Overview of the Estonian ICT sector

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Contents

Introduction

At a global level, Estonia is considered a successful e-country. A primary reason for this is that there have been no significant obstacles in existence due to historical reasons, for example there was no legislative structure that would have stood in the way of developing an information society. Moreover, the right decisions were made, starting from a strongly pro-market government agenda from the very beginning of the transition from the Soviet regime, such as a growth-supporting corporate tax system that helped boost investments. Prioritising various national e-services has made Estonia a textbook international model for how digital solutions can be integrated into people's everyday life (e.g. ID card and its applications, e-tax board, X-road, e-prescription, e-citizenship, etc.).[1] Estonia hosts the NATO Cooperative Cyber Defence Centre of Excellence (CCDCOE), European Union Agency for the Operational Management of Large-Scale IT Systems in the Area of Freedom, Security and Justice, and has been widely influential for its various e-solutions and services (ID-Card and its applications, e-tax board, X-road, e-prescription, etc.), and globally successful companies have emerged in Estonia (Skype, Wise, GrabCAD, Bolt and many others).

Purpose of the overview

In Estonia, the ICT sector has been considered as the main driver of Estonia's economic growth over the last decade and its importance is believed to be increasing. Given that the needs for personnel in the ICT sector have been growing, in cooperation with the Estonian state, universities, vocational schools and ICT companies, the IT Academy programme was designed to raise the quality of ICT education, generate research, and ensure the necessary labour resources. Part of the IT Academy programme is the ICT science support measure, which supports ICT research in three Estonian universities: University of Tartu, Tallinn University of Technology and Tallinn University. The ICT science support measure is institutional- rather than project-based financing. During the financing period of 2018–2022 the total amount paid to universities was 14 million euros. For more detailed information about funding the of universities from the IT Academy programme see Appendix 4.

The ICT research measure of the IT Academy programme also states the priority areas which the programme should target. These include the following: artificial intelligence and machine learning; data science and big data; robot-human collaboration and Internet of Things in Industrial Processes; software reliability; Internet of Smart Things; security and reliability of hardware and systems; digital transformation and lifelong learning.

This overview is part of the targeted evaluation of the IT Academy programme ICT science support measure based on the Estonian Minister of Education and Research's Directive No. 1.1-2/22/348. The evaluation procedure specified in the directive states that the Evaluation Panel consisting of international and national experts should build up a broader picture regarding the Estonian ICT landscape from a field overview in order to support the Panel's conclusions concerning the evaluation subjects. This field overview is intended to concentrate on the following questions:

- What is the volume of funding for ICT research and development, and what are the main types of funding sources (including external funds, private sector financing)? How is the funding distributed between research areas?
- What directions of ICT research and development are advanced in Estonia and to what extent do the selected directions overlap with the country's strategic priorities and global development trends?
- What are the other main resources of the ICT R&D areas of the institutions (incl. number of employees, doctoral students, involved foreign researchers, infrastructure, and other indicators)

[1] Estonian Business and Innovation Agency, e-Estonia Briefing Centre. https://e-estonia.com/ (22.05.2023).

and outputs (incl. publications, intellectual property, contracts with the private and public sector, and other indicators)?
- How does ICT research and development support higher education?

Consequently, the following report is divided into three main chapters. Before the main chapter, a short overview of the methodology is provided. The first chapter gives an overview of the importance of the ICT sector for the Estonian economy. The second describes the resources available for R&D in the field of ICT in Estonia and the impact of Estonian ICT research. Finally, the third chapter analyses to what extent Estonian R&D responds to the IT Academy's selected priority areas and country's strategic priorities and global trends as well as giving the main indicators about the impact of Estonian R&D research.

Methodology

Data sources. Macroeconomic data are primarily drawn from Estonian Statistics[2] and Eurostat[3]. In addition, data obtained by inquiry from Estonian Ministry of Education and Research are used, which in turn complements data from the Estonian Education Information System (EHIS, Teadussilm[4]) and Estonian Tax and Customs Board. R&D funding and project data, as well as information about researchers in the field of ICT are acquired from the Estonian Research Information System (ETIS)[5], which is managed by the Estonian Research Council and the European Commission framework projects from the European Funding and the tender opportunities platform[6]. The overview also uses consolidations from the IT Academy programme. For patent search the Espacenet[7] worldwide service is used, which has been developed by the European Patent Office. Additionally, bibliometric data were taken from inCites by Clarivate[8]. IT Academy priority areas, the country's strategic priorities and global trends in ICT as well as responding keywords in ICT have been discussed and approved by the Steering Committee of this targeted evaluation.

The Education and Youth Board of Estonia (HARNO) has commissioned a study ”Higher education and research and development activities in the field of ICT in 2022“[9], a thorough exploration of the sustainability of ICT education in Estonia. Therefore, this current overview concentrates less on topics that have already been deeply analysed there and instead refers to the HARNO report where necessary. The Estonian Research Council also ordered a translation of the report into English. Therefore, it serves as valuable supportive material to this overview.

Two notable reports (also cited further) prepared by the Estonian Qualifications Authority (Kutsekoda) also deserve highlighting: "OSKA Study on Information and Communication Technology Sector" (2022)[10] and "Labor and Skill Needs of Research and Development Employees in the Business Sector" (2023)[11].

[2] Statistics Estonia. https://www.stat.ee/en (25.04.2023).
[3] Eurostat. https://ec.europa.eu/eurostat/data/database (25.04.2023).
[4] Haridussilm. https://www.haridussilm.ee/ee (25.04.2023).
[5] Estonian Research Information System. www.etis.ee (25.04.2023).
[6] European Commission. Funding and tender opportunities. https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/horizon-dashboard (25.04.2023).
[7] Espacenet. https://worldwide.espacenet.com/ (24.04.2023).
[8] InCites. https://access.clarivate.com/login?app=incites (24.04.2023).
[9] IT Akadeemia. IKT valdkonna kutseharidusõppe, kõrgharidusõppe ning teadus- ja arendustegevuse ülevaade 2021. https://harno.ee/sites/default/files/documents/2023-01/IKT%20valdkonna%20ylevaade%202021_1.pdf (25.04.2023).
[10] Mets, U., Viia, A. (2022) Tulevikuvaade tööjõu- ja oskuste vajadusele: info- ja kommunikatsioonitehnoloogia valdkond (OSKA Study on Information and Communication Technology Sector). Estonian Qualifications Authority (Kutsekoda). https://oska.kutsekoda.ee/wp-content/uploads/2022/01/OSKA_IKT_2021_terviktekst_.pdf (16.06.2023).
[11] Mets, U., Leemet, A. (2023) Ettevõtlussektori uurimis- ja arendustöötajate tööjõu- ja oskuste vajadus (Labor and Skill Needs of Research and Development Employees in the Business Sector). Estonian Qualifications Authority (Kutsekoda). https://oska.kutsekoda.ee/wp-content/uploads/2023/05/OSKA-uurimis-ja-arendustootajate-uuring-02.05.2023_FINAL-1.pdf (16.06.2023).

These reports provide an overview of the current state and future needs of the ICT sector regarding workforce and educational requirements.

Period of study. As the targeted evaluation of IT Academy programme science support measure evaluates the programme period of 2018–2022, most of the R&D project data focus on this period to provide comparability. However, longer-term statistics are provided for most macroeconomic data to better describe the trends that take effect over a longer period or when the 2021–2022 data were unavailable.

Definition of Information and Communication Technology (ICT) sector. For macroeconomic data, the overview bases its definition for the ICT sector on the Estonian Classification of Economic Activities (EMTAK 2008) based on Nace Rev.2 (classification of economic activities corresponding to International Standard Industrial Classification of all Economic Activities) and used by Statistics Estonia/Eurostat, where the ICT sector is defined as a set of economic activities. The ICT sector is also divided into ICT industrial production and ICT services. For more detailed information please see Appendix 1. Where not possible (data are not available in detailed economic activities) sometimes economic activity termed Information and Communication instead of ICT is used, which is shorter version of the EMTAK codes (Appendix 2).

For the Estonian Research Information System (ETIS) data, ICT projects are defined according to the Estonian research information system fields of research classification scheme[12] and draw together projects where the sum of the following subfields is at least 50%: Computer science (code 4.6), Information and communication technology (code 4.7) and Electrical engineering and electronics (4.8).

1. The importance of ICT for the Estonian economy

The role of the ICT sector in the Estonian economy is substantial and even in the past ten years it has been growing significantly. According to Statistics Estonia, the number of ICT companies has grown from 4,788 in 2017 to 9,027 in 2021. ICT companies comprised 5.5% of all people employed in the business sector in 2017 whereas the proportion had risen up to 6.9% (almost 36 thousand) in 2021. The growth in the number of people employed in the ICT sector during the period of 2017–2021 was 36.2%, which is significantly higher than the overall growth in the number of people employed in the entire business sector during the same period (8.6%). At the same time, the ICT sector created 9% of the added value generated by the business sector, provided 7% of the sales revenue (turnover) and provided 12% of the wages paid by companies. The ICT sector's contribution to Estonian exports has increased from 4% in 2017 to almost 12% in 2021. Some of the most important indicators relating to the significant role of ICT sector and its growth for the Estonian economy are shown in Figure 1.1.

[12] Estonian Research and Information System. Fields of research. https://www.etis.ee/Portal/Classifiers/Index (25.04.2023).

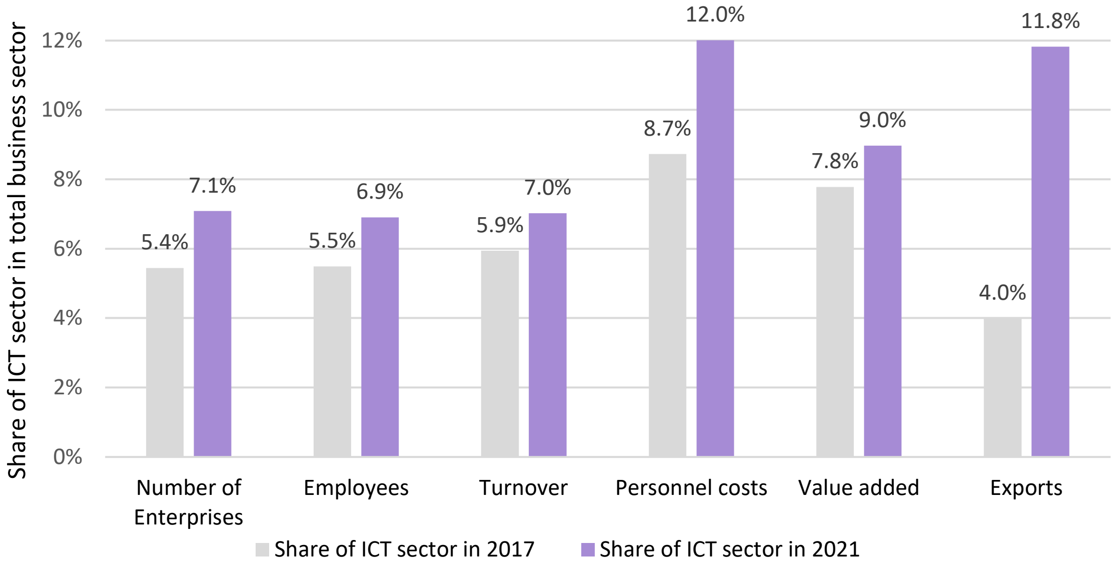


Figure 1.1. Share of ICT sector in Estonian economy 2017 and 2021.
Source: Statistics Estonia,[13] calculations by Estonian Research Council.

When looking at a longer period of ICT sector development, the changes in the economic structure towards a more digital economy become even more apparent. As of 2012 there were 2,917 ICT companies in Estonia, which accounted for 4.4% of all Estonian businesses, while in 2021 the respective numbers were 9,027 and 7.1% (3.1 times growth). Figure 1.2 below indicates that the main driver of the change has been the considerable growth in ICT services, namely in programming and consultations enterprises. In 2021 there were 6,953 companies classified under programming and consultations in ICT, which accounted for 77% of Estonian ICT companies. The number of enterprises operating in ICT industrial production was around 2% until 2017 and thereafter around 1% (between 69 and 77) of all ICT companies in Estonia.

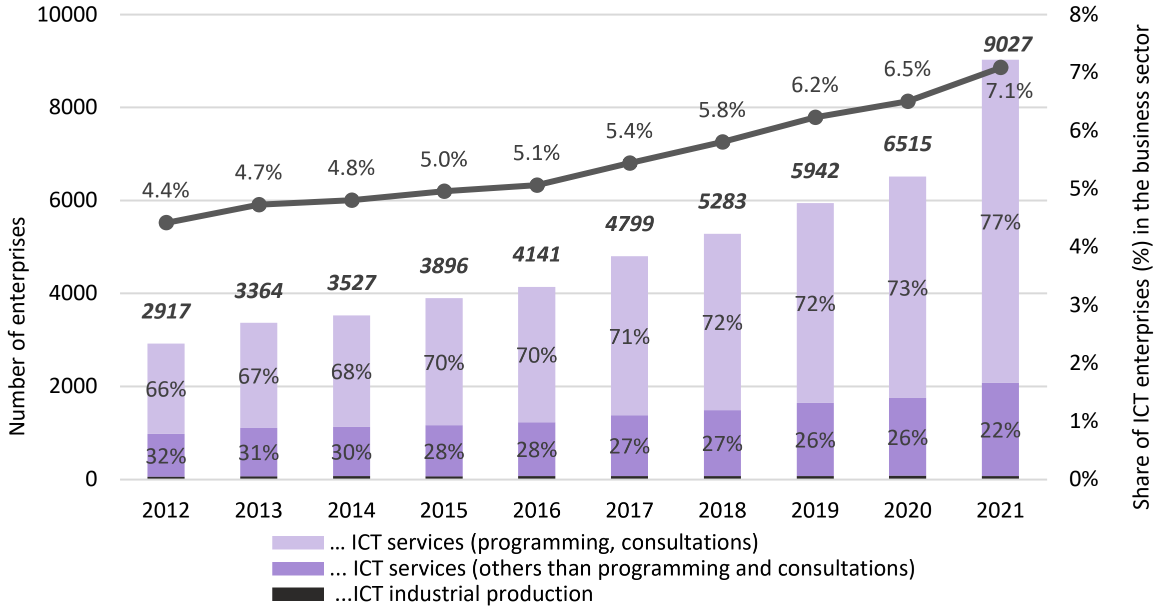


Figure 1.2. Number of ICT companies and share in the business sector (%) in 2012–2021.
Source: Statistics Estonia,[14] calculations by Estonian Research Council.

[13] Statistics Estonia. www.stat.ee (08.03.2023).
[14] Statistics Estonia. www.stat.ee (13.03.2023).

The sales revenue (turnover) of the Estonian ICT sector was 5.61 billion euros in 2021, which accounted for around 7% of the turnover earned by the business sector (Figure 1.3). Therefore, the remarkable proportion of the number of enterprises in programming and consultations in other ICT fields of activity indicates their importance when comparing revenue shares (sectoral data were missing for 2021). Despite programming and consultations being at the forefront of this impetus, other ICT services also show an almost equal contribution. Moreover, although the number of companies in ICT industrial production is around 1%, their turnover is less marginal, providing around 23% of all the ICT sector's sales revenue.

On the one hand, Estonia's gross value added per employee in the ICT sector is still significantly lower than the European Union average, on the other hand, the value added created by the ICT sector in Estonia has greater significance in the country's economy compared to Europe on average. This seemingly contradictory situation can be attributed to lower labour productivity in other sectors (Figure 1.1), which amplifies the role of the ICT sector in Estonia's economy.

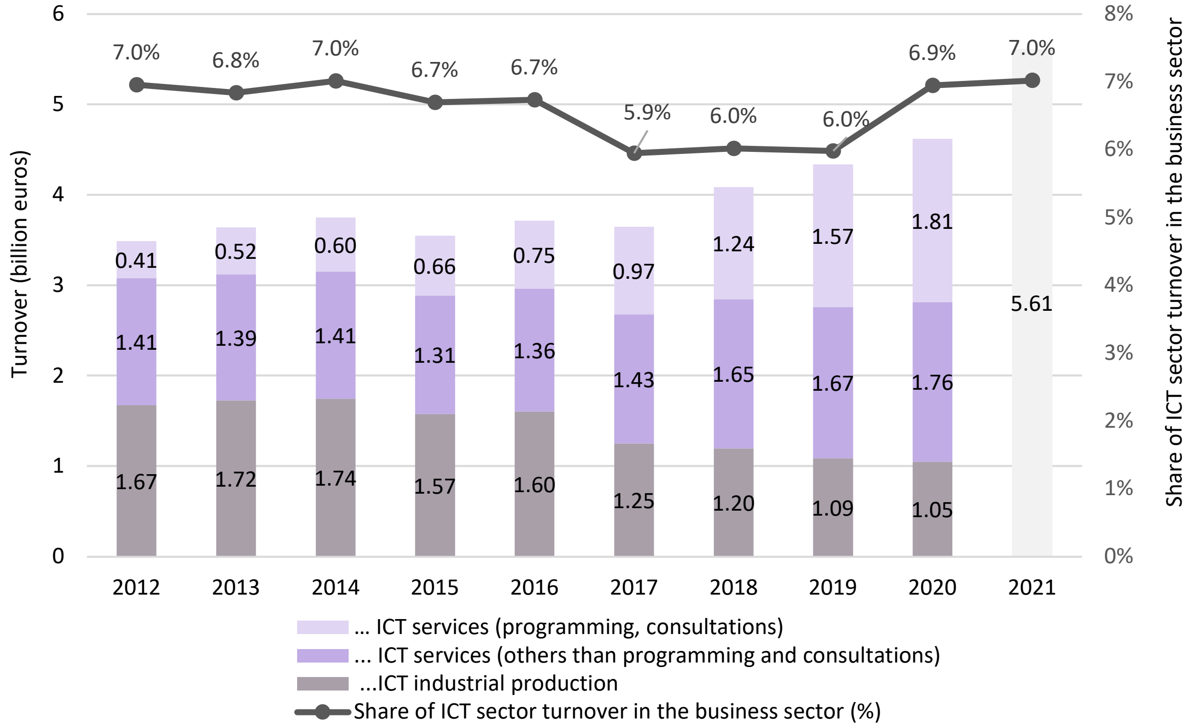


Figure 1.3. Turnover of ICT sector (billion euros) and share in the business sector (%) in 2012–2021. Source: Statistics Estonia,[15] calculations by Estonian Research Council.

Exports are important since this provides an indication of the international competitiveness of the country's products and services. Expanding exports helps businesses to earn additional profits and increases the gross national product (GDP). It is therefore extremely important for countries such as Estonia where the small size of the domestic market does not ensure sufficient economic growth in the long run. Therefore, more exports will result in faster growth of wealth. The ICT sector's contribution to Estonian exports has grown substantially and accounted for almost 16% of the total Estonian exports in 2022 (Figure 1.4). The growth rate in the importance of Estonian total exports generated by the ICT

[15] Statistics Estonia. www.stat.ee (08.03.2023).

sector during the last six years is remarkable (from 4% in 2017 to 16% in 2022). Most of this contribution comes from ICT services, namely programming and consultations.

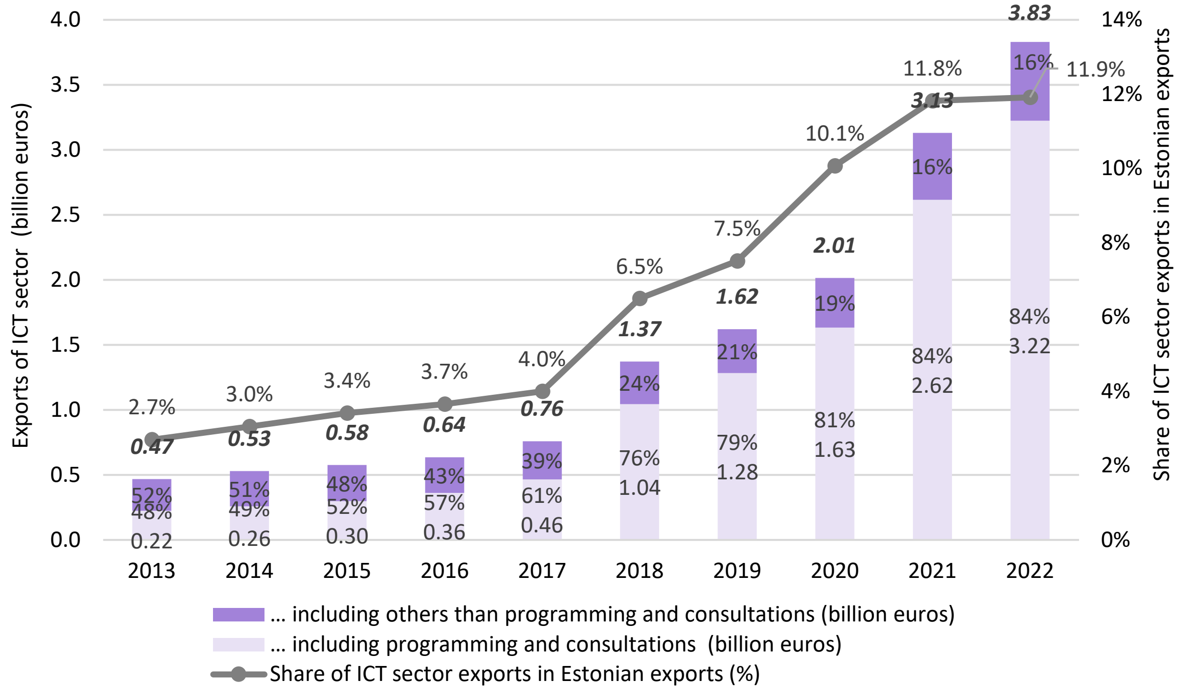


Figure 1.4. Exports of the ICT sector (billion euros) and share of ICT sector exports in Estonian total exports (%) in 2013–2022.
Source: Statistics Estonia,[16] calculations by the Estonian Research Council.

