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Value Through Knowledge

LATVIAN SMART SPECIALISATION STRATEGY (RIS3)
SPECIALISATION AREAS

Information and communication technology

RESEARCH ECOSYSTEM REPORT
(2014–2018)

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Ministry of
Education and
Science

THE NATIONAL
DEVELOPMENT
PLAN 2014-2020

EUROPEAN UNION
European Regional
Development Fund

INVESTMENT IN YOUR FUTURE

Abbreviations

HEI – Higher Education Institutions

BMC – Latvian Biomedical Research and Study Centre

CORDIS – Community Research and Development Information Service

CSB – Central Statistical Bureau

DU – Daugavpils University

IECS – Institute of Electronics and Computer Science

EU – European Union

EUROSTAT – European Statistical Office

HPC – High Performance Computing

ICT – Information and Communication Technologies

AI – Artificial Intelligence

ULiep – University of Liepāja

LMA – Latvian Maritime Academy

LULST – Latvia University of Life Sciences and Technologies

UL – University of Latvia

ISSP UL – Institute of Solid State Physics, University of Latvia

LU LFMI – Institute of Literature, Folklore and Art, University of Latvia

UL MII – Institute of Mathematics and Computer Science, University of Latvia

LSIWC – Latvian State Institute of Wood Chemistry

NACE – *Code in the Statistical Classification of Economic Activities in the European Community*

NRIS – National Research Information System

OECD – *The Organisation for Economic Co-operation and Development*

R&D – Research and Development

R&I – Research and Innovation

RIS3 – Smart Specialisation Strategy

RTA – Rezekne Academy of Technologies

RTU – Riga Technical University

STEM – Science, Technology, Engineering and Mathematics

TRL – Technological Readiness Level

TTI – Transport and Telecommunication Institute

VUC – Ventspils University College

ViA – Vidzeme University of Applied Sciences

WoS – *Web of Science*

RI – Research Institutions

STDIG – Guidelines for Science, Technology Development, and Innovation

Content

Summary

The objective of research and innovation in the area of the RIS3 specialisation "Information and Communication Technologies" is to promote the creation of higher value-added products and services aimed at the increase of Latvia's global competitiveness, to promote the growth of high and medium-tech products and services in Latvia's export structure, and to promote the digital transformation of Latvia.

The projects implemented during the period of 2014–2018 in the area of the RIS3 specialisation "Information and Communication Technologies" were worth EUR 32.9 million or 17% of the total research and innovation funding attracted for RIS3 specialisation areas. Areas, where research and innovation projects were implemented, include computational linguistics, machine translation, algorithms, quantum algorithms and computing, machine learning, educational technologies and digitalization, business process management systems, electronics - screens, semiconductors and micro-chips, smart road transport, 3D printers, audio and precision equipment, smart sensors and the Internet of Things, robotics, computer vision, big data, smart cities and bioinformatics, data storage, transmission and systems, including cloud platforms, space technology and remote sensing, public security and cybersecurity.

In the future of RIS3 implementation process, it is important to create a system of support, cooperation and coordination in the specialisation area of "Information and Communication Technologies", which promotes the development of ICT research areas that conform to global trends, European Union digital strategy objectives and have already established research and innovation capacities in Latvia.

Introduction

Latvia's *Research and Innovation* Strategy *for Smart Specialisation (RIS3)* is a national-level research and innovation strategy for economic transformation that seeks to identify ongoing competitive advantages, to select strategic priorities, and to design policy tools that maximise the country's knowledge-based socioeconomic development potential. The smart development strategy is aimed at promoting the creation of higher value-added products and services aimed at the increase of Latvia's global competitiveness and one of its objectives is to promote the growth of high and medium-tech products and services in Latvia's export structure. Taking into account the prospective directions of economic transformation and priorities of economic development, 5 smart specialisation areas, as well as Social Sciences and Humanities have been defined in Latvia as an area with a horizontal impact for the achievement of the RIS3 objectives.

One of the smart specialisation areas is "Information and Communication Technologies" (hereinafter – ICT Area), which plays an important role in promoting the transformation of the national economy in order to advance the growth of high- and medium-high technologies in the Latvian export of goods and services. The analytical review of the research ecosystem of the area provides insight into the niches of the sector, where the R&D capacity has already been developed, as well as those, where this capacity could develop in the future, and into the human capital available in the R&D environment, as well as scientific excellence.

Since 2014, Latvia has been on the EU RIS3 platform[1], to develop expertise in the implementation of RIS3 and to develop research and innovation cooperation with other regions of the EU. In 2015, the first analytical description of the "Information and Communication Technologies" ecosystem was created[2]. A RIS3 monitoring system has been introduced since 2016 to assess the progress of RIS3 implementation and the effectiveness of the funding invested. The objective of RIS3 monitoring is to evaluate the progress of economic transformation within a specific period of time in accordance with the defined indicators of achievable goals and results.

The review of the research ecosystem of the RIS3 specialisation area "Information and communication technologies" has been developed with the aim of providing an in-depth insight into the dynamics of research capacity and competence development over the period of time from 2014 to 2018, as well as in comparison with the international environment. The results and conclusions of the data analysis performed within the framework of RIS3 monitoring, as well as current data of research projects and research results – publications, as well as students and scientific personnel were used for the preparation of the report. Data sources used in the preparation of the review:

- National Research Information System;
- Scientific publications database *Web of Science* and *InCites* analytical network;
- Data of the Central Statistical Bureau;
- Data of the Statistical Office of the European Union *Eurostat*;

- Cohesion Policy Fund Management Information Systems for 2014–2020 *CP FMS*;
- Latvian Council of Science data on the Basic and Applied Research Programme and National Research Programmes;
- European Commission *CORDIS* database on "Horizon 2020" projects.

1 International and national context of the development of the RIS3 specialisation area "Information and Communication Technologies"

The Digital Agenda of the European Commission is one of the seven priorities of the Europe 2020 strategy and aims at the development of a single digital market[3] to promote smart, sustainable and socially inclusive growth in Europe. Information and communication technologies are an important driver of growth, both as a sector, and as a catalyst of growth and digital transformation of other sectors, as well as the driver of modernisation in the public sector.

However, investing in ICT alone is not enough to implement digital growth strategies. Investment must go hand in hand with the development of capacities and skills, simplification of existing processes, provision of appropriate infrastructure, support to start-ups and the digitalisation of existing industry sectors[4].

In many regions and Member States of the European Union, smart areas of specialisation are directly or indirectly linked to ICT. It is a wide range of topics from data processing and management, cybersecurity, visualisations, sensors, data protection and privacy, cloud computing, open data, e-government, geographic information systems to future internet applications, industry 4.0, robotics and 3D printing research[5].

In accordance with the Latvian Guidelines for Science, Technology Development and Innovation for 2014–2020, RIS3 provides for the constant finding of competitive advantages, selection of strategic priorities and such policy instruments that maximally unleash the knowledge-based development potential of the country and, thus, ensure economic growth. Considering the objectives of RIS3, RIS3 public investment programmes are aimed at strengthening the innovation capacity of the Latvian economy and reducing barriers to innovation.

The RIS3 strategy aims at channelling the R&D resources into those areas of knowledge that have the R&D capacity, or those with the highest potential. The RIS3 strategy is a mutually coordinated part of the national economic development plan represented in the national planning documents *Guidelines for Science, Technology Development, and Innovation 2014–2020* and *National Industrial Policy Guidelines for 2014–2020* and ensures that a common objective is achieved, namely, the transformation of the economy into the creation of products and services with higher added value and greater competitiveness in the global market.

The area of smart specialisation includes all representatives of industry, science and education, who create knowledge within the field of smart specialisation, for whom this knowledge is crucial for their profitability, as well as those who provide education based on this knowledge. The ecosystem of smart specialisation includes the players in the

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[3] https://ec.europa.eu/digital-single-market/en/news/digital-single-market-strategy-europe-com2015-192-final
[4] https://s3platform.jrc.ec.europa.eu/digital-growth
[5] https://s3platform.jrc.ec.europa.eu/digital-agenda-and-ict

area and their interrelationships, as well as transactions between them.

Information and communication technologies are an area of smart specialisation with a direct horizontal contribution to the development of other areas of smart specialisation and its role in the economy of Latvia has rapidly growing added value. The area of ICT has a horizontal development impact on other areas of smart specialisation of Latvia – bio-economy, biomedicine, smart energy and also social sciences and humanities. In turn, the results of research in the RIS3 area of smart materials and technologies can stimulate the development of ICT research and innovation or the creation of new equipment.

The development of research and innovation in the EU priority themes and on the EU scale is being implemented in the relevant thematic directions of the *Horizon 2020* programme, which will be continued in 2021–2027 within the framework of *the Horizon Europe* programme. In order to promote the integration of Latvian R&D into the European Research Area and greater added value from international co-operation in research and innovation, especially within the framework of *Horizon Europe* programme, Latvia's R&D development instruments should be developed in thematic synergy with the priorities and principles of *Horizon Europe*.

