Aslan, J. et al. (2017), Electricity Intensity of Internet Data Transmission, Untangling the Estimates, Journal of Industrial Ecology, Vol. 22, No. 4, p. 785.
47. IEA, Digitalization & Energy, OECD/IEA, 2017 (Website: www.iea.org)
48. Pihkola, H. et al., Evaluating the Energy Consumption of Mobile Data Transfer—From Technology Development to Consumer Behaviour and Life Cycle Thinking, Sustainability 2018, 10, 2494; doi:10.3390/su10072494
49. Pål Frenger and Richard Tano, More Capacity and Less Power: How 5G NR can Reduce Network Energy Consumption, Ericsson Research 2019. Download: https://www.ericsson.com/en/reports-and-papers/research-papers/how-5g-nr-can-reduce-network-energy-consumption
50. IEA-4E, Intelligent Efficiency For Data Centres & Wide Area Networks, Report Prepared for IEA-4E EDNA, May 2019.
51. https://www.iea.org/commentaries/the-carbon-footprint-of-streaming-video-fact-checking-the-headlines?utm_campaign=IEA%20newsletters&utm_source=SendGrid&utm_medium=Email#calculator
52. Yan and Fang, Reliability evaluation of 5G C/U-planedecoupled architecture for high-speed railway, EURASIP Journal on Wireless Communications and Networking 2014,2014:127 http://jwcn.eurasipjournals.com/content/2014/1/127
53. Blackman, C., Forge, S., 5G Deployment - State of Play in Europe, USA and Asia, Report for the European Parliament ITRE, 2019. Accessible at http://www.europarl.europa.eu/supporting-analyses
54. 10 emerging trends from Huawei for in telecom energy for the next 5 years (Feb. 2020). https://sciencebusiness.net/author/communication-huawei
55. https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Could_High-Altitude_Pseudo-Satellites_Transform_the_Space_Industry.

4 Group III.- Electronic Displays

1. COMMISSION REGULATION (EU) 2019/2021 of 1 October 2019 laying down ecodesign requirements for electronic displays pursuant to Directive 2009/125/EC of
2. European Parliament and of the Council, amending Commission Regulation (EC) No 1275/2008 and repealing Commission Regulation (EC) No 642/2009
3. VHK, IA study Review Ecodesign and Energy Labelling Electronic Displays, 2019
4. AEA with Intertek, Lot 3 – Sound and imaging equipment, Ecodesign preparatory study for EC DG Grow, November 2010.

5 Group IV.- Audio/Video

1. http://www.futuresource-consulting.com/
2. https://tweakers.net/nieuws/151508/markt-voor-blu-rays-en-dvds-is-binnen-vijf-jaar-gehalveerd.html
3. https://www.telegraph.co.uk/news/2018/10/23/death-dvd-players-john-lewis-stop-stocking/
4. https://www.electropages.com/blog/2019/06/dlp-vs-lcd-vs-led-vs-lcos-vs-laser-shedding-light-projector-technology
5. https://en.wikipedia.org/wiki/History_of_film_technology#Development_of_the_film_industry
6. https://futuresource-consulting.com/reports/posts/2019/september/futuresource-front-projector-market-track-worldwide-q2-19/?locale=en
7. AEA with Intertek, Lot 3 – Sound and imaging equipment, Ecodesign preparatory study for EC DG Grow, November 2010.
8. Intertek, Independent Inspector Annual Compliance Report – Games Consoles Self-Regulatory Initiative, Reporting Period 2018, Oct. 2019.
9. https://www.theverge.com/2019/4/18/18274498/game-streaming-services-pc-mac-ps4-android-cloud-google-stadia
10. Koomey, J. et al., REPORT ON THE 2017 REVIEW OF THE GAME CONSOLE SELF-REGULATORY INITIATIVE, July 2017.
11. CSES, Ökopol, TU Wien, Review Study of the Ecodesign Voluntary Agreement for the Product Group “Videogames Consoles”, study for the European Commission, 2019.
12. https://ecostandard.org/wp-content/uploads/2020/01/10.01-ECOS-eNGO-Comments-on-Games-Consoles-VA.pdf
13. https://www.thumbsticks.com/xbox-series-x-12-teraflops-big-deal-good-number/
14. COMMISSION REGULATION (EU) 2019/2021 of 1 October 2019 laying down ecodesign requirements for electronic displays pursuant to Directive 2009/125/EC of the European Parliament and of the Council, amending Commission Regulation (EC) No 1275/2008 and repealing Commission Regulation (EC) No 642/2009, OJ, L315, 4.12.2019, p. 241
15. https://www.futuresource-consulting.com/reports/categories/pro-av/pro-displays/interactive-displays/
16. The OECD Teaching and Learning International Survey (TALIS) 2013 Results - Excel Figures and Tables.
17. ITU-T H.323, TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU (12/2009), SERIES H: AUDIOVISUAL AND MULTIMEDIA SYSTEMS, Infrastructure of audiovisual services – Systems and terminal equipment for audiovisual services, Packet-based multimedia communications systems
18. Internet Engineering Task Force (IETF), Session Initiation Protocol
19. COMMISSION REGULATION (EU) No 801/2013 of 22 August 2013 amending Regulation (EC) No 1275/2008 with regard to ecodesign requirements for standby, off mode electric power consumption of electrical and electronic household and office equipment, and amending Regulation (EC) No 642/2009 with regard to ecodesign requirements for televisions. OJ, L255, p.1, 23.8.2013
20. Conor Cawley, Best Video Conferencing Equipment 2020, March 28th 2019. https://tech.co/web-conferencing/best-video-conferencing-equipment#pricequote
21. https://futuresource-consulting.com/press-release/professional-av-press/video-conferencing-hardware-to-ship-36-million-units-
22. Eurostat extracted March 2020 for 2017 in EU27 (EU28 minus UK), https://ec.europa.eu/eurostat/statistics-explained/images/5/57/BD_2019_publ_data_28.1_clean-update-REV.xlsx Note that depending on source and scope these numbers can be 10% less (e.g. OECD) or much more (e.g. including all self-employed)
23. https://www.dolby.com/us/en/professional/products/dolby-voice-room/data-sheet.pdf
24. https://www.cisco.com/c/en/us/products/collateral/collaboration-endpoints/spark-room-kit-series/datasheet-c78-738729.html
25. https://www.techtimes.com/articles/207213/20170513/the-mp3-is-dead-heres-a-brief-history-of-mp3.htm
26. https://www.marketwatch.com/press-release/global-mp3-player-market-2020-industry-analysis-chain-economics-segment-overview-forecast-2024-2020-01-24