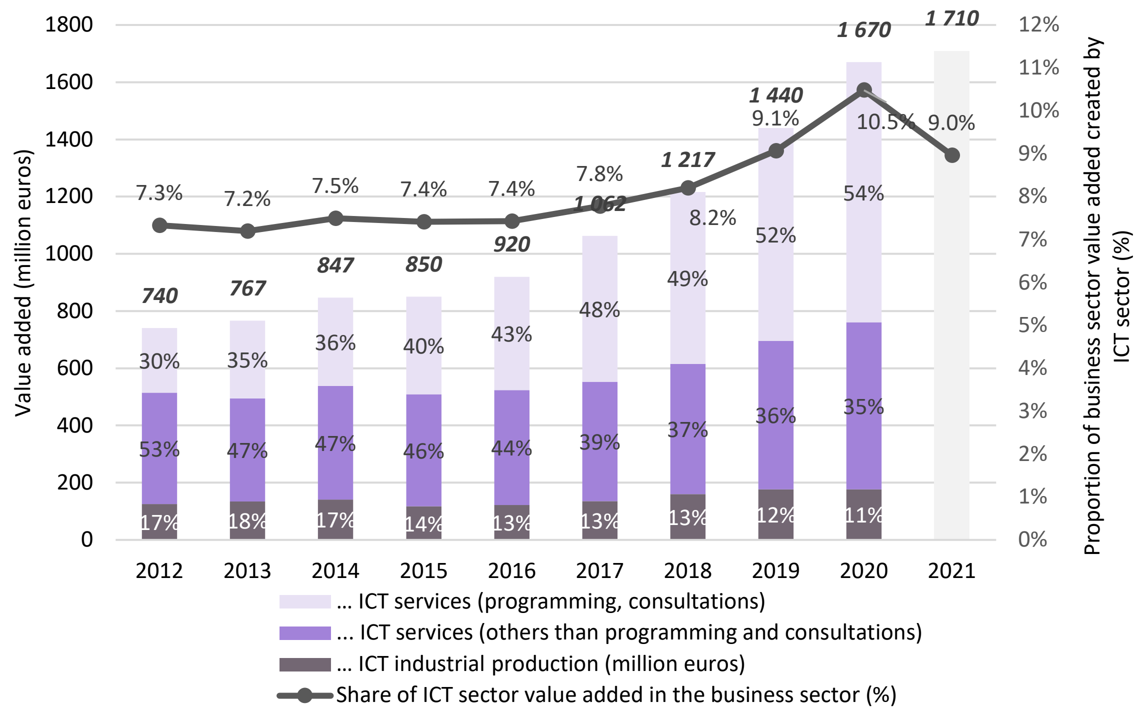


Figure 1.5. Value added by ICT companies (million euros) and share in the value added created by the Estonian business sector (%) in 2012–2021.
Source: Statistics Estonia, 13.03.2023, calculations by the Estonian Research Council.
**2021 data only include total values.*

[16] Statistics Estonia. www.stat.ee (13.03.2023).

Added value is the monetary value of production from which production costs have been deducted.[17,18] Value added does not reflect the quantity of work done but indicates how much money is received for it – that is to say how much profit and salary was earned. Therefore, as the increase in turnover tells us relatively little about the contribution of the ICT sector in the well-being of people living in Estonia, it is necessary to analyse how much of the added value the ICT sector created. The value added of the Estonian ICT sector has grown rapidly, 61% during the last five years (2017–2021), and the ICT services sector has given the vast majority (90%) of the total value added for the ICT sector during the last few reference years. More specifically, programming and consultations amounted to more than half of the created value added from 2019 and 2020 (Figure 1.5).

Although on a local level the added value of the Estonian ICT sector seems impressive, it is necessary to add some context and view it from an international scale (Figures 1.6 and 1.7). Value added per employee often characterises the state of innovation in companies. In comparison with the European countries, value added per employee of the Estonian ICT sector still has significant potential for growth while being almost two times lower than the European Union (27) average (Figure 1.6). The reasons for this may be that the core business of Estonian ICT companies is at a global level providing services with a relatively low added value – most companies are small, and their core profile is providing software development services for the non-tech industry. Larger ICT companies are often Estonian branches of international corporations (Elisa, Tele2, TeliaSonera, Ericsson Eesti, Enics, etc.) that are there for other reasons than creating innovative and high-value products.

However, the relative weight and importance of the ICT sector for the country's economy is shown in the following figure, Figure 1.7, where value added relative to GDP has been measured. While in 2020 the value added by the EU's ICT sector was equivalent to 5.2% of GDP, for Estonia it was 6%, making Estonia similar to Finland, Sweden, Luxembourg and Hungary. Significant changes in the development of the ICT sector have taken place in all countries. In the European Union (27) value added relative to GDP has grown from 4% in 2015 to 5.2% in 2020. Similarly to Estonia, the growth has been due to a rise in the value added by ICT services while the contribution of ICT manufacturing has remained stable.[19]

In summary, on the one hand, Estonia's gross value added per employee in the ICT sector is still significantly lower than the European average. On the other hand, the value added created by the ICT sector in Estonia holds greater significance in the country's own economy compared to Europe on average. This initially contradictory situation can be attributed to the relatively higher share of wage costs in IT companies and the even lower labour productivity in other sectors of the Estonian economy (Figure 1.1). As a result, the role of the ICT sector is more significant in the context of Estonian economy.

[17] Statistics Estonia. https://juhtimislauad.stat.ee/et/info-ja-kommunikatsioonitehnoloogia-14 (25.04.2024).
[18] According to Statstics Estonia when calculating the added value, the sales revenue, the change in inventories of unfinished and finished products (the difference between the end and the beginning of the reporting year), fixed assets manufactured for own use and other business income (except for the profit from the sale of fixed assets) are added, and the amount of goods, materials, purchased products and services, electricity and heat energy, fuel, the cost of product and production taxes, as well as other business costs (except loss from the sale of fixed assets) is subtracted from this amount. https://juhtimislauad.stat.ee/et/info-ja-kommunikatsioonitehnoloogia-14 (25.04.2024).
[19] Eurostat. ICT sector – value added, employment and R&D. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=ICT_sector_-_value_added,_employment_and_R%26D#The_size_of_the_ICT_sector_as_measured_by_value_ (30.03.2023).

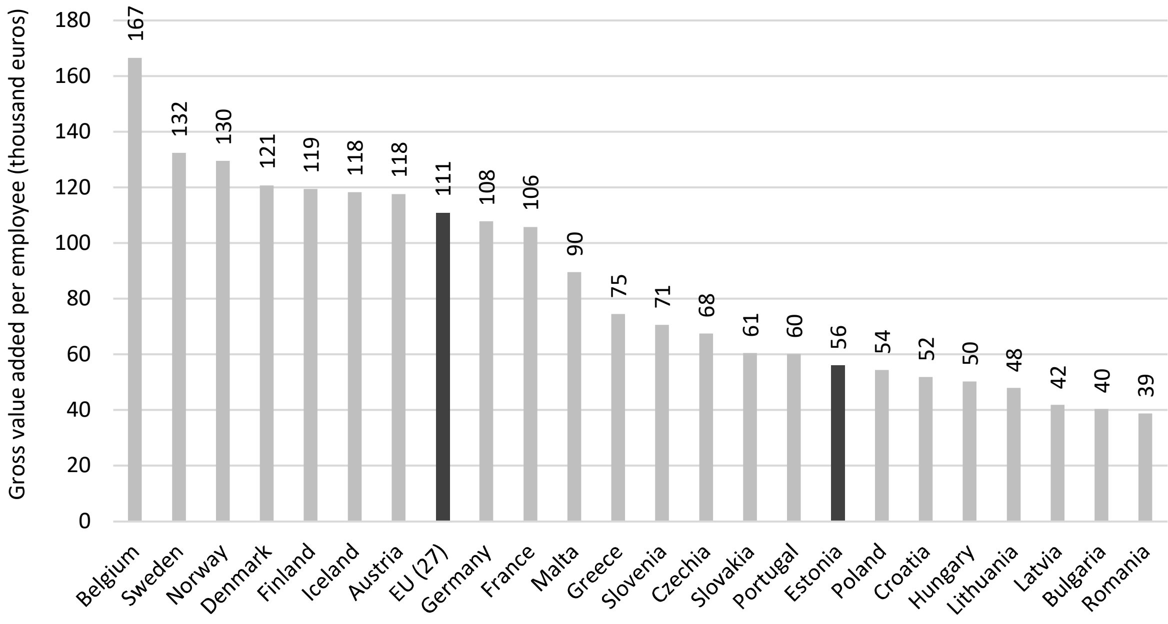


Figure 1.6. Gross value added per employee (thousand euros) of the ICT sector in 2020.
Source: Eurostat.[20]

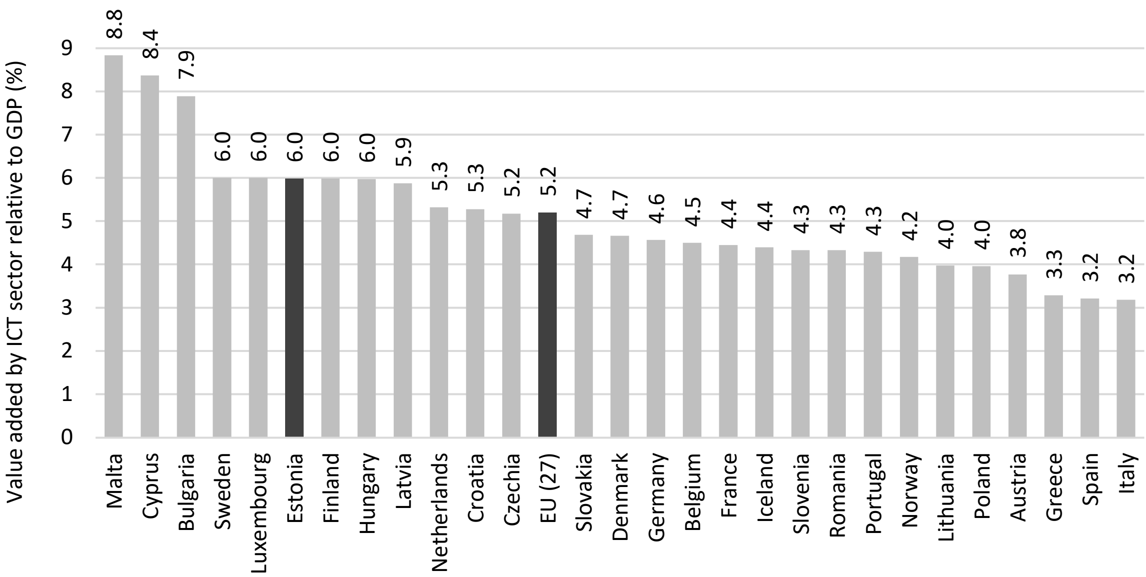


Figure 1.7. The size of the ICT sector in the European Union as measured by value added relative to GDP (%) in 2020
Source: Eurostat.[21,22]

Venture capital focuses on financing small, early stage and innovative companies with high growth potential. It is often seen as a catalyst for economic growth and job creation. Venture capital is an important way of raising capital especially for innovative businesses, since traditional bank-based

[20] Eurostat. https://ec.europa.eu/eurostat/data/database (23.03.2022).
[21] [21] Eurostat. https://ec.europa.eu/eurostat/data/database (30.03.2022).
[22] Eurostat. ICT sector – value added, employment and R&D. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=ICT_sector_-_value_added,_employment_and_R%26D#The_size_of_the_ICT_sector_as_measured_by_value_ (30.03.2023).

business financing involving high risk might often remain unfounded by banks.[23] Moreover, to obtain a loan from a bank, you need physical capital as a guarantee, which a start-up company or a company that is based on intangible assets (e.g. intellectual property) does not have.[24]

Therefore, a diversified capital market has played an important role in overcoming these bottlenecks. Estonian companies have been remarkably successful at raising venture capital and it has helped several of them to make a global kick-start. The year 2022 brought a new record, with investments exceeding 1.3 billion euros. The vast majority of the investments were obtained from across the border (93% in 2022), not from the Estonian market (Figure 1.8). Venture capital investments are important to bring up when talking about the competitiveness and potential of the ICT sector in Estonia, since the majority of the companies that raised venture capital investments base their business model on ICT developments (for example Bolt, Wise, Starship, Veriff.me, Monese.com, etc.).

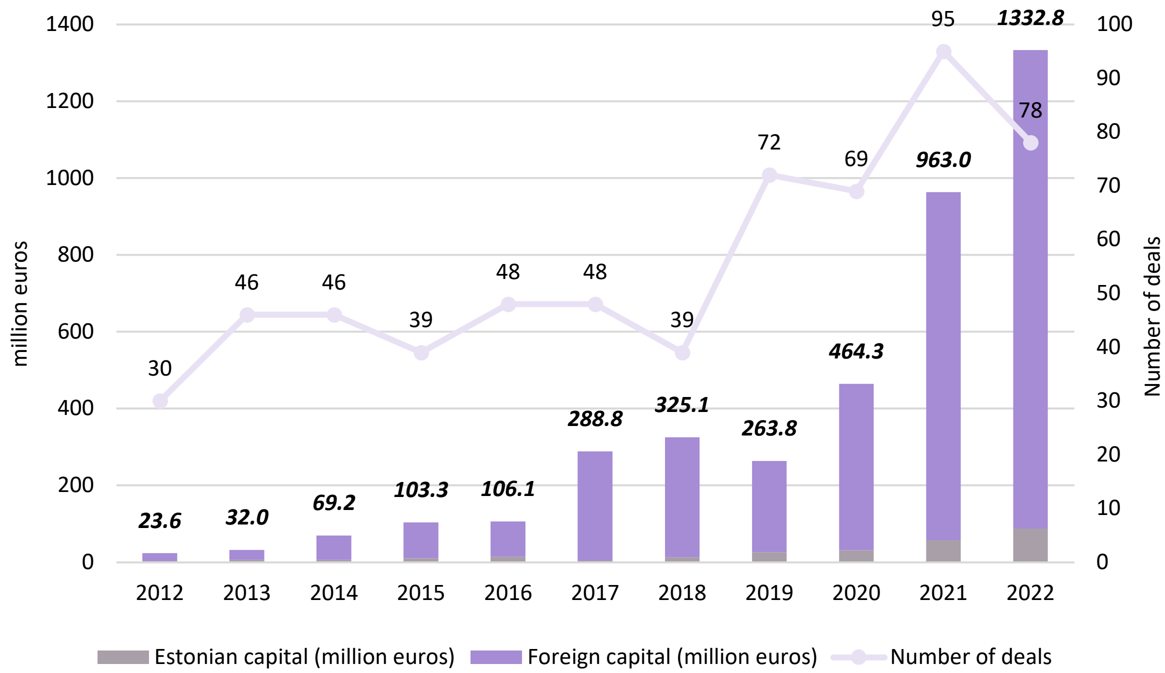


Figure 1.8. Venture capital investments in Estonian enterprises 2012–2022.
Source: EstVCA.[25]

On an international level, venture capital investments are monitored as an innovation indicator. According to the OECD, Estonia venture capital investments directed at young firms in the ICT sector as a percentage of GDP exceed most of the OECD countries in 2021, at 0.37 (Figure 1.9). This gives an indication of the strong potential of the Estonian ICT sector.

[23] Demertzis, M., Viegi, N. (2021). Low interest rates in Europe and the US: one trend, two stories. – Policy Contribution Issue n 07/2021, Bruegel.
https://www.bruegel.org/2021/03/low-interest-rates-in-europe-and-the-us-one-trend-two-stories/ (01.10.2021).
[24] Danilov, T. (2022). Relationship between research and innovation in Estonia. – Estonian Research 2022 (ed. K. Raudvere), pp. 79–99, Estonian Research Council, Tartu. https://doi.org/10.23673/tead/002
[25] Estonian Private Equity & Venture Capital Association (EstVCA). www.estvca.ee (22.03.2023).

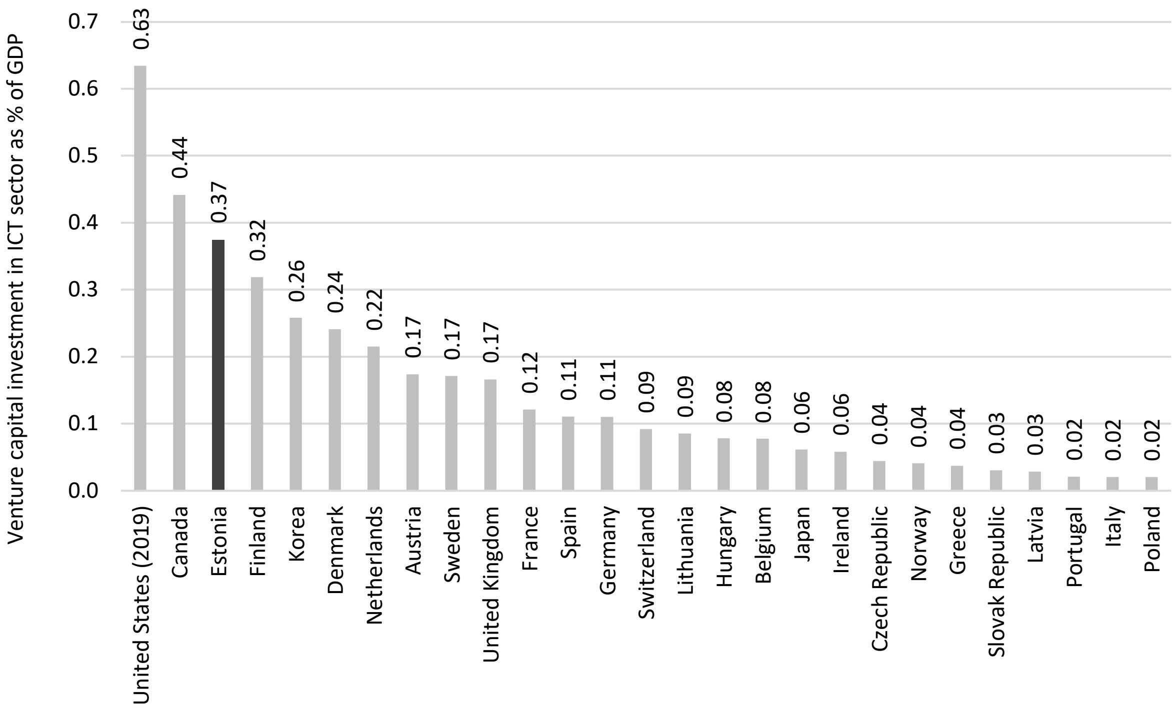


Figure 1.9. Venture capital investment in the ICT sector as a share of GDP (%) in 2021.
Source: OECD.[26]

As the share of people employed in the ICT sector was 6.9% out of all people employed in the business sector (2021), ICT companies paid 12% of all personnel costs of the business sector – meaning that ICT companies could pay relatively higher salaries compared to other sectors (Figures 1.10 and 1.1). Similarly to other economic indicators, the vast majority of the contribution of personnel costs came from programming and consultation activities. Only 1% of ICT companies operate in the industrial production sector out of all companies in Estonia (Figure 1.2). However, their share in the personnel costs of the ICT sector is 10%, which can be explained by the fact that ICT industrial production companies are significantly larger by number of employees compared to ICT services companies. On average, an ICT industrial production company had 63.6 full-time employees, while an ICT service-providing company had 3.7 employees (as of 2020)[27].

[26] OECD. The OECD Going Digital Toolkit, based on the OECD Venture Capital Investments Database. https://goingdigital.oecd.org/en/indicator/35 (26.04.2023).
[27] Statistics Estonia. www.stat.ee (23.05.2023).