2 Scope of information and communication technologies sector, stages of the value chain, research and development opportunities

2.1. Scope of ICT in the economy

In the smart specialisation strategy, the field of ICT has a horizontal impact on almost all sectors of the economy and areas of smart specialisation, but the development of the ICT sector itself and the readiness to create solutions for other sectors plays a crucial role in the development of the entire economy of Latvia. The share of the added value of the ICT sector in the gross domestic product of Latvia in 2018 was 4.3% (at current prices, % of the total value added), and, since 2013, the contribution of the ICT sector to Latvia's GDP has increased by 13%.

Export indicators of the ICT sector in the period from 2014 to 2018 have been good. Export of ICT goods directly contributes to the increase in products of high and medium-high technology industries within the export structure of Latvia. The increase in the volume of export of ICT goods in 2018 amounted to 40% compared to 2013, with the telecommunications equipment being the largest group of exported goods, amounting to 62% of all export of ICT goods in 2018. Export of ICT services has demonstrated even better performance, as the growth of the export of computer services and information services from 2013 has reached 164% in 2018[6].

In 2018, a total of 6,894 companies operate in the ICT sector of Latvia, of which 111 operate in the ICT manufacturing sector and 6,239 are engaged in the provision of ICT services and most of them – 4,067 in the provision of programming services. In general, since the end of 2013, the number of ICT companies has increased by 36%, the number of ICT manufacturing companies has increased by 12%, the number of ICT service providers has increased by 40%, including the increase in the number of programming service providing companies – by 52%.

Similar trends are reflected in the employment area of the sector. In 2018, 36,956 employees worked in the sector, with 1,631 employees employed by the ICT manufacturing sector and 32,529 by the ICT sector that provides ICT services, of which 17,312, or more than half, were employed by companies that provided programming services. The number of employees in the ICT sector has increased by 59% since late 2013 compared to the end of 2018, the number of employees in the ICT manufacturing sector has increased by 51%, in the provision of ICT services – by 64%, including an increase in the number of employees in programming services companies by 78%.

The total productivity in the ICT sector has also increased by 63% in 2018 compared to the late 2013, in the ICT manufacturing sector by 119% and in the ICT services sector by 66%, including an increase of 110% among programming service providers. Comparing productivity per employee, the growth indicators are as follows – the total productivity growth of

[6] Bank of Latvia statistics, Balance of Payments statistics C11350

the ICT sector per employee in 2018/2013 is 3%, in ICT manufacturing – 46%, in the provision of ICT services – 1%, including the provision of programming services, where productivity per employee has increased by 18%.

2.2. Stages of ICT value chain

The ICT value chain can be divided into 3 major stages: hardware, software and data. Hardware is everything from components, semiconductors, chips to sensors, robots, drones and smart cars. In turn, the software can already be integrated in specific devices or used standalone; it can be an integration platform or a machine learning algorithm. And finally, data as a component ensures the transfer of information to the user of ICT systems – a person or a device. And, as the hardware and software capacity increases, it is possible to process ever-increasing amounts of data, opening up ever-increasing research and innovation opportunities in areas such as big data, data storage and processing systems, remote sensing and data security.

In each of the stages, a detailed value chain can be revealed and the specific application can be analysed in cross-section. A partnership ESCEL – Electronic Components and Systems for European Leadership, in the Strategic Plan for 2020[7] offers such a value chain of the electronics industry (**see Figure 2.2.1.**).

Figure 2.2.1. Electronics value chain (Source: ESCEL)

[7] https://www.ecsel.eu/publications

Latvian smart specialisation strategy (RIS3) specialisation areas
"Information and communication technology" research ecosystem report (2014–2018)

In order to assess Latvia's opportunities to join global value chains, as well as to assess the potential of each stage, the waterfall method can be used to predict what part of the global and European market the Latvian ICT sector could occupy in the future (**see Figure 2.2.2.**).
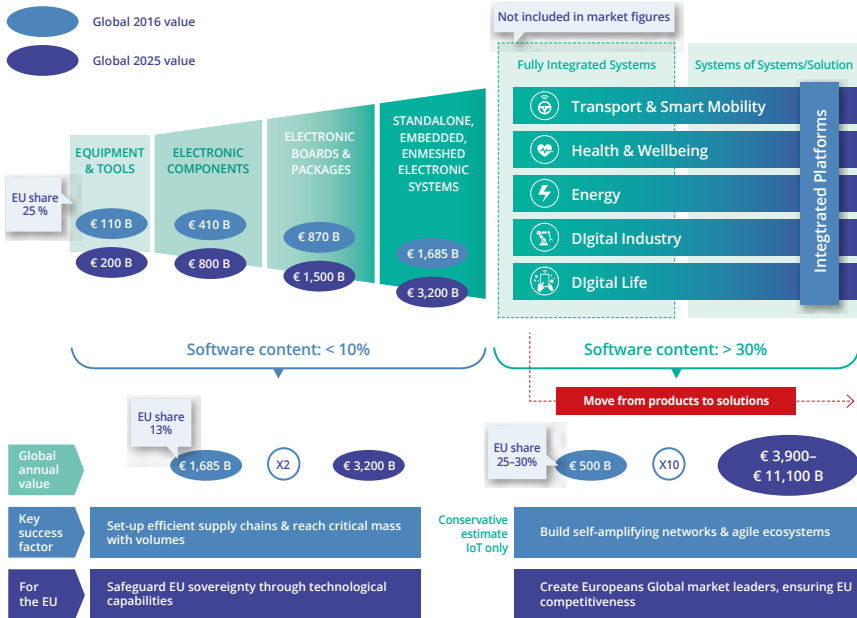

Figure 2.2.2. Global and European value chain of electronics sector 2016–25 (Source: ESCEL[8])

2.3. ICT research and development opportunities

The first industrial revolution took place at the time of the creation of the steam engine and the commencement of the mechanisation of production, a number of important discoveries in the sectors of transport, telecommunications, manufacturing occurred during the second industrial revolution, the use of electricity and mass production began. The third industrial revolution introduced the internet and other digital technology innovations. Society is currently moving through the fourth Industrial revolution; a time, when scientific and technological advances are changing industries, merging geographical boundaries and challenging the existing regulations. New technologies such as artificial intelligence, robotics, drones, precision medicine, nanotechnology, quantum computing, biotechnology, the Internet of Things and blockchains are cited as drivers of the fourth industrial revolution[9].

Artificial intelligence technologies are one of the priorities of Latvian technology development, which is currently described in the informative report *On the development of artificial intelligence*

[8] https://www.ecsel.eu/sites/default/files/2020-02/ECS%20SRA%202020%20%281%29.pdf
[9] https://www.weforum.org/centre/the-fourth-industrial-revolution/

solutions developed by the Ministry of Environmental Protection and Regional Development (MEPRD) and approved by the Cabinet of Ministers on 4 February 2020, which emphasises that, given the resources of Latvia, it may become the leader in the area of specific AI solutions and the skills of AI use need to be acquired not only by ICT professionals, but also by a wider range of users and managers. In the period of 2014–2018, within the framework of ICT research and innovation projects, various technologies of AI were developed, including machine learning, neural networks, computer vision, voice recognition with total investment around ~5 mln EUR. Considering global trends and already developed R&D capacity in the AI sector, this technology should be developed in Latvia even more. The Internet of Things and precision medicine are areas where the Latvian R&D ecosystem has already developed certain capacity as well, and, potentially, they are areas, where the creation of export products and services is possible in the future.

Blockchain technologies are an area, where Latvia currently lacks research capacity; however, it is mentioned as one of the driving forces of the fourth industrial revolution. According to a study by the World Economic Forum, 64% of blockchain technology initiatives are funded from IT or research budgets, and the primary goal of these projects is to develop blockchain technologies themselves rather than the introduction thereof at organisations[10]. Currently, blockchain technology projects have failed to yield the planned return in the commercial sector; the World Economic Forum survey respondents estimate the return to be at up to 10%, thus it can be concluded that blockchain technology is a potential area for research. Furthermore, the development of blockchain technologies requires an ecosystem and energy-efficient solutions for their use must be found. The development of blockchain technologies can serve as a breakthrough, or even a new approach to the global digital transformation.

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[10] http://www3.weforum.org/docs/WEF_Building_Value_with_Blockchain.pdf

3 Research and innovation competencies of the ICT sector

3.1. ICT specialisation niches and funding attracted

The ICT technology niche includes R&D projects aimed at creating a set of new and cutting-edge knowledge, methods, techniques and technical equipment to ensure the acquisition, storage and dissemination of any information by means of equipment, computers and means of communication. These are new and modern tools used by specialists of all sectors.