27. Meaning an amplifier with integrated tuner.
28. E.g. self-powered (sub)woofer systems
29. Shift Innovatie -Analyse huishoudelijke apparaten, studie voor klimaatbureau HIER, Nov. 2016
30. Karen B. Rosen and Alan K. Meier, Energy Use of Home Audio Products in the U.S., LBNL, December 1999
31. Fraunhofer IZM, EuP Preparatory Study Lot 6 "Standby and Off-mode Losses", for the EC, Oct. 2007.
32. COMMISSION REGULATION (EC) No 1275/2008 of 17 December 2008 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for standby and off mode electric power consumption of electrical and electronic household and office equipment OJ, L339, 18.12.2008, p. 45 (audio equipment is included, as stated in Annex I)
33. Source: https://en.wikipedia.org/wiki/Smart_speaker
34. https://whatis.techtarget.com/definition/smart-speaker
35. Brown, Rich. "Echo Show, Nest Hub, Facebook Portal and more: How to pick the best smart display in 2019". CNET. Retrieved 2019-06-19.
36. Faulkner, Cameron (9 October 2018). "How Google's new Home Hub compares to the Echo Show and Facebook Portal". The Verge. Retrieved 2019-06-19.
37. Lacoma, Tyler (October 26, 2018). "What is a smart display?". Digital Trends.
38. The Smart Audio Report from NPR and Edison Research, Fall-Winter 2017 (PDF)
39. https://www.mordorintelligence.com/industry-reports/global-bluetooth-speaker-industry
40. https://www.grandviewresearch.com/industry-analysis/portable-bluetooth-speakers-market
41. https://www.howtogeek.com/348219/how-much-electricity-does-the-amazon-echo-use/
42. https://www.the-ambient.com/features/power-smart-home-tech-yearly-cost-374
43. https://support.sonos.com/s/article/256?language=en_US
44. Viegand Maagoe: Review study on Standby Regulation(EC) No 1275/2008, Final report-Draft version for the EC, 7 April 2017.
45. Kaufmann, L. and Kyburz, R., Network Connected Audio Products, measurements and analysis, report for IEA 4E EDNA, July 2016.
46. Voluntary Industry Agreement to improve the energy consumption of Complex Set Top Boxes within the EU,
47. posal from the industry group, Version 5.0,
48. September 2017. See www.cstb.eu
49. Minutes annual meeting CSTB VA 20181121
50. https://technology.ihs.com/438415/defying-multiscreen-challenge-set-top-box-market-to-achieve-record-shipments-in-2013
51. http://cstb.eu/wp-content/uploads/2013/02/2017-10-24-Report-Independent-Inspector-2015-2016_final.pdf
52. Viegand Maagoe: Review study on Standby Regulation(EC) No 1275/2008, Final report-Draft version for the EC, 7 April 2017.
53. European Audiovisual Observatory, ON-DEMAND AUDIOVISUAL MARKETS
54. THE EUROPEAN UNION, study for the European Commission DG Communications Networks, Content & Technology, 2014.
55. https://www.detect-project.eu/2020/01/16/3746/

6 Group V. - Personal IT Equipment

1. https://computerregulationreview.eu/documents
2. Definition from Techopedia: https://www.techopedia.com/definition/26221/feature-phone
3. https://www.rfdtv.com/story/41265863/ereader-market-size-share-2019-global-business-trends-share-progress-insight-modest-analysis-statistics-regional-demands-and-forecast-to-2024
4. Impact assessment study on common chargers of portable devices
5. https://www.gartner.com/en/newsroom/press-releases/2019-08-01-gartner-says-worldwide-smartphone-sales-will-decline-
6. https://www.gsmaintelligence.com/research/?file=c5f35990dcc742733028de6361ccdf3b&download
7. https://www.eea.europa.eu/data-and-maps/indicators/total-population-outlook-from-unstat-3/assessment-1
8. https://ec.europa.eu/energy/sites/ener/files/documents/eia_status_report_2017_-_v20171222.pdf
9. https://www.marketwatch.com/press-release/landline-phones-global-market-report-2018-industry-analysis-size-share-trends-scope-growth-future-opportunities-major-key-vendors-and-trends-by-forecast-to-2023-2019-08-22
10. https://www.quora.com/How-long-is-the-lifespan-of-a-kindle-paperwhite
11. Entwicklung des IKT-bedingten Strombedarfs in Deutschland - page 169
12. https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx (Excel sheet fixed-telephone subscribers)
13. Entwicklung des IKT-bedingten Strombedarfs in Deutschland - page 169