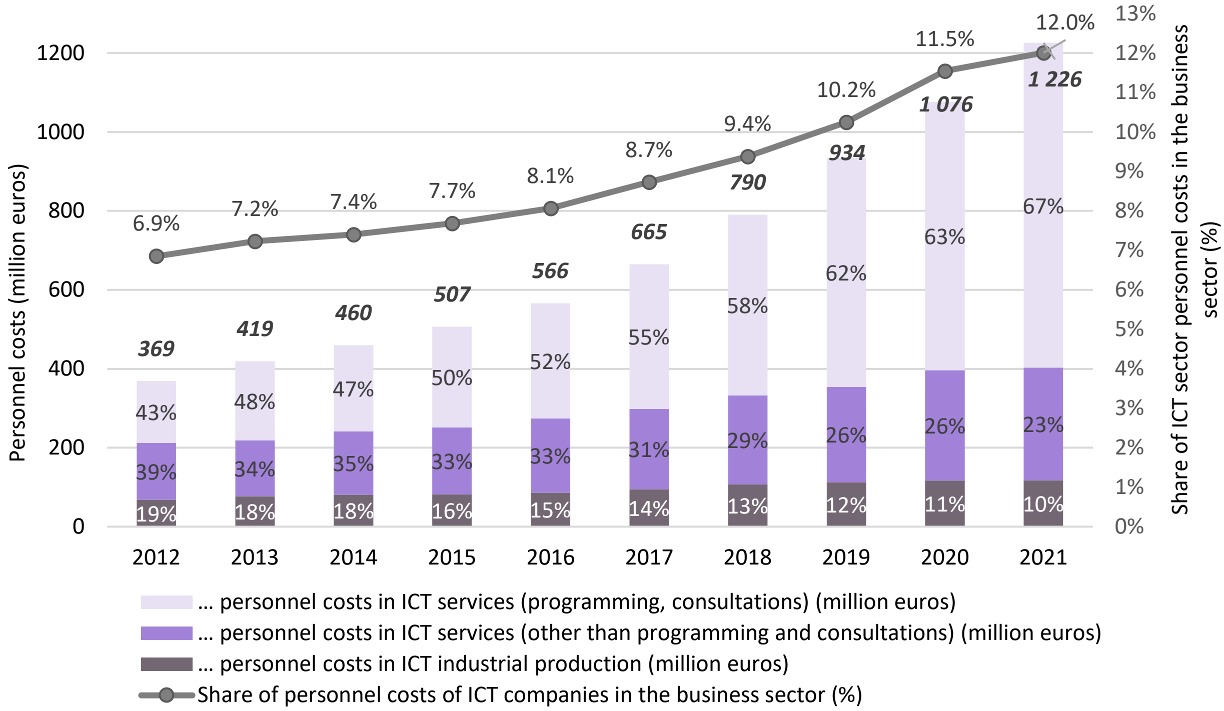


Figure 1.10. Personnel costs in ICT companies and share of personnel costs of ICT companies in the Estonian business sector (%) in 2012–2021.
Source: Statistics Estonia,[28] calculations by the Estonian Research Council.
*2021 data for ICT industrial production are partly an estimation from 2020 data.

The specific nature of the ICT sector, where a small number of highly qualified employees could create a great amount of value, is a perfect model for a small country where there is always a shortage of employees. This is the reason why a small nation needs to focus on education to gain more qualified workers and to create prosperity. When looking at the relative share of ICT personnel in total employment, 5.4% of all Estonian workers were hired in the ICT sector in 2021, which means around 35,500 people (Figure 1.11). The number of people hired in the ICT sector has grown steadily over the years and the main contribution in the growth comes from programming and consultation activities, which employed around 21,600 people in 2021. ICT industrial production has hired approximately 5,000 people during the last decade and this number has not grown, and even decreased in 2021.

[28] Statistics Estonia. www.stat.ee (13.03.2023).

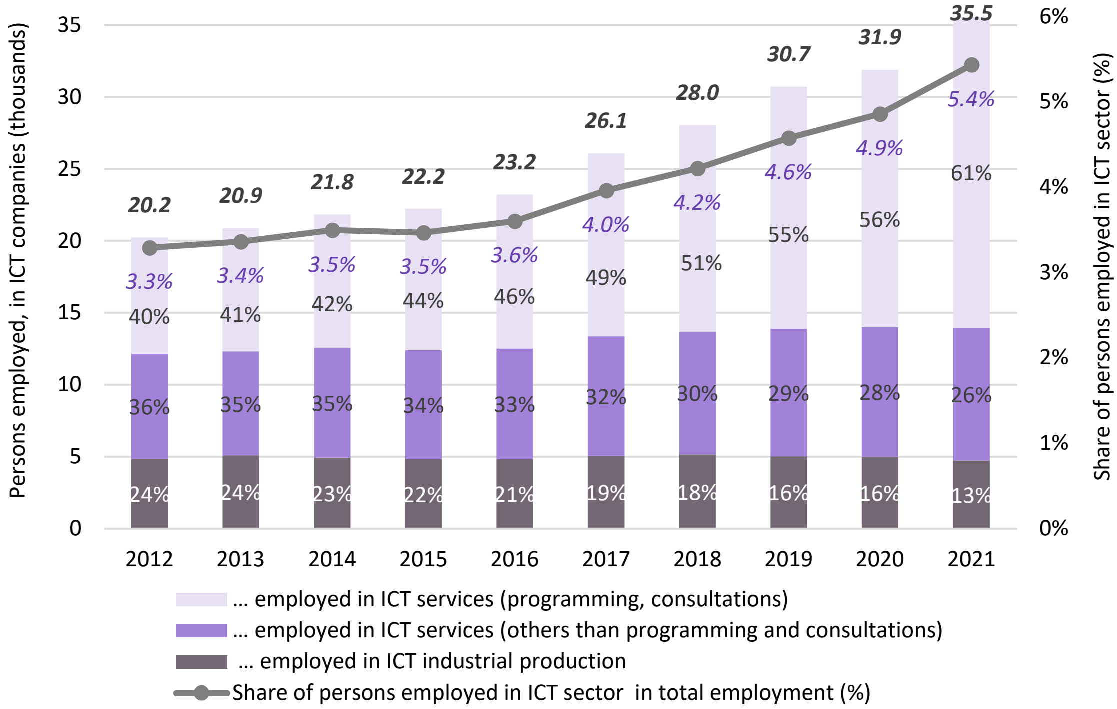


Figure 1.11. Number of people employed in ICT companies and share of employed in the Estonian business sector (%) in 2012–2021.
Source: Statistics Estonia,[29] calculations by the Estonian Research Council.
**2021 data is partly an estimation from 2020 data.*

As the ICT sector hires people from other fields of education, people with ICT higher education are required in all fields of activity, not just in the ICT sector. Combined data from the Estonian Tax and Customs Board and Estonian Education Information System (EHIS) indicate that out of those who acquired higher education degrees (bachelor's, master's, PhD) ICT during the years 2005–2022 in the field of, 6,099 individuals were employed in 2021.[30] According to the taxes paid in 2021, out of the 6,099 individuals 54% (3,267 people) were occupied in the ICT sector while 46% in other fields of activity (Figure 1.12). Other major sectors besides the ICT sector that employ ICT professionals with higher education degrees include education (7%), finance and insurance (6%), and public administration and defence; compulsory social security (6%), and education (6%).

[29] Statistics Estonia. www.stat.ee (13.03.2023).
[30] This is when each person is included in the data only once, which means if a person graduated, for example, in 2013 with a bachelor's degree and in 2015 with a master's degree, it is reflected in the data as a master's degree graduate in 2015.

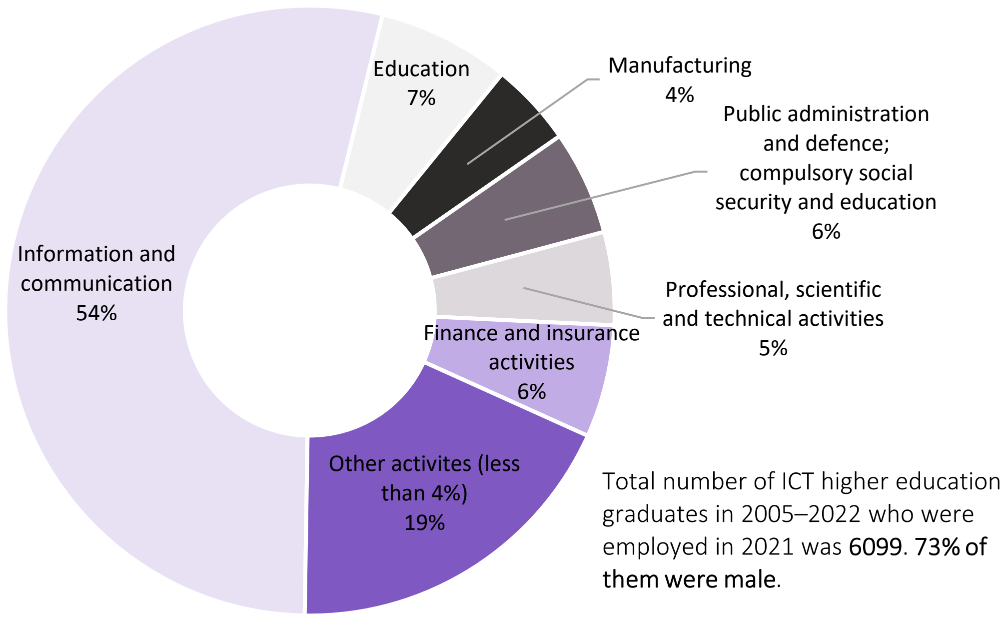


Figure 1.12. Distribution of ICT higher education graduates (graduated between 2005 and 2020) by field of activity in 2021.[31,32]
Source: Ministry of Education and Research.[33]

According to the forecast by the Estonian Qualifications Authority, to maintain and enhance the competitiveness of the Estonian economy, it is necessary to increase the number of ICT specialists by at least 1.5 times by 2027. This means 47,600 ICT specialists working across the entire economy by 2027. As in 2020 there were 30 900 ICT specialists hired in ICT companies and other fields of economy it means an annual growth of approximately 2,600 new employees per year.[34]

In addition to the above, there is a strikingly low proportion of women amongst ICT graduates. Among ICT higher education graduates between the years 2005 to 2022 who were hired in 2021, the proportion of men was 73% (4,438 people) and women 27% (1,661 people). Within different fields of activity, the ratio of men was higher in the ICT and manufacturing sectors (respectively 78% and 79% were male). The low representation of women among ICT graduates might be related to their lesser interest in pursuing ICT studies. Despite the proportion of women entering higher education (all levels) in ICT having consistently increased, it is still much lower (33% in academic year 2022/23) than the average proportion of women amongst admitted students (59% in academic year 2022/23). However, there has been notable progress in the total number of students admitted in the field of ICT – the number of

[31] Each person is included in the data only once, which means if a person graduated, for example, in 2013 with a bachelor's degree and in 2015 with a master's degree, it is reflected in the data as a master's degree graduate in 2015.
[32] Other activities include fields of activity that amounted to 4 or less percent out of the total ICT gradutes in 2005–2020 or where the field of activity was missing (Agriculture and forestry; Mining and quarrying; Electricity, gas and steam supply; Water supply; Sewerage, waste management, remediation activities; Construction; Wholesale and retail trade; Repair of motor vehicles and motorcycles; Transportation and storage; Accomodation and food service activities; Real estate activities; Administrative and support service activities; Human health activities; Arts, entertainment and recreation; Other service activities; Activities of extraterritorial bodies).
[33] Ministry of Education and Research, special request that assembles data from Estonian Tax and Customs Board (EMTA) and Estonian Education Information System (EHIS), 30.03.2023.
[34] Mets, U., Viia, A. (2022) Tulevikuvaade tööjõu- ja oskuste vajadusele: info- ja kommunikatsioonitehnoloogia valdkond (OSKA Study on Information and Communication Technology Sector). Estonian Qualifications Authority (Kutsekoda). https://oska.kutsekoda.ee/wp-content/uploads/2022/01/OSKA_IKT_2021_terviktekst_.pdf (16.06.2023).

admitted students in ICT has increased by 20.9% in the last ten years (2013/13–2022/23) despite the decline in the total number of admitted students in higher education (due to demographic reasons) and the number of women admitted in ICT studies has increased by 46% during the last ten academic years.[35] Therefore, although the representation of women in ICT-related positions is likely to increase, women will remain underrepresented in ICT positions in the near future. Although achieving a gender balance in the field of ICT still has a long way to go, the number of women in the industry is indeed on the rise. A more detailed analysis of ICT higher education can be found in the report "Higher education and research and development activities in the field of ICT in 2022" compiled by the Education and Youth Board. [36]

The fact that ICT graduates earn higher income than average on the labour market is shown in Figure 1.13. The higher salary range also points to the shortage of ICT specialists in the workforce. As the average monthly gross salary according to Estonian Tax and Customs Board (EMTA) in 2021 was 1,921 euros, for ICT graduates it was around 45% higher, i.e. 2,789 euros. ICT graduates who were employed in finance and insurance activities, and in the sector that encompasses electricity, gas, steam and water supply earned the most (respective monthly salaries 3,238 and 3,133 euros). The sector that hired the most ICT graduates – information and communication – also had significantly above average salaries compared to the Estonian average: 3,030 euros for ICT graduates. When analysing average salaries, it must be kept in mind that the numbers presented here should not be compared to the average salaries in Estonia published by Statistics Estonia where the averages are somewhat lower, since the data presented in this overview are based on a sample of higher education graduates between 2005 and 2020, and their incomes (105,112 people in total) and does not consider all employed in Estonia.

Another striking aspect in the data is the gender wage gap of ICT graduates in most sectors of activity. On average (over all fields of activity), female ICT graduates earned 16.8% less than their male colleagues, but in seven fields of activity the wage gap is over 20%. However, the gender wage gap in ICT is smaller than average in Estonia, which in 2021 was 22.3% for all higher education graduates of 2005–2020 employed in all fields of activity. As determining a gender wage gap has always been a difficult issue, it is not possible to give precise explanations. It might be (partly) explained by women working more frequently part time (salaries presented in Figure 1.13 reflect actual average income deducted from tax information and this is not adjusted to full time). The proportion of women working part time in 2021 was 23.6% while for men it was 11.4%.[37] However, relative sectoral data in ICT are not available. Indeed, the discrepancy in salaries without accounting for workload could potentially reflect gender disparities in different job positions within the same sector. According to Statistics Estonia's salary statistics[38], it is also possible to compare the number of employees by gender working in typical ICT positions: System Analysts, Software Developers and Software and Applications Developers and Analysts not Elsewhere Classified[39]. It appeared that while there were 7,235 men working as Software Developers, there were only 1,114 female Software Developers (13.3%). However, Software Developers are the highest paid group amongst different ICT occupations (and men earned 19.5% more than

[35] Haridussilm. Haridussilm.ee (23.05.2023).
[36] Education and Youth Board. IT Academy Programme. Uuringud ja analüüsid. https://harno.ee/it-akadeemia-programm#uuringud-ja-analuusid (24.05.2023).
[37] Statistics Estonia. www.stat.ee (24.05.2023).
[38] Statistics Estonia. palgad.stat.ee (24.05.2023).
[39] In order to stay within the scope of this overview, only three main positions are analysed here although the list of positions in the classifier is somewhat longer. According to the classification system used by Statistics Estonia (Classification of Occupations 2008 floating, based on International Standard Classification of Occupations ISCO-08 managed by the International Labour Organization (ILO)) the observed occupations are with codes 2511 (System Analysts), 2512 (Software Developers) and 2519 (Software and Applications Developers and Analysts Not Elsewhere Classified). More information: Statistics Estonia. Classification of Occoupations. https://klassifikaatorid.stat.ee/item/stat.ee/b8fdb2b9-8269-41ca-b29e-5454df555147/24 (24.05.2023).

women). On the other hand, amongst ICT Analysts 44.4% were women; however, male ICT analysts earned on average 3,710 euros per month and female ICT Analysts 14.8% less.

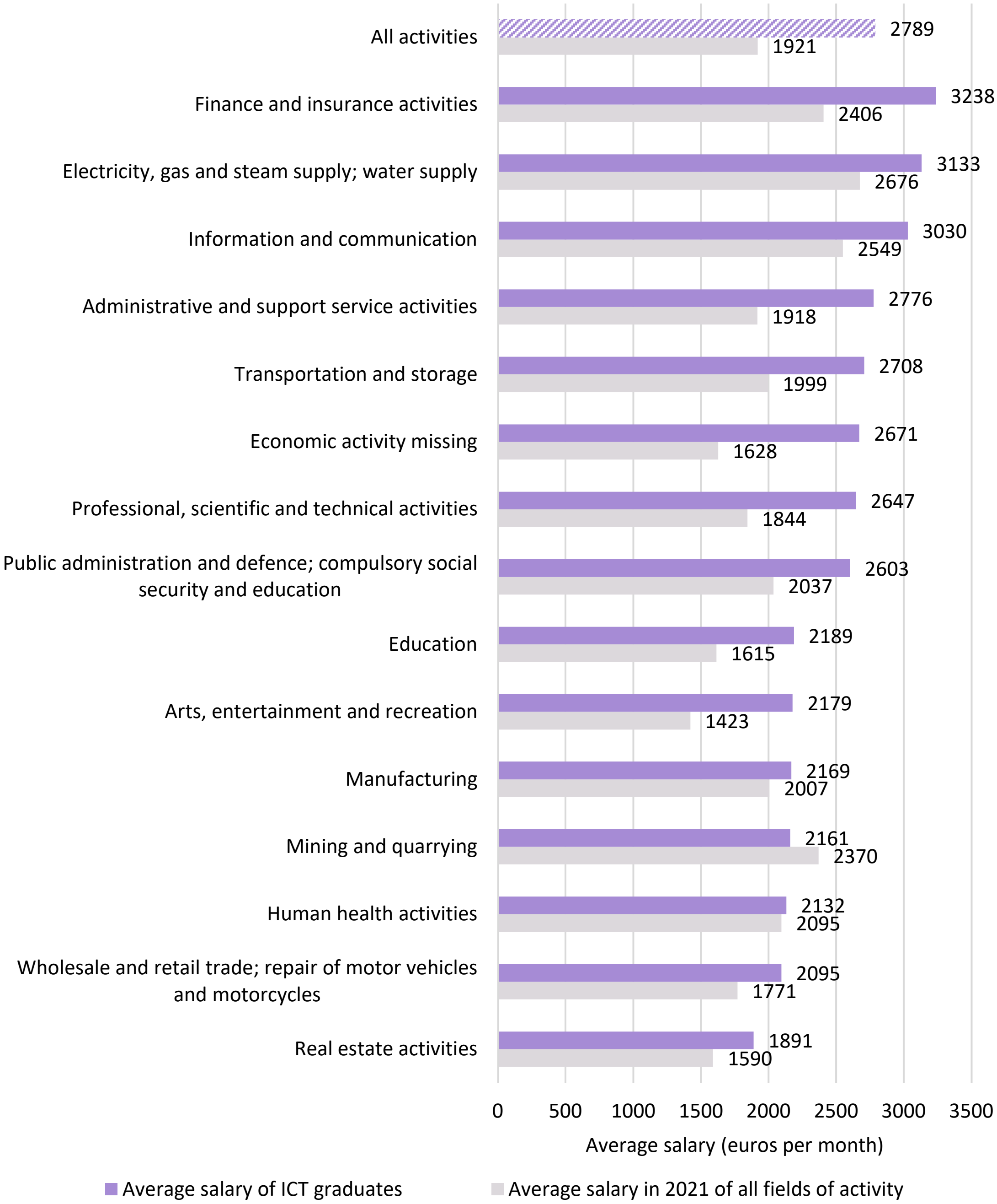


Figure 1.13. Average salaries of ICT graduates and higher education graduates in general in the different fields of activity (graduated between 2005 and 2020) in 2021.
Source: Ministry of Education and Research.[40]

R&D activity is often associated with remarkable costs, and profitable returns for companies are not guaranteed, since the research for new technologies is unpredictable. Previous studies have not proven a clear relationship between R&D expenditure and growth. The role of industrial innovation processes on economic growth has been examined at the macro level since early economists such as Schumpeter,

[40] Ministry of Education and Research, special request that assembles data from Estonian Tax and Customs Board (EMTA) and Estonian Education Information System (EHIS), 30.03.2023.

Solow[41] and Swan[42]. Later studies have found that there are several other country-, sector- and company-specific factors affecting the R&D-growth relationship. In addition, there is the time lag between the point of R&D expenditure and the benefits companies experience as well as what is considered under growth (sales, firm value, productivity, etc.), and other aspects have been found, thus affecting the results.[43,44,45] T. Danilov, the Head of the Foresight Centre in Estonia, concludes in her article in "Estonian Research 2022" that there is no clear answer about the relationship and the economy, it significantly depends on the data on which the conclusions are based, as well as the worldview of the interpreter. However, it has been acknowledged earlier that the so-called science push mechanism which translates research results into economic applications remains too weak to have a wider economic impact. Therefore, the science push mechanism must be complemented by the demand pull of entrepreneurship. This is especially true of the so-called transition countries, which still applies to Estonia as well.[46]

In most developed countries around half to two thirds of R&D expenditure is seen in the business sector. In 2020, on average 64% of R&D expenditures of OECD countries were financed by business enterprise sector. In Estonia the proportion was 50%, which leaves Estonia in the middle of the list of OECD countries. It is necessary to mention that the OECD average was highly driven by the United States, which is a leading technology country with high business-sector-financed R&D. While comparing internationally all the financial means available in R&D, Estonia maintains a remarkable unused potential compared to developed countries. The OECD average gross domestic expenditure on R&D (GERD) as a percentage of GDP was 2.71% in 2021 and the business enterprise expenditure on R&D as a percentage of GDP (BERD) accounted for 1.99%; in Estonia, the relative shares were 1.75 and 0.98. [47]

In monetary terms, the 0.98% of GDP business-financed R&D expenditure in 2021 translates into 307.7 million euros. The positive side is the increase of 115% of R&D expenditures of Estonian businesses within five years (from 0.6% of GDP in 2017 to 0.98% in 2021 which in absolute terms means from 143.6 million to 307.7 million euros). [48] This is still worrying, despite the larger jump in 2021, yet there were only 370 companies investing in R&D in 2021, of which 39 enterprises made 75% of all the R&D investments. Between 2015 and 2021, 40–50% of the businesses that had R&D expenditures belonged to the manufacturing sector and 16–22% of enterprises were ICT companies (Figure 1.14). This means that in 2020 there were 53 and in 2021 there were 67 ICT companies in Estonia reporting R&D expenditures.