To evaluate ICT research and innovation competences, the mapping of the areas of research and innovation developed in Latvia was performed relative to the financial instruments in 2014–2018. During this period, a research and innovation competence, as well as capacity in the RIS3 ICT specialisation area has been developed in the following research niches:

- **Computational linguistics**, including machine translation research,
- **algorithms**, including research on quantum algorithms and computing,
- **machine learning**,
- **educational technologies and digitalization of culture**,
- **business process management systems**,
- **electronics**, including research on screens, semiconductors and chips, smart vehicles, 3D printers, audio and precision equipment,
- **smart sensors and the Internet of Things,**
- **robotics**, including computer vision research,

- **big data**, including smart cities and bioinformatics research,
- **data storage, transmission and systems, including cloud platforms**,
- **space technologies and remote sensing**,
- **public security and cyber security**.

In total, funding of EUR 32.9 million has been attracted and invested in these research niches, or 17% of the total amount of research and innovation funding attracted in all areas of RIS3 specialisation. The largest funding has been attracted for thematic niches of research: *Electronics* – EUR 5.36 million or 16%, Computational *Linguistics* – EUR 4.76 million or 14% and *Smart sensors and the Internet of Things* – EUR 3.65 million or 11% of the total ICT R&D funding (**see Figure 3.1.1**).

As much as 33% or EUR 10.78 million of the total R&D funding attracted in the field of ICT came from the funding of the financial instrument of the Ministry of Economics *1.2.1.1. Support for the development of new products and technologies in competence centres*, the second largest source of funding from 2014 to 2018 was the Horizon 2020 framework programme, which attracted 23% of the total ICT funding or EUR 7.51 mln. The third largest source of funding has been the financial instrument of the Ministry of Education and Science *1.1.1.1 Practical Research Support* – 16% or EUR 5.24 million (**see Figure 3.1.2**).

- ● Computational linguistics
- ● Algorithms
- ● Machine learning
- ● Educational technology and digitization
- ● Business process management systems
- ● Electronics
- ● Smart sensors and the Internet of Things
- ● Robotics
- ● Big data
- ● Data storage, transmission and systems
- ● Space technologies and remote sensing
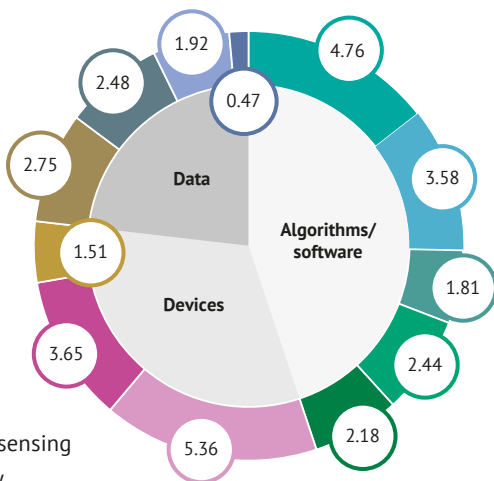- ● Public security and cybersecurity

Figure 3.1.1. Distribution of the amount of funding in the RIS3 ICT thematic niches during the period from 2014 to 2018, mln euro.

- ● BAR – Basic and applied research programme (national budget)
- ● 1.1.1.2. – Post-doctoral research support (EU)
- ● 1.1.1.1. – Practical research (EU)
- ● H2020 – Horizon 2020 framework programme (EU)
- ● 1.2.1.2. – Support for the upgrading of technology transfer system (EU)
- ● 1.2.1.1. – Support for new product and technology development within the framework of competence centres (EU)
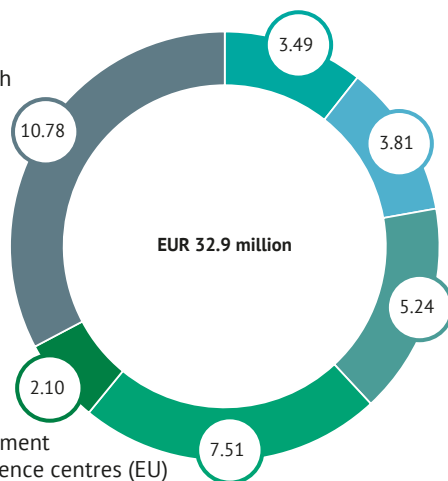
Figure 3.1.2. Distribution of RIS3 ICT funding by programme in the period from 2014 to 2018, mln euro.

Higher education institutions, research institutions and companies are equally actively involved in the implementation of R&D projects, however, the predominance of one of the sectors in the implementation of R&D projects is observed at the level of certain activities (**see Figure 3.1.3, Figure 3.1.4**). Two competence centres are operating in the area of ICT in Latvia – the IT competence centre and the Latvian electrical and optical equipment industry competence centre, which unite both businesses and research institutions.
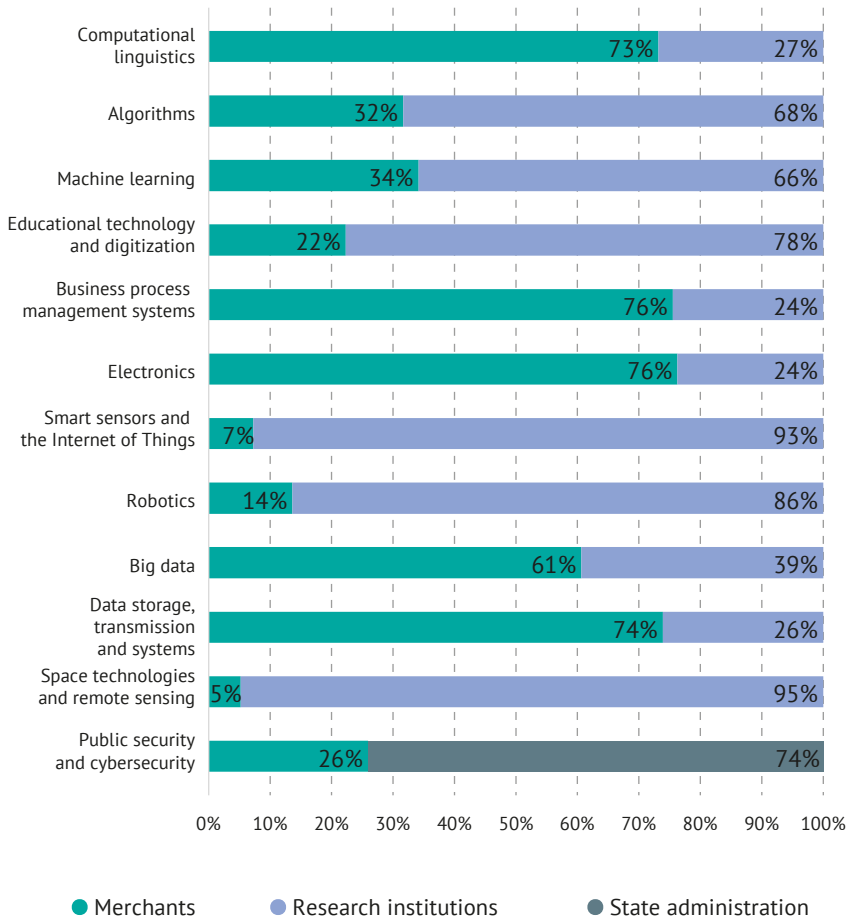

Figure 3.1.3. Percentage distribution of the financing of R&D projects implemented by research institutions, merchants and public administration in RIS3 ICT thematic niches during the period from 2014 to 2018.
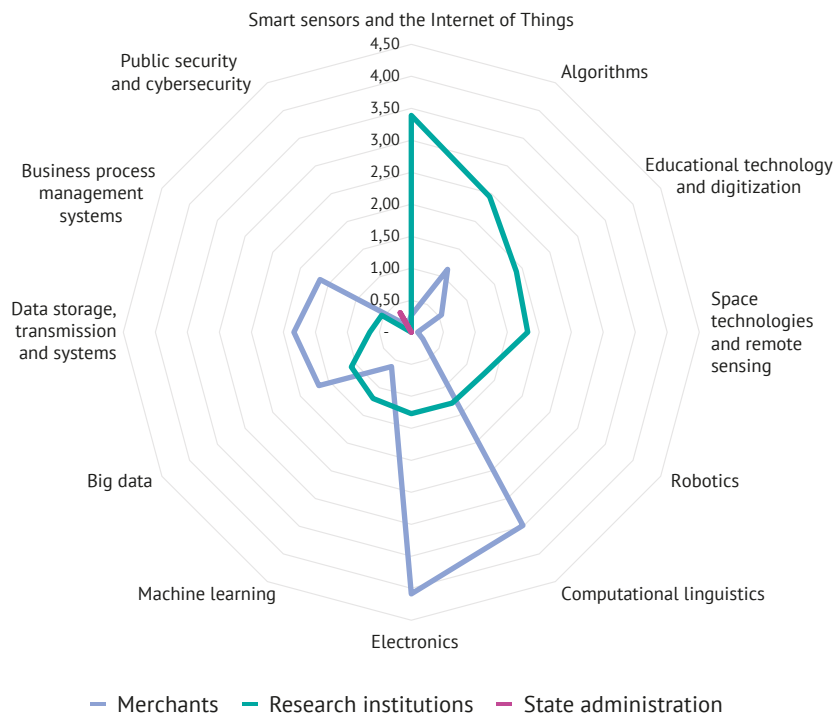
Figure 3.1.4. Amount of funding for R&D projects implemented by RI and merchants in millions of euros in the thematic niches of the RIS3 ICT area during the period from 2014 to 2018.

