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Energy and Electricity Consumption of the Information Economy Sector in Finland

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Abstract

The role of digital technologies is becoming increasingly important in our day-to-day life. Digital technologies have become part of our social life as well as business operations across different industrial and public sectors. Because of digitalization, the internet protocol and data traffic have been on the rise for several years. Several estimates of the growth in energy consumption of data networks and the information economy sector have been presented in recent years. Occasionally consumer behavior has been claimed to be behind of these increases in electricity use.

This report analyzes the energy and electricity consumption of the Finnish information economy sector from 2011 until 2018. Additionally, we compare the Finnish electricity use to other European countries with similar data available. Our report shows that the energy efficiency of the technologies used in the information sector has not kept pace with the growth in the volumes of data transferred on fixed and mobile networks.

Tiivistelmä

Informaatiosektorin energian- ja sähkönkäyttö Suomessa

Informaatiosektorin ja ohjelmistopohjaisten sovellusten rooli jokapäiväisessä toiminnassa on yhä merkittävämpi. Ohjelmistot ovat läsnä niin ihmisten välisessä sosiaalisessa yhteydenpidossa kuin eri alojen yritysten liiketoiminnassakin. Viime vuosina on esitetty useita arvioita tietoverkkojen ja informaatiosektorin energiankäytön kasvusta. Datan määrän ja informaatiosektorin lisääntyneen energiankäytön taustalla ovat muuttuneet kuluttajatottumuksemme. Informaatiosektorilla hyödynnettävien teknologioiden energiatehokkuus ei ole pysynyt kiinteän verkon datan ja mobiiliverkkodatan kasvun tahdissa.

Tässä tutkimuksessa käydään läpi, kuinka energian- ja sähkönkäyttö on informaatiosektorilla kasvanut vuosina 2011–2018. Lisäksi kuvataan kuluttajien sähkönkäytön kasvua ja kuluttajatottumusten muutosta.

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Kiitokset: Tämä raportti on laadittu osana Suomen itsenäisyyden juhlarahasto Sitran Hiilineutraali kiertotalous -teeman työtä ja Suomen Akatemian rahoittamaa Teollisuuden digitaalinen murros -tutkimusprojektia. Sitran kiertotaloustyön yhtenä tavoitteena on lisätä tietoa digitalisaation systeemitason ympäristövaikutuksista, niin positiivisista kuin negatiivisista, sekä selvittää, millaiset digitaaliset ratkaisut edistävät kiertotaloutta. Tämä raportti tarjoaa uutta tietoa informaatiosektorin energiankäytöstä Suomessa ja energiadatan saatavuudesta sekä yksilöi aiheeseen liittyviä jatkotutkimustarpeita. Tämä raportti on käännös vastaavasta suomenkielisestä Etla Raportista no 104 "Informaatiosektorin energian- ja sähkönkäyttö Suomessa" (julkaistu 8.6.2020).

Keywords: Information economy sector, ICT sector, IP traffic, Data usage, Energy consumption, Electricity consumption

Avainsanat: Informaatiosektori, ICT-ala, IP-liikenne, Datankäyttö, Energiankäyttö, Sähkönkulutus

JEL: L8, L82, L86, L94

Contents

1 Introduction

The information economy sector is playing an increasingly important role in the everyday activities of people and organizations. It is present in the communication between individuals and in the business activities of companies of various types. The latter includes companies in traditional sectors and the software companies at the forefront of digitalization.

Digital services and the use of such services are consuming an increasing amount of people's time (e.g., Lane et al., 2018; Morley et al., 2018; Widdicks & Pargman, 2019; Widdicks et al., 2017). This increases the information economy sector's energy consumption – especially its electricity consumption – despite constant improvements in the sector's energy efficiency (e.g., Belkhir & Elmeligi, 2018; Andrae & Edler, 2015; Morley et al., 2018). This development cannot be overlooked. Creating an overall view of energy consumption, covering the various sub-areas of the information economy sector, is the first step toward solutions for curbing the growth in energy and electricity consumption and, thereby, reducing the sector's emissions.

A common definition of the information economy sector exists, but operators in the sector rarely provide any information about their energy and electricity consumption. Indeed, it can be stated that the energy and electricity consumption of the information economy sector is not measured on a national or worldwide scale. In order to gain an overall view, it would be good to be able to agree on the common use of the concept of the information economy sector in various reports and studies. The area is a wide-ranging and complex systemic entity. It reaches into many different sectors, and its operations are international by nature.

The purpose of this study is to: 1) create a common definition of the information economy sector based on the industry classification. This would enable the measurement of energy and electricity consumption, the creation of statistics, and a comparison between countries based on open data[1]. An overall view of the information economy sector's energy consumption consists of the total energy consumption of companies engaged in business activities in the sector concerned, including manufacturing endpoint and network devices as well as operating fixed and mobile networks, and data centers. This estimate of the energy and electricity consumption of the information economy sector does not include the energy and electricity consumption of ICT hardware and data centers in other industrial sectors or the public sector; 2) answer the following research questions with the help of prior research information and open data:

a) How have the volumes of internet protocol (IP) traffic[2,3,4] and data used by consumers and industry increased globally and in Finland from 2006 to 2020?
b) Has the growth in the volume of IP traffic/data affected the energy and electricity consumption of the information economy sector and consumers in Finland?
c) How has energy and electricity consumption increased in the information economy sector in Finland (Europe) from 2011 to 2018 (2017)?
d) How has the electricity consumption of other consumer electrical appliances (including televisions, computers, and mobile devices) increased from 2011 to 2018?
e) How much of the procurement of Finland's information economy sector is outsourced to entities beyond Finland's borders?

In addition, we describe what data is openly available on private data centers in relation to their energy and electricity consumption and energy efficiency.

Our preconception was that very little data was openly available on the energy and electricity consumption of the information economy sector and on data centers. Our assumption proved incorrect. We were able to form a good general impression of the information economy sector's energy and electricity consumption using open data from Statistics Finland and Eurostat. It also became apparent that a comparison between European countries is possible.

The key findings of this study are as follows:
The total growth in IP traffic has been significant globally.[5] Consumers' share of global IP traffic is 84%. Europe's share of consumers' global annual IP traffic is approximately 22%. Cisco (2019) measures the volume of IP traffic in exabytes per month. Cisco's report forecasts

an average annual increase of 41% in the mobile IP traffic in Europe over the next five years. The greatest growth will occur in Asia. (Cisco, 2019.)

The increase in data usage is forecast to continue in Finland. This includes an estimate of the total growth in volumes of data on the fixed network and mobile data. In Finland, mobile data accounts for approximately 29% of all data usage (Finnet, 2019). The proportion of mobile data in relation to data on the fixed network is higher in Finland than in any of the comparison countries (OECD, 2018). We can identify two different reasons for the stronger growth in the volume of mobile data in Finland than in the comparison countries (other reasons probably also exist): 1) consumer subscriptions that include unlimited data usage for a fixed price and 2) Finland's prominent role as a developer of mobile technologies.

The energy consumption of Finland's information economy sector consists of three energy sources: 1) fuels, 2) electricity, and 3) heat. Of these, electricity consumption accounts for 67.8% of the information economy sector's total energy consumption. The information economy sector's energy consumption as a proportion of Finland's total energy consumption was 1.1% in 2018.[6] According to our definition of the information economy sector, the total growth in energy consumption was 18.8% from 2011 to 2018 while electricity consumption increased by 26.6% in the same period. As the usage of data has increased by approximately 43% every year, the information economy sector's energy and electricity consumption increased by annual rates of 2.5% and 3.4%, respectively. The updated data used in this study indicate that the energy and electricity consumption of the information economy sector has increased more than suggested in our previous estimates (Hiekkanen, Seppälä, and Ylhäinen, 2020).

The increase in the volume of mobile data is not directly indicative of an increase in the electricity consumption of other consumer electrical devices, such as TVs, computers, tablet computers, and phones. Although the use of mobile data has increased by approximately 72% every year, the electricity consumption of other consumer electrical devices has increased by only 2.6% annually. It should be noted that a significant proportion of the total growth in consumer data traffic is due to IP traffic on the fixed network.

However, based on the reported forecasts, the endpoint devices account for a decreasing proportion of the electricity consumed by other electrical devices in the United States (EIA, 2020). There is no research data available for Finland after 2013. It should also be noted that consumers may charge their endpoint devices in locations other than their homes. More broadly, the increased usage of mobile data by consumers is not directly reflected in an increase in consumers' electricity consumption at home.