14. Commission Regulation (EU) No 617/2013 of 26 June 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for computers and computer servers
15. ENERGY STAR® Program Requirements. Product Specification for Computers. Eligibility Criteria. Version 7.1
16. https://www.energysistem.com/en_es/ereader-pro-4-44671
17. E.g. https://www.techulator.com/resources/18388-top-10-benchmarking-tools-for-android-smartphones
18. https://www.washingtonpost.com/technology/2018/11/01/its-not-your-imagination-phone-battery-life-is-getting-worse/
19. https://www.slideshare.net/QualcommDeveloperNetwork/69-minimize-powerconsumptioninappsschwartz918gg67
20. https://www.washingtonpost.com/technology/2018/11/01/its-not-your-imagination-phone-battery-life-is-getting-worse/
21. https://computerregulationreview.eu/sites/computerregulationreview.eu/files/Preparatory%20study%20on%20review%20computer%20regulation%20-%20Task%207%20VM%2019072018.pdf
22. Viegand Maagøe (2018), Internal modelling files that supports the computer regulation. Figures in blue font are recent updates for this report
23. https://www.rfdtv.com/story/41265863/ereader-market-size-share-2019-global-business-trends-share-progress-insight-modest-analysis-statistics-regional-demands-and-forecast-to-2024
24. https://www.amazon.co.uk/Amazon-Kindle-Paperwhite-Waterproof-Twice-Storage/dp/B07747FR44/ref=sr_1_1?ascsubtag=UUacUdUnU77109YYwYg&keywords=kindle%2Bpaperwhite%2Bnow%2Bwaterproof%2Bwith%2B2x%2Bthe%2Bstorage%2Bincludes%2Bspecial%2Boffers&qid=1578656390&sr=8-1&th=1
25. https://www.batteri-butik.dk/Batteri-Detaljer/1.64.AMA.2.16,Batteri-til-Amazon-Kindle-Paperwhite-2014.html?gclid=EAIaIQobChMIivvBoo755gIVg9DeCh3jQAtSEAQYASABEgKnCfD_BwE
26. https://www.gsmarena.com/battery-test.php3
27. https://www.standard.co.uk/tech/top-smartphones-2019-kantar-samsung-a-series-a4268926.html
28. VHK, Preparatory Study to establish the Ecodesign Working Plan 2015-2017 implementing Directive 2009/125/EC Task 3 Final Report.
29. Entwicklung des IKT-bedingten Strombedarfs in Deutschland - page 169
30. Entwicklung des IKT-bedingten Strombedarfs in Deutschland - page 168
31. https://computerregulationreview.eu/documents
32. https://www.komplett.dk/product/1141964/pc-tablets/tablets-e-bogslaesere/e-bogslaesere/onyx-boox-note-pro-103-64gb?gclid=EAIaIQobChMIysvgsf2U5wIVyuJ3Ch0qhw5LEAQYCyABEgKbwvD_BwE&gclsrc=aw.ds#

7. Group VI. - Imaging Equipment

1. Industry voluntary agreement to improve the environmental performance of imaging equipment placed on the European market. VA v.5.2. April 2015
2. ENERGY STAR® Program Requirements Product Specification for Imaging Equipment. Test Method for Determining Imaging Equipment Energy Use. Rev. Dec-2018
3. Development of ICT-related electricity demand in Germany - Study commissioned by the Federal Ministry for Economic Affairs and Energy Project no. 29/14

8. Group VII. - Home/Office Equipment

1. https://ec.europa.eu/energy/en/studies/ecodesign-impact-accounting-0 https://www.energystar.gov/ia/partners/product_specs/program_reqs/StorageV1.0_Program_Requirements.pdf?cb43-b421
2. https://www.energystar.gov/products/office_equipment/small_network_equipment/key_product_criteria
3. https://www.techopedia.com/definition/5358/gateway
4. https://ec.europa.eu/energy/sites/ener/files/documents/eia_status_report_2017_-_v20171222.pdf
5. https://www.i-scoop.eu/internet-of-things-guide/cellular-iot-gateway-market-2023/
6. https://www.telecomstechnews.com/news/2016/oct/31/iot-gateway-shipments-to-reach-64m-units-by-2021/
7. https://www.iea-4e.org/document/384/energy-efficiency-of-the-internet-of-things-technology-and-energy-assessment-report
8. https://www.energystar.gov/productfinder/product/certified-data-center-storage/results?formId=fcfc2996-cf57-4df6-915c-611fee23047a&scrollTo=1300&search_text=&snia_online_taxonomy_category_filter=&brand_name_isopen=0&storage_model_connectivity_filter=Block+I%2FO+and+Network+Attached+Storage+%28NAS%29&

zip_code_filter=&product_types=Select+a+Product+Category&sort_by=brand_name&sort_direction=asc&currentZipCode=5750&page_number=0&lastpage=0 – Download excel sheet to get values
9. https://www.energystar.gov/ia/partners/product_specs/program_reqs/StorageV1.0_Program_Requirements.pdf?cb43-b421
10. https://www.iea-4e.org/document/384/energy-efficiency-of-the-internet-of-things-technology-and-energy-assessment-report
11. https://ec.europa.eu/energy/sites/ener/files/documents/eia_status_report_2017_-_v20171222.pdf see EFSBAU and LOADBAU Annex A.
12. https://www.iea-4e.org/document/384/energy-efficiency-of-the-internet-of-things-technology-and-energy-assessment-report
13. https://www.ikea.com/dk/da/p/tradfri-gateway-hvid-40337806/?gclid=EAIaIQobChMIxdScmcPs5wIVBud3Ch0ypwlfEAQYAyABEgIw9vD_BwE&gclsrc=aw.ds
14. https://www2.meethue.com/en-us/p/hue-bridge/046677458478
15. https://www.develcoproducts.com/products/gateways/squidlink-gateway/#SquidlinkGatewayTechnicalSpecifications