By grouping the research topics into blocks by the funding programme under which the project of the respective area is implemented, it is possible to get an idea of the technology readiness levels (TRL) of the conducted research (**see Figure 3.1.5**). It is typical for research institutions to implement research at lower technological readiness levels TRL1–TRL6, while companies work with research where the technological readiness level is higher and closer to the finished product or service TRL4-TRL8 (a detailed explanation of TRL levels can be found in the annex to the review). By developing research competencies at all levels of technological readiness,

an opportunity to reach higher levels of innovation and a potential competitive advantage in a certain area.

Research at all technological readiness levels is currently being carried out in *Computational Linguistics*, where a total of 13 projects have been implemented. High levels of competence and the competitiveness of solutions at a European and global level in the area of small languages have been achieved in this area. Research into voice recognition solutions is also taking place in this niche, which will enable other technological solutions to be used in the state language in the future, as well as to offer small language solutions to other countries.

Figure 3.1.5. Thematic niches of the RIS3 ICT sector broken down by funding programmes and mapping by funding share from 2014 to 2018.

Thematic niche	Total number of projects in the thematic niche	TRL 1-2 Basic and applied research programme (national budget)	TRL 1-2 1.1.1.2. Post-doctoral grants (EU)	TRL 2-3 1.1.1.1. Practical research (EU)	TRL 3-6 Horizon 2020	TRL 3-5 1.2.1.2. Commercialisation of Research results (EU)	TRL 4-6 1.2.1.1. Competence centres (EU)
		Proportion of funding (%) relative to the total funding of the thematic niche					
Computational linguistics	13	10%	3%	28%	29%	0%	30%
Algorithms	17	20%	22%	26%	0%	1%	32%
Machine learning	9	39%	15%	0%	1%	0%	46%
Educational technology and digitization	7	8%	16%	75%	0%	0%	0%
Business process management systems	6	0%	0%	0%	24%	0%	76%
Electronics	17	0%	0%	10%	20%	0%	70%
Smart sensors and the Internet of Things	20	8%	29%	0%	43%	20%	0%
Robotics	9	20%	18%	0%	36%	22%	4%
Big data	12	0%	15%	0%	61%	25%	0%
Data storage, transmission and systems	8	0%	16%	0%	10%	0%	74%
Space technologies and remote sensing	9	42%	3%	33%	5%	17%	0%
Public security and cybersecurity	6	0%	0%	0%	85%	0%	15%
Total number of projects by financial instrument	133	14	29	9	33	16	32

● Financial instruments of the Ministry of Education and Science

● European Union Research and Innovation Programme

● Financial instruments of the Ministry of Economics

The thematic niches, where the attraction of additional funding at all levels of TRL could yield the highest possible R&D results are: *Smart Sensors and the Internet of Things, Robotics, Big Data, Machine Learning, Data Storage, Transmission and Systems*, as research results in these areas can create synergies. These topics have a high horizontal impact in many areas of future technology, such as the transformation to industry 4.0, smart cities, precision medicine, etc. Furthermore, artificial intelligence technologies are used and developed in a considerable part of these research areas.

70% of all research in the thematic area *Electronics* and 76% of the research in the thematic area *Business Process Management Systems* are financed from the financial instrument of the Ministry of Economics *1.2.1.1. Support for the development of new products and technologies in competence centres*, where applied research dominates with a very low involvement of RI.

In general, there is a balanced interest of the public and private sector in the implementation of research with the involvement of R&D instruments of the Ministry of Education and Science and the Ministry of Economics; however, the domination of either only the public or private sector in the implementation of research within certain thematic niches is observed, which creates risks for the sustainability of the particular thematic niche or unused opportunities in the further commercialisation of research results.

3.2. Topics of ICT research and innovation at research institutions

More extensive development with the participation of more RI is performed in certain areas of research and innovation, other areas are only developed by a few RI, while the area of *Public Security and Cyber Security* is only implemented in research by public administration (**see Figure 3.2.1**).

Figure 3.2.1. ICT topics studied by Latvian research institutions in 2014–2018

Computational linguistics	UL MII
Algorithms	UL, UL MII, TTI, VUC
Machine learning	UL, ViA, UL MII, IECS, RTU
Educational technologies and digitisation	RTU, RTA, UL LFMI, LAC
Business process management systems	LULST
Electronics	IECS, UL
Smart sensors and the Internet of Things	IECS, RTU, LULST, UL, ISSP UL, ViA, VUC
Robotics	RTU, IECS
Big data	UL, TTI, RTU
Data storage, transmission and systems	RTU, UL MII
Space technologies and remote sensing	VUC, IECS, UL, RTU
Public security and cyber security	National government: STATE BORDER GUARD, STATE POLICE, DATA STATE INSPECTORATE

4 ICT research and development capacity

4.1. Human capital of research and its renewal

ICT researchers account for 22% of all research personnel of Latvia elected in the higher education sector. Analysis of scientists by the areas of science that they represent (**see Figure 4.1.1**) shows that the largest number of scientists work in the area of electrical engineering, electronics, information and communication technology sciences – 41%, 9% of all

ICT scientific personnel work in the area of computer science and informatics. In contrast, 12% of all ICT researchers work in two areas of science: electrical engineering, electronics and information technology, as well as computer science and informatics, and a large proportion or 31% of all ICT researchers are specialising in the area of physics and astronomy.

- Electrical engineering, electronics, information and communication technology sciences
- Physics and astronomy
- Electrical engineering, electronics, information and communication technology and computer science and informatics
- Computer science and informatics
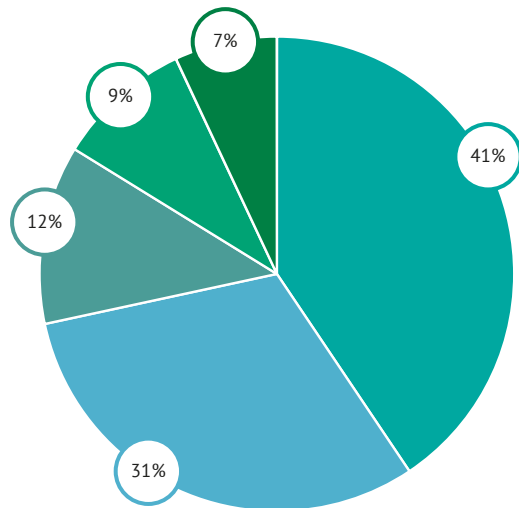- Mathematics and the natural sciences

Figure 4.1.1. Distribution of elected scientific personnel related to the ICT area in 2019 by the sector of science as a percentage of the total number. Source: National Research Information System (NRIS), 2019.

In the areas associated with the ICT sector, young leading researchers are working in the areas of electrical engineering, electronics, information and communication technologies, and computer science and informatics, which

shows that the generation exchange of researchers in these areas has occurred. Meanwhile in the basic sciences, such as physics and astronomy, mathematics and the natural sciences, a pronounced ageing of leading researchers is observed

and there is limited replacement of the generation of young researchers.

By dividing all ICT-related elected research personnel by age group (**see Figure 4.1.2**), a conclusion can be made that more than half or 57% of all elected researchers are in the middle age group or 25–44 years old, and a slow but gradual replacement of researcher generations is observed. Half of all researchers, including research assistants, are more than 40 years old, the highest number of researchers are 33 years old and the average researcher age is 46.
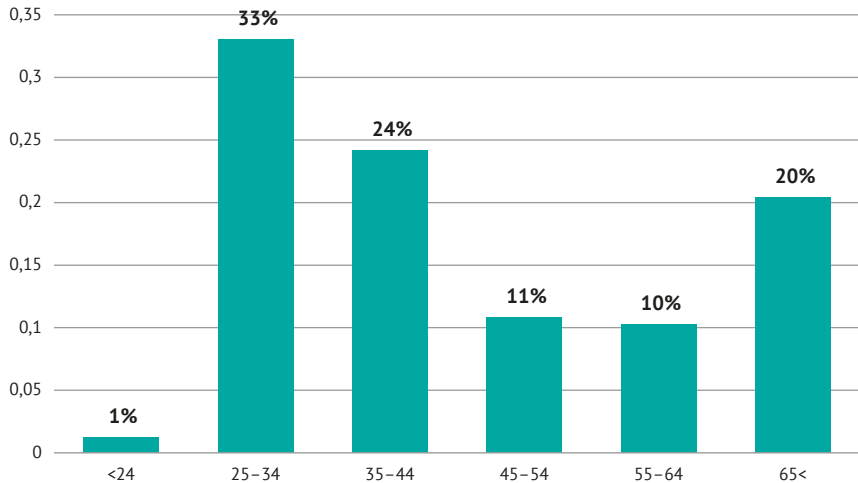

Figure 4.1.2. Distribution of elected scientific personnel related to the ICT area in 2019 by age group as a percentage of the total number. Source: National Research Information System (NRIS), 2019.