Companies in the information economy sector generate 48% of the turnover of this sector with their own resources. The remaining 52% is in the form of direct procurement from other companies. Procurement is further divided into direct purchases from Finland and from abroad. Direct procurement from foreign entities in the information economy sector accounts for 29% of the sector's entire turnover. Based on this analysis, we can state that at least 29% of the behavior of Finnish consumers related to data is outsourced beyond Finland's borders. This study only takes into consideration the purchases of services by consumers in Finland from companies registered in Finland. Consumers can buy services directly from foreign service providers.

The key policy recommendations of this study are as follows:

Although the OECD and European countries have a common definition of the information economy sector, it is rarely used for measurements, statistics, reporting, and research. We recommend adopting the OECD definition in order to enable a global comparison of the key indicators for the information economy sector.

In Finland, Statistics Finland or operators like Fingrid, Motiva, and Finnish Energy – and Eurostat at the European level – could act as the custodians of key indicators and statistics for the information economy sector. These entities could maintain indicators and statistics on energy and electricity consumption and other key resources in accordance with the OECD's definition of the information economy sector. These could be published annually or quarterly.

Company- or country-level analysis provides insufficient depth to understand energy and electricity consumption. Extending the analysis to the supply and value chains would provide a better understanding of the use of resources in companies and countries, as well as the potential carbon-neutrality of the sector. An examination of supply and value chains would enable an understanding of the impacts of production and consumer behavior beyond Finland's borders. This would provide an idea of how the usage of data by consumers in Finland is reflected beyond Finland's borders.

Nowadays, public information on individual data centers is almost non-existent. Public information is only available from the environmental permits of data centers consuming more than 5 MW. We recommend that a public body and companies jointly agree on flexible reporting practices for smaller data centers in the >1 MW size category.

This report continues as follows. Initially, we describe the definitions of the information economy sector as used by the OECD and in this report. In chapter two of the report, we present prior research on the energy and electricity consumption of the information economy sector. In the third chapter, we review the development of IP and data traffic worldwide, in Europe, and in Finland. In the fourth chapter, we analyze the energy and electricity consumption of Finland's information economy sector and the change in electricity consumption of other consumer electrical devices, such as computers, tablet computers, and other mobile devices. The fourth chapter also provides a discussion on the services that the Finnish information economy sector purchases from abroad. Furthermore, the chapter provides an overview of the data centers located in Finland and key indicators for them. In the fifth chapter, we compare the electricity consumption of Finland's information economy sector with other European countries. Finally, we present the study's key findings, policy recommendations, limitations of the data, and recommendations for future research.

Definition of the information economy sector

The OECD's definition of the information economy sector from 2006 and 2007 is based on the sectors in the UN's International Standard Industrial Classification (ISIC) of economic activities Rev. 4 (OECD, 2011). The information economy sector includes the ICT sector – encompassing the provision of goods and services – and content production. The 2008 Standard Industrial Classification used in Finland (TOL 2008) is based on the classifications in the Rev. 2 of the NACE, which is used in Europe. The NACE classification is derived from the international ISIC classification.

The energy accounting statistics of Statistics Finland and Eurostat are available at a less granular industrial classification level than the OECD's definition of the information economy sector. For this reason, the following sectors were excluded from this study: *465 Wholesale of information and communication equipment* and *951 Repair of computers and communication equipment*. The European Commission's narrow definition of the ICT sector from 2012 also excludes the ICT wholesale business from its examination due to the limitations of the data[7] (Mas et al., 2012; ITU, 2018). Table 1 shows the definition of the information economy sector used in this study compared with the OECD's definition. The OECD's definition is described according to the TOL 2008 classification used in Finland (Statistics Finland, 2020). The division of industries in the definition that we use in this study follows the two-digit industry classification used in the national accounts, wherein some classifications are consolidated.

2 Prior research

In general terms, the role of the information economy sector in the transition toward a low-carbon economy is twofold. Firstly, it has been suggested that the information economy sector enhances the efficiency of energy consumption (e.g., Kander et al., 2013) and lays the foundation for a greener economy (e.g., Perez, 2013). On the other hand, the growth in energy consumption in the information economy sector and the intensity of rare metals in the hardware used in the sector have also been seen as a threat to sustainable development (Court & Sorell, 2020; Lange & al., 2020; Coroama & Mattern, 2019). In their research, both Court and Sorell (2020) and Lange et al. (2020) have reached the conclusion that digitalization and dematerialization will increase energy consumption in the present and the future. This is because the use of information services will continue to grow rapidly, and the sector's development measures are insufficient to mitigate its energy consumption.

Scientific research covering the energy consumption of the information economy sector is, by nature, approximate and based on micro-level calculation models and estimates. Given the absence of consistent data, different studies have modeled the matter from the bottom-up and top-down perspectives. The most cited bottom-up study in the last decade (Koomey, 2011) calculated the electricity consumption of data centers at approximately 1.1–1.5% in 2010. Most of the subsequent studies have been top-down estimates.

In 2012, the information economy sector accounted for 4.6% of the world's electricity consumption (Van Heddeghem et al., 2014). Andrae and Edler (2015), on the other hand, forecast that consumption in 2020 will fall within the 6–21% range. The International Energy Agency's estimate of the electricity consumption in 2020 is 14% (Hoang et al., 2014). A research group set up by the European Commission estimates the energy consumption of the information economy sector at 7% globally, and it forecasts growth of 13% by 2030 (Bertoldi et al., 2017). Belkhir and Elmeligi (2018), on the other hand, estimated the information economy sector's electricity consumption and, thereby, arrived at a rate of increase in the sector's calculated carbon dioxide emissions of 7–8%.[8]

For Germany, the electricity consumption of data centers from 2010 to 2018 is estimated to have increased from 10.5 billion kWh to a total of 14 billion kWh, with average annual growth of 4% in the same period (Hintemann, 2019a; Hintemann & Clausen, 2018). However, the rate of growth of electricity consumption in the period has accelerated. In 2018, the year-on-year increase was as high as 6%. The study also estimates that if the sector continues to grow in line with the current trend in the period from 2018 to 2030, electricity consumption will increase by 50% from the current state by 2030. As regards Western Europe, different studies have estimat-

Table 1 Information economy sector definition: OECD vs. this study

Information economy sector (OECD)		Information economy sector (this study)	
ICT sector			
261	Manufacture of electronic components and boards	26	Electronics industry
262	Manufacture of computers and peripheral equipment		
263	Manufacture of communication equipment		
264	Manufacture of consumer electronics		
268	Manufacture of magnetic and optical media		
4651	Wholesale of computers, computer peripheral equipment and software		
4652	Wholesale of electronic and telecommunications equipment and parts		
582	Software publishing		
61	Telecommunications	61	Telecommunications
62	Computer programming, consultancy and related activities	62–63	Computer and information service activities
631	Data processing, hosting and related activities; web portals		
951	Repair of computers and communication equipment		
Content and media sector			
581	Publishing of books, periodicals and other publishing activities	58	Publishing activities
591	Motion picture, video and television programme activities	59–60	Audio-visual activities
592	Sound recording and music publishing activities		
601	Radio broadcasting		
602	Television programming and broadcasting activities		
639	Other information service activities		

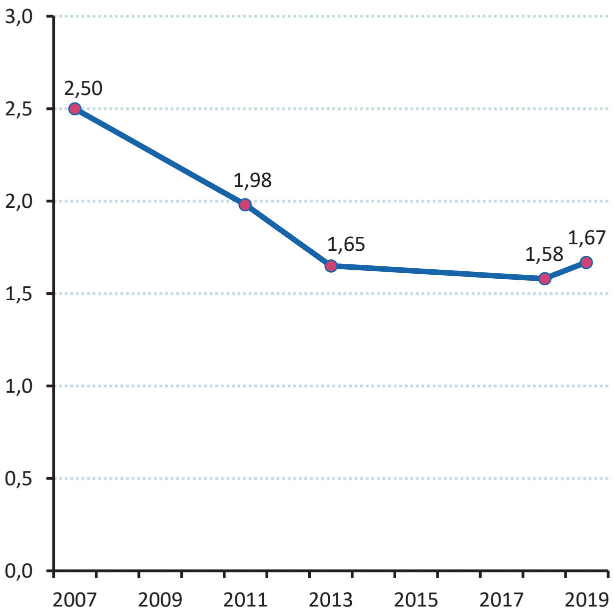
Sources: OECD definition: OECD (2011) and Statistics Finland (2020).

ed significant increases in electricity consumption in the sector in the 2010s. The consensus value for growth from 2010 to 2020 is 30% (e.g., Deloitte & Fraunhofer IZM, 2016; Hintemann, 2019b; Hintemann & Hinterholzer, 2019; Prakash et al., 2016).