9 Group VIII. - ICT in Public Spaces

1. https://www.cennox.com/uk/financial-services/self-service-banking-terminals/automated-teller-machines/the-diebold-5500
2. https://www.association-secure-transactions.eu
3. https://www.association-secure-transactions.eu/industry-information/atm-numbers-europe/
4. Roth, K.W. et al, Energy Consumption by Office and Telecommunications Equipment in Commercial Buildings, Volume I: Energy Consumption Baseline, A.D.Little for the Office of Building Equipment (DOE), Jan. 2002.
5. https://www.prnewswire.com/news-releases/diebold-innovation-leads-to-worlds-greenest-most-power-efficient-atm-250600621.html
6. Singh, H.K., Pra-kash, R. and Shukla, K.K. (2016) Energy and Emission Reduction Potential for Bank ATM Units in India. Open Journal of Energy Efficiency, 5, 107-120. http://dx.doi.org/10.4236/ojee.2016.54010
7. Polish regulation on cash registers, Communication from the Commission - TRIS/(2018) 00135, Directive (EU) 2015/1535, Notification: 2018/0023/PL
8. Norwegian Cash Register Act.
9. p://www.eftasurv.int/media/notification-of-dtr/notifikasjon-skjema-cash-register-9007.pdf
10. https://www.geregistreerdkassasysteem.be/nl (GKS)
11. Kassensicherungsverordnung (KassenSichV). Published 2017. Implemented Jan. 2020. The Kassensicherungsverordnung (KassenSichV) regulates the technical requirements for electronic recording and security systems, such as computerized cash register systems and cash registers. The regulation is designed to protect against manipulation of companies' basic digital records.
12. Kemna, R.B.J., MEErP 2011 – Methodology Report – Part 2, VHK for the EC, 28.11.2011.
13. Eurostat, Number of retail stores (NACE Rev.2, G47) [dt_oth_n47_r2]
14. Component prices estimated by VHK from internet offers, Feb. 2020.
15. https://www.ecb.europa.eu/press/pr/stats/paysec/html/ecb.pis2017.en.html
16. https://www.epson.eu/verticals/business-solutions-for-retail/eco-point-of-sale-printers
17. https://www.epson.eu/products/sd/pos-printer/epson-tm-t88v-series#specifications
18. https://www.bypos.be/thermische-bonprinters/star-tsp100eco-tsp143eco-bonprinter-kassalade-bypos-1774
19. https://www.epson.eu/products/sd/pos-printer/tm-p20-series#specifications
20. https://www.apple.com/environment/pdf/products/ipad/iPadPro_11-inch_PER_oct2018.pdf : 2.23 W in display on-idle mode, 0.23W
21. https://blog.constellation.com/2019/12/16/energy-efficiency-of-different-pos-systems/
22. https://parking.brussels/fr/smart/stationner-en-voirie-mobile
23. https://www.alvaradomfg.com/mobile-ticket-validation-pocketgate/
24. https://www.payprint.it/en/payment-systems/banknote-reader-with-stacker.html
25. https://www.payprint.it/images/pdf/lettore-banconote-ict-lx7-datasheet.pdf
26. Scope of parking in Europe, data collection by the European Parking Association (EPA), 2019. www.europeanparking.eu
27. B5-Wifi4EU_Factsheet_2020_ENpdf.pdf
28. https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html
29. https://www.energystar.gov/sites/default/files/specs//private/SmallNetworkEquipment_V1_ENERGYSTAR_ProgramRequirements_Nov2013_0.pdf
30. http://www.turn-keytechnologies.com/blog/network-solutions/what-is-target-wake-time

31. Associazione Italiana Societá Concenssionarie Autostrade e Trafori http://www.aiscat.it/pubblicazioni/downloads/aiscat-in-cifre-2018.pdf
32. Association Européenne des Concessionaires d'Autoroute et d'Ouvrages a Péage http://ASECAPKeyFigures2019RevisedEdition%20(1).pdf
33. ASECAP members minus Morocco, Turkey, Russia, Serbia, UK.
34. https://www.researchgate.net/publication/264438998_Energy_consumption_evaluation_framework_for_passive_RFID_tag_anti-collision_algorithms
35. https://www.researchgate.net/publication/244994628_Global_Navigation_Satellite_System_based_tolling_State-of-the-art
36. https://www.gsa.europa.eu/system/files/reports/gnss_user_technology_report_webb.pdf
37. https://www.sdmmag.com/articles/92407-rise-of-surveillance-camera-installed-base-slows
38. https://www.theverge.com/2019/12/9/21002515/surveillance-cameras-globally-us-china-amount-citizens
39. https://ihsmarkit.com/research-analysis/tape-and-disk-storage-present-viable-long-term-video-surveillance-storage.html
40. https://security.panasonic.com/training_support/support/technical_information/power_consumption_info/
41. https://reolink.com/cctv-ip-security-camera-power-consumption/

12 Group IX.- Building automation

1. Communication from the Commission. Ecodesign Working Plan 2016-2019. COM(2016) 773 final.
2. Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency
3. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast) (consolidated version)
4. Ecodesign preparatory study for Building Automation and Control Systems (BACS) implementing the Ecodesign Working Plan 2016 -2019. Initial draft Task 2 report on Markets. VITO & Waide Strategic Efficiency) for the European Commission.
5. Ecodesign preparatory study for Building Automation and Control Systems (BACS) implementing the Ecodesign Working Plan 2016 -2019. Task 5 report: Environment & Economics. VITO et al. for the European Commission. January 2020.
6. Ecodesign preparatory study for Building Automation and Control Systems (BACS) implementing the Ecodesign Working Plan 2016 -2019. Task report on scoping. VITO and Waide Strategic Efficiency for European Commission Directorate-General for Energy. July 2018.
7. Electricity consumption of building automation, P. Kräuchi et al. Energy Procedia 122 (2017) 295–300
8. http://bpie.eu/wp-content/uploads/2016/02/Deep-dive-4-Building-automation.pdf
9. https://eco-smartappliances.eu/en
10. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02010L0031-20181224 (consolidated)
11. https://smartreadinessindicator.eu/
12. https://www.bsria.com/uk/market-intelligence/market-reports/building_controls/
13. https://www.ecostandbyreview.eu/
14. https://www.odyssee-mure.eu/publications/efficiency-by-sector/households/electricity-consumption-dwelling.html
15. Preparatory Study to establish the Ecodesign Working Plan 2015-2017 implementing Directive 2009/125/EC. Task 3 Final Report.
16. Renewable Space Heating under the Revised Renewable Energy Directive. First interim report. TU WIEN et al. for the European Commission. Internal report. May 2020.
17. Waide Strategic Efficiency Limited for eu.bac. 2019.
18. Waide Strategic Efficiency Limited with ABS Consulting (UK) Limited, Birling Consulting Ltd and William Bordass Associates prepared for the European Copper Institute. Second edition, 13 June 2014.
19. www.ecodesignbacs.eu
20. www.eubac.org
21. www.eubac.org/cms/upload/eu.bac_guidelines_on_revised_EPBD_June_2019.pdf
22. www.vdma.org/en/