The number of male researchers exceeds the number of female researchers in all age groups; a total of 696 men and 248 women. Respectively, women make up 26% and men 74% of the total number of elected scientific personnel. The highest proportion of women among ICT researchers belong to the age group of 45–54 years old, with 36% of women researchers in this age group, while the largest number of men is in the age group of over 65–86% (**see Figure 4.1.3**).
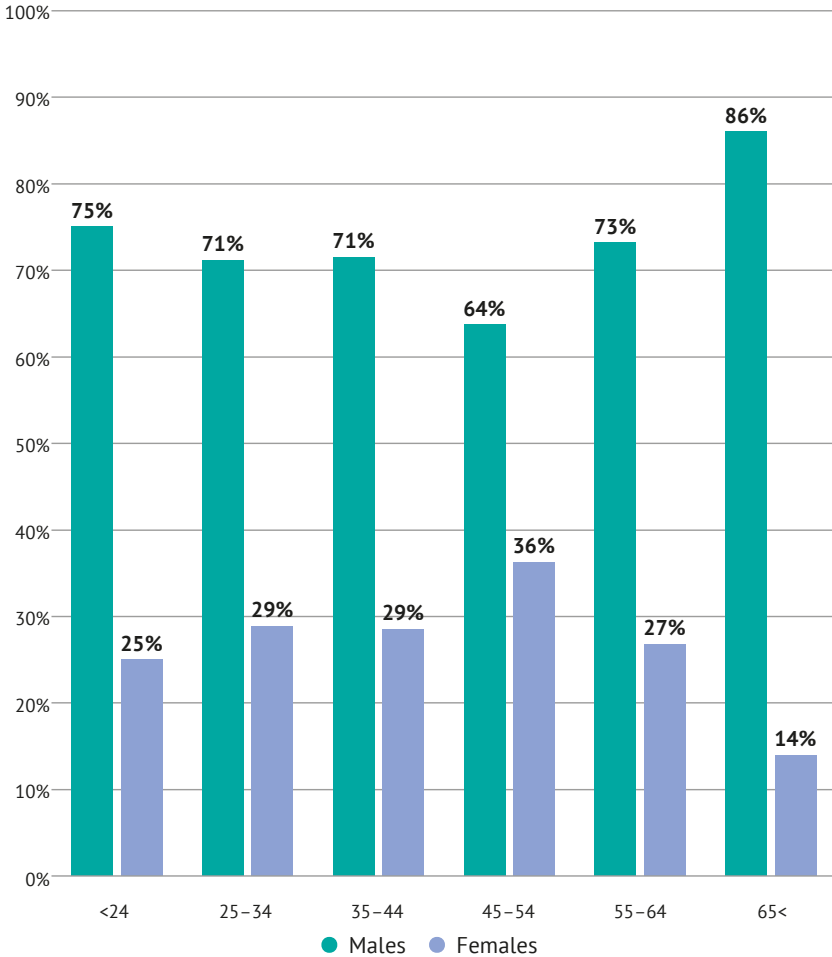
Figure 4.1.3. Distribution of elected scientific personnel related to the ICT area in 2019 by age group and gender as a percentage of the total number. Source: National Research Information System (NRIS), 2019.

4.2. Study curricula and graduates in the area of ICT

The number of research personnel is also directly related to the dynamic changes in the numbers of students and doctoral students. To ensure the generational renewal of scientists, doctoral and master's students, who study in study programmes related to the area of ICT, the offer of study programmes and the

number of students, who complete basic studies in the area of ICT, play an important role.

At the beginning of the 2018/2019 academic year, a total of 80,500 students studied in the higher education institutions of Latvia, of which 11% had chosen to study in the area of ICT. Of all doctoral students, 14% studied in the area of ICT, the percentage of master's students amounted to 8%, and 12% of undergraduate students were involved in undergraduate ICT studies.

The number of graduates in the ICT area is proportionally lower than the number of applicants interested in studies at HEI. This is due to the drop-out rate at all levels of education; the total number of ICT students that have graduated HEI in the time period from 2009 to 2019 amounted to 41% of the number of students, who have been enrolled at HEI (**see Figure 4.2.1**), and the highest drop-out rate was registered among students enrolled for basic studies, with only 35% of students graduating HEI. This is a serious challenge that needs to be addressed in order to stabilise the number of students, who obtain degrees or qualifications.
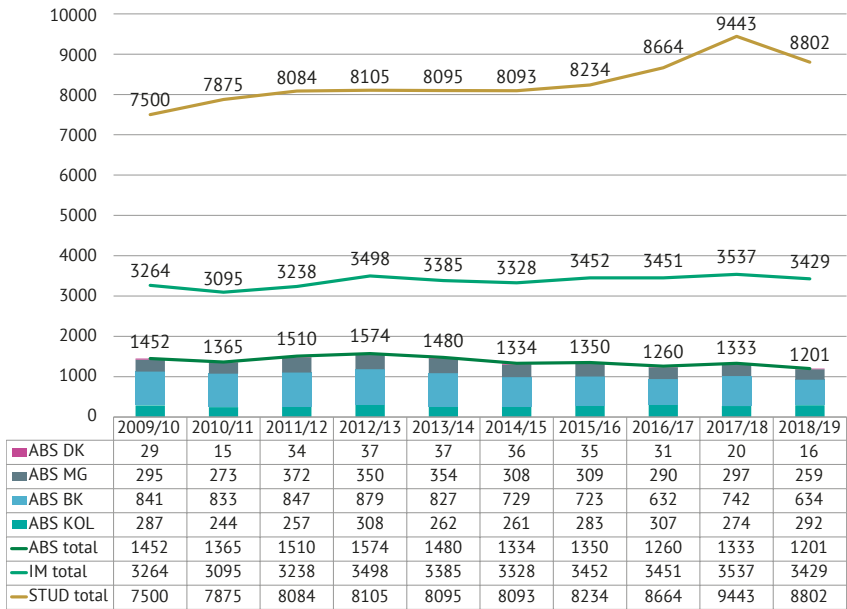

	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
ABS DK	29	15	34	37	37	36	35	31	20	16
ABS MG	295	273	372	350	354	308	309	290	297	259
ABS BK	841	833	847	879	827	729	723	632	742	634
ABS KOL	287	244	257	308	262	261	283	307	274	292
ABS total	1452	1365	1510	1574	1480	1334	1350	1260	1333	1201
IM total	3264	3095	3238	3498	3385	3328	3452	3451	3537	3429
STUD total	7500	7875	8084	8105	8095	8093	8234	8664	9443	8802

Figure 4.2.1. Number of enrolled, graduating and studying youths by academic year in the programmes related to the ICT area, including the first level professional bachelor's and college level study programmes, in the period from 2009 to 2019. [ABS DK – graduates of doctoral programmes, ABS MG – graduates of master's study programmes, ABS BK – graduates of undergraduate study programmes, ABS COL – graduates of college level study programmes, ABS total – graduates total, IM total – enrolled total, STUD total – studying total]. Source: CSB, Ministry of Education 2019.

The number of graduating doctors has been declining since the 2014/15 academic year, despite the fact that the offer of doctoral programmes is wide and available throughout Latvia. The number of enrolled students in doctoral study programmes has also decreased over the last two academic years (**see Figure 4.2.2**). In total, only 36% of enrolled students have completed doctoral studies during the last 10 years.
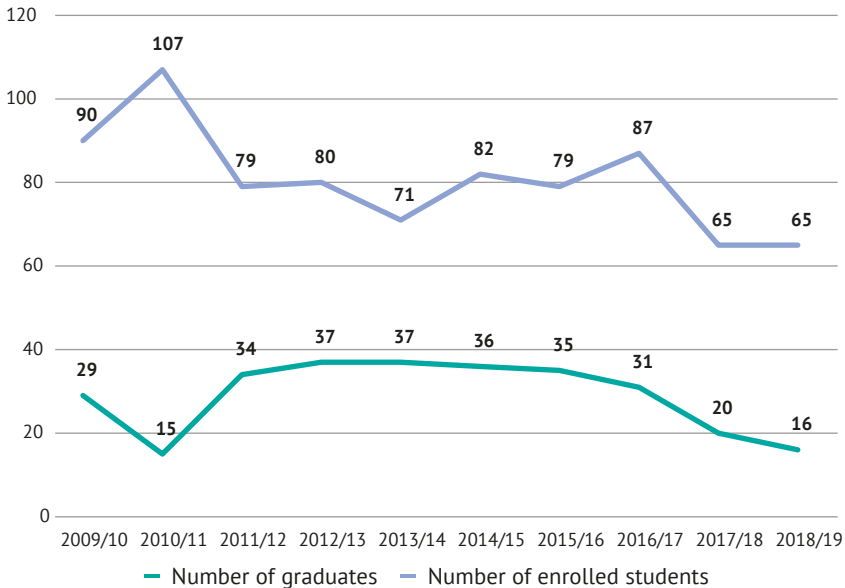

Figure 4.2.2. Number of enrolled and graduating students of doctoral study programmes related to ICT by academic years during the period from 2009 to 2019. Source: CSB, Ministry of Education 2019.