On the other hand, the academic literature also includes more conservative estimates indicating that the information economy sector's electricity consumption did not increase significantly in the 2010s (Malmodin & Lundén, 2018; Masanet et al., 2020). However, Hintemann (2019a) criticizes the assumptions behind the conservative studies. He states that the dramatic global increase in the total number of data centers and information on the trends in hardware sales to data centers do not support the claims made in the aforementioned studies that the sector's electricity consumption showed virtually no growth in the 2010s.

Conservative studies forecasting moderate growth in electricity consumption often assume that improvements in the energy efficiency of computer hardware and peripheral technology mean that the electricity consumption of data centers is no longer increasing. However, based on Hintemann's (2019a) research, the average power usage effectiveness (PUE) of data centers in Germany decreased from 1.98 to just 1.70 from 2010 to 2018. A corresponding trend has also been reported by the Uptime Institute, which conducted a survey of its members showing that the PUE of data centers has not undergone significant improvement in recent years (Figure 1).

Figure 1 Average power usage effectiveness (PUE) of data centers 2007–2019



Source: Uptime Institute, Data Center Industry Survey Results 2019.

In summary, the following can be stated. The majority of studies suggest that the information economy sector's energy and electricity consumption is growing and, in the future, will constitute an increasingly significant proportion of the world's electricity consumption. The key driver of this growth is the continuous increase in the use of digital services designed for consumers, which several researchers believe has already reached an unsustainable level (e.g., Lane et al., 2018; Morley et al., 2018; Widdicks & Pargman, 2019; Widdicks et al., 2019).

3 Growth in IP and data traffic volumes

The advancement of digitization and digitalization is accelerating the growth in volumes of industrial and consumer IP traffic. As IP volumes increase, data traffic also increases. Public discourse often references the growth in data traffic while the growth in IP traffic remains in the background. From 2006 to 2011, IP traffic volumes increased by a multiple of 7.3, and from 2011 to 2017, they increased by a multiple of 4.0 (Table 2). Where current reporting practices lack clarity is whether the current assumption of the increase in IP and data traffic volumes is based on "gross on gross" calculation. In other words, if IP traffic/data travels from Finland to Denmark, Denmark to Ireland, Ireland to the United States, and then back again, is the IP traffic/data traffic reported in the statistics of all the countries along the route or only in the statistics for Finland and the United States? Do the present reporting practices exaggerate the growth in IP traffic and data volumes?

In the last 14 years, we have undergone two major transformations affecting the growth in IP traffic: 1) in industry, companies have switched from their own data centers to using cloud service architectures[9], and 2) consumers' service usage has shifted from home endpoint devices to the same cloud service architectures[10]. In both cases, the so-called fixed costs have become variable costs – i.e., service costs. Both changes have a material impact on the global growth in IP traffic because cloud and service architectures can be geographically located in different continents to the location of demand for the service.

Table 2 shows the annual growth in IP traffic. In 2020, consumers accounted for approximately 83% of all IP traffic; the share of global consumer IP traffic (83%) attributable to Europe is approximately 22% (Cisco, 2008; 2012; 2019).

IP traffic can be divided into fixed network and mobile network IP traffic. The majority – 84% – of IP traffic travels on the fixed network, and only 16% travels on the mobile network (Table 3). When a consumer buys services from different operators or applications, the majority of the IP traffic travels on the fixed network.[11] The mobile network is mostly intended for so-called last-mile services. In terms of future development, it is worth noting that fifth- and sixth-generation mobile networks (known as 5G and 6G, respectively) may shorten the final mile to the final meter.

The fixed network and mobile network constitute a key part of the overall IP traffic infrastructure. Data centers are a part of the fixed IP traffic network – the mobile network sends IP traffic between consumers and service providers.

Cisco (2019) forecasts that the share of all IP traffic attributable to mobile IP traffic will increase by 19.4% by 2022 (Table 3). The majority of the growth in IP traffic taking place in the mobile network will be due to the increasingly widespread use of 5G smartphones. A further key factor is that, for example, videos are being transferred at increasingly higher resolutions (Full HD video replaced by 4K UHD, and, in the future, by 8K UHD). As service technologies develop, faster endpoint devices and networks will be needed.

In Finland, statistics on IP traffic are randomly gathered using VALOR analysis – i.e., based on the volume of data. The growth in data volumes on the fixed and mobile networks has been approximately 43% per year on Finland's networks (Finnet, 2019, see Figure 2). The growth in mobile data volumes has been approximately 72% per year (Finnet, 2019). In Finland, mobile data accounts for

Table 2 Share of consumers and firms in global IP traffic, 2006–2022

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Global IP traffic, total (exabytes)	4	7	11	16	24	31	43	55	69	87	110	122	156	201	254	319	396
Consumers' share of IP traffic (%)	62	66	71	74	75	84	86	86	86	87	88	82	83	83	83	84	84
Firms' share of IP traffic (%)	38	34	29	26	25	16	14	14	14	13	12	18	17	17	17	16	16

One exabyte = 1 000 000 000 000 000 000 bytes.

Sources: Cisco (2008; 2012; 2019).

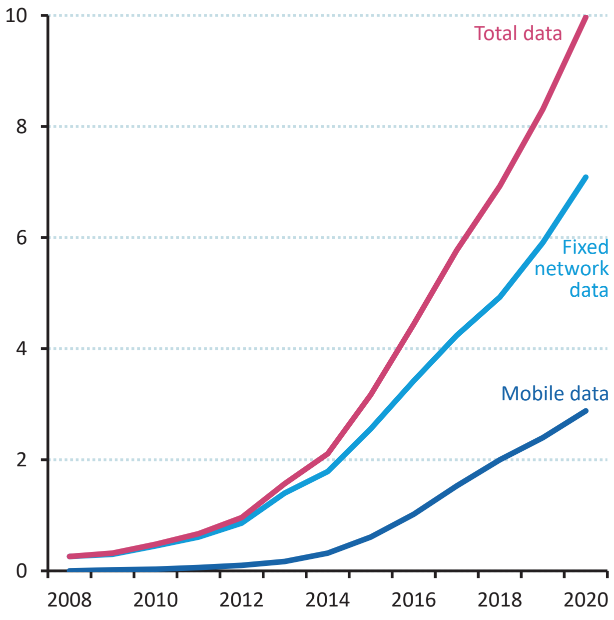
Table 3 Share of mobile IP traffic in global IP traffic, 2006–2022

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Global IP traffic, total (exabytes)	4	7	11	16	24	31	43	55	69	87	110	122	156	201	254	319	396
Mobile IP traffic, total (exabytes)	0,001	0,003	0,007	0,1	0,2	0,4	0,9	1,5	2,6	3,7	6,2	12	19	29	41	57	77
Mobile IP traffic, share (%)	0,02	0,04	0,06	0,6	0,9	1,3	2,0	2,7	3,8	4,2	5,6	10	12	14	16	18	19

One exabyte = 1 000 000 000 000 000 000 bytes.

Sources: Cisco (2008; 2012; 2019).

Figure 2 **Use of data in fixed and mobile networks and in total in Finland 2008–2020, million terabytes**



Figures for year 2020 are forecasts.

Source: Finnet (2019), VALOR analysis.

year. The share of the use of fuels has been on the decline. The use of heat has risen. Overall, electricity holds a dominant share of the energy products (fuels, electricity, and heat) used by the information economy sector: 67.8% in 2018.

The electricity consumption of Finland's information economy sector and its share of the total consumption of electricity is shown in Figure 4. The information economy sector's electricity consumption increased by 26.6% from 2011 to 2018. This represents annual growth of 3.4%. In 2018, the information economy sector's share of Finland's total electricity consumption was 1.1%.[13,14] According to the energy accounts, Finland's total electricity consumption in 2018 was 92.8 TWh (334.1 PJ). Furthermore, the total electricity consumption increased by 1.8% from 2011 to 2018. The information economy sector's electricity consumption has, therefore, increased by proportionately more than Finland's electricity consumption as a whole.