13 Group X. - Other Controls/ Industrial sensors

1. Tyler Wojciechowicz, Smart Sensor vs Base Sensor - What's the Difference? Semiconductorstore, Sep 18, 2018.https://www.semiconductorstore.com/blog/2018/Smart-Sensor-vs-Base-Sensor-Whats-the-Difference-Symmetry-Blog/3538/
2. Gary W. Hunter, Joseph R. Stetter, Peter J. Hesketh, Chung-Chiun Liu - Smart sensor systems, Article in NATO Science for Peace and Security Series B: Physics and Biophysics · January 2012 https://www.researchgate.net/publication/258734399_Smart_Sensor_Systems

3. The IEEE 1451 family of standards (with the most recent addition of 1451.7 in 2010) provides a digital communication interface standard for transducers and network-capable processors.
4. Global Market Insights, Report on Smart Sensors: https://www.gminsights.com/industry-analysis/smart-sensor-market
5. https://www.slideshare.net/Abhishekjha244/smart-sensor-market-forecast-and-industry-analysis-report-2016-2024
6. Several market reports (Global Market Insights, Variant Market Research and Esticast Research and Consulting) for 2016-2024.
7. https://www.variantmarketresearch.com/press-release/global-smart-sensors-market-is-estimated-to-reach-101-billion-by-2025-says-variant-market-research
8. Variant Market Research and Research Nester.
9. https://www.techniekwebshop.nl; https://ncd.io/; https://www.technischeunie.nl/product/prd1894719575; https://www.conrad.de/de/p/bosch-connected-devices-and-solutions-multi-sensor-modul-connected-industrial-sensor-solution-i-ciss-2148499.html
10. https://www.marketreportsworld.com/global-energy-harvesting-systems-market-12344294
11. https://www.powerelectronics.com/technologies/energy-harvesting/article/21851975/whos-harvesting-energy
12. https://www.slideshare.net/sherrythomas13/energy-harvesting-market-by-source-system-application-forecast-20172024
13. https://www.slideshare.net/spansion/spansion-energy-harvesting-pmics
14. https://www.slideshare.net/Funk98/energy-harvesting-for-iot - IDTechEx Energy Harvesting report (2017)
15. https://switches-sensors.zf.com/us/energy-harvesting-technology/
16. https://www.efficientplantmag.com/2004/07/temperature-monitoring-is-key-to-motor-reliability/
17. https://www.iotforall.com/darpas-take-iot-battery-problem-n-zero/
18. https://www.enocean.com/en/technology/energy-harvesting-wireless/
19. https://www.enocean.com/fileadmin/redaktion/pdf/white_paper/White_Paper_Internet_of_Things_EnOcean.pdf
20. https://www.electronicdesign.com/power-management/article/21796369/energy-harvesting-and-wireless-sensor-networks-drive-industrial-applications (2013)
21. Optimization Method for Designing Multimodal Piezoelectric MEMS Energy Harvesters, Conference: SPIE 9517, Smart Sensors, Actuators, and MEMS VII; and Cyber Physical Systems, Barcelona, Spain, Volume: 9517 (https://www.researchgate.net/publication/277138101_Optimization_Method_for_Designing_Multimodal_Piezoelectric_MEMS_Energy_Harvesters)
22. https://www.nrel.gov/pv/cell-efficiency.html
23. https://www.3gsolar.com/technology
24. https://www.embedded-computing.com/guest-blogs/low-battery-self-discharge-the-key-to-long-life-remote-wireless-sensors
25. https://en.wikipedia.org/wiki/Solid-state_battery
26. https://deepmind.com/blog/article/alphago-zero-starting-scratch
27. https://towardsdatascience.com/advances-in-few-shot-learning-a-guided-tour-36bc10a68b77?gi=616c6c1779dc; https://arxiv.org/abs/1904.05046
28. https://www.ebmpapst.com/media/content/info-center/downloads_10/brochures/ebm-papst_GreenTech-EC-Technology_en.pdf
29. https://hte.ebmpapst.com/content/dam/ebm-papst/corporate/downloads/catalogues/products/en/Brennwerttechnik_2017-03_EN.pdf
30. Niki Bishop, Improve reliability with essential asset monitoring, InTech, 2012
31. Eurovent 1-11, FANS and SYSTEM STALL: PROBLEMS and SOLUTIONS, Eurovent WG 1, 2007
32. Engineering Data 600, Twin City Fan Companies, Ltd., 1999
33. Eurovent 1-11, FANS and SYSTEM STALL: PROBLEMS and SOLUTIONS, Eurovent WG 1, 2007
34. M.P. Boyce, in Combined Cycle Systems for Near-Zero Emission Power Generation, 2012
35. Flow-Induced Vibrations, editors Shigehiko Kaneko, Tomomichi Nakamura, Fumio Inada et al., 2014 (https://www.sciencedirect.com/book/9780080983479/flow-induced-vibrations)
36. https://en.wikipedia.org/wiki/Compressor_stall
37. https://www.turbomachinerymag.com/compressor-rotor-failure-due-to-fouling/
38. https://www.emerson.com/documents/automation/cracked-gas-compressor-white-paper-en-41052.pdf
39. https://semiwiki.com/wp-content/uploads/2016/08/IWS20201320wireless20power20consumption.pdf
40. https://journals.sagepub.com/doi/full/10.1155/2014/782710
41. Gopalakrishna Palem, Condition-Based Maintenance using Sensor Arrays and Telematics, International Journal of Mobile Network Communications & Telematics (IJMNCT) Vol. 3, No.3, June 2013. DOI: 10.5121/ijmnct.2013.3303
42. Gulati, Ramesh (2012-08-17). Maintenance Best Practices. Industrial Press, Inc.