In the ICT sector, there is a great demand for specialists who, in addition to technological knowledge, also have competence in the processes of other sectors, therefore it is definitely necessary to mention the interdisciplinary bachelor's study programme Computer Science and Organisational Technologies newly established in 2019. The study programme has been offered by UL and RTU, in co-operation with the University at Buffalo (USA), and coordinated by Riga Business School (RBS) of RTU since 2019/2020. Enrolment of 60 students was scheduled on the study programme during the first academic year, the language of studies is English and four specialisations are offered within the framework of the programme: in computer science – artificial intelligence and data representation, algorithms and computer control, and in management – finance and general management. Cabinet of Ministers allocated funding in the amount of EUR 693,813 for the launching of the programme in 2019.

5 Excellence in research

Quantitative and qualitative evaluation of research capacity and excellence, visibility of research results, and international cooperation, incl. within the framework of RIS3 monitoring, is carried out using a number of measurable indicators that have been adopted in international practice:

- **number and dynamics of publications** – demonstrates the volume and regularity of publications by scientists and research institutions;
- **citation of publications** – visibility of publications and recognition of research results in the field of science and at the international level;
- **quality of scientific journals** (measured by the *Journal Impact Factor*) – demonstrates the quality, international recognition, and competitiveness of publications.

The quantity and quality of scientific publications on research directions in the area for the period from 2014 to 2018 was evaluated in the *Web of Science* database by using the InCites data analysis tool. The research directions and sub-directions defined by the *Web of Science* database that directly correspond to the RIS3 ICT area are:

- COMPUTER SCIENCE, ARTIFICIAL INTELLIGENCE
- COMPUTER SCIENCE, CYBERNETICS
- COMPUTER SCIENCE, INFORMATION SYSTEMS
- COMPUTER SCIENCE, INTERDISCIPLINARY APPLICATIONS
- COMPUTER SCIENCE, SOFTWARE ENGINEERING
- COMPUTER SCIENCE, THEORY & METHODS
- COMPUTER SCIENCE, HARDWARE & ARCHITECTURE
- ENGINEERING, ELECTRICAL & ELECTRONIC
- ROBOTICS
- TELECOMMUNICATIONS
- AUTOMATION & CONTROL SYSTEMS
- MEDICAL INFORMATICS

5.1. Scientific publications in the ICT sector

During the period from 2014 to 2018, a total of 1,474 publications were published in the WoS topics of the RIS3 ICT area, amounting to an average of 14% of the total number of Latvian publications. Of these, 210 are open access publications. The total number of ICT publications in Estonia is higher – 1,791, but they amount to approximately 12% of the total number of publications in Estonia. Meanwhile, Lithuania has a lower total number of publications in the ICT area amounting to 1,449 publications, which is only 8% of the total number of WoS publications (**see Figure 5.1.1**). On average, approximately 300 publications are published annually in Latvia, Lithuania and Estonia (**see Figure 5.1.2**). The results are similar for the number of cited publications, but Estonia's results in the area of ICT are generally better, due to the higher number of publications, including cited publications (**see Figure 5.1.3**).
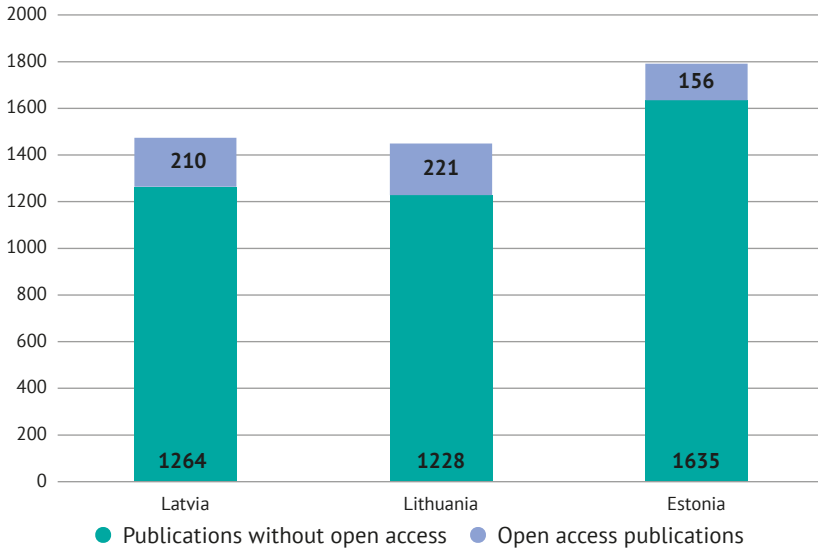
Figure 5.1.1. Total number of publications and proportion of open publications in the ICT sector in the Baltic states 2014–2018. Source: WoS.

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Latvia	155	190	242	194	245	229	300	281	369	295
Lithuania	466	455	393	426	375	299	355	292	355	258
Estonia	182	205	173	252	239	353	347	400	354	337
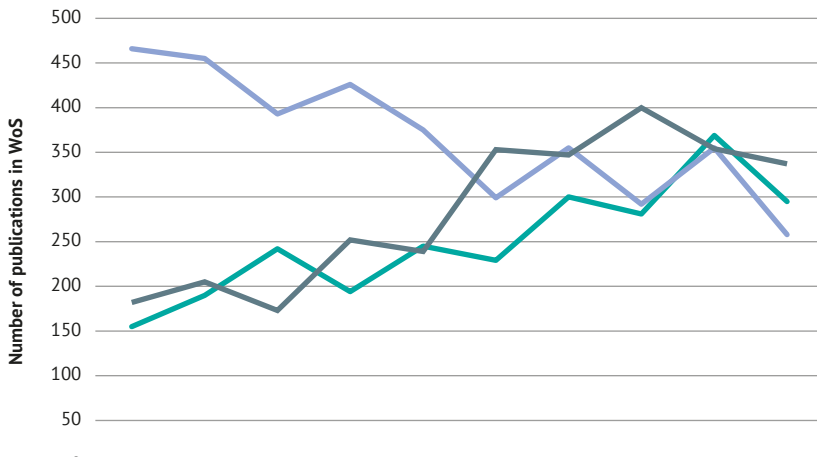
Figure 5.1.2. Dynamic changes in the number of ICT publications in the Baltic states 2009–2018. Source: WoS.

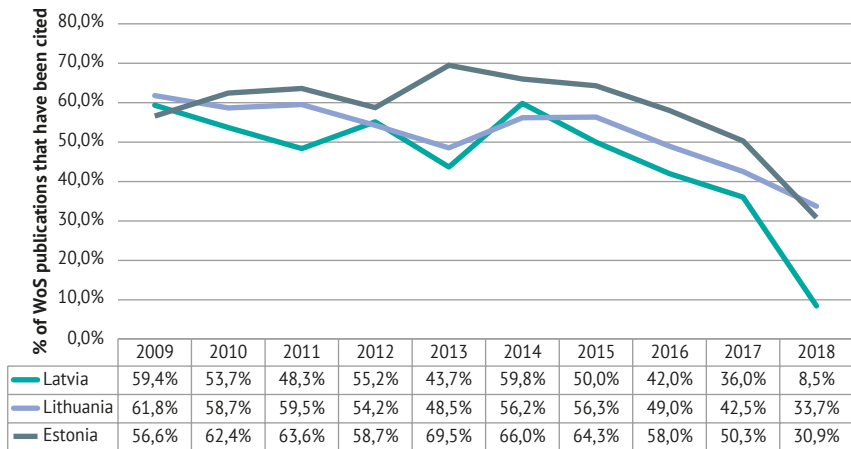|	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Latvia	59,4%	53,7%	48,3%	55,2%	43,7%	59,8%	50,0%	42,0%	36,0%	8,5%
Lithuania	61,8%	58,7%	59,5%	54,2%	48,5%	56,2%	56,3%	49,0%	42,5%	33,7%
Estonia	56,6%	62,4%	63,6%	58,7%	69,5%	66,0%	64,3%	58,0%	50,3%	30,9%

Figure 5.1.3. Dynamic changes in the percentages of WoS cited publications in the area of ICT. Baltic states 2009–2018. Source: WoS.