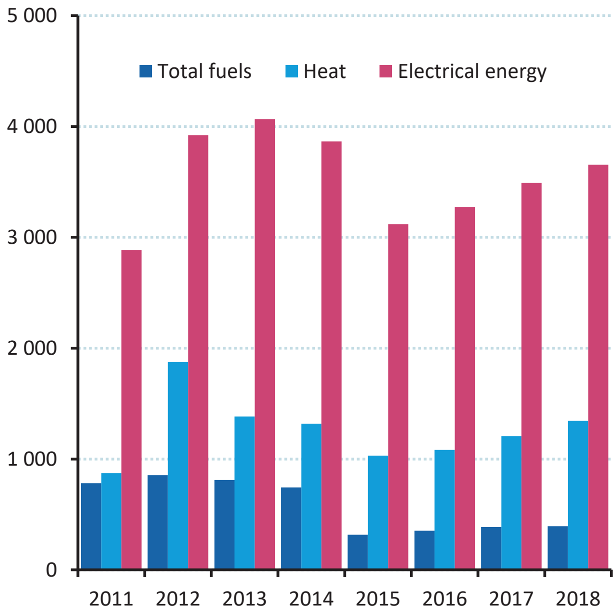
approximately 29% of all data usage. In one sense, the large percentage share is not surprising, as more mobile data is used in Finland than anywhere else in the world – 19.39 GB/person/month (OECD, 2018).[12]

Has the growth in the volume of IP traffic/data affected the energy and electricity consumption of the information economy sector and consumers in Finland? We will cover this next.

4 Energy and electricity consumption of the information economy sector

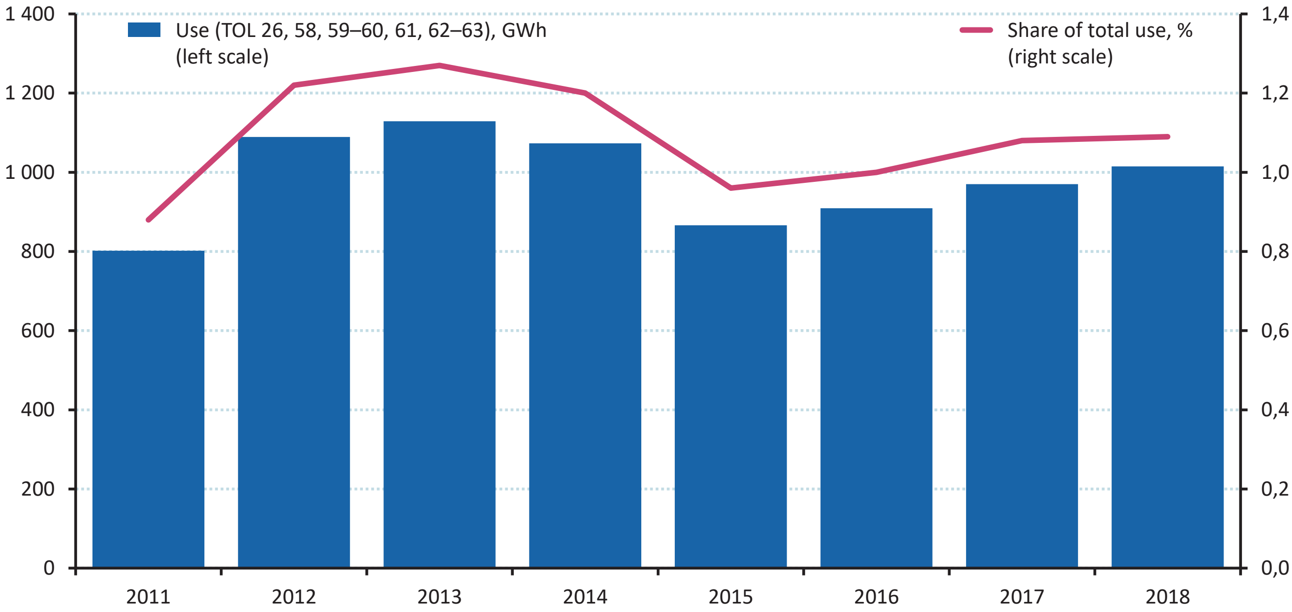
Figure 3 shows the usage of energy products – fuels, electricity, and heat – by Finland's information economy sector from 2011 to 2018. During this period, the electricity consumption of the information economy sector increased in comparison with the value in the initial

Figure 3 **Use of energy products in the Finnish information sector 2011–2018, terajoules**



Sources: Energy Accounts, Statistics Finland (accessed on November 4, 2020); Etla's calculations.

Figure 4 Electricity consumption in the Finnish information sector and its share of total consumption 2011–2018



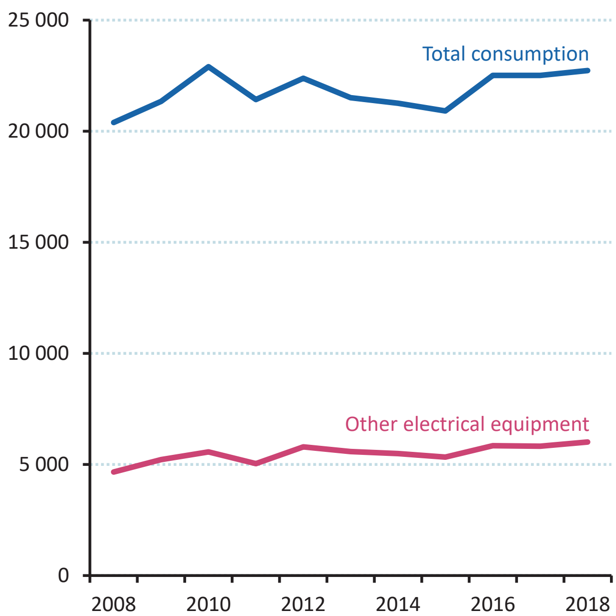
Sources: Energy Accounts, Statistics Finland (accessed on November 4, 2020); Etla's calculations.

Consumers' electricity consumption

Figure 5 shows the residential consumption of electrical energy in Finland from 2008 to 2018 in terms of overall consumption and other electrical devices. The residential energy consumption is divided by application into the following sub-areas: heating premises, heating domestic water, heating saunas, lighting, preparing food, and other electrical devices. The electrical energy consumption of other electrical devices, which include domestic electrical devices, such as computers, increased by 19.3% from 2011 to 2018.[15] This represents annual growth of 2.6%.

Based on the information provided by Adato Energia Oy's (2013) research report, the share of computers and peripherals in the consumption of domestic electrical devices in 2011 (2006) was 14.7% (8.1%), and in the total consumption of auxiliary electricity in housing units, it was 4% (2%) in Finland.[16] A recent international comparison can be found in the EIA's (2020) statistics, which show that computers and peripherals consumed 1.8% of the total residential electricity consumption in the United States in 2019.

Figure 5 Energy consumption in households: other electrical equipment and total consumption 2008–2018, GWh



Sources: Energy consumption in households, Statistics Finland (accessed on November 4, 2020); Etla's calculations.

Data centers in Finland and key indicators

According to the Cloudscene website, there are approximately 2,700 data centers in Europe (Cloudscene, 2020).[17] Europe's largest data center countries are Germany, England, France, and the Netherlands. These countries each host from more than 200 to more than 400 data centers. Other European countries have data centers numbering in the tens or just over 100. According to the website, there are 35 private data centers in Finland (Table 4).

The largest data center countries in proportion to the population are Luxembourg, the Netherlands, Sweden, and Ireland. Finland is around the European average in terms of the number of data centers in proportion to the population, with 0.64 data centers per 100,000 residents, while the average is 0.63 per 100,000. The majority of the data centers in Finland are located in Uusimaa. There are also data centers in other regions, including Häme, Kainuu, Central Finland, Kymenlaakso, and North Ostrobothnia.

Companies' own data centers in various fields are absent from the figures reported above. In addition, the figures do not include public-sector data centers. It should also be noted that some public-sector data centers are related to Finland's security of supply, which is why there is no information available about them. We estimate that there are dozens of private- and public-sector data centers in Finland.

The energy and electricity consumption of private- and public-sector data centers is included in the overall statistics for the sector in which each company operates. In order to gain a better understanding of the energy and electricity consumption of private- and public-sector data centers, more expansive ICT sector reporting on energy and electricity consumption should consider these extended principles.

There is limited information available on the key indicators for data centers. For Tuike Finland Oy and Telia Finland Oy, information is available thanks to their environmental permits. There is very little other information. As such, the information is very random in scope.