43. Niki Bishop, Improve reliability with essential asset monitoring, InTech, 2012
44. Intel IoT Industrial Automation – Solution Brief – Improving Downtime and Energy Efficiency with IoT-Connected Air Compressors (https://cdrdv2.intel.com/v1/dl/getcontent/333853)
45. MTTR is the total corrective maintenance time for failures divided by the total number of corrective maintenance actions for failures during a given period of time.
46. https://www.efficientplantmag.com/2000/09/comparing-maintenance-costs/;
47. Introducing operations and maintenance costs, Emerson Process Management, 2003 (https://www.emerson.com/documents/automation/product-data-sheet-reducing-operations-maintenance-costs-en-41038.pdf)

14. UPS

1. Agreement between the Government of the United States of America and the European Community on the coordination of energy-efficient labelling programs for office equipment - Exchange of diplomatic Notes
2. Directive 2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC, OJ L 266, 26.9.2006, p. 1–14 (latest status: https://ec.europa.eu/environment/waste/batteries/)
3. Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment OJ L 174, 1.7.2011, p. 88–110
4. Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electric equipment Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment Text with EEA relevance
5. Directive 2014/30/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to electromagnetic compatibility (recast)
6. Directive 2014/35/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of electrical equipment designed for use within certain voltage limits, OJ L 96, 29.3.2014, p. 357–374
7. E.g. IEC 60146 Semiconductor Electronic Converters; EN 50171 Central power supply systems; EN IEC 60439 Low voltage switchgear and control gear assemblies; EN 50272-2 Safety requirements for secondary batteries and battery installations, stationary batteries; etc.
8. EN IEC 62040-1:2019. Uninterruptible power systems (UPS). Safety requirements
9. EN IEC 62040-2:2018. Uninterruptible power systems (UPS). Electromagnetic compatibility (EMC) requirements
10. EN IEC 62040-3:2011. Uninterruptible power systems (UPS). Method of specifying the performance and test requirements
11. EN IEC 62040-4:2013. Uninterruptible power systems (UPS). Environmental aspects. Requirements and reporting
12. https://carrier.huawei.com/~/media/CNBGV2/download/products/network-energy/5G-Telecom-Energy-Target-Network-White-Paper.pdf
13. http://www.pep-ecopassport.org/create-a-pep/.
14. https://download.schneider-electric.com/files?p_enDocType=Product+environmental&p_File_Name=GWOG-8WPL63_R0_EN.pdf&p_Doc_Ref=SPD_GWOG-8WPL63_EN
15. https://ec.europa.eu/energy/sites/ener/files/technology_analysis_-ongoing_projects_on_battery_based_energy_storage.pdf
16. https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_UPS.pdf
17. https://ec.europa.eu/jrc/en/energy-efficiency/code-conduct/ups and https://e3p.jrc.ec.europa.eu//communities/ict-code-conduct-ac-uninterruptible-power-systems
18. https://www.datacenterknowledge.com/business/report-lithium-ion-gain-one-third-data-center-ups-market-2025
19. https://www.mordorintelligence.com/industry-reports/global-data-center-ups-market-industry
20. https://www.renewableenergyworld.com/2019/04/03/why-lithiumion-technology-is-poised-to-dominate-the-energy-storage-future/#gref
21. Ibid.
22. OJ L 172, 26.6.2001, p. 3–32
23. OJ L 174, 1.7.2011, p. 88–110 electronic equipment (WEEE) OJ L 197, 24.7.2012, p. 38–71
24. OJ L 96, 29.3.2014, p. 79–106
25. Qualified under Uninterruptible Power Supplies specification 1.0. See https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-products/energy-star_en
26. Stephanie Boulos, Chris Nuttall, Bob Harrison, Pedro Moura & Christoph Jehle, ErP Lot 27 – Uninterruptible Power Supplies; Preparatory Study – Final Report (2014), Ricardo-AEA/R/ED56828, Issue no. 1.

27. The Commission, Establishment of the working plan for 2009-2011 under the Ecodesign Directive, COM(2008) 660 final, p.5 and Annex I. Following Martijn van Elburg et al. , Study on Amended Working Plan under the Ecodesign Directive, VHK for the EC DG ENTR (now DG GROW), July 2011.
28. Whitepaper https://download.schneider-electric.com/files?p_Doc_Ref=SPD_VAVR-A5AJXY_EN
29. Wierda, L. and Kemna, R., Ecodesign Impact Accounting, VHK for the EC, 2018.