[41] Solow, R. (1956), "A Contribution to the Theory of Economic Growth", Quarterly Journal of Economics, 70(1), 65-94.
[42] Swan, T. (1956), "Economic Growth and Capital Accumulation", Economic Record, 32(63), 334-361.
[43] Demirel, P., and Mazzucato, M. (2012). Innovation and Firm Growth: Is R&D worth it? Industry and Innovation. Vol. 19, Issue 1. p. 45-62 https://doi.org/10.1080/13662716.2012.649057
[44] Chung, H., Eum, S., and Lee, C. (2019). Firm Growth and R&D in the Korean Pharmaceutical Industry. Sustainability, Vol. 11, Issue 2865. https://doi.org/10.3390/su11102865
[45] Usman, M., Shaique, M., Khan, S., Shaikh, R., & Baig, N. (2017). Impact of R&D Investment on Firm Performance and Firm Value: Evidence from Developed Nations (G-7) . Revista de Gestão, Finanças e Contabilidade, 7(2), 302-321.
[46] Danilov, T. (2022). Relationship between research and innovation in Estonia, Estonian Research 2022 (ed. K. Raudvere), pp. 79–99, Estonian Research Council, Tartu. https://doi.org/10.23673/tead/002
[47] OECD. Main Science and Technology Indicators Database. www.oedc.org/sti/msti.htm (27.04.2023).
[48] Statistics Estonia. www.stat.ee (28.04.2023).

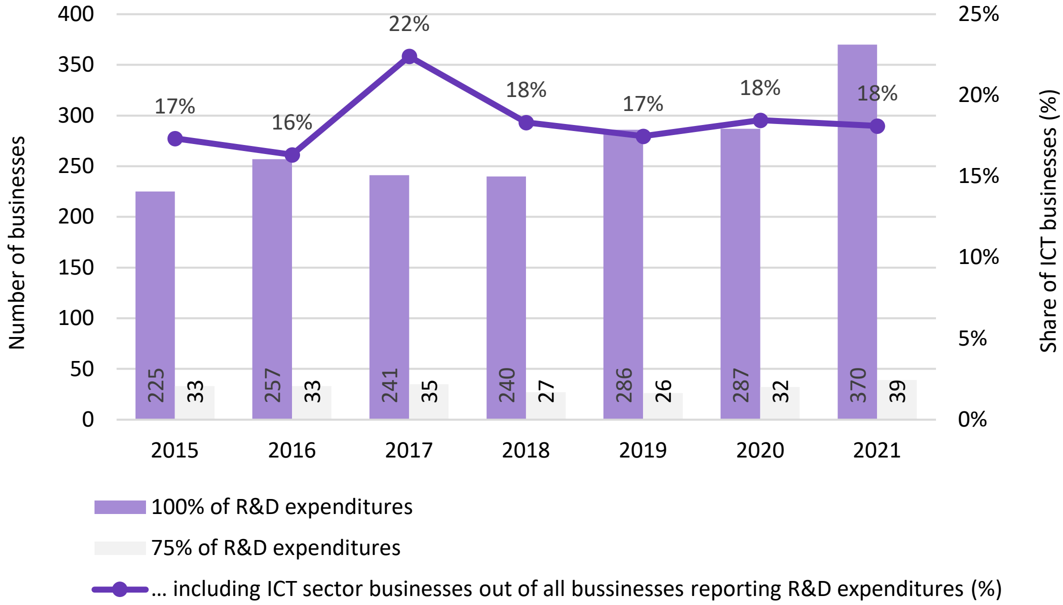


Figure 1.14. The number of businesses reporting R&D expenditures (including share of ICT companies) and the concentration of R&D expenditures in Estonia.
Source: Statistics Estonia.[49]

Although the proportion of ICT companies out of all Estonian businesses reporting R&D expenditures in 2021 was 18%, the financial contribution of the ICT sector into business R&D was 151.4 million euros, which is approximately half of total Estonian business sector R&D expenditures (307.7 million euros). Therefore, the ICT sector could be considered one of the main sources of Estonian business R&D and as seen from Figure 1.15 the ICT sector has been the main driver of Estonian business R&D growth during the past five years.

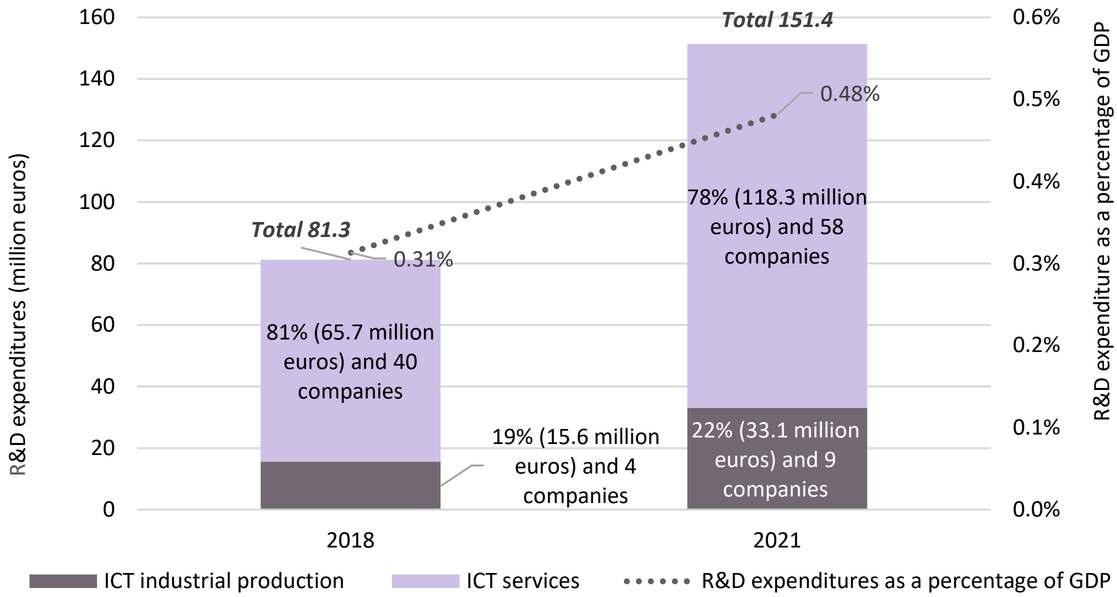


Figure 1.15. ICT sector R&D expenditures in Estonia in 2018 and 2021.
Source: Statistics Estonia.[50]

[49] Statistics Estonia, requested data. www.stat.ee (21.03.2023).
[50] Statistics Estonia, requested data. www.stat.ee (21.03.2023).

Despite the Estonian ICT sector being a leading sector financing Estonian business R&D, it does not attract R&D personnel with a doctoral degree. Figure 1.16 shows that the total private sector[51] R&D personnel in 2021 was 4,492 people and information and communications sector had a considerable part in it, hiring 1,617 people (36%). While the proportion of doctoral degree holders in R&D personnel in other sectors (i.e. other than information and communication) was 9.6%, it was 2.5% in information and communication, and the trend has been somewhat downwards. This may reflect several reasons and needs further analysis about the potential rate of return and barriers of doctoral degree holders in Estonian ICT companies.

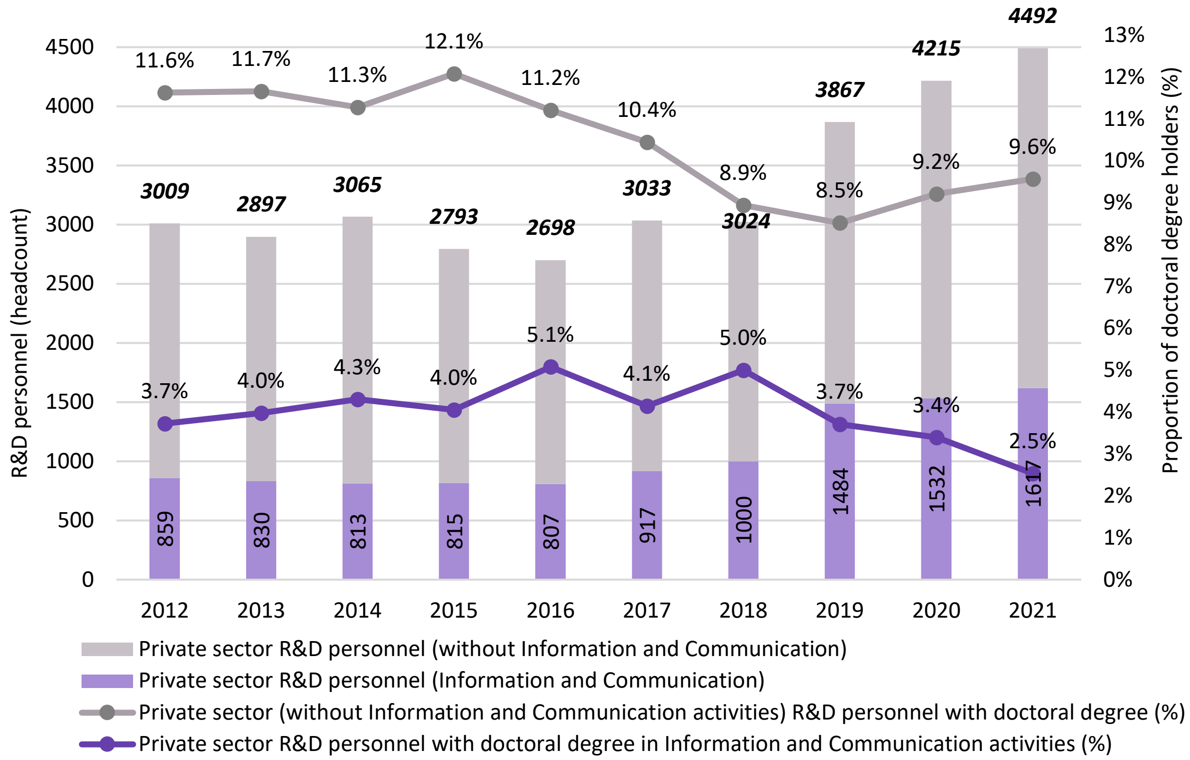


Figure 1.16. R&D personnel in Estonia and the share of doctoral degree holders in the Information and Communication sector (%).
Source: Statistics Estonia,[52] calculations by Estonian Research Council.

Looking even more specifically at companies (the private sector shown in Figure 1.16 also reflects the private non-profit organisations), in 2021 6.3% of R&D personnel in companies had a doctorate degree, for information and communication companies the ratio was 2.5%. In the neighbouring countries of Finland and Sweden, the number of R&D personnel with a doctorate degree in companies is somewhat higher compared to Estonia, but similarly to Estonia, the proportion is lower in information and communication companies. In 2021, 12.4% of the R&D personnel of all Swedish companies had a doctorate degree, for information and communication companies the share was 7.3%[53]. In Finland, an average of 7.0% of R&D personnel of companies had a doctorate degree; in the Information and Communication sector 4.8% of R&D personnel had obtained a doctoral degree[54].

[51] Private sector includes both business sector (enterprises) and private non-profit organisations.
[52] Statistics Estonia. www.stat.ee (23.03.2023).
[53] Statistics Sweden. https://www.statistikdatabasen.scb.se/pxweb/en/ssd/ (25.05.2023).
[54] Statistics Finland. https://pxdata.stat.fi/PxWeb/pxweb/en/StatFin/ (25.05.2023).

2. Resources and outputs of ICT research in Estonia

This chapter provides an overview of the resources (financial resources and human capital) used for ICT research and analyses its main research outputs. Firstly, it discusses the amount and sources of funding used (including the significance of IT Academy programme science support measure funding for institutions) as well as the amount spent on infrastructure. Secondly, it analyses the human resources – changes in the number and qualifications of researchers in the ICT research, as well as in the IT Academy priority research areas. Thirdly, the quality and quantity of main research outputs are analysed.

Most of the data provided in this chapter are based on the information of ICT research projects and researchers available in Estonian Research Information System (ETIS). The data regarding projects in ETIS is based on information organisations carrying out research projects have inserted into the system themselves. Although the accuracy of data depends on the data entry, it could still be considered one of the most comprehensive datasets of Estonian research projects. It generally consists of projects carried out by the Estonian public sector research institutions. These are in fact the main actors in the Estonian research landscape and due to different reporting and financial factors are interested in having their project data updated in the system. At the same time, all other organisations and businesses can also add their research projects to ETIS. Mostly the dataset contains information about personal research grants and projects from other project-based funding schemes, also collaboration projects with local as well as foreign public and private sector organisations, including framework programme projects and others. The dataset covers most research projects of the three universities that are the subjects of the targeted evaluation of IT Academy programme ICT science support measure, but also all other institutions with projects. Outputs of the ICT research are mainly analysed based on the data from InCites database (publications) and Espacet (patents).

The ETIS dataset for analysis contains ongoing ICT project data for the years 2012–2022. The ICT projects in the sample are defined according to the Estonian Research Information System fields of research classification scheme[55]. The sample comprises of the following projects where the sum of the following subfields is at least 50%: Computer science (code 4.6), Information and communication technology (code 4.7) and Electrical Engineering and Electronics (4.8). By this definition the database contains 1,100 projects altogether for the period of 2012–2022 and 656 projects for the period of 2018–2022.

The following Figure 2.1, an overview of the project sample under analysis by yearly payments of projects ongoing each year is presented. It can be seen that the largest amounts of payments for ICT projects were made in 2020–2021 when ICT projects received more than 26 million euros and when there were more than 300 ICT projects ongoing. The decline in payments in 2021–2022 could be associated with the usual fluctuations that happen at the end of one financing period and the beginning of a new one. In 2020 the framework programme Horizon 2020 ended as well as the support period 2014–2020 of European Union structural funds. However, the next framework programme, Horizon Europe, has started up and the structural fund period 2021–2027 still takes time to start.

[55] Estonian Research and Information System. Fields of research. https://www.etis.ee/Portal/Classifiers/Index (25.04.2023).

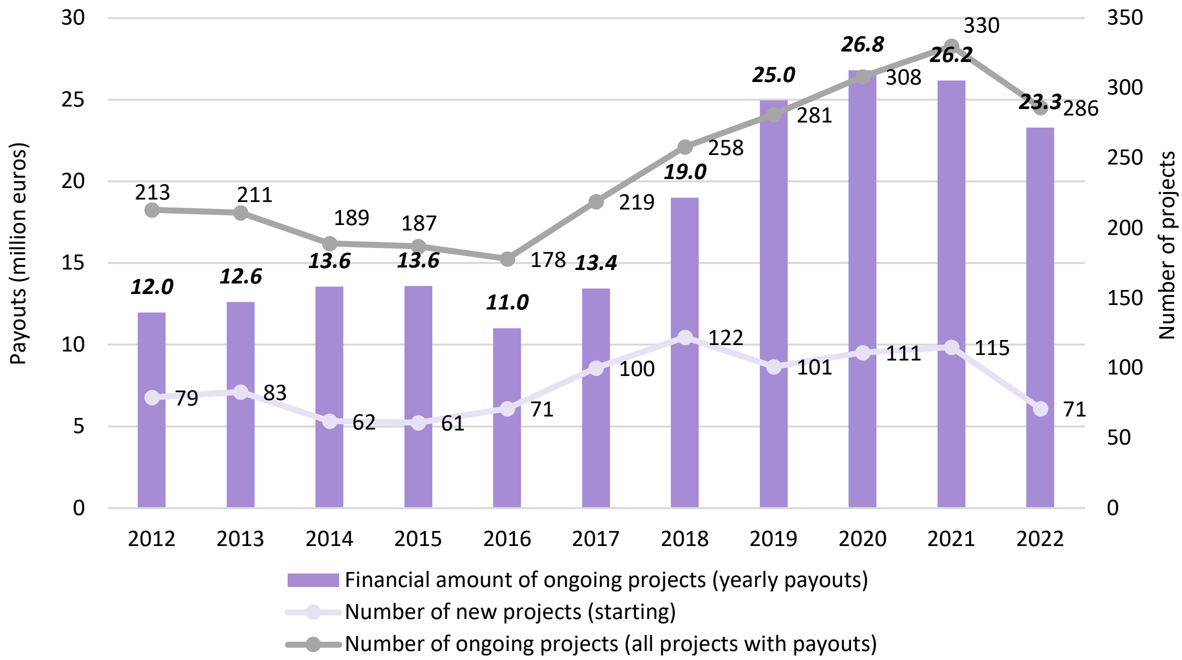


Figure 2.1. The number of ICT projects and their financial amount (million euros) in the field of information and communication and computer science (ETIS fields 4.6, 4.7 and 4.8).
Source: Estonian Research Information System.[56]

As seen from the following Figure 2.2., around half of the Estonian ICT research project funding in 2022 came from the public sector (grants and EU Structural Funds). It is necessary to add that, in Estonia, EU Structural Funds are included in (local) public sector funding whereas EU framework programmes are considered foreign public financing. However, the dependence on (local) public sources started to change from 2016–2017 when more resources from the private sector and foreign public sources were allocated. Foreign public sources (mainly framework programmes and cooperation with foreign public institutions) have played a significant role distributing around 6–9 million euros and amounting to around 25–30% of the total financing in 2018–2022. Payments from the cooperation with the Estonian private sector rose remarkably in 2019 up to 4 million euros per year, accounting for around 16–17% of the total project funding but declined in 2022. This is probably due to economic uncertainty and the decline in support measures for business R&D together with the end of the structural funding period. Foreign private funding (mostly foreign businesses) has remained modest, amounting to approximately 1% throughout all years under analysis.

[56] Estonian Research Information System (ETIS). www.etis.ee (30.03.2023).

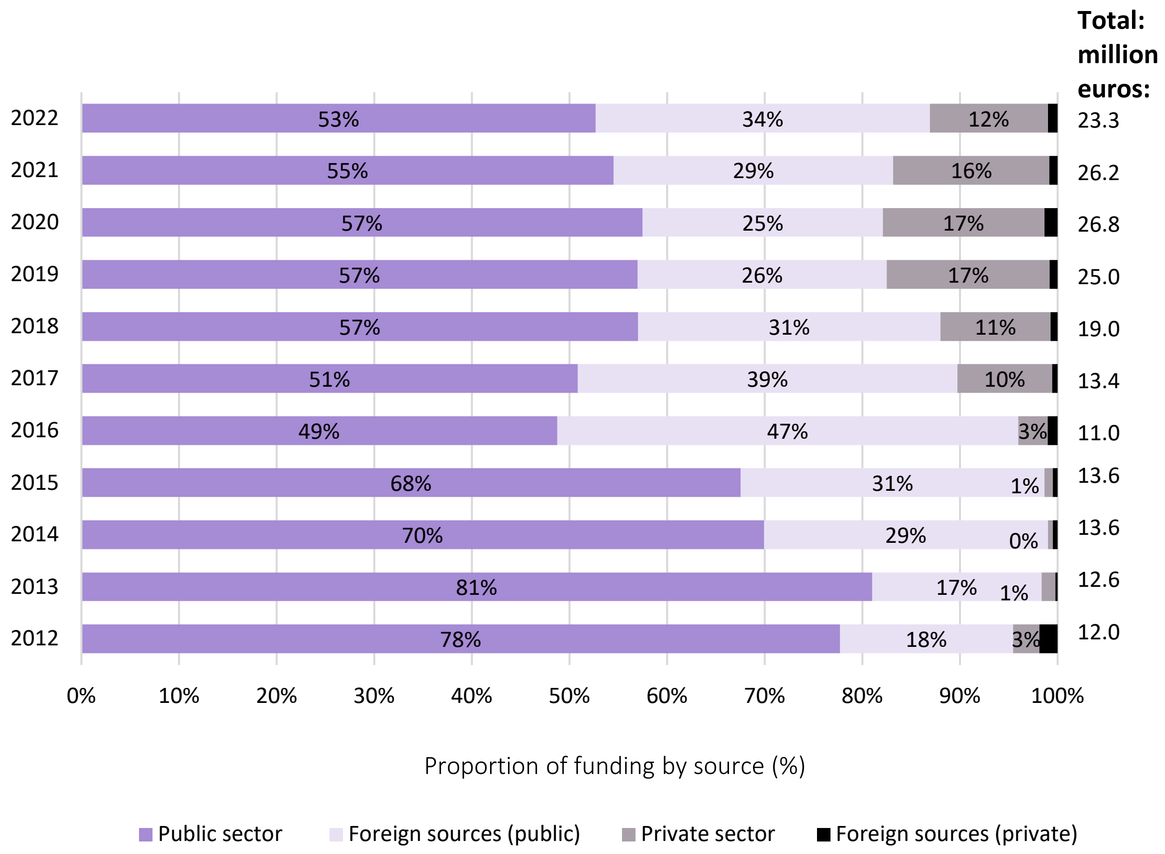


Figure 2.2. The number of ICT R&D projects by source of funds.
Source: Estonian Research Information System.[57]

The majority of ICT research projects during the period of 2018–2022 were ongoing at the University of Tartu (256 projects) and Tallinn University of Technology (226 projects) (Figure 2.3). In monetary terms, two largest universities received almost equal amounts of project money – Tallinn University of Technology a total of 48.4 million euros and the University of Tartu 47.1 million euros. Tallinn University had 81 projects. Despite numerous projects, the earnings remained much lower (altogether 4.40 million euros was earned), indicating that Tallinn University on average had much smaller projects.