Tuike Finland Oy, which is responsible for Google's data center in Hamina, has been operating a data center in the Summa factor area since mid-2011 (Regional State Administrative Agency, no. 235/2015/1).[18] The 2010 environmental permit for Tuike Finland Oy's Hamina data center states an annual electrical energy consumption of approximately 280 GWh (1,000 TJ) (Regional State Administrative Agency, no. 16/2010/1).[19] In this permit, the annual consumption of fuel oil by generators is estimated at less than 60 m3, and the consumption of natural gas required to heat the buildings is stated at approximately 2.1 million Nm3 per year. The data center and the extensions that have subsequently been built are cooled by a refrigeration system that uses seawater. According to the 2015 environmental permit, natural gas has not been used in the facility since the start of 2014, and some of the heat generated by the data center is used to heat the center's premises (Regional State Administrative Agency, no. 235/2015/1). According to

Table 4 Private data centers in Finland

Data center operator	Number	Location
Alcon	1	Maarianhamina
Boftel	1	Helsinki
Capnova	1	Tampere
CenterServ	1	Helsinki
CSC/Funet	2	Helsinki, Kajaani
Datalahti	1	Helsinki
Digita	2	Helsinki
DNA	1	Helsinki
Equinix	6	Helsinki
Ficix	1	Helsinki
Ficolo	3	Helsinki, Pori, Tampere
Herman IT	1	Kajaani
Hetzner	1	Helsinki
IBM	1	Helsinki
IP-Only	1	Helsinki
Louhi	1	Helsinki
Mediam	1	Helsinki
Oulun Datacenter	2	Oulu
RUNNet	1	Helsinki
TDC	1	Helsinki
Telia	3	Helsinki
Tuike (Google)	1	Hamina
Yandex	1	Mäntsälä

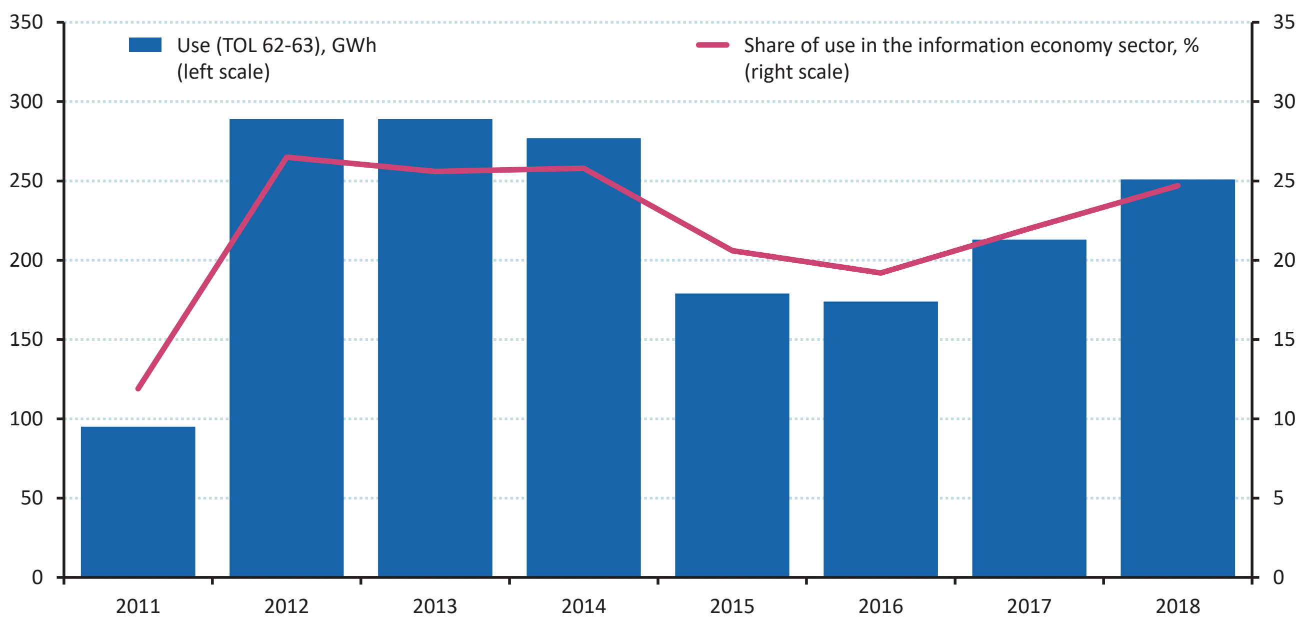
Source: Cloudscene (2020).

the information in the decision by the Centre for Economic Development, Transport and the Environment (ref. no. KASELY/1867/2019), the return water from data centers 1 and 2 is used in the cooling of data centers 3–5.[20] The cooling water for data centers 6 and 7 is taken from the Gulf of Finland with the help of a new seawater pumping station. The plant has been granted permission to discharge 2,200 TJ of thermal energy into the sea every year. The heat load of data centers 1–7 is less than this figure.

The environmental permit for Telia Finland Oy's Helsinki Data Center in Pitäjänmäki (Regional State Administrative Agency, no. 258/2017/1) contains information about the electrical energy used in the facility.[21] In the initial phase, the data center's IT capacity is at least 6 MW, and the capacity will be expanded according to demand. When the data center is operating at full capacity, its IT power is 24 MW, encompassing 200,000 servers. The waste heat output by the servers is recovered and transferred to the district heating network to the maximum possible extent. In the initial phase of the data center's operations, on warm summer days and in other circumstances where it is not possible to transfer waste heat to the district heating network, a solvent-based cooling system located on the roof of the building is used for condensation. The cold air units inside the facility are also used. The data center's operations are secured using a duplicated fixed power supply (2 x 110 kV), emergency power batteries, and emergency generators.

Tuike Finland Oy's 2015 environmental permit only states an energy efficiency based on a PUE value for the entire group of companies (Regional State Administrative Agency, no. 235/2015/1); the consolidated PUE value for all of the group's data centers is given as 1.12, and the comparison value for 2008 is 1.21. Tuike Finland Oy did not provide the Regional State Administrative Agency with more precise electricity consumption and energy efficiency information specific to the Hamina data center, and it justifies keeping this information confidential on competition grounds, according to requests for additional information in relation to the permit application (ref. no. ESAVI/8564/2014).[22] Likewise, no information concerning energy consumption is provided in the 2019 application for an environmental permit on the grounds of business secrecy (ESAVI/35528/2019).[23] According to Google, the PUE value for the Hamina da-

Figure 6 **Electricity consumption in the Computer and information service activities (TOL 62–63) and its share of consumption in the information sector 2011–2018**



Sources: Energy Accounts, Statistics Finland (accessed on November 4, 2020); Etla's calculations.

ta center was 1.09 in 2020 (Google, 2020). According to Google's 2019 environmental report, its average global PUE value is 1.11 (Google, 2019). The following information is available on the energy efficiency of other data center operators: Yandex states a PUE value of 1.15 for its data center in Mäntsälä, and this value includes the office buildings as well as the data center (Yandex, 2018). The waste heat from Yandex's Mäntsälä data center is recovered and fed into the district heating network. The planned PUE target value for Telia Finland Oy's Helsinki Data Center is less than 1.2 (Telia, 2017). The average international PUE value of IBM's data centers is 1.76, and the range is 1.1–3.4 (IBM, 2018). According to the survey by the Uptime Institute, the average PUE value for international data centers was 1.67 in 2019 (Uptime Institute, 2019).

Figure 6 shows the electricity consumption of the two-digit level industrial classification covering data centers (Computer and information service activities, TOL 62–63) and its proportion of the information economy sector's electricity consumption from 2011 to 2018. The electricity consumption of this industry increased by 163.0% from 2011 to 2018. This equates to annual growth of 14.8%. The share of this industry in the information economy sector's electricity consumption more than doubled over the period; in 2018, the share was 24.7%.

How much of the investment in the information economy sector comes from foreign entities? We will focus on this next.

To what extent is Finland's information economy sector dependent on foreign investment?

This section analyzes the extent to which the sub-sectors within the information economy sector and the companies in the sectors are dependent on the use of external resources. External resources refer to all purchases made by the sector and their share of the sector's turnover. In addition, we analyze how much of the information economy sector's purchasing is from foreign operators in relation to purchases from Finnish operators.[24]

On average, 48% of the information economy sector's turnover is generated using the own resources of companies operating in this sector – i.e., the companies' own value-added. The amount of procurement in the information economy sector (the use of external resources) correspondingly averages 52% of the turnover of the information economy sector. As shown in Table 5, there is a minor sector-specific variation of +/-8% within the information economy sector. The same range also recurs with respect to purchases.