15. Home Audio

1. COMMISSION REGULATION (EC) No 1275/2008 of 17 December 2008 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for standby and off mode electric power consumption of electrical and electronic household and office equipment OJ, L339, 18.12.2008, p. 45 (audio equipment is included, as stated in Annex I)
2. Brown, Rich. "Echo Show, Nest Hub, Facebook Portal and more: How to pick the best smart display in 2019". CNET. Retrieved 2019-06-19.
3. Faulkner, Cameron (9 October 2018). "How Google's new Home Hub compares to the Echo Show and Facebook Portal". The Verge. Retrieved 2019-06-19.
4. HIER Klimaatbureau, Een vernieuwde analyse van huishoudelijke apparaten, 2016
5. https://advanced-television.com/2019/01/08/smart-display-sales-12-of-smart-speaker-market-in-2019/
6. https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=proj_19np&lang=en
7. https://bigtechquestion.com/2019/07/22/smarthome/amazonalexa/echo-show-5-electricity/
8. https://en.wikipedia.org/wiki/Smart_speaker
9. https://futuresource-consulting.com/press-release/consumer-electronics-press/worldwide-loudspeaker-market-under-pressure-but-with-pockets-of-growth/
10. https://www.alliedmarketresearch.com/smart-speaker-market
11. https://www.androidpit.com/smart-home-consumption-costs#home
12. https://www.apple.com/environment/pdf/products/homepod/HomePod_PER_feb2018.pdf
13. https://www.audioholics.com/audio-amplifier/amplifier-classes
14. https://www.bluetooth.com/learn-about-bluetooth/bluetooth-technology/topology-options/le-mesh/mesh-faq/
15. https://www.cenelec.eu/dyn/www/f?p=104:7:176303021958201::::FSP_ORG_ID:1258737
16. https://www.consumentenbond.nl/wifi-speakers/producten
17. https://www.euromonitor.com/home-audio-and-cinema
18. https://www.gfk.com/press/audio-devices-become-smarter-and-sound-better
19. https://www.klipsch.com/education/speaker-sensitivity
20. https://www.researchandmarkets.com/research/p88ftf/global_home_audio
21. https://www.riaa.com/u-s-sales-database/
22. https://www.riaa.com/u-s-sales-database/ (permission to copy is granted as long as due credit is given)
23. https://www.smart2zero.com/news/always-mems-mic-uses-sound-energy-wake-system
24. https://www.statista.com/outlook/15010500/102/speakers/europe
25. https://www.statista.com/statistics/801522/global-home-audio-market-size-by-category/
26. https://www.strategyanalytics.com/access-services/devices/connected-home/smart-speakers-and-screens/market-data/report-detail/global-smart-display-forecast-by-region-2014-2023;
27. https://www.the-ambient.com/features/power-smart-home-tech-yearly-cost-374
28. https://www.worlddab.org/public_document/file/1283/WorldDAB_Infographic_Q2_2019_A4_with_sources_FINAL_ONLINE_ENGLISH_23_03_2020.pdf
29. Intertek Technical Report 101092233MKS-001b, 2013
30. Karen B. Rosen and Alan K. Meier, Energy Use of Home Audio Products in the U.S., LBNL, December 1999
31. Lacoma, Tyler (October 26, 2018). "What is a smart display?". Digital Trends.
32. Stefan Vrijdag, Consumentengids, January 2015, p.60
33. Stefan Vrijdag, Consumentengids, January 2018, p.26
34. Stefan Vrijdag, Consumentengids, January 2019, p.50
35. Stefan Vrijdag, Consumentengids, January 2020, p.52
36. The energy impacts of smart speakers and video streaming devices, Natural Resources Defense Council, 2019 https://www.nrdc.org/sites/default/files/gadget_report_r_19-07-b_13_locked.pdf
37. Tweakers.net on 23 June 2020: 77 mono wireless speakers without voice assistants and no (rechargeable) battery.
38. Tweakers.net on 24 June 2020: 364 receivers and amplifiers, 20 HTiB, 233 Hi-Fi systems, 34 Hi-Fi CD-player components.
39. Tweakers.net, Fnac.fr, Mediamarkt.de on 25 June 2020: 307 FM clock radios and 56 DAB clock radios.
40. Voicebot Smart Speaker Consumer Adoption Report, January 2019
41. Worldwide Home Audio Market Report, Futuresource Consulting, 2018

16. Consumer behaviour

1. Agcom, Rapporto sul consumo di informazione, Autorita'per Le Garanzie Nelle Comunicazioni, servizio economico-statistico, Feb. 2018.
2. Arbeitsgemeinschaft Media-Analyse e. V. (agma) https://www.agma-mmc.de/
3. Destatis, Spartenbericht Film, Fernsehen, Hörfunk, Statistisches Bundesamt, 2017. https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Bildung-Forschung-Kultur/Kultur/Publikationen/Downloads-Kultur/spartenbericht-film-fernsehen-hoerfunk-5216207199004.pdf?__blob=publicationFile
4. Destatis, Zeitverwendungserhebung - Aktivitäten in Stunden und Minuten für ausgewählte Personengruppen - 2012/2013, published 2015.
5. EC DG COMM, 2018) , Eurobarometer 88 "Media use in the European Union", Field: November 2017, 2018. https://ec.europa.eu/commfrontoffice/publicopinion/index.cfm/ResultDoc/download/DocumentKy/82871
6. https://d110erj175o600.cloudfront.net/wp-content/uploads/2018/02/Agcom-Consumo-di-informazione.pdf
7. https://digitaal.scp.nl/trends-in-mediatijd/assets/pdf/trends-in-mediatijd.pdf
8. https://kijkonderzoek.nl/
9. https://www.abc.es/play/television/noticias/abci-television-tradicional-marca-datos-consumo-hace-17-anos-202001070857_noticia.html?ref=https:%2F%2Fwww.google.com%2F
10. https://www.abc.es/play/television/noticias/abci-television-tradicional-marca-datos-consumo-hace-17-anos-202001070857_noticia.html?ref=https:%2F%2Fwww.google.com%2F
11. https://www.agcom.it/
12. https://www.agf.de/
13. https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html
14. https://www.cnet.com/news/8k-tv-what-you-need-to-know/ , 3 Jan. 2020
15. https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Einkommen-Konsum-Lebensbedingungen/Zeitverwendung/Publikationen/Downloads-Zeitverwendung/zeitverwendung-5639102139004.pdf;jsessionid=80E66340948F1B6AAF5CE19F68888B28.internet8722?__blob=publicationFile
16. https://www.ipb.be/nl/cross-media/content/articles/de-tijdsbesteding-van-de-belgen-onder-de-loep
17. https://www.kantarmedia.com/
18. https://www.mediametrie.fr/fr/laudience-de-la-television-au-mois-de-mai-2020
19. https://www.nordicom.gu.se/sites/default/files/mediefakta-dokument/Nyhetsbrev_Norden/nordicom_mediatrends_nordic_1-2014.pdf
20. https://www.nordicom.gu.se/sites/default/files/mediefakta-dokument/Nyhetsbrev_Norden/nordicom_mediatrends_nordic_1-2014.pdf
21. https://www.primaonline.it/2020/01/28/300556/radio-ecco-i-nuovi-dati-di-ascolto-anno-e-2-semestre-2019-deejay-recupera-la-terza-posizione-boom-radiofreccia-virgin-rmc-e-m2o/
22. https://www.statista.com/statistics/1037609/poland-linear-tv-viewing-time/
23. https://www.statistics.gr/documents/20181/1515741/GreeceInFigures_2020Q1_EN.pdf/4ab68b3f-bd6c-d77d-8bf9-cfcbf91aa937
24. Insee, enquête Emploi du temps 2009-2010.
25. LEVNADSFÖRHÅLLANDEN RAPPORT 123, Nu för tiden, I denna rapport ges en bred statistisk belysning av svenska folkets tidsanvändning år 2010/11. www.scb.se (Sweden Statistics office)