[57] Estonian Research Information System (ETIS). www.etis.ee (30.03.2023).

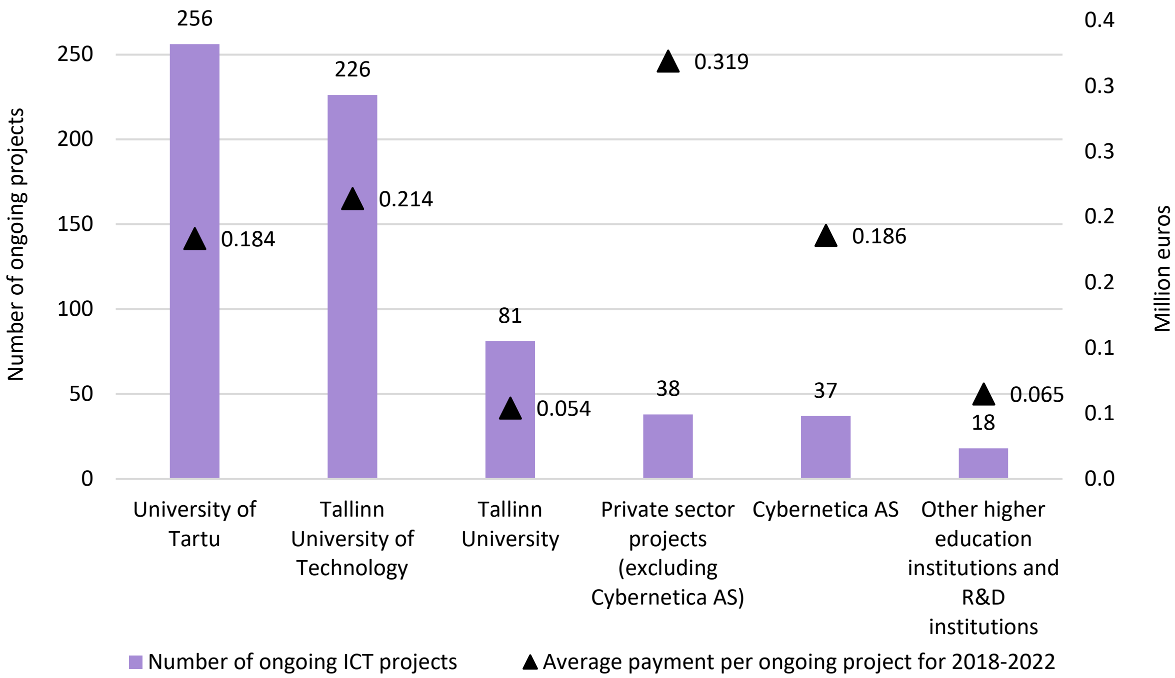


Figure 2.3. The distribution of the number of ICT projects among institutions and the average annual payment per institution between 2018 and 2022.[58]
Source: Estonian Research Information System.[59]

One of the objectives of this overview is to analyse the impact of IT Academy programme science support measure to the participating universities' financial state. Compared to total project payments of participating universities between 2018 and 2022, Figure 2.4 shows that the proportion of funds from the IT Academy, relative to each university's funds received from other projects, was remarkably different depending on year and institution. The support measure had the most profound significance for financing ICT research at Tallinn University where altogether it accounted for approximately 27% of all project money in the period of 2018–2022. For the University of Tartu and Tallinn University of Technology the support measure was relatively smaller in proportion, accounting for approximately 12% and 16% from their project funding in 2018–2022.

[58] "Other higher education institutions and R&D institutions" are in this context smaller higher/applied education institutions (for example Estonian Aviation Academy, Estonian Academy of Security Sciences, TTK University of Applied Sciences, etc.) or research organisations with fewer ICT projects (e.g. Estonian Environment Agency, The Institute of the Estonian Language, etc.).
[59] Estonian Research Information System (ETIS). www.etis.ee (30.03.2023).

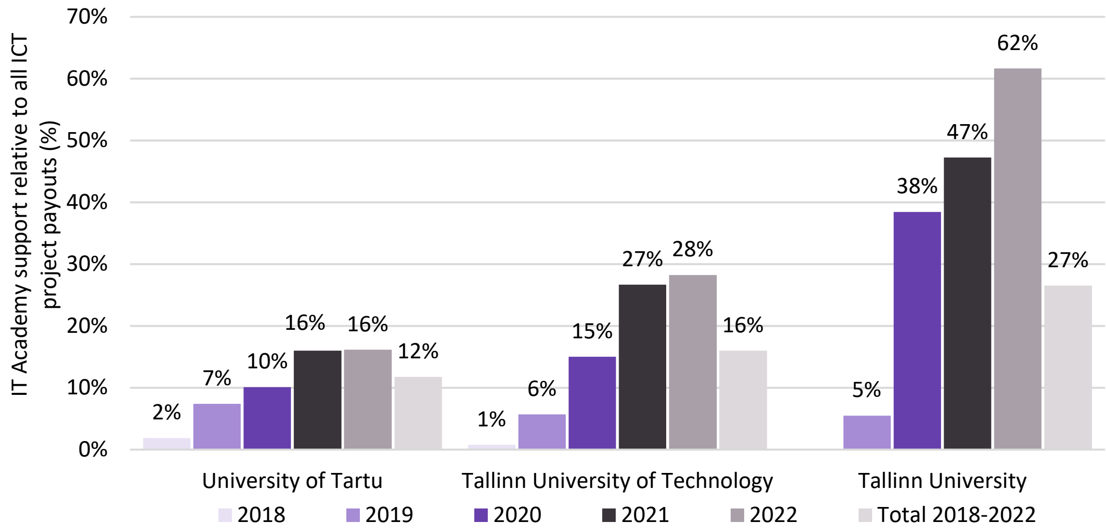


Figure 2.4. Proportion of IT Academy science support measure relative to all ICT projects' payments in 2018–2022 at three universities which received support from the IT Academy programme.
Sources: Estonian Research Information System[60] and IT Academy programme.

Quality of research infrastructure is more than just an attractive environment, it is also an important factor in conducting high-level research. In Estonia, the research infrastructure has undergone a comprehensive renovation largely owing to the European Structural Funds. A list of research infrastructure projects in ICT between 2007 and 2023 is given in Table 2.1. The total amount invested in ICT research infrastructure during this period is 25.6 million euros, from which 97.6% was financed by European Structural Funds. Lately, as European funding has decreased, the state has also started to invest in infrastructure. It should be noted that more than half of the infrastructure investments (14.3 million euros, 55.9%) were spent on a single object – the construction of the Delta building (a new joint building for the institute of Computer Science, and School of Economics and Business Administration at the University of Tartu). It also means that less than half of the infrastructure investments were allocated to the development of technological infrastructure, while over half were dedicated to the construction of new buildings. In the future, it is important that with the continued decrease in European funding, the state is able to take over the necessary infrastructure investments and the modernisation of existing facilities.

Table 2.1. Research infrastructure projects in ICT in 2007-2023.

Project/infrastructure name	Financial support (million euros)	Financial measure	Financial source
Estonian science and education optical backbone network	2.61	National infrastructure measure 2007–2013	EU Structural Funds
Estonian Scientific Computing Infrastructure (ETAIS)	2.81	National infrastructure measure 2007–2014	
Estonian science and education optical backbone network	0.55	National infrastructure measure 2014–2020	
Estonian Scientific Computing Infrastructure (ETAIS)	2.08	National infrastructure measure 2014–2021	
Center for Scientific Computing Phase II	0.52	Middle infrastructure measure 2007–2013	
Modernisation of Cybernetica's scientific apparatus and equipment	0.36	Middle infrastructure measure 2007–2014	
Modernisation of Cybernetica's scientific apparatus and equipment II	0.17	Middle infrastructure measure 2007–2015	
Modernisation of Cybernetica's scientific apparatus and equipment III	0.20	Middle infrastructure measure 2007–2016	

[60] Estonian Research Information System (ETIS). www.etis.ee (30.03.2023).

Modernisation of Cybernetica's scientific apparatus and equipment IV	0.13	Middle infrastructure measure 2007–2017	
Scientific Computing in Cloud and Grid Computing (KBFI)	0.15	Middle infrastructure measure 2007–2018	
Increasing the calculation and electronic capacity of the physics side (KBFI)	0.18	Middle infrastructure measure 2007–2019	
Support for Small-Scale Research Equipment (Computer Science)	0.90	Mini infrastructure measure 2007–2020	
Delta house investment from the ASTRA project	14.30	ASTRA funds 2014–2020	
Estonian Scientific Computing Infrastructure (ETAIS)	0.48	IUT core infrastructure support 2014–2020	State budget
Estonian Scientific Computing Infrastructure (ETAIS)	0.14	ETAG core infrastructure support 2021–2023	

Source: Estonian Research Council

Besides direct financial means, another defining resource for sustainable and high-quality research is the availability of human resources. In the following section, the number of principal investigators (PIs) and senior research staff in ICT projects is compared at the start year of the IT Academy science support measure in 2018 to the end year of the measure, i.e. in 2022. In addition, the proportion of doctoral degree holders is analysed by projects belonging to the IT Academy priority research areas and by the rest of the projects.[61] Each person appears in the analysis once regardless of the number of projects in which they participate. If at least one project of a researcher with several projects belongs to the IT Academy research area, the researcher is considered as contributing to the IT Academy research area. Individuals with a doctoral degree are considered those who had doctoral degree in the years analysed, which were 2018 and 2022. As a result, it was possible to deduct whether the number and proportion of researchers contributing in IT Academy priority research areas has grown and whether the qualification of people has risen as well during the support period.

As seen in Figure 2.5, in 2018 there were in total 422 PIs or senior research staff in ICT projects, of which 52% (220 people) contributed to projects in IT Academy priority research areas. The average proportion of doctoral degree holders in IT Academy priority area projects was nearly 75%, whereas for other projects it was around 9 percentage points lower. By 2022, the total number of PIs or senior research staff in ICT projects had increased to 498 people (rise 18%) as the number of ongoing projects was also approximately 11% higher (returning to Figure 2.1). However, although more researchers had shifted to IT Academy research areas by 2022, the share of doctoral degree holders in IT Academy priority research area projects had fallen to 70% (whereas for other projects the ratio had declined less than a percentage point).

The movement of more PIs and senior research staff towards the priority areas of IT Academy may indicate a certain trend to support these priority areas more and it might be related to the impact of the programme. As one of the goals of the IT Academy was to develop the competence of junior researchers and provide a pathway to obtaining a doctoral degree, it was examined whether there was an increase in the number of junior researchers without a doctoral degree and doctoral students among the principal investigators or senior research staff members in 2021 compared to 2018. In the dataset for 2018, there were a total of 29 principal investigators or senior research staff members without a doctoral degree, whose position according to their ETIS CV was either a junior researcher or a doctoral student. By 2021, this number had increased to 52 (an increase of 0.8 times). Among them, in projects associated with IT Academy priority research areas, there were 9 such individuals in 2018, and in 2021,

[61] All projects in the dataset were divided into projects contributing in IT Academy priority research areas and other research projects. For the division, text analysis finding research area specific keywords in project abstract and title was used. The research-area-specific keywords were discussed and agreed with the Steering Committee of the targeted evaluation.

there were 30 (an increase of 2.3 times). In projects not associated with the IT Academy priority research areas, the respective numbers were 20 in 2018 and 22 in 2021 (an increase of 0.1 times). Thus, the proportion of junior researchers and doctoral students had increased significantly in projects associated with the IT Academy's priority research areas, which may explain the overall decrease in the proportion of individuals with a doctoral degree in IT Academy research directions. Similarly, as the changes in other research areas other than IT Academy priority areas were smaller, the change in the proportion of doctoral degree holders is also smaller. Therefore, the results are in line with the goal of the IT Academy to support the competence of junior researchers and provide opportunities to pursue doctoral degrees.

It must be kept on mind that with the previous results, especially when attempting to explain small changes, as in the current case, are highly dependent on the quality of data in ETIS. ETIS data that are taken from researchers' CV-s (educational background, employment history) directly depends on the individuals themselves and their diligence in keeping their data in ETIS up to date. In the current case, it should also be noted that for both 2018 and 2021, there were 38 PI-s or members of senior research staff whose CV did not include updated data for 2018 or 2021 or who did not have their CV in ETIS. The issue primarily concerned mostly researchers with non-Estonian origin who might have not been aware of the the requirement to update their ETIS profile.

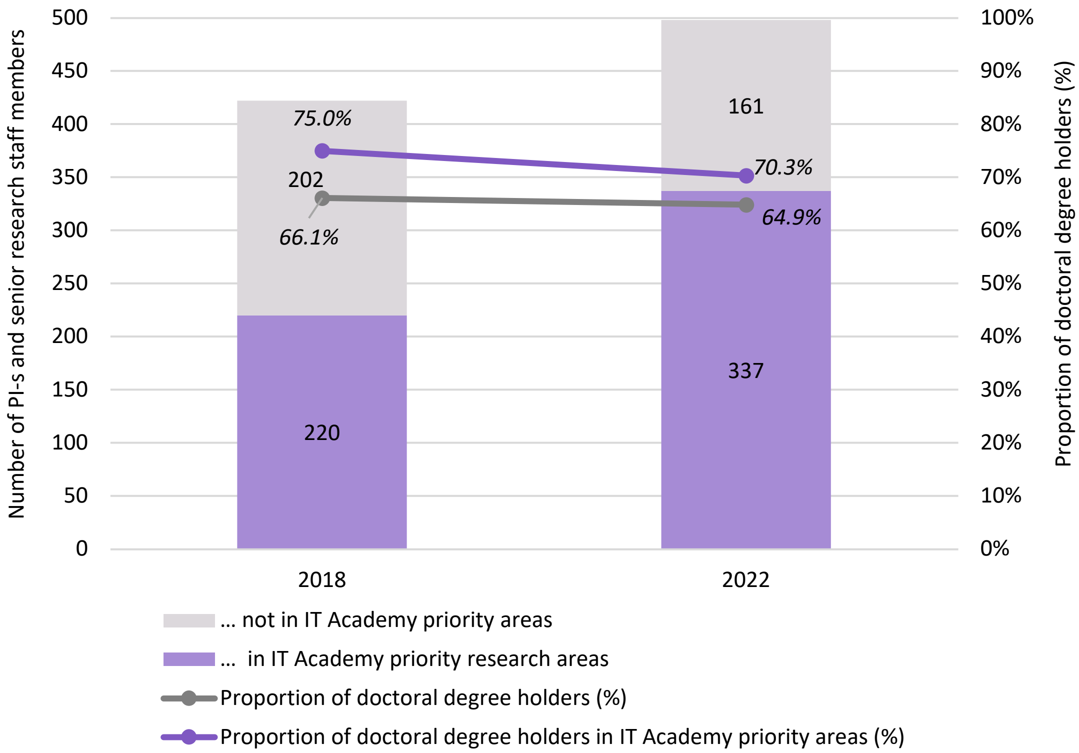


Figure 2.5. Doctoral degree holders participating in ICT projects as principal investigators (PIs) and members of senior research staff in 2018 compared to 2022.
Source: Estonian Research Information System.[62]

The specific nature of the ICT sector, where a small number of highly qualified employees could create a great amount of value, is a perfect model for a small country where there is always a shortage of employees. The sustainability of higher education and research relies on qualified personnel, primarily on faculty members with doctoral degrees. Over the past ten academic years (2012/13–2021/2022), 191 students have completed doctoral studies in the field of ICT, of which 117 graduates were Estonian

[62] Estonian Research Information System (ETIS). www.etis.ee (30.03.2023).

(61%). The bigger picture in the field of ICT regarding the number of people who have obtained a doctoral degree indicates yearly fluctuations and no clear trend (Figure 2.6). The only noticeable trend is the increase in the number and share of foreign students who have obtained a doctoral degree in Estonia. However, the number of Estonians graduating from doctoral studies in the field of ICT has not shown a growth tendency.

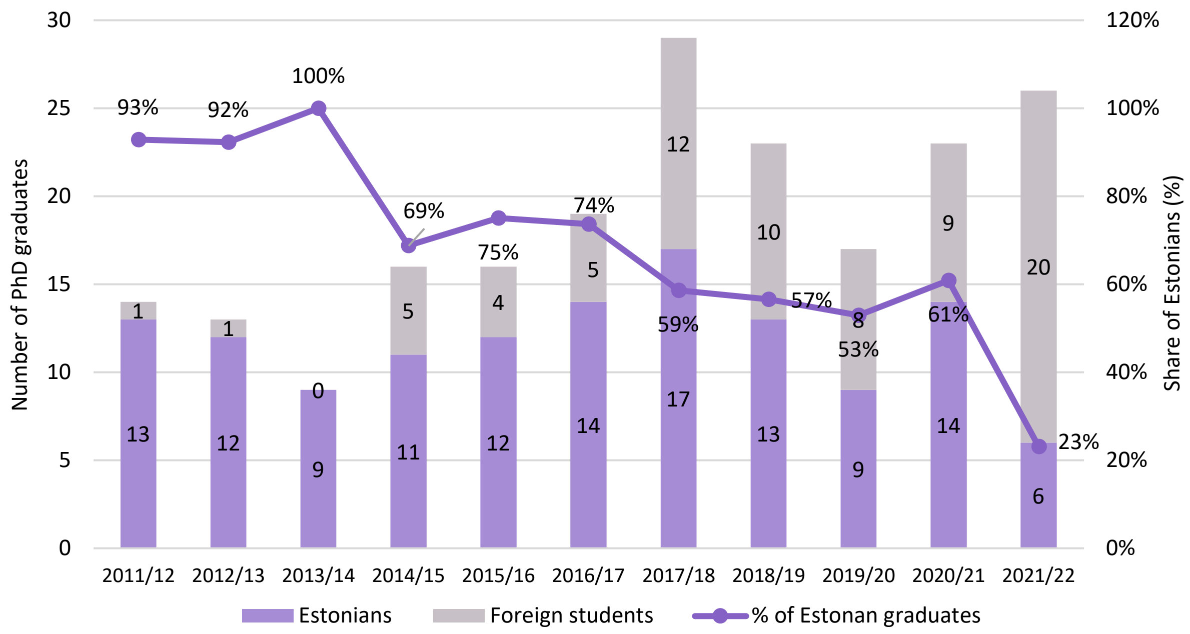


Figure 2.6. PhD graduates in ICT in academic years 2011/12–2021/22.
Source: Haridussilm.ee.[63]

What is of concern is not the rise in the number of foreign students obtaining doctoral degrees in Estonia, but that the number of Estonians entering doctoral studies in ICT has not shown an upward trend. In some years, even twice as many foreign students have been admitted as Estonians (Figure 2.7). From the academic year 2017/18 and onwards the proportion of foreign students admitted to PhD studies in ICT has been higher than for Estonians. Foreign doctoral degree students often might not see their future research career in Estonia. The study conducted by the Estonian Qualifications Authority also highlighted that higher education institutions lack academic staff to conduct teaching, supervise students, and engage in research and development activities in the field. This raises concerns about the sustainability of Estonian-language higher education in ICT and the sustainability of research and development activities in the field.[64]

[63] Haridussilm.ee (14.04.2023).
[64] Mets, U., Viia, A. (2022) Tulevikuvaade tööjõu- ja oskuste vajadusele:
info- ja kommunikatsioonitehnoloogia valdkond (OSKA Study on Information and Communication Technology Sector). Estonian Qualifications Authority (Kutsekoda). https://oska.kutsekoda.ee/wp-content/uploads/2022/01/OSKA_IKT_2021_terviktekst_.pdf (16.06.2023).

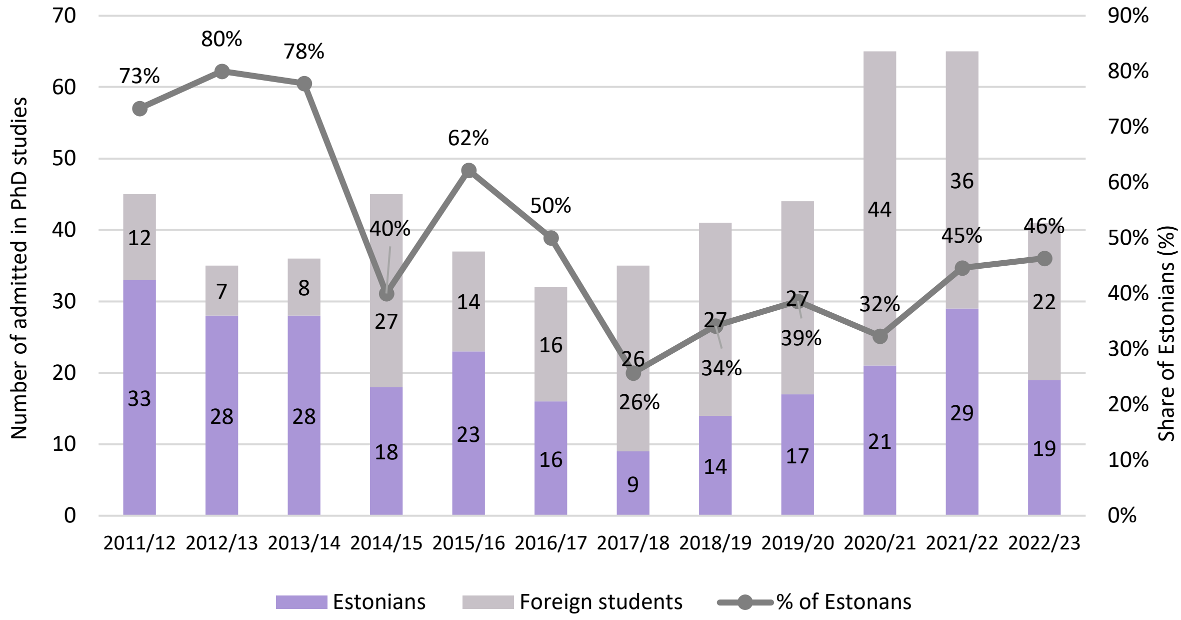


Figure 2.7. Admitted in PhD studies in ICT in academic years 2011/12–2022/23.
Source: Haridussilm.ee.[65]

A detailed overview of Estonia's ICT education and research can be found in the report "Overview of ICT education and research"[66] compiled by the Education and Youth Board (HARNO). A translation of the report into English is being made available by ETAG. The report by HARNO is supplementing this overview and therefore the topics covered there are not repeated here. The HARNO report provides a comprehensive overview of the role of the Estonian ICT sector in higher education, study programmes, graduates at different levels of education, curricula of educational institutions, and the labour market outcomes. The report also addresses ICT research funding and academic staff.