An average of 29% of the information economy sector's direct purchases come from abroad, and 71% come from Finland (Table 6). However, we were not able to use the value chain analysis method to estimate how many of the Finnish first-step suppliers are middlemen who redirect their service offerings for procurement from abroad. In order to understand this, it would be necessary to have information about how the first-step suppliers allocate

Table 5 **Value added and purchases in the information economy sector, percentage of industry's net sales**

Information economy sector (this study)	Value added, % of net sales	Purchases, % of net sales
26 Electronics industry	40	60
61 Telecommunications	43	57
62–63 Computer and information service activities	49	51
58 Publishing activities	50	50
59–60 Audio-visual activities	56	44

Source: Input-output use tables for imports at basic prices (Statistics Finland). Etla's calculations.

Table 6 Direct foreign and domestic purchases in the information economy sector, percentage of industry's purchases

Information economy sector (this study)	Foreign purchases, % of all direct purchases	Domestic purchases, % of all direct purchases
26 Electronics industry	53	47
61 Telecommunications	34	66
62–63 Computer and information service activities	24	76
58 Publishing activities	15	85
59–60 Audio-visual activities	20	80

Source: Input-output use tables for imports at basic prices (Statistics Finland). Etla's calculations.

their purchases to Finland and abroad. Furthermore, the analysis and results presented here do not take into consideration the case where Finnish consumers purchase services directly from foreign suppliers.[25] In addition, this section of our analysis does not take into consideration matters related to the energy and electricity consumption of the information economy sector because there is insufficient detail in the available data.

Case study: Amazon Web Services (AWS) – information economy sector's services outsourced from Finland

The turnover and value-added of the AWS companies are very low in Finland. For example, in 2018, Amazon Data Services Finland Oy's turnover in Finland was EUR 2.85 million. How many Finnish companies make purchases from Amazon Data Services Finland Oy? Or do the Finnish companies partner with one of the foreign subsidiaries of the AWS companies? In order to comprehend this, we would need to understand the ways in which

Figure 7 AWS data centers

Source: https://aws.amazon.com/about-aws/global-infrastructure/ (accessed on May 26, 2020).

companies make agreements. This would provide us with an idea of how the ICT giants arrange the intra-Group transfer pricing of their internal digital services. Amazon's data centers are described in Figure 7.

5 The information economy sector's share of electricity consumption – case study: Europe

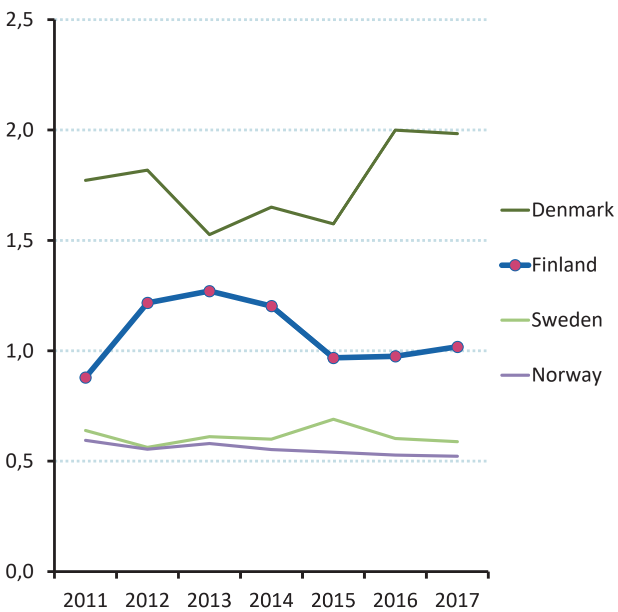
The definition of the information economy sector used in this study and Eurostat's data together enable a pan-European comparison of the information economy sector's energy and electricity consumption. We will next describe the findings of our analysis.

Figures 8 and 9 present the information economy sector's share of electricity consumption in the Nordic countries and in the European countries for which data is available for 2011–2017.[26] Data concerning the electricity consumption in the remaining EU28 countries has been available since 2014. Figures 10 and 11 show the information economy sector's share of electricity consumption for a wider group of countries and the average for the EU28 countries from 2014 to 2017.

The electricity consumption of Finland's information economy sector is in the middle range of the Nordic comparison for the period from 2011 to 2017. The Finnish information economy sector's share of electricity consumption in 2017 (1.0%) is higher than in Sweden (0.6%) or Norway (0.5%) but lower than in Denmark (2.0%) (Figure 8). As regards other European countries, the German information economy sector's share (2.1%) was higher than Denmark's in 2017 and throughout the review period, although the gap has narrowed (Figure 9). Belgium (1.0%), Italy (1.2%), and Portugal (1.1%) are in the midrange near Finland.

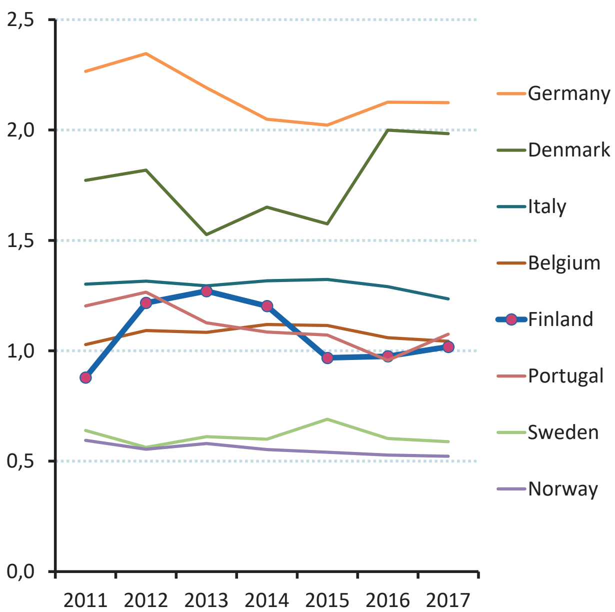
Under a more comprehensive analysis of the EU28 group of countries from 2014 to 2017, it can be discerned that the information economy sector's share of electricity consumption was clearly highest in Ireland (6.4%) in 2017 (Figure 10). Of the major European countries, the ones near the three-percent mark are the United Kingdom (2.9%) and France (2.9%). In the Netherlands, Germany,

Figure 8 Share of the information sector in electricity use in Europe 2011–2017, %



Sources: Eurostat (accessed on April 29, 2020), Etla's calculations.

Figure 9 Share of the information sector in electricity use in Europe 2011–2017, %

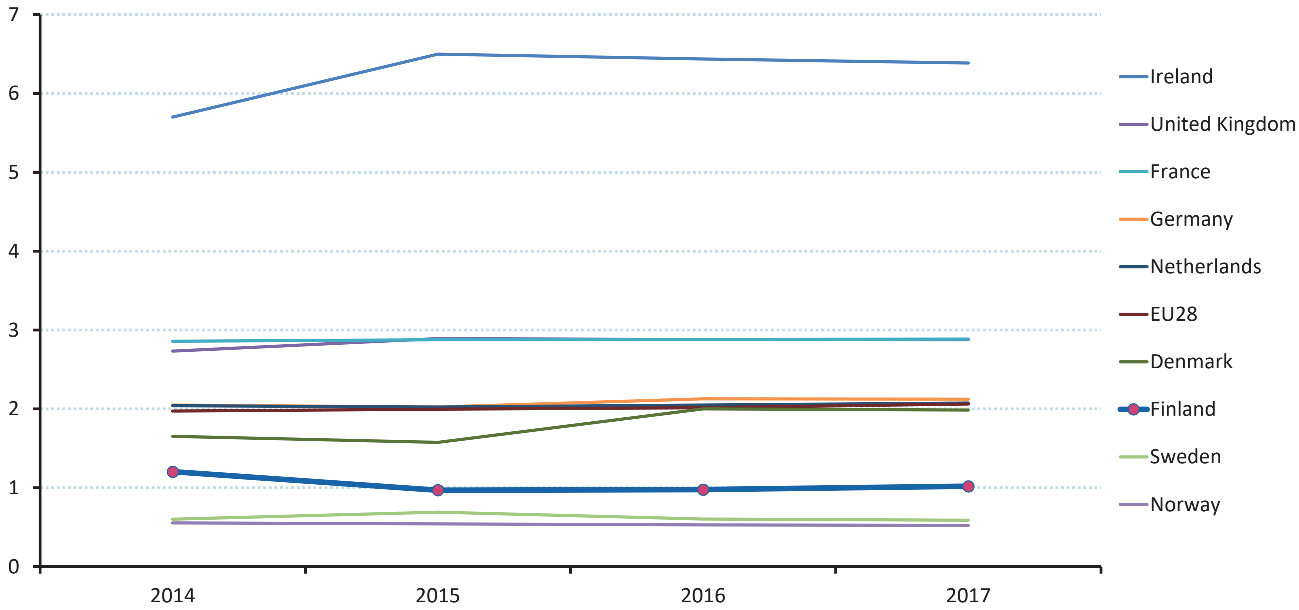


Sources: Eurostat (accessed on April 29, 2020), Etla's calculations.

and the EU28 countries on average, the information economy sector's share of electricity consumption remained around two percent throughout the review period.