5.2. Research excellence in the ICT sector

The proportion of thematic publications in the total number of publications of a research institution (**see Figure 5.2.1**) allows one to judge the degree of specialisation of a scientific institution in the specific area. The largest proportion of publications on ICT topics have been published by IECS and TTI, while RTU and UL have the largest number of publications in general.
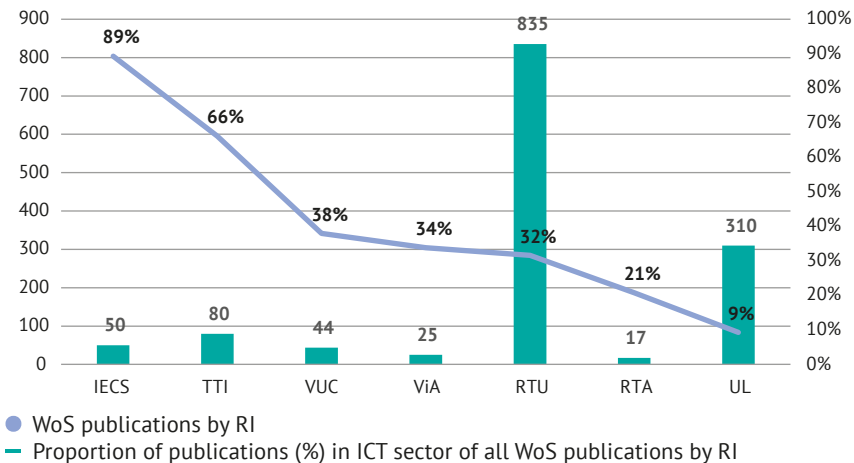

● WoS publications by RI

– Proportion of publications (%) in ICT sector of all WoS publications by RI

Figure 5.2.1. The number of publications in the area of ICT by research institution and their share in the total number of publications by research institutions (2014–2018). Source: WoS.

The comparison of the excellence of Baltic RI publications by the proportion of cited publications and publications in Q1 magazines demonstrates that the convincing leader by percentage of ICT publications is the University of Tartu. UL demonstrates the leadership trend among RI of Latvia, but only slightly exceeding the average indicators by the proportion of cited publications and publications in Q1 magazines and by the percentage of international co-operation publications. RTU surpasses LU in terms of the proportion of all WoS publications in Q1 journals, but stays behind in terms of the total number of cited publications, as well as in terms of international cooperation (Figure 5.2.2). Thus, it can be concluded that in the time period from 2014 to 2018, UL and RTU have been the leading RI in the area of ICT research in Latvia and the Baltics, falling behind the University of Tartu and Tallinn University of Technology.
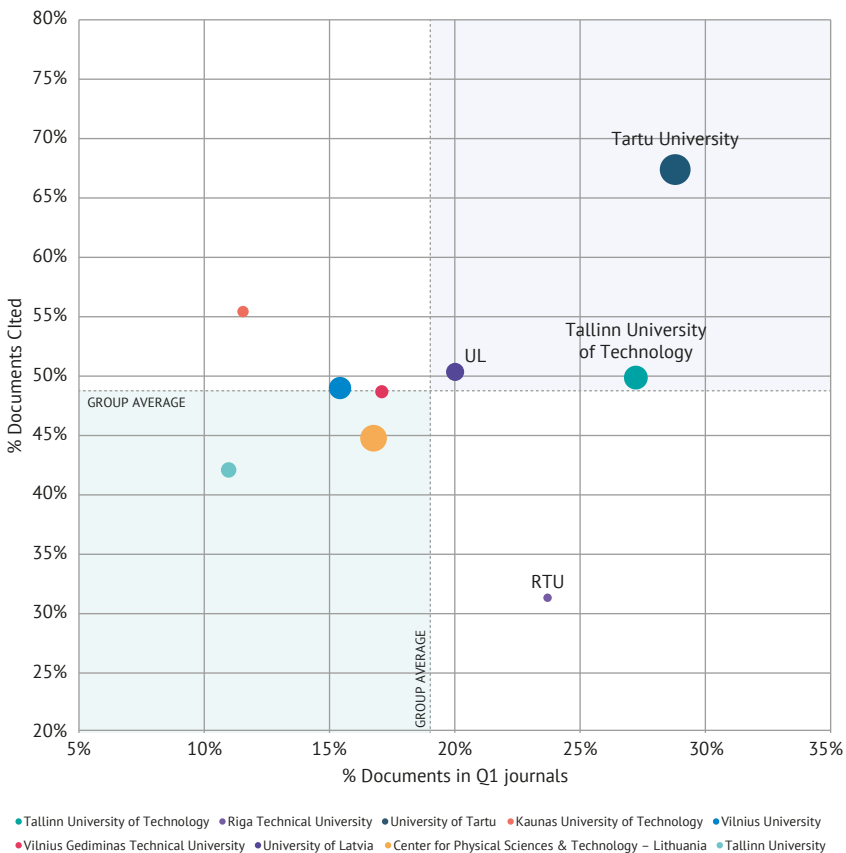

Figure 5.2.2. Scientific publications in the area of ICT at the RI of the Baltic states, by percentage of citations, percentage of publications in Q1 journals. The size of the circle indicates the percentage of the number of publications created in international co-operation. Source: WoS.

6 Research collaboration

Collaboration is one of the main catalysts for the creation of a broader research impact (*research impact*). Co-operation in the context of RIS3 is assessed both as co-operation between researchers an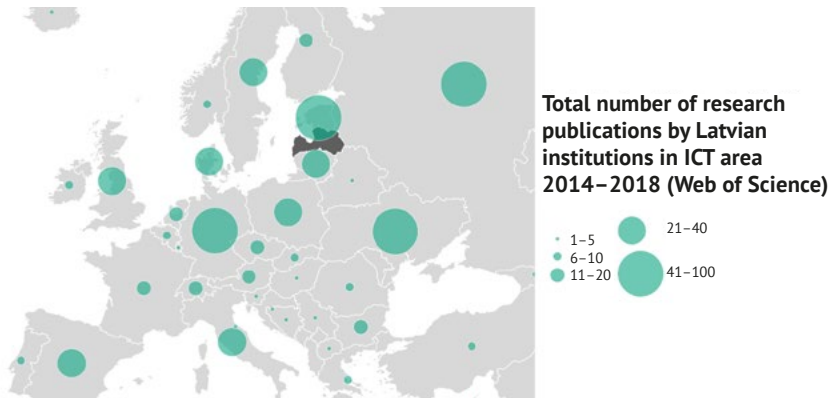d research institutions on a national and international scale, and as co-operation outside the academic environment – with industry and other social partners. The main indicators for evaluating co-operation are the number of joint publications and research project partnerships.

6.1. International cooperation

In the period from 2014 to 2018, the total number of international joint publications in the area of ICT accounted for 28.55% or ~ 420 of all publications in the WoS area. The largest number of international joint publications in the area of ICT was published by ViA – 72%, VUC – 47.73%, RTA – 41.18%, which is a positive trend, but the total number of ICT publications for these RI is low. In turn, UL has published 39.87% or 124 publications and RTU – 22.94% or 191 of all publications in the area of ICT produced within the framework of international co-operation. Country-wise, the largest co-operation partners of Latvian RI are situated in Estonia, Germany, Ukraine and Russia (**see Figure 6.1.1**). In the countries of the European Union, on average 40% of all publications in the area of ICT are developed and published within the framework of international co-operation, thus Latvian scientists are enabled to develop co-operation with RI of European countries in order to get better integrated into the European science area.

Figure 6.1.1. Latvia's international co-operation in the area of ICT by the number of joint publications at the European level in the period from 2014 to 2018. Source: WoS.