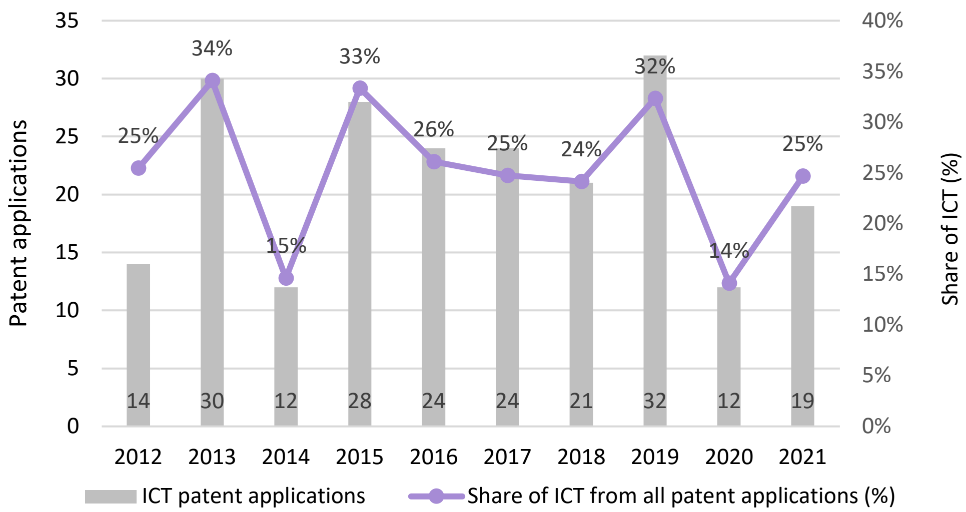
If the necessary inputs for science can be summarised in terms of financial resources and human capital, it is also important to look at the outputs of research and evaluate the quality and the possible impact of research. Assessing the impact of science for the just ended period is complicated and involves many uncertainties. To obtain a more complete overview, it would need to be reanalysed in years to come. In the short term, initial conclusions can be drawn, for example, based on patents and publications.

Patents are granted for innovative ideas, inventions, or technological solutions. The existence of a patent indicates that the idea or technological solution is novel, creative, and industrially applicable. Therefore, the number of patents can be a good indicator of the effectiveness of research and development and how many new technological solutions and ideas have come from science usually takes at least a couple of years, or sometimes even longer from patent application to receiving the patent.. Figure 2.8 presents both the patent applications and patents. The data on patents with Estonian inventors were downloaded from the Espacenet database, which aggregates information from patent offices around the world. One patent might have inventors from several countries, and it may have several patent classifiers attached (research fields), but the following figure 2.8 shows full counts of patents that had at least one inventor from Estonia and at least one of the CPC classifiers indicating ICT (i.e. not fractionalised with the number of inventors and research fields).

[65] Haridussilm.ee (14.04.2023).
[66] Education and Youth Board. IT Academy Programme. Uuringud ja analüüsid. https://harno.ee/it-akadeemia-programm#uuringud-ja-analuusid (24.05.2023).

A query made from the Espacenet database for ICT patent applications by Estonian inventors during the period of 2012–2022 yielded a result of 220 applications. A search with the same parameters made on the same parameters regarding Finland and Sweden resulted in 4,179 and 6,052 patent applications respectively. For the analysis, only patent applications and granted patents registered in the patent offices of North American and European countries were included in the dataset. Additionally, patent applications with exceptional codes were excluded from the analysis, as interpreting all the different variations would have taken an unreasonable amount of time. As a result, the final dataset decreased by 12%, and the final analysis included 216 patent applications from the field of ICT and 630 from other fields (total 846 patent applications). The number of patents with an Estonian inventor during the period 2012−2022 was 457, of which 104 (23%) were in the field of ICT.

Figure 2.8 shows that, throughout the past ten years, the patenting activity in ICT has been fluctuating. The total number and proportion of Estonian ICT patent applications out of all patent applications with an Estonian inventor ranged from 14% to 34% in 2012−2021, the average was 26%. During the period of 2012−2022, the share of ICT patents out of all patents with Estonian inventors ranged from 12% to 35% (average 23%). The patent/application query, showing the total numbers, is based on inventor country (Estonia). Therefore, it was also possible to connect each patent/application with the organisation that was behind the inventor while submitting the patent application. There are a few Estonian companies or their branches that clearly stand out with the number of patents and applications. These are the following: Skype, Microsoft Corporation, Starship Technologies OÜ and Guardtime OÜ. All these companies could be associated with 8–16 patents and with 16–26 patent applications.



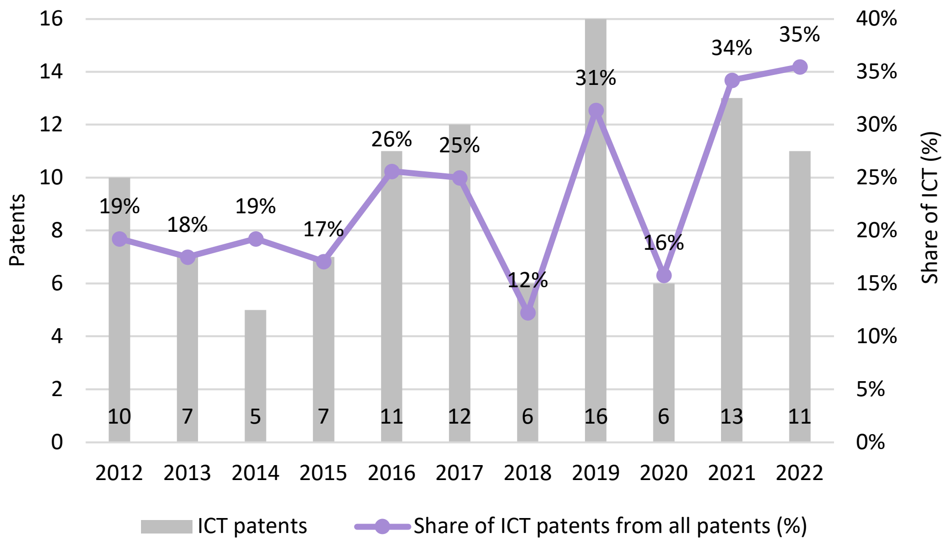


Figure 2.8. ICT[67] patent applications and patents granted in 2012–2021 their share from all patents and patent applications with an Estonian inventor.
Source: Espacenet.[68]
** Data are not fractionalised, i.e. show full counts and have not been divided between inventor countries or other research fields if the patent (application) has more than one.*

Traditionally, the quantity of research outputs is measured by the volume of research publications. Assessing the quality of research is somewhat more complex, typically relying on various citation-based metrics. In this overview, bibliometric data based on the research analytics platform InCites that is associated with the Web of Science (WoS) database (a comprehensive collection of scientific literature), is used. Since WoS has its own research field classifier that includes several fields related to ICT, a set of WoS fields was selected[69] to define the ICT domain in this overview. The publication types included in this overview are articles, proceedings papers, book chapters and reviews. For quality indicators, only publications with up to 50 authors are taken into account. Understanding the dynamics of quantity is a complex procedure. The problem lies in the fact that the WoS database is only relatively static, it evolves over time as journals and conference proceedings are continuously added to the database. Additionally, there is the issue that articles are added to the database with a lag, which leads to lower publication numbers in later years compared to the earlier ones.

Despite these constraints, it is possible to observe a significant increase in the number of ICT articles (Figure 2.9) and the growth is observable when considering indicators relative to the population size of the country (Figure 2.10). The proportion of ICT publications among all Estonian publications has also shown a growth trend over the years, reaching 14% in 2022. Relative to the population size of neighbouring countries, Estonia has caught up with Sweden and has significantly higher number of ICT related publications per million inhabitants than other Baltic countries.

[67] ICT is defined here as a combination of codes from Cooperative Patent Classification System (CPC) and includes patents/patent applications marked with the following CPC codes: G16B, G16Y, G06F, G06G, G06J, G06N, G06Q, G06T, G06V.
[68] Espacenet. https://worldwide.espacenet.com/ (17.04.2023).
[69] These WoS research fields are: Engineering Electrical Electronic, Computer Science Information Systems, Telecommunications, Computer Science Theory Methods, Computer Science Interdisciplinary Applications, Computer Science Software Engineering, Computer Science Artificial Intelligence.

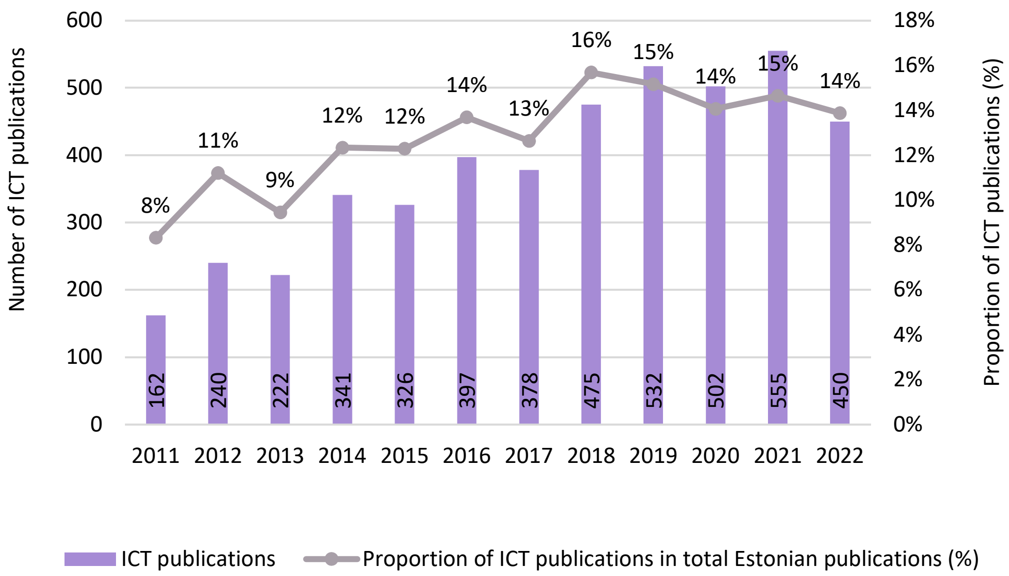


Figure 2.9. Number of ICT publications by Estonian researchers and its share from all publications with an Estonian author.
Source: InCites.[70]

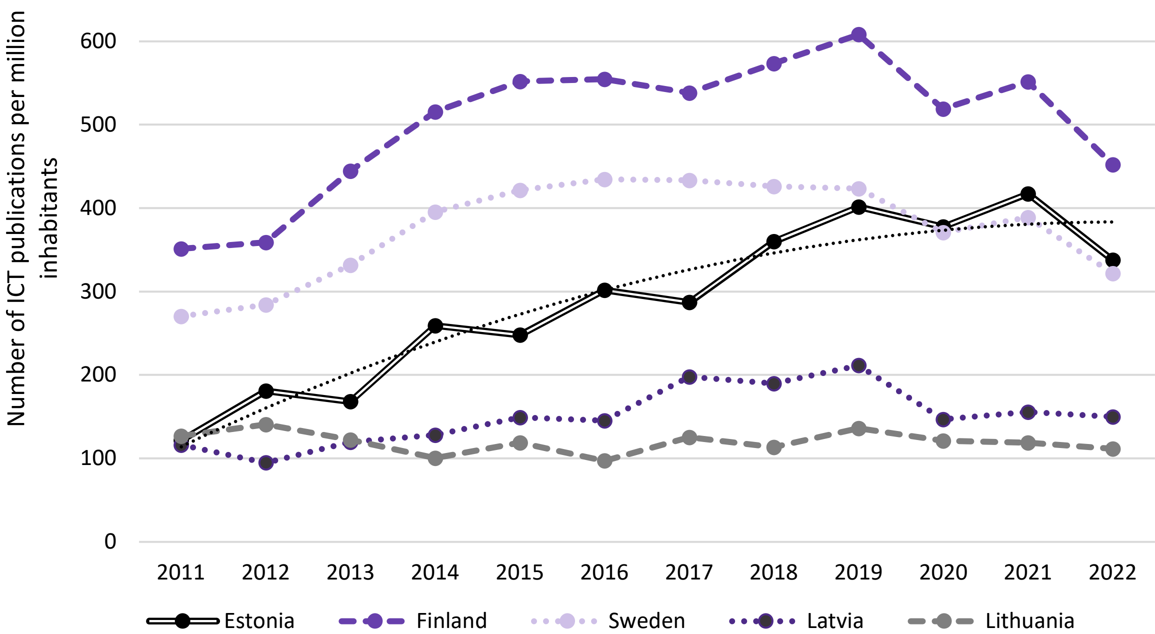


Figure 2.10. Number of ICT publications per million inhabitants.
Source: InCites[71] and Eurostat[72].

For describing Estonian ICT research quality, two indicators are assessed: top 10% of documents and Category Normalised Citation Impact (CNCI). The top 10% documents indicator is calculated by dividing the number of top 10% cited documents by the total number of the documents. For example, value of "10" means that 10% of the publications in the set are among the top 10% most cited worldwide. This

[70] InCites. https://incites.clarivate.com/ (02.05.2023).
[71] InCites. https://incites.clarivate.com/ (02.05.2023).
[72] Eurostat. https://ec.europa.eu/eurostat/data/database (14.04.2023).

indicates that they are performing at the same level as the global average. If the value exceeds "10", it means that more than 10% of the papers in the set are in the top 10% globally. The CNCI of a document is calculated by dividing the actual count of citing items by the expected citation rate for documents with the same document type, year of publication, and subject area.[73] A CNCI score greater than 1 indicates that the publication has received more citations than the field average. Conversely, a score of less than 1 indicates lower than expected citation rates, implying a relatively lower impact. Therefore, the CNCI provides a more nuanced understanding of the impact of scientific publications within specific research domains, enabling the possibility to evaluate the significance and influence of research within a particular field. Since citations appear with a time lag, the data for recent years are not yet complete to be used for final assessments. According to Wang[74] citation analyses require a minimum 2-year citation window; otherwise, estimates would have unacceptable measurement errors. Therefore, the first year where reliable assessments about research quality can be made is 2020.

As shown in Figure 2.11, the share of Estonian ICT publications among the top 10% has been volatile. At the beginning of the period, it was below 10%, it then increased to 19% in 2017. In the period of 2015–2019 around 14–19% of Estonian ICT publications belonged to the top 10% of most cited publications globally. Although more fluctuating, the indicator remains close to that of Finland and Sweden throughout the years from 2015. The fluctuating dynamics of Estonian CNC and the upward trend similar to that of Scandinavian countries somewhat confirms the top 10% indicator. CNCI in the beginning of the period was only significantly below one, from 2013 it is slightly above it and from 2017, it is similar to Sweden and Finland.

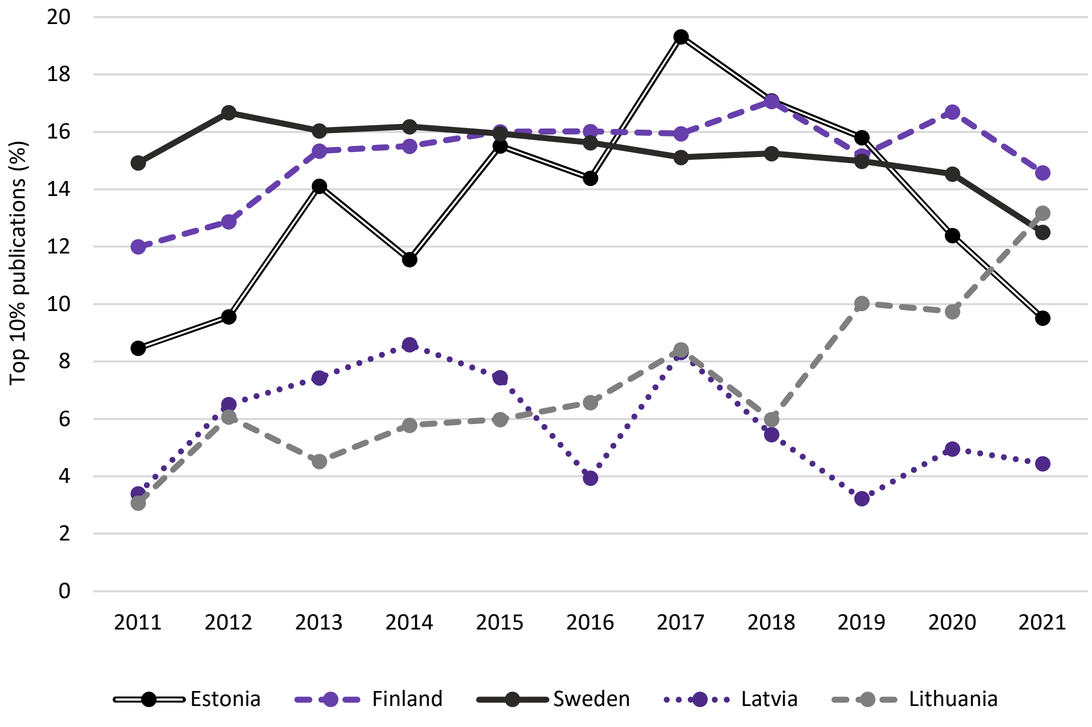


Figure 2.11. Top 10% most cited ICT publications in 2011–2021.
Source: InCites.[75]

[73] InCites. Category Normalized Citation Impact. http://help.prod-incites.com/inCites2Live/indicatorsGroup/aboutHandbook/usingCitationIndicatorsWisely/normalizedCitationImpact.html (09.05.2023).
[74] Wang, J. Citation time window choice for research impact evaluation. Scientometrics 94, 851–872 (2013). https://doi.org/10.1007/s11192-012-0775-9
[75] InCites. https://incites.clarivate.com/ (02.05.2023).

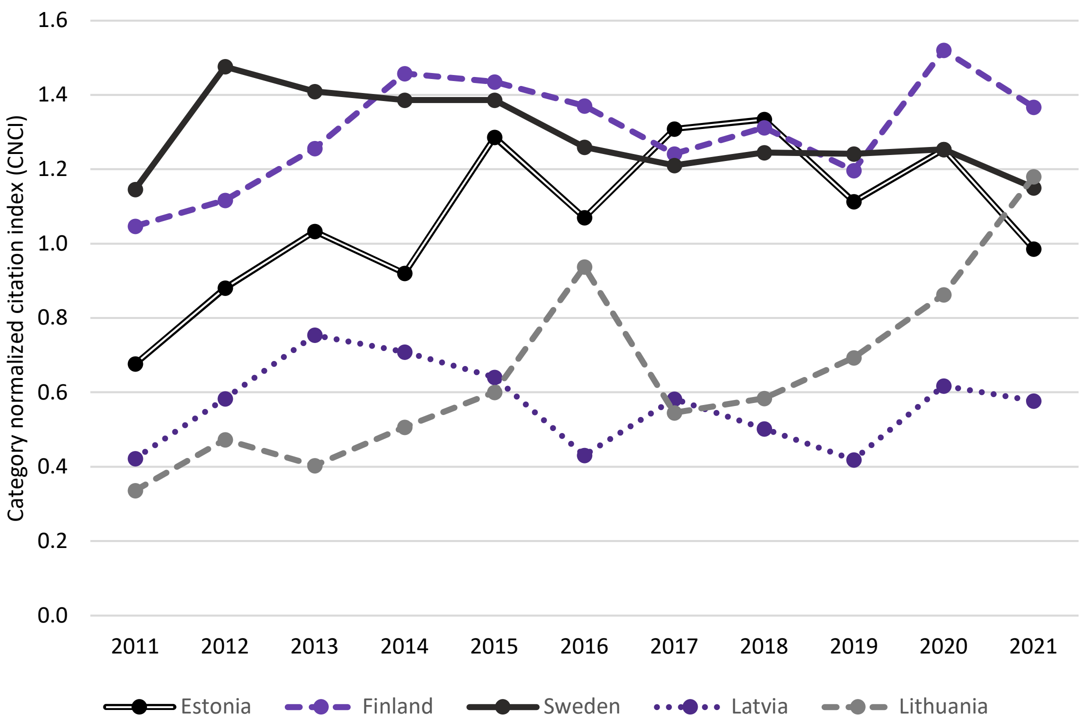


Figure 2.12. Category normalised citation index (CNCI) in 2011–2021.
Source: InCites.[76]

In addition, the share of international co-publications is also an indirect indicator of the quality of research. On the one hand, it is desirable to collaborate with top research institutions, on the other, publications created in international cooperation are often more cited. According to Figure 2.13, approximately 67% of Estonia's ICT publications in 2021 were collaborations with foreign partners. The proportion of collaboration has been significant in the last decade and is at a similar level as Finland and Sweden.