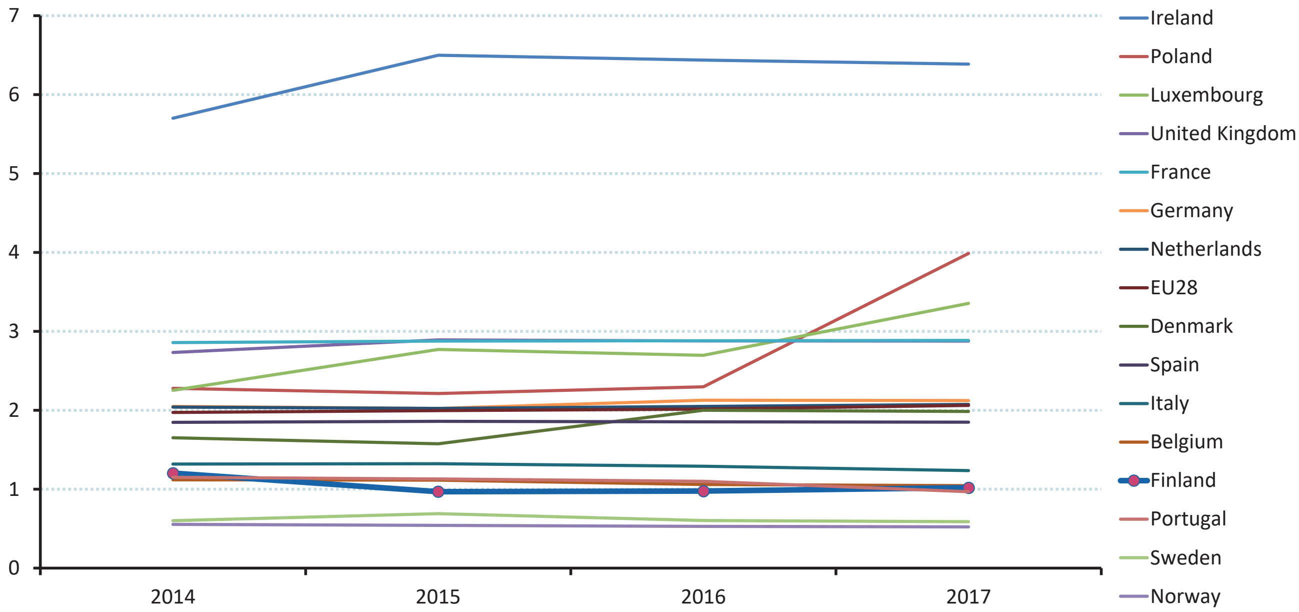
The statistics for 2017 show that the Polish information economy sector's share of electricity consumption rose to four percent (see Figure 11). In Luxembourg, the

Figure 10 **Share of the information sector in electricity use in Europe 2014–2017, %**



Sources: Eurostat (accessed on April 29, 2020), Etla's calculations.

Figure 11 **Share of the information sector in electricity use in Europe 2014–2017, %**



Sources: Eurostat (accessed on April 29, 2020), Etla's calculations.

information economy sector's share of electricity consumption also increased: in 2017, the sector's share of electricity consumption was 3.4%. In Spain, the information economy sector's share of electricity consumption remained around two percent throughout the review period, and the share stood at 1.8% in 2017. Austria ranks near Finland with its share of about one percent of electricity consumption.

On a broader scale, the present data enables us to gain a good picture of the energy and electricity consumption of the information economy sector. An analysis of the energy and electricity consumption based on public statistics can be expanded to cover all industries. In addition, a pan-European comparison of sectors is possible using open statistics.

6 Findings, policy recommendations, and conclusions

The overall growth in IP traffic has been significant globally. Consumers' share of global IP traffic is 84%, and Europe's share of consumers' global annual IP traffic is approximately 22%. Cisco (2019) measures the volume of IP traffic in exabytes per month. Cisco's report forecasts an average annual increase of 41% in the mobile IP traffic in Europe over the next five years. The greatest growth will occur in Asia. (Cisco, 2019.)

Data usage in Finland is forecast to grow in the future. This includes the volumes of data on the fixed network and mobile data. In Finland, mobile data accounts for approximately 29% of all data usage (Finnet, 2019). The proportion of mobile data in relation to data on the fixed network is higher in Finland than in any of the comparison countries (OECD, 2018). We can identify two main reasons for the stronger growth in the volume of mobile data in Finland than in the comparison countries: 1) unlimited data subscriptions offered to consumers and 2) Finland's prominent role as a developer of mobile technologies.

The energy consumption of Finland's information economy sector consists of three energy sources, which are fuels, electricity, and heat. Of theseelectricity consumption accounts for 67.8% of the information economy sector's total energy consumption. The information economy sector's share of Finland's total electricity consumption was 1.1% in 2018. According to our definition of the information economy sector, the total growth in energy consumption was 18.8%, and the increase in electricity consumption was 26.6% from 2011 to 2018. As the usage of data has increased by approximately 43% every year, the information economy sector's energy and electricity consumption increased by annual rates of 2.5% and 3.4%, respectively. The updated data used in this study indicate that the energy and electricity consumption of the information economy sector has increased more than suggested in our previous estimates (Hiekkanen, Seppälä, and Ylhäinen, 2020). According to our research, energy and electricity consumption in the ICT sector will continue to increase unless the sector's energy efficiency (for example, the PUE values of data centers) improves so as to mitigate the growth and reduce emissions.

The increase in the volume of mobile data is not directly indicative of an increase in the electricity consumption of other consumer electrical devices. These devices include TVs, computers, tablet computers, and phones. Although the use of mobile data has increased by approximately 72% every year, the electricity consumption of other consumer electrical devices has increased by only 2.4%. It should be noted that a significant proportion of the total growth in consumer data traffic is due to IP traffic on the fixed network.

However, based on the reported forecasts, we can state that the endpoint devices account for a decreasing proportion of the electricity consumed by other electrical devices in the United States (EIA, 2020). There is no research data available for Finland after 2013. It should also be noted that consumers may charge their endpoint devices in locations other than their homes. More broadly, the increased usage of mobile data by consumers is not directly reflected in an increase in consumers' electricity consumption at home.

Companies in the information economy sector generate 48% of the turnover of the sector with their own resources. The remaining 52% is in the form of direct procurement from other companies. Procurement is further divided into direct purchases from Finland and from abroad. Direct procurement from foreign entities in the information economy sector accounts for 29% of the sector's entire turnover. Based on this analysis, we can present an estimate that at least 29% of the behavior of Finnish consumers related to data is outsourced beyond Finland's borders. However, this figure only takes into consideration the purchases of services by consumers in Finland from companies registered in Finland. Consumers can buy services directly from foreign service providers. Therefore, the share attributable to foreign countries is actually higher.

Our report partially refutes results previously presented in the literature and publicity (compare with Andrea & Edler, 2015 with regard to electricity consumption and growth, and with Malmodin & Lundén, 2018 with regard to calculating electricity consumption). The electricity consumption of the information economy sector in Finland increased at an annual rate of 3.4% from 2011 to 2018. An analysis of the consumption of different forms of energy and the growth in electricity consumption based on public statistics can be expanded to cover all of the various sectors.

The key policy recommendations of this study are as follows:
Although the OECD and European countries have a common definition of the information economy sector, it is rarely used for measurements, statistics, reporting, and research. According to the OECD's definition, the information economy sector includes the ICT sector (provision of goods and services) and content production. The definition is based on the industries in the UN's ISIC Rev. 4. We recommend adopting the OECD definition in Finland, as well as in the other European Union Member States, in order to enable a global comparison of the key indicators for the information economy sector.