Annex C: Assessment of 3D Printers

1. https://www.forbes.com/sites/tjmccue/2019/03/27/wohlers-report-2019-forecasts-35-6-billion-in-3d-printing-industry-growth-by-2024/#3c9c3d557d8a
2. https://www.amazon.com/Comgrow-Creality-Printer-Upgrade-Certified/dp/B07GYRQVYV/ref=sr_1_3?keywords=3D+printer&qid=1578298073&sr=8-3
3. https://www.forbes.com/sites/tjmccue/2019/03/27/wohlers-report-2019-forecasts-35-6-billion-in-3d-printing-industry-growth-by-2024/#4ddbd92d7d8a
4. https://www.idtechex.com/de/research-article/who-buys-consumer-level-3d-printers/7519
5. https://www.forbes.com/sites/tjmccue/2019/03/27/wohlers-report-2019-forecasts-35-6-billion-in-3d-printing-industry-growth-by-2024/#4ddbd92d7d8a
6. https://www.forbes.com/sites/tjmccue/2019/03/27/wohlers-report-2019-forecasts-35-6-billion-in-3d-printing-industry-growth-by-2024/#4ddbd92d7d8a
7. Peng, T. (2016). Analysis of Energy Utilization in 3D Printing Processes. Procedia CIRP.

8. Yoon, H. S., Lee, J. Y., Kim, H. S., Kim, M. S., Kim, E. S., Shin, Y. J., Chu, W. S., & Ahn, S. H. (2014). A comparison of energy consumption in bulk forming, subtractive, and additive processes: Review and case study. International Journal of Precision Engineering and Manufacturing - Green Technology.
9. https://all3dp.com/1/types-of-3d-printers-3d-printing-technology/
10. Verhoef, L. A., Budde, B. W., Chockalingam, C., García Nodar, B., & van Wijk, A. J. M. (2018). The effect of additive manufacturing on global energy demand: An assessment using a bottom-up approach. Energy Policy.
11. https://www.forbes.com/sites/tjmccue/2018/06/04/wohlers-report-2018-3d-printer-industry-rises-21-percent-to-over-7-billion/#35c2b86d2d1a
12. https://www.thebalance.com/world-s-largest-economy-3306044
13. https://www.forbes.com/sites/tjmccue/2018/06/04/wohlers-report-2018-3d-printer-industry-rises-21-percent-to-over-7-billion/#35c2b86d2d1a
14. https://www.forbes.com/sites/tjmccue/2018/06/04/wohlers-report-2018-3d-printer-industry-rises-21-percent-to-over-7-billion/#35c2b86d2d1a
15. https://downloads.3dhubs.com/3D_Printing_Trends_Q1_2019.pdf?utm_campaign=Gated%20Content%20Downloads&utm_source=hs_automation&utm_medium=email&utm_content=79739036&_hsenc=p2ANqtz--BDChoHHvpKbJUKNKTT2y_ElYmSG15eBZF1C35fna-Paj9gmTxsXI3T3xp2ZAbfQKZ42saJbsrjogO0CkofO4wf7uKbg&_hsmi=79739036
16. https://www.fisherunitech.com/blog/history-of-3d-printing
17. https://3dsourced.com/3d-printers/history-of-3d-printing/
18. Walls, S., Corney, J., & Vasantha, G. (2014). Relative Energy Consumption of Low-Cost 3D Printers. Pure.Strath.Ac.Uk.
19. https://3dprintingindustry.com/news/personal-3d-printing-user-study-indicates-market-evolving-18122/
20. https://3dprinterly.com/how-long-does-it-take-to-3d-print/
21. Half of the desktop printers are estimated to be sold to leisure users based on prediction from IDTechEx: https://www.idtechex.com/de/research-article/who-buys-consumer-level-3d-printers/7519
22. Half of the desktop printers are estimated to be sold to professional users based on prediction from IDTechEx: https://www.idtechex.com/de/research-article/who-buys-consumer-level-3d-printers/7519
23. https://www.review-imagingequipment.eu/documents
24. https://whambamsystems.com/blog/f/turning-off-the-eco-setting-on-a-cr-10s
25. https://pinshape.com/blog/guide-green-3d-printing/