[76] InCites. https://incites.clarivate.com/ (02.05.2023).

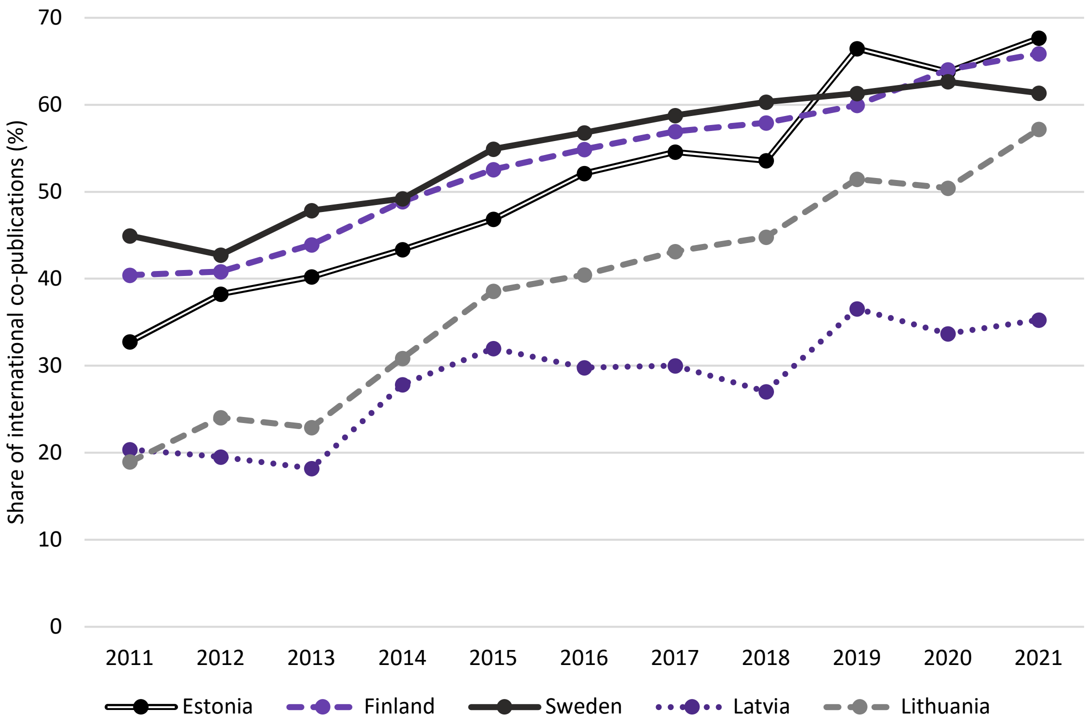


Figure 2.13. Share of international co-publications in ICT in 2011–2021.
Source: InCites.[77]

The overview of publications suggests that Estonian ICT research is internationally recognised and at a high level. While there may be fluctuations over the years, the overall trend indicates both an increase in quality and quantity.

3. Estonian ICT research directions

The following chapter focuses on what directions of ICT research and development are advanced in Estonia and to what extent the selected directions overlap with the country's strategic priorities and global development trends. For this, the dataset of ETIS projects concerning ICT is primarily used. Using text analysis, a comparison of the overlap of project themes with Estonian priorities and global trends has been conducted. The keywords used in the text analysis have been approved by the Steering Committee of the targeted evaluation.

Since the targeted evaluation of the IT Academy programme ICT science support measure focuses on assessing ICT research in seven IT Academy programme priority areas, Figure 3.1 summarises the distribution of projects and funding across these areas. In the period of 2018–2022 out of 656 ongoing projects, 249 (38%) were related to at least one IT Academy priority area. Concerning the projects in 2018–2022, out of the 120.2 million euros paid, 63.8 million euros (53%) supported priority areas. Compared to the previous five-year period of 2013–2017, 26% of ongoing projects (96) and 38% of funding (16.2 million euros) were related to priority areas.

Although the total yearly funding of ICT research projects has increased substantially since 2018, the funding of IT Academy priority area projects has increased even more: in 2013–2017 the total funding of 369 ongoing projects was 42.5 million euros and in 2018–2022 it was 120.2 million euros (183% rise). In the IT Academy priority areas the respective numbers were 16.2 million euros and 63.8 million euros (294% rise). The rise in the number of projects in IT Academy priority areas was 159%. The total funding

[77] InCites. https://incites.clarivate.com/ (02.05.2023).

of projects that were not in IT Academy priority areas rose to 115% and the number of projects 49% (comparing periods 2013–2017 and 2018–2022). **Summing up the increase in funding volume and the number of projects in IT Academy priority areas and other fields, is clear that priority areas have undergone significant development – funding and project numbers have grown manyfold and at a faster rate than the funding of all fields.**

A more detailed look at the development in the funding volume and project numbers of IT Academy priority areas can be found in Figure 3.1. The robot-human collaboration and Internet of Things in Industrial Processes is a field that has received the highest funding among priority areas and where the most ongoing projects were between 2018 and 2022 (119 projects). There were also many projects (113) connected to artificial intelligence and machine learning (many of them about language technology) and the field of Internet of Smart Things also received generous funding. In 2013–2017 the most money and projects in IT Academy priority areas were connected to the field of artificial intelligence and machine learning (46 projects) and robot-human collaboration, and Internet of Things in Industrial Processes (25 projects). Only the field of software reliability has not undergone a significant increase in the number of projects and funding.

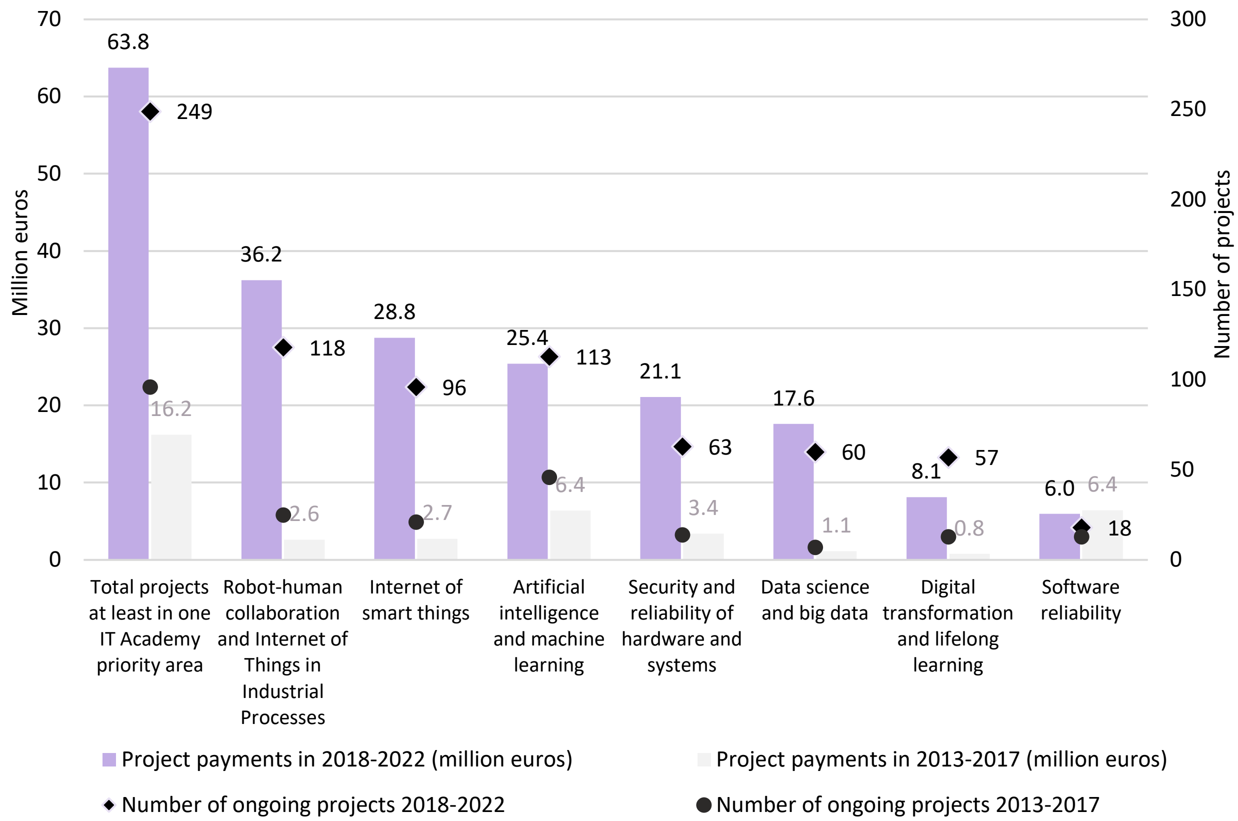


Figure 3.1. ICT R&D projects falling into IT Academy priority areas (number of ongoing projects and payments during 2018–2022).[78]
Source: Estonian Research Information System.[79]

Besides IT Academy programme priorities, it is necessary to analyse to what extent the Estonian ICT research responds to national strategies. This is due to a large number of different national documents created during the observation period of the targeted evaluation, highlighting priorities or in force in Estonia. The following ICT development guiding strategies were analysed and in cooperation with the Steering Committee of the targeted evaluation, national priorities were formulated for this overview:

[78] Project may belong to more than one priority area (i.e. total does not equal the sum of priority areas).
[79] Estonian Research Information System (ETIS). www.etis.ee (30.03.2023).

- Estonian Research and Development, Innovation and Entrepreneurship Strategy 2021–2035[80]
- Estonian Research and Development and Innovation Strategy 2014–2020[81]
- Estonian National Artificial Intelligence (AI) Strategy or Kratt Plan 2022–2023[82] and associated documents[83]
- The Digital Society Development Plan 2030[84].

The national priorities were associated with projects using thematic keywords. The national strategic priorities for ICT development are shown in Figure 3.1 together with the number of projects and funding volumes for the period of 2018–2022 compared to the period of 2013–2017 by selected national priority areas. During the period of 2018–2022, out of the 656 ongoing projects 34% were associated with national priorities and 76.6 million euros (46% of total funding) was used; for the period of 2013–2017 the corresponding indicators were 75 projects (20% of all projects) and 10.8 million euros (25% of all funding).

The field of privacy-enhanced technologies and natural language processing had the most projects and funding. Somewhat smaller volumes of projects and funding were in the areas of augmented reality, data governance and green ICT. Compared to the periods of 2013–2017 and 2018–2022, the financing of all projects grew from 43.5 million euros to 120.2 million euros (183%) while the rise in nationally prioritised fields was from 10.8 million to 76.6 million euros (610%). The number of projects also grew in nationally prioritised fields more rapidly than the average – 196% (for all projects it was 78%). Therefore, it can be said that more has indeed been invested in priority areas, and more research projects have been initiated on these topics than on average. Although funding for national priority areas has grown significantly, there is still room for further discussion as to whether this is a sufficient proportion or not – after all, almost two thirds of the projects are not related to priority areas.

[80] Minsitry of Education and Research. Strategic planning for 2021–2035. Estonian Research and Development, Innovation and Entrepreneurship Strategy 2021–2035 (RDIE Strategy 2021–2035) https://www.hm.ee/en/ministry/ministry/strategic-planning-2021-2035#documents--2 (05.05.2023).
[81] Riigiteataja. Eesti teadus- ja arendustegevuse ning innovatsiooni strateegia 2014–2020 „Teadmistepõhine Eesti” https://www.riigiteataja.ee/aktilisa/3290/1201/4002/strateegia.pdf (05.05.2023).
[82] Ministry of Economic Affairs and Communications. Estonian National Artificial Intelligence (AI) Strategy or Kratt Plan 2022–2023 https://www.kratid.ee/_files/ugd/7df26f_65582ae6b6d24daa8511d8ea50cab1dd.pdf (05.05.2023).
[83] Information System Authority. Bürokratt. https://www.ria.ee/en/state-information-system/machine-learning-and-language-technology-solutions/burokratt (05.05.2023).
[84] Ministry of Economic Affairs and Communications. Digiühiskonna arengukava 2030. https://www.mkm.ee/digiriik-ja-uhenduvus/digiuhiskonna-arengukava-2030 (05.05.2023).

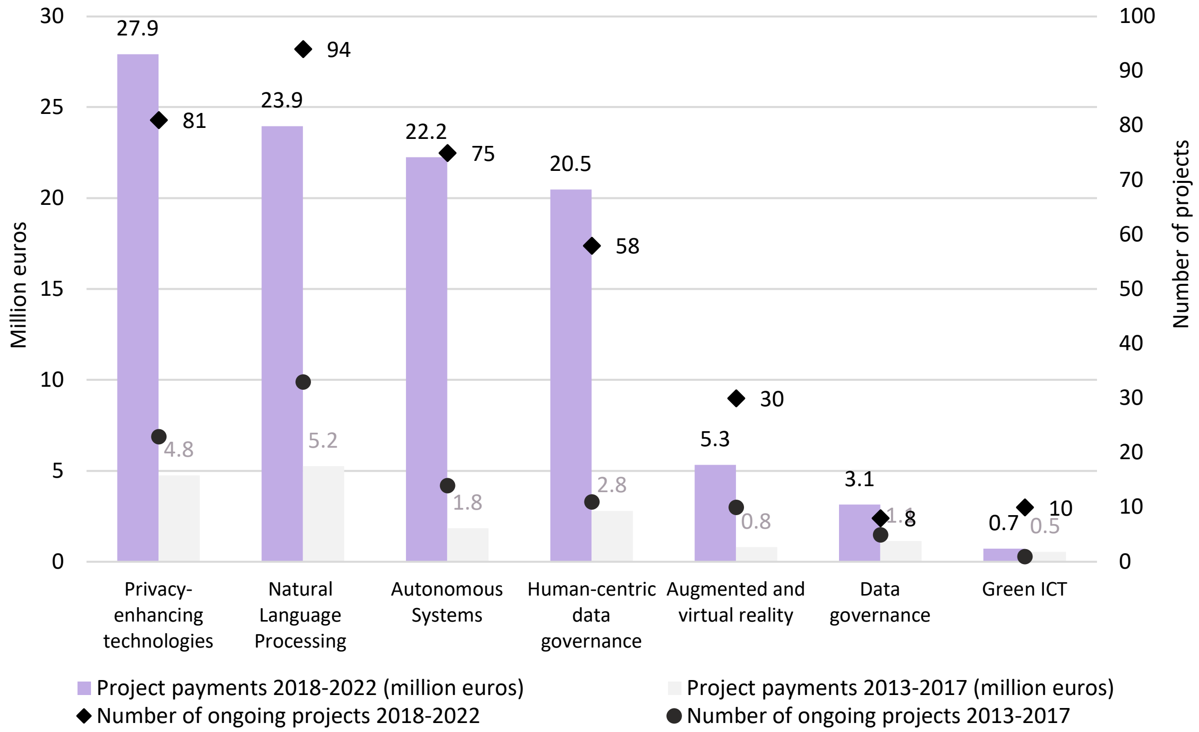


Figure 3.2. ICT R&D projects falling into national priority areas (number of ongoing projects and payments during 2018–2022 compared to 2013–2017).
Source: Estonian Research Information System.[85]

It is also essential to follow global trends in ICT because this field is rapidly evolving and constantly changing. By keeping abreast of the latest developments and emerging trends, individuals, businesses, and governments can stay competitive, identify new opportunities, and better understand how technology can be leveraged to improve various aspects of society. Staying up to date with global ICT trends is crucial for remaining relevant and thriving in the digital age. Therefore, next is presented an analysis focusing on the extent Estonia is engaged in the latest trends.

The identification of global trends relied on the Gartner report and additional discussion with the Steering Committee of the targeted evaluation. The Gartner report is a reprint of a research document published by Gartner, Inc., a leading research and advisory company that provides information technology insights for businesses and organisations worldwide.[86]

Since the latest global trends in ICT are fresh and futuristic, there are also topics that have a relatively small proportion among the projects in 2018–2022. Topics that were not much researched in Estonia were connected to Superapps and Adaptive AI. However, digital security and artificial intelligence are rather significantly represented in Estonian research already.

[85] Estonian Research Information System (ETIS). www.etis.ee (30.03.2023).
[86] Gartner, Inc. Top Strategic Technology Trends for 2023. https://www.gartner.com/doc/reprints?id=1-2BSGE4GK&ct=221122&st=sb (05.04.2023).

Table 3.1. The number of Estonian R&D projects (ongoing 2018–2022) compared to global technology trends in ICT in 2023.

	Number of ongoing projects	Project payout (million EUR)
Digital Immune System (incl. Cybersecurity)	76	26.9
Applied Observability (incl. Artificial intelligence)	82	21.8
AI Trust, Risk and Security Management (AI TRiSM)	52	17.0
Industry Cloud Platforms	21	5.0
Platform Engineering	1	0.4
Wireless-Value Realisation	47	12.7
Superapps	0	0.0
Adaptive AI	1	1.2
Metaverse	30	5.3
Sustainable Technology	9	0.7
Total*	216	60.6
All ongoing projects:	656	120.2
% of projects connected to global trends	32.9%	50.4%

Sources: Estonian Research Information System[87] ; Global trends: Gartner Report.

** Some projects belong to more than one global technology trend.*

In order to compare Estonia's international competitiveness as a contributor to ICT global trends, link between the topics of projects with Estonian participation in framework programmes and global trends was examined. The framework programme data consist of Horizon 2020 projects, from which IT-related projects have been extracted.

Altogether, Estonia participated in 702 Horizon 2020 projects that have started during the years 2014–2022. Out of all projects 139 projects could be categorised as ICT projects (20%)[88]. Out of those 139 projects, text analysis found 44 projects that could be connected to global technology trends (32%). While Estonia received in total 274.8 million euros from Horizon 2020, the contribution to ICT projects was 51.6 million (19%). Out of all the Estonian ICT project funding, 16.0 million went to projects with global technology trends (31%). A more detailed overview of global technology trends in the Estonian ICT projects in Horizon 2020 could be seen in Table 3.2.

Table 3.2. The number of Estonian ICT projects in Horizon 2020 that deal with global technology trends in ICT in 2023.

[87] Estonian Research Information System (ETIS). www.etis.ee (30.03.2023).

[88] The ICT-related projects and applications (in later part) were identified by the programme part abbreviation code (2.1.1), Call ID and by text analysis filter that used same filtering terms as for ETIS projects. In the case of conflicts, projects were checked manually.

	Number of projects	EU financial contribution (million euros)
Digital Immune System (incl. Cybersecurity)	10	5.29
Applied Observability (incl. Artificial intelligence)	25	7.04
AI Trust, Risk and Security Management (AI TRiSM)	1	0.38
Industry Cloud Platforms	3	0.15
Platform Engineering	1	0.00
Wireless-Value Realisation	7	4.16
Superapps	0	0
Adaptive AI	1	1.16
Metaverse	4	1.25
Sustainable Technology	0	0
Total:	44	15.98

Sources: eCORDA.[89]

** Project can represent several technology trends.*

The application for framework programmes, both in terms of different research topics and application activity, is dependent on the open calls and their conditions within the framework programmes. For example, in case of Estonia, the proportion of Horizon 2020 applications associated with ICT varied between 17% and 38% (with an average of 30%) from 2014 to 2021. Similarly, when assessing the success of proposals, it is important to consider the conditions and priorities of the framework programme. Therefore, a broader evaluation of the success in the ICT field and a fair interpretation would go beyond the scope of this overview. It can be noted that there is a relatively higher number of SME applicants (Small and Medium-sized Enterprises) among the ICT-related applications in Estonia (approximately 51.9%) compared to the non-ICT-related applicants (30.2%). Since the average success rate of SMEs in Horizon 2020 is slightly lower than the overall average (both in Estonia and other countries, with an average of 9.6%), and a higher proportion of Estonian ICT applications involve SME-flagged institutions, the success rate of ICT proposals in Estonia is lower than the average (9.2% compared to an average success rate of 13.4% for Estonian proposals).

To evaluate the impact of Estonian ICT research projects on the economy and society, the Technology Readiness Levels (TRLs)[90] of Estonian ICT projects were examined. Since TRLs were only available (and even there not always) for Horizon 2020 projects, and not for ETIS projects, the impact based on TRL was only analysed on the basis of Horizon 2020 projects. TRLs for Horizon 2020 projects had to be found manually for each project according to its call from the European Commission Funding and Tender opportunities page under Horizon call information and added to the project data.[91] To determine which of the IT Academy priority areas have a greater impact, the projects were also classified into the IT Academy priority areas (similarly to the text analysis method used earlier). For many projects, an expected range of TRLs rather than a specific TRL is anticipated, hence, in the following analysis, the

[89] External Common Research Data Warehouse (eCORDA). European Commission https://webgate.ec.europa.eu (30.03.2023).
[90] European Commission. Horizon 2020 – Work programme 2014–2015. Technology readiness levels (TRL). https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf (08.05.2023).
[91] European Commission. Funding ja Tender opportunities. https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-search (08.05.2023).