In Finland, Statistics Finland and, at the European level, Eurostat could act as the custodians of key indicators and statistics for the information economy sector. On the other hand, individual indicators, such as energy consumption, could also be maintained by operators like Fingrid, Motiva, or Finnish Energy. These entities could maintain indicators and annual/quarterly statistics on energy and electricity consumption and other key resources in accordance with the OECD's definition of the information economy sector.

More broadly, analysis by company or country provides insufficient depth to be able to understand energy and electricity consumption, carbon neutrality, and other key uses of the information economy sector's internal and external resources. Instead, an examination of the supply and value chain provides better insight into the use of the resources of companies and nations and the carbon neutrality of the sector, taking into consideration the links to other sectors. An examination of supply and value chains would enable an understanding of the impacts of production and consumer behavior on other countries. This would provide a better understanding of factors such as how much of the consumer behavior surrounding data has been outsourced beyond Finland's borders. What is the geography of the distribution of value-added in production and services? And how are resources distributed between different countries and continents?

At present, public information on individual data centers is almost non-existent. Public information is only available from the environmental permits of data centers consuming more than 5 MW. Many industrial and service companies still own their own data centers. So far, this information has not been made publicly available. In addition, the data centers of public entities are often intertwined with Finland's digital security of supply, so it is not necessary to distribute information about these to outsiders. We recommend that a public body and companies jointly agree on flexible reporting practices for smaller data centers in the >1 MW size category.

Limitations of the data

The limitations of the study are related to the data utilized in the report. Our definition of the information economy sector is derived from the OECD's definition of the information economy sector and is based on the two-digit sector in the classification of industries (TOL 2008). At present, more detailed data applying to the four-digit sector classification is not openly available for researchers to access via the websites of Statistics Finland or Eurostat. Open data that applies to four-digit sector classifications and that follows the OECD's definition would enable more precise and detailed calculations of the energy and electricity consumption of the information economy sector. We recommend that public entities or other research institutions who have access to such data should conduct an analysis in accordance with the OECD's definition using four-digit level sector classifications.

Future research

The use of new digital technologies is progressing on several fronts in several different sectors. Electricity is becoming more widespread as a "fuel" for vehicles, and the utilization of data and algorithms in product development is increasing along with the optimization of various resources. Decision-making is also becoming more automated. Digital technologies are, therefore, increasingly being applied to various functions in society. The current trend, for example, with regard to algorithms, suggests that the digital technologies on the horizon will be increasingly energy- and electricity-intensive. In particular, energy and electricity intensity should be understood in more depth from the perspectives of personal consumption as well as industrial and public-sector entities. Just as we demand that every investment has a robust business case, investments should also be assessed from the perspectives of sustainable development and digital ecology.

Endnotes

1 An industry classification is a business category defined on the basis of the primary activity of a company or entrepreneur engaged in economic activity.

2 Internet Protocol (IP) is the basic packet-switching protocol of the data transfer layer of the internet. In other words, it is a method for connecting network-attached devices and servers to each other. In practice, we can say that all internet traffic is IP traffic.

3 IP enables a very wide range of applications. The most popular applications on the internet include the World Wide Web (www), email, online gaming, remote operation of devices, Voice over Internet Protocol (VoIP), and other communication and conferencing applications.

4 It has been claimed that the growth in IP traffic increases the information economy sector's energy and electricity consumption. The growth in IP traffic represents the increase in the number of internet-connected devices, pieces of software, and volumes of data.

5 IP traffic includes the wide area and access networks for data traffic. Wide Area Networks (WANs) are the telecommunications operators' networks and the connections between telecommunications operators and data centers. Access networks (or subscriber networks) are the part of the network that enables end-users to connect to their telecommunications operator's connection point.

6 This figure does not include the electricity consumption of different industries that are related to the operation and maintenance of ICT networks and hardware. The electricity consumption of consumers' endpoint devices at home has also been excluded from the study.

7 In addition, this definition excludes the manufacturing of storage media.

8 In this report, we do not focus on evaluating the information economy sector's carbon dioxide emissions, but we are aware of the importance of the matter as a part of a broader picture of the information economy sector, energy consumption, and emissions.

9 The debate about the Internet of Things (IoT) first started up at the end of 2008 and the start of 2009. Around the same time in 2008, a wider-ranging debate began about the transition of companies onto cloud service architectures. Discussion of the industrial IoT became more intense in 2012 when the major US corporation General Electric published a white paper on the industrial IoT.

10 Apple (iPhone/App Store) and Google (Android phone & market) opened their application stores in 2008. By 2010, both the Apple and Google application stores had expanded, first to Europe and then to the rest of the world. In Asia – mainly China – the growth in IP traffic took off in earnest in 2012 when separate application stores were created for the Chinese market. These stores now number more than 100.

11 There may be some national variations in the percentage distribution of IP traffic.

12 OECD (2018).

13 If the two-digit sector classifications Wholesale trade (except of motor vehicles and motorcycles) (TOL 46) and Repair of computers and personal and household goods (TOL 95) were included in the examination, the share of electricity consumption in 2018 would rise by a multiple of 1.8 entirely due to the electricity consumption of the wholesale trade. However, this level of detail does not allow for the wholesale trade in the information economy sector to be differentiated from other wholesale trades. The energy and electricity consumption figures reported in this study are higher than those in the previous version of the paper (Hiekkanen, Seppälä & Ylhäinen, 2020) due to data updates by Statistics Finland. According to our previous pre-update estimates, the figures were reported as follows (see Hiekkanen et al., 2020, updated figures in parentheses): The information economy sector's energy consumption as a proportion of Finland's total energy consumption was 1.0% (1.08%) in 2017. The total growth in energy consumption in the information economy sector was 5.4% (11.9%) from 2011 to 2017 while electricity consumption increased by 13.9% (21.0%) in the same period. The information economy sector's energy and electricity consumption increased by annual rates of 0.9% (1.9%) and 2.2% (3.2%), respectively. The Eurostat data used for the European comparison relies on the previous versions of the statistics.

14 This figure does not include the electricity consumption of different sectors that are related to the operation and maintenance of ICT networks and hardware.

15 This figure does not include estimates related to the charging of consumer endpoint devices outside the home.

16 According to Adato Energia Oy (2013), the electricity consumption of computers and peripherals in 2011 was 848 GWh, and the total electricity consumption of housing units was 19,237 GWh. These figures are not identical to the statistics on residential energy consumption provided by Statistics Finland, despite the same classification concepts. These differences in statistics relate to differences in study approaches. The study by Adato Energia Oy (2013) is based on a sample that applies to permanently occupied dwellings. The energy consumption data of Statistics Finland is based on the sector-specific sales data of energy companies that apply to all residential buildings occupied by households.

17 https://cloudscene.com/ (accessed on May 11, 2020).

18 https://tietopalvelu.ahtp.fi/Lupa/AvaaLiite.aspx?Liite_ID=1975501 (accessed on May 25, 2020).

19 http://www.avi.fi/documents/10191/56820/esavi_paatos_16-10-1_2010-05-11.pdf (accessed on May 25, 2020).

20 https://www.ymparisto.fi/fi-FI/Asiointi_luvat_ja_ymparistovaikutusten_arviointi/Ymparistovaikutusten_arviointi/YVApaatokset?f=KaakkoisSuomen_ELYkeskus (accessed on May 25, 2020).

21 https://tietopalvelu.ahtp.fi/Lupa/AvaaLiite.aspx?Liite_ID=3779203 (accessed on May 25, 2020).

22 https://tietopalvelu.ahtp.fi/Lupa/AvaaLiite.aspx?Liite_ID=1772547 (accessed on May 25, 2020).

23 https://tietopalvelu.ahtp.fi/Lupa/AvaaLiite.aspx?Liite_ID=6899060 (accessed on May 25, 2020).

24 The research data and methodology in this part are the same as in the publication by Ali-Yrkkö & Kuusi (2020).

25 ETLA studied digital services using the value chain analysis method in 2014. For more, see Kalm et al., 2014.

26 For each country, we have presented the electricity consumption of industry classifications 26, 58, 59–60, 61, and 62–63 belonging to the information economy sector in relation to the energy flows over all activities based on Eurostat's statistics on physical energy flow accounts.

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