TRLs were grouped into three categories: 1–3 (discovery), 4–6 (development), and 7–9 (demonstration and deployment phase). A project falling into two ranges was placed in the lower range to avoid overestimation.

As previously seen, there were 139 ICT projects with Estonian participants in Horizon 2020. Out of those 139 ICT projects, 74 were conducted by private sector enterprises (53%) and 39 by higher education institutions (28%) and 29 by other institutions. According to text analysis, 78 Estonian Horizon 2020 projects fell at least in one IT Academy priority area (11% of total Estonian projects and 56% of Estonian ICT projects in Horizon 2020), capturing 46.6% of all financial contribution to Estonian ICT projects. This may mean that the European Commission's priorities in the field of ICT align quite well with the priority directions for further development of the IT Academy. The highest number of projects were in the priority areas of Internet of Things (33), robot-human cooperation, and the Internet of Things in industrial processes (29). The least were found in software reliability (1).

For all 139 Estonian ICT projects TRL information was given for 44 projects and for those 78 projects falling into IT Academy priority areas, TRL information was provided for 28 projects. It is necessary to emphasise that a sample of 28 projects is certainly not representative and does not reflect the distribution of the entire population. There may also be a sampling bias here, as it is evident that the applicants for TRL projects have typically been companies (out of those 28 projects 16 (57%) were conducted by private sector enterprises). Therefore, the following figure 3.3 gives an overview of the division of TRLs between IT Academy priority areas using the existing data but is not sufficient for generalisation. It can be seen that the picture is diverse and varied. The most significant projects that presented an expected technological outcome were in the areas of Internet of Smart Things and robot-human cooperation, and the Internet of Things in Industrial Processes. Most of the expected TRLs were from the development, demonstration and deployment phase. It should be kept in mind that for the majority of ICT projects, there was a lack of TRL information, and the sample formed from the remaining ones is quite small.

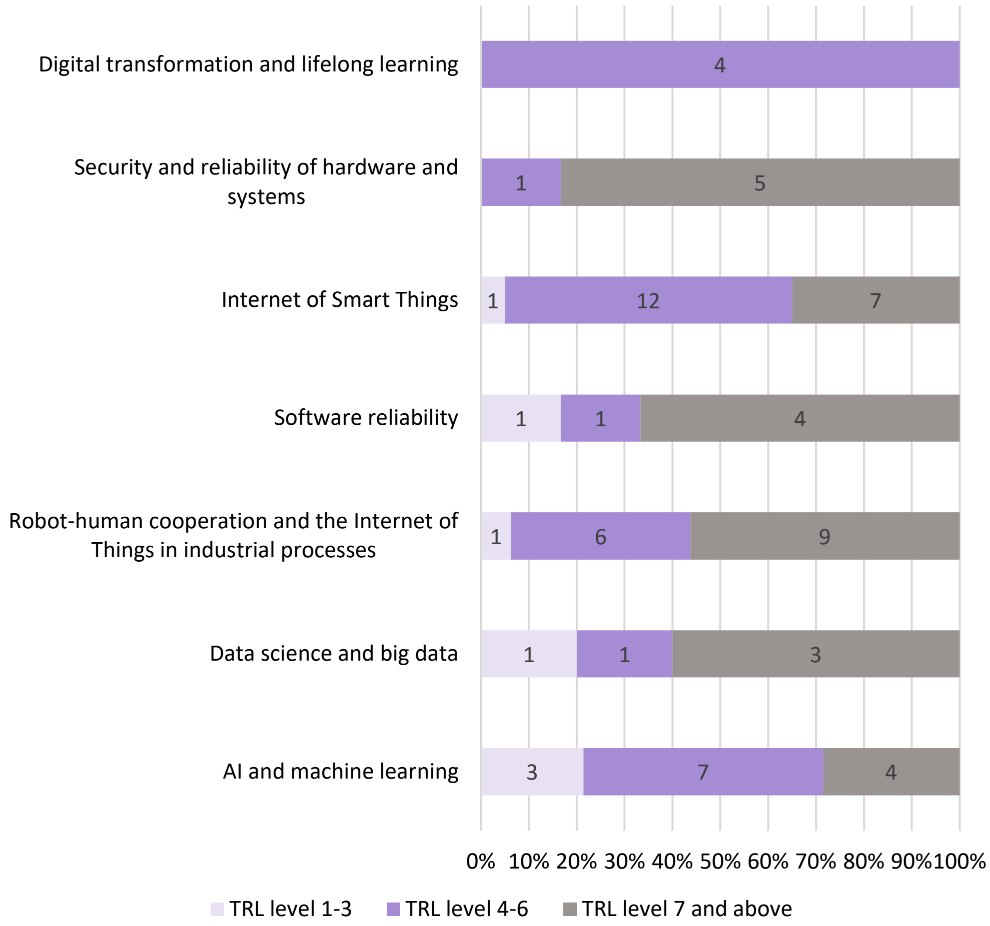


Figure 3.3. External impact of framework programme H2020 projects according to TRL level in seven priority areas of the IT Academy ICT research measure
Sources: eCORDA[92] and Funding and tender opportunities database[93], European Commission.
* Project can be in more than one priority field.

Based on the performance indicators of the IT Academy research support measure, the implementation of the programme's objectives is monitored, and the desired impact of the measure is evaluated. Three indicators are used in the evaluation of the results of the IT Academy research support measure, which are presented in Figures 3.4a–3.4c. Since Tallinn University joined the programme later, no indicators are collected based on Tallinn University data, and therefore, the figures include the University of Tartu and Tallinn University of Technology only.

The first indicator was the number of theses defended under the supervision of added researchers who were hired with the means of the measure (all study levels). It aims to evaluate firstly the addition of new researchers who were hired additionally with the financing of the measure to universities and, secondly, their impact on higher education. The goal of this indicator for 2023 is to receive the cumulative number of 200. However, even though the 2023 numbers are provisional, it is highly likely it will be achieved: the total number will be 280 theses. University of Tartu is contributing with 180 and Tallinn University of Technology with 100 theses. The indicator increases year by year, as it is a reference indicator – in some cases, it may take several years from supervision to the defence of the final thesis.

[92] External Common Research Datawarehouse (eCORDA). https://webgate.ec.europa.eu (31.03.2023).
[93] European Commission. Funding and tenders opportunities database. https://ec.europa.eu/info/funding-tenders/opportunities/portal/ (31.03.2023).

The second indicator – number of new researchers hired with the means of the measure [94] – is directly related to the IT Academy goal of increasing the universities' ICT research and development capability in the priority research areas. The programme's initial goal was to cumulatively increase the number of researchers by 45 by 2023. However, the goal has been achieved threefold – 151 new researchers have been employed, including 79 by the University of Tartu and 72 by Tallinn University of Technology. The largest numbers of new researchers were joined in 2020 and 2021. In March 2023, a total of 104 researchers were still employed at the University of Tartu and Tallinn University of Technology combined, both universities 52 researchers each.

The third indicator – number of publications by new researchers – aims at evaluating the contribution and productivity of the added researchers directly through their volume of research work. The goal of this indicator, 100 publications, has been exceeded by approximately five times. During the four years under observation, the added researchers published a total of 467 publications, with the articles divided between Tallinn University of Technology and the University of Tartu with 269 and 198 publications respectively.

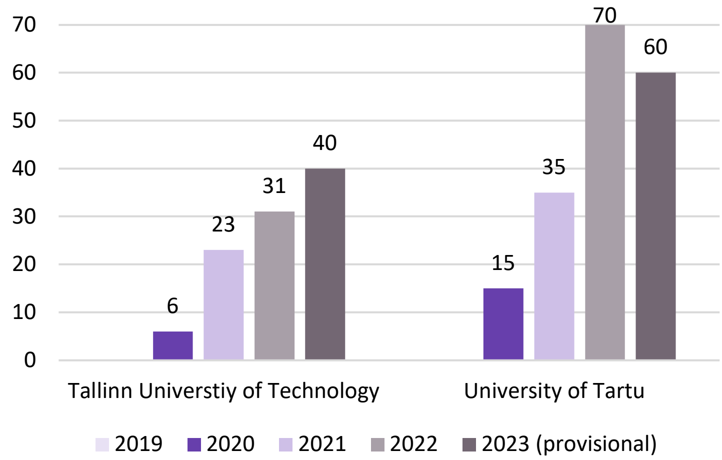


Figure 3.4a. Number of theses defended under the supervision of added researchers (all study levels) in 2019–2023 (performance indicator of IT Academy programme).
Source: IT Academy.

[94] Under the current conditions for granting the IT Academy support, researchers who have not worked at the University of Tartu or Tallinn University of Technology in a research position for at least one year prior applying for the funding, qualify. Researchers whose employment contracts with University of Tartu or Tallinn University of Technology were not signed earlier than September 1, 2018, or whose suspended employment contracts with the univeristies ended no earlier than September 1, 2018, are included in the calculation of the activity. Education and Youth Board. Conditions for granting the IT Academy support. https://harno.ee/sites/default/files/documents/2023-05/TAT%20ITA%20teaduse%20toetusmeetme%20rakendamine%202019-2023.pdf (02.06.2023).

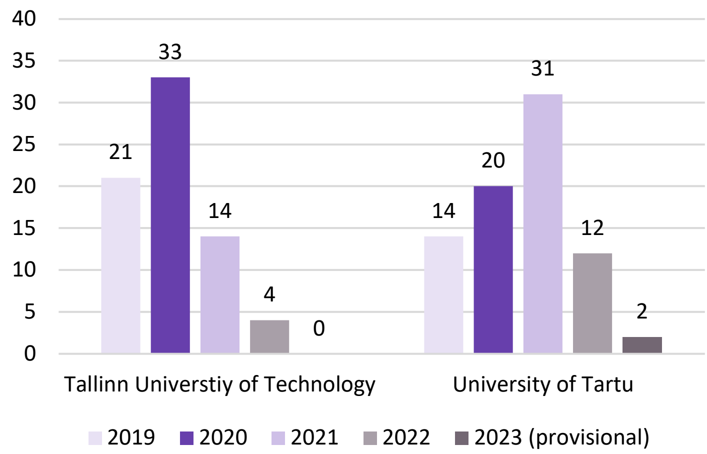


Figure 3.4b. Number of new researchers hired with the means of the measure in 2019–2023 (performance indicator of IT Academy programme).
Source: IT Academy.

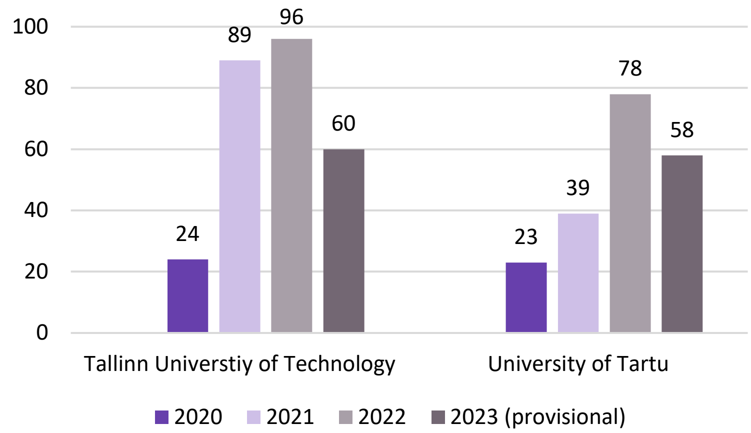


Figure 3.4c. Number of publications by new researchers in 2019–2023 (performance indicator of IT Academy programme).
Source: IT Academy.

Conclusions

This overview is part of the targeted evaluation of IT Academy programme ICT science support measure based on the Minister's Directive No. 1.1-2/22/348 and aims to provide a broader overview of research and development in the field of ICT in Estonia as a whole. It serves as input for the external evaluation of the IT Academy programme science support measure.

This overview concluded that:

- The ICT sector and its importance for Estonia has been increasing considerably. The ICT sector has had a significant impact on Estonia's economic growth over the last decade.
- The number of ICT companies has grown from 4,788 in 2017 to 9,027 in 2021.
- The ICT sector hired 5.4% of all Estonian workers, meaning around 35,000 people in 2021. The number of people hired in ICT sector has grown steadily over the years and the main

contribution in the growth comes from programming and consultation activities, which hired around 21,600 people in 2021.

- According to the forecast by the Estonian Qualifications Authority, it is necessary to increase the number of ICT specialists by at least 1.5 times by 2027. This means 47,600 ICT specialists working across the entire economy by 2027. As in 2020 there were 30 900 ICT specialists hired in ICT companies and other fields of economy it means an annual growth of approximately 2,600 new employees per year between the years 2020-2027.
- ICT companies paid 12% of all personnel costs of the business sector, meaning that ICT companies could pay relatively higher salaries compared to other sectors.
- The ICT sector's contribution to Estonian exports has grown substantially and accounted for almost 16% of total Estonian exports in 2022.
- Significant changes in the development of the ICT sector have taken place in all countries and the in the 27 countries of the European Union. Value added relative to GDP has grown from 4% in 2015 to 5.2% in 2020. For Estonia, it was 6% and, with that, Estonia was similar to Finland, Sweden, Luxembourg and Hungary.
- Estonia has been an attractive country for foreign venture capital investments, and a large proportion of these investments have been directed towards companies in the IT sector.
- People with higher education in ICT are required in most fields of activity. According to the taxes paid in 2021, around 54% of them (3,267 people) were occupied in the Information and Communication sector and around 46% in other fields of activity. ICT graduates' average salaries exceed the averages in most sectors of activity.
- The Estonian business sector R&D is heavily concentrated. There were 370 enterprises in 2021 reporting R&D expenditures and 75% of business R&D expenditures were set by 39 enterprises.
- The number of ICT companies reporting R&D expenditures was 53 in 2020 and 67 in 2021. However, these 67 ICT companies had R&D expenditures in the amount of 151.4 million euros, which is approximately half of the total Estonian business sector R&D expenditures in 2021 (307.7 million euros).
- Information and Communication sector companies employed 36% of the R&D personnel working in the business sector in 2021.
- The share of R&D personnel with a doctoral degree in the Information and Communication sector was 2.5% (2021) whereas the average in other sectors' was 9.6%.
- In the period of 2012–2022 there were 1,100 research projects in the Estonian Research Information System that were classified as ICT projects according to the methodology used for this overview (see Methodology).
- In 2018–2022 the highest number of ongoing ICT research projects belonged to the University of Tartu (256 projects) and Tallinn University of Technology (226 projects); in monetary terms, the two largest universities received an almost equal amount of project money (48.4 and 47.1 million euros). Tallinn University had 81 projects (4.4 million euros).
- In 2022, 53% of Estonian ICT research projects' funding came from domestic public sources, 34% from foreign public sources, 12% from the private sector and 1% from foreign private sources.
- The total amount invested in ICT research infrastructure during 2007–2023 is 25.6 million euros from which 97.6% was financed by the European Structural Funds. More than half of the infrastructure investments (55.9%, 14.3 million euros) were spent on a single object – the construction of the Delta building.
- The number of PIs or senior research staff in ICT projects has risen from 422 to 498. The proportion of these people contributing to IT Academy research areas has risen from 52% to

68%. The average percentage of doctoral degree holders among ICT projects PI-s or senior research staff was 66.1% in 2018 and 64.9% in 2022. The proportion of doctoral degree holders within PIs and senior research staff in IT Academy priority areas has decreased from 75.0% in 2018 to 70.3% in 2022. The decline in the proportion of doctoral degree holders might be explained by the IT Academy goal to develop the competence of junior researchers and provide a pathway to obtain doctoral degree, since there was an observable increase in the number of junior researchers without a doctoral degree and doctoral students amongst PI-s or senior research staff between 2018 to 2022.

- Over the past ten academic years (2012/13–2021/2022) 191 students have completed doctoral studies in the field of ICT, 117 graduates were Estonians (61%). The total number of students admitted in PhD studies in ICT has grown until 2021/2022, but the number of Estonian students admitted has not shown considerable growth. From the academic year 2017/18 the proportion of foreign students admitted in PhD studies in ICT has been higher compared to Estonians.
- Throughout the past ten years, the patenting activity in ICT has been fluctuating. There are a few Estonian companies or their branches that clearly stand out with the number of patents and applications.
- IT Academy priority areas have undergone a significant development. Comparing the five-year period before IT Academy programme (2013–2017) and the programming period (2018–2022) funding volumes and numbers of projects belonging to IT Academy priority areas, a manyfold growth and a faster rate compared to the funding of all fields can be observed.
- The robot-human collaboration and Internet of Things in Industrial Processes is a field that has received the most funding among IT Academy priority areas and where the number of ongoing projects between 2018 and 2022 (119 projects) was the highest. Additionally, many projects (113) connected to artificial intelligence and machine learning (many of them about language technology) and the field of Internet of Smart Things received considerable funding.
- During the period of 2018–2022, of the 656 ongoing projects 34% were associated with national priorities with a cost of 76.6 million euros (46% of total funding). Analysing the dynamics of the number of projects and funding, it can be said that more investments have been than the average and more projects have been initiated in national priority areas.
- From the period of 2018–2022, out of all ongoing ICT projects 32.9% (50.4% of funding) were connected to global technology trends.
- The target levels of performance indicators of the IT Academy have been attained with a significant surplus. The IT Academy programme has contributed to the addition of new researchers to Estonian universities and with that, there is an impact on higher education. Over the years, 151 new researchers hired with the means of the measure have been added to the universities participating the IT Academy programme, which is considerably more than originally planned (45). By March 2023, a total of 104 researchers were still employed at the University of Tartu and Tallinn University of Technology combined, both universities 52 researchers each. The number of publications by added researchers has been substantially higher than originally planned (467 instead of planned 100) and under their supervision 100 students' theses have been successfully completed.

Appendixes

Appendix 1. Information and Communication Technology (ICT) sector according to the EMTAK (2008).

		EMTAK code	Economic activity
ICT	ICT Industrial production	26.1	Manufacture of electronic components and boards
		26.2	Manufacture of computers and peripheral equipment
		26.3	Manufacture of communication equipment
		26.4	Manufacture of consumer electronics
		26.8	Manufacture of magnetic and optical media
	ICT services	95.1	Repair of computers and personal and household goods
		46.5	Wholesale of information and communication equipment
		58.2	Software publishing
		61	Telecommunications
		62	Computer programming, consultancy and related activities
		63.1	Data processing, hosting and related activities; web portals

Appendix 2. Information and Communication sector according to EMTAK (2008).

	EMTAK code	Economic activity
Information and Communication	58	Publishing activities
	59	Motion picture, video and television programme production, sound recording and music publishing activities
	60	Programming and broadcasting activities
	61	Telecommunications
	62	Computer programming, consultancy and related activities
	63	Information service activities

Appendix 3. Steering Committee of targeted evaluation of IT Academy programme ICT science support measure based on the Minister's Directive No. 1.1-2/22/348.

Name	A representative role
Jürgo-Sören Preden	Thinnect OÜ, Head of Steering Committee
Ott Velsberg	Ministry of Economic Affairs and Communications, Department of e-State Development, Head of Data Division.
Kaupo Reede	Enterprise Estonia, Development Manager for Applied Research
Katrin Pihor	Ministry of Education and Research, Director of Research and Development Policy Department.
Margus Haidak	Ministry of Education and Research, Director of Higher and Vocational Education Policy and Lifelong Learning Department
Heli Mattisen	Estonian Quality Agency for Education, Director
Katrin Kiisler	Government Office, Strategy Unit, Adviser

Dan Bogdanov	Cybernetica AS, Director of the Institute of Cyber Security (representative of ICT researchers who do not work in the target monitored institution)
Ivo Lasn	Representative of the IT Academy Steering Committee, Playtech Estonia, Director
Marek Rei	Representative of an ICT company that is not a member of the Estonian Association of Information Technology and Telecommunications (ITL), Perception labs OÜ, Imperial College London, lecturer
Jüri Jõema	Representative of the Estonian Association of Information Technology and Telecommunications (ITL).

Appendix 4. Budget of IT Academy programme ICT science support measure and yearly payouts to universities.

		University of Tartu	Tallinn University of Technology	Tallinn University	Total budget for universities	Education and Youth board (programme administration)	TOTAL BUDGET
Total budget for 2018-2022	State budget	1 336 500	1 573 500	1 200 000	4 110 000	30 000	4 140 000
	EU Structural Funds	5 255 100	6 422 900	0	11 678 000	322 000	12 000 000
	Total budget	6 591 600	7 996 400	1 200 000	15 788 000	352 000	16 140 000
Yearly payouts (euros)	2018	96 870	59 280	0	156 151	30 000	186 151
	2019	589 076	545 823	37 162	1 172 061	41 343	1 213 404
	2020	1 136 451	1 501 179	353 160	2 990 790	46 558	3 037 348
	2021	2 045 169	2 762 147	397 054	5 204 370	54 630	5 259 000
	2022	1 817 838	2 660 839	381 033	4 859 709	46 398	4 906 108
	Total payouts 2018-2022 (euros)	5 685 404	7 529 269	1 168 408	14 383 080	218 930	14 602 010
	Budget used by 31.12.2022	86%	94%	97%	91%	62%	90%

Source: Education and Youth Board (HITSA), IT Academy programme