Total number of research publications by Latvian institutions in ICT area 2014–2018 (Web of Science)

- 1–5
- 6–10
- 11–20
- 21–40
- 41–100

The specialisation of Latvian RI in the ICT specialisation area is a comparatively wide range of foreign co-operation partners, which differs by institution (**see Figure 6.1.1**) and in approximately 50% of cases the co-operation with foreign research institutions is confirmed by a single joint publication over the period of 5 years, which predominantly points to short-term co-operation within the framework of one project, instead of long-term co-operation.
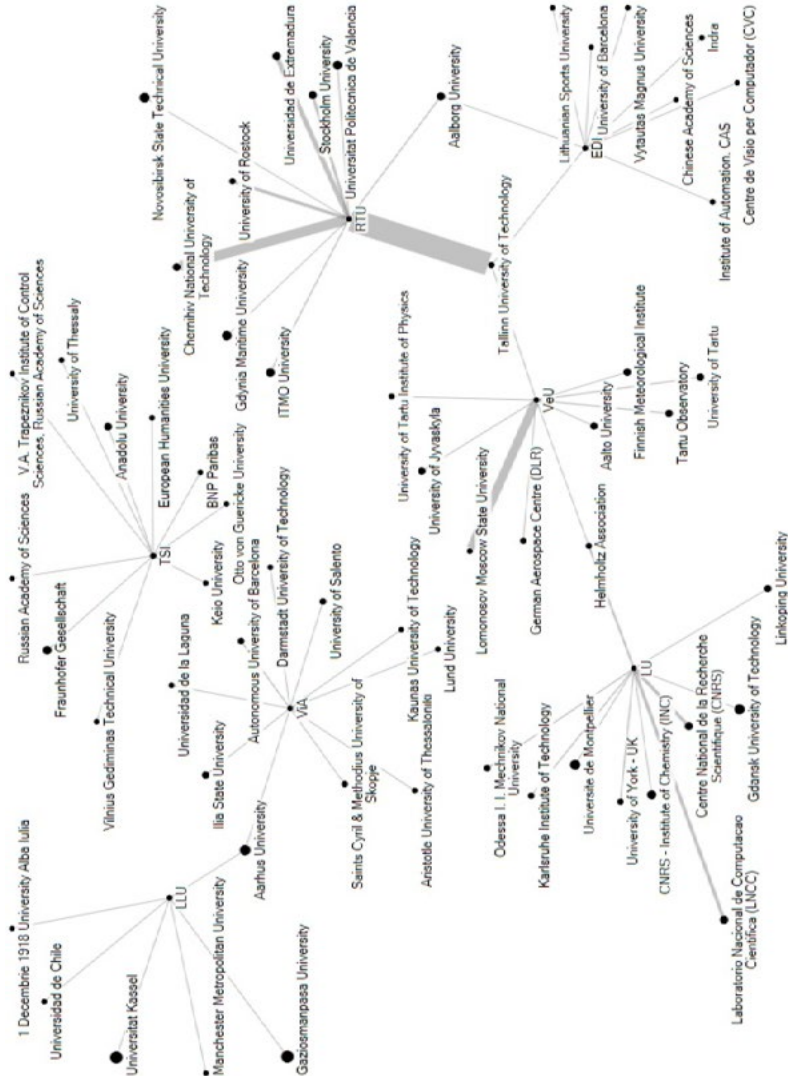

Figure 6.1.2. International cooperation partners of the leading HEI and RI in the Area. Link - joint publications. Source: WoS.

6.2. Cooperation with industry sector

Meanwhile, only 0.97% or 14 of all publications in the ICT area were created as a result of co-operation with the industry sector. An average of 5% of all ICT area publications in the countries of the European Union are created as a result of RI co-operation with the industry sector. Only three of the RI in Latvia have worked on research in co-operation with the industry sector – UL, where 1.61% of publications have been created in co-operation with the sector, TTI – 1.25% and RTU – 0.84%. Thus, a conclusion can be made that the co-operation of RI with the industrial sector in the time period from 2014 to 2018 has been very weak and this co-operation needs to be improved.

In total, ICT research projects have been implemented by 36 merchants and the largest corporate implementers of scientific projects have been A/S *Alfa RPAR*, SIA *BALTIJAS DATORU AKADĒMIJA*, SIA *DIVI grupa*, SIA *EuroLCDs*, A/S *Hansamatrix*, SIA *Lattelecom*, LETA, A/S *RIX technologies*, A/S *SAF Tehnika*, SIA *TILDE*.

6.3. Activities within the Horizon 2020 framework programme

A total of 391 projects were submitted for the ICT-related themes *Information and Communication Technologies, Space* and *Secure Society – Protection of Freedom and Security of Europe and its Citizens* of the framework programme *Horizon 2020* from Latvia in 2014–2018, with 55 projects of the submitted projects funded. Only 41% or 162 project applications have been rated as being above the quality threshold (Figure 6.3.1) and the average success of project applications is 14%. The largest number of project applications – 251, were submitted within the *Information and Communication Technologies* (LEIT-ICT) theme, where 93 projects were scored above the threshold and 34 projects were funded, 41 project applications were submitted for the *Space* (LEIT-SPACE) theme with 20 projects scored above the threshold and 6 projects funded. Meanwhile, 99 project applications were submitted under the theme *Secure Society – Protecting the Freedom and Security of Europe and its Citizens* (SECURITY), with 49 projects rated as above the threshold and 15

projects funded. Projects that are not closely related to the RIS3 ICT area and are not included into the mapping of specialisation niches in Chapter 3 of this review have also been funded under these themes. In the time period from 2014 to 2018, the goal was to achieve a 30% success rate of project applications in Horizon 2020 projects. In the ICT area this goal was not achieved, which poses a challenge to improve the result in the next period.

Meanwhile, in terms of institutions, project applications are regularly submitted by IECS, UL and RTU with differing success rates. IECS stands out for the overall quality of project applications, reaching 40% of the above threshold assessment of project applications. UL and RTU have similar indicators in terms of the quality of project applications, UL has done better in the attraction of funding compared to RTU. LULST cannot be considered a regular project applicant in *Horizon 2020* ICT programmes, but in general, considering the low number of

project applications, the success rate is very high – 33%. The other RI of the ICT sector have also submitted a few project applications; there have been above threshold projects, but they have not been funded.
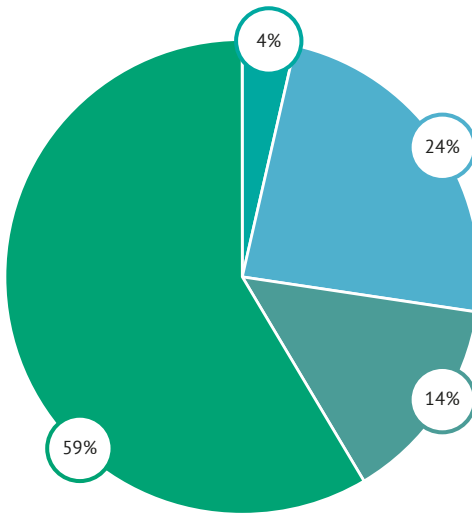

Figure 6.3.1. Success of project applications in ICT-related topics of the Horizon 2020 framework programme from 2014 to 2018, percentages by number of project applications. Source: CORDIS

Institution	Project applications, number	Above threshold projects, number and % of applications	Funded projects, number and % of applications
IECS	35	14 (40%)	6 (17%)
LULST	3	1 (33%)	1 (33%)
UL	32	5 (16%)	5 (16%)
RTU	33	5 (15%)	3 (9%)

Figure 6.3.2. Applications submitted by Latvian research institutions in the framework programme Horizon 2020 from 2014 to 2018 under the themes Information and Communication Technologies, Space and Secure Society – Protection of Freedom and Security of Europe and its Citizens. Source: CORDIS

7   Challenges in the ICT area

When defining the priorities of ICT research and innovation, it should be taken into account that they should be focused not only on the Latvian internal market, but also on the European and global market. It is important to assess how Latvia can participate in the strengthening of European technological autonomy in the next period, and where exactly the ICT sector of Latvia has the capacity to achieve this EU goal.

In the time period from 2014 to 2018, the ICT sector had a very good performance in export, where the export of goods has increased by 40% and export of services – by 164%. Consequently, the challenge will be to maintain this export growth in the next period, while maintaining productivity growth.

There is a significant need to increase public sector procurement for research in the ICT area, especially in those thematic niches, where public sector capacity is currently insufficient compared to private sector interest and activities. Such an increase in intensity must occur by means of ensuring a close link between private and public sector R&D activities, and the mutual complementarity thereof. In addition, active measures are required to strengthen ICT study curricula, in particular – by reducing the drop-out rate in undergraduate programmes and paying more attention to doctoral studies (where, as in other RIS3 areas, the number of doctoral graduates has fallen sharply in recent years).

It can be concluded that in the area of ICT business there is still a weak demand for employees with high scientific and technological qualifications, in 2016 – only 0.7% of all employees. Consequently, such a scenario poses risks to the ability of companies to create and implement innovation projects that would result in the development and introduction into the production of technologically intensive, knowledge-based, demanded on the market and exportable solutions (products, technologies, services).

At the level of study programmes, the challenge is to improve the efficiency of doctoral study programmes, where currently, despite the diverse study programme offer, the number of doctoral graduates is low – on average 27 graduates per year during the last 5 years in 18 doctoral study programmes. At the undergraduate level, the biggest challenge is to ensure a sufficient number of graduates, at least 3,000 graduates per year, to provide both human resources for industry to meet export goals, as well as the number of potential master's level students, doctoral students and researchers. The currently identified obstacle for the achievement of this goal is the high drop-out rate of students, already in the first years of studies.

Unfortunately, upon the assessment of the excellence of Latvian ICT research in the European Research Area, it must be concluded that the results of 2014–2018 place us in one of the last places in terms of citation and proportion of publications in Q1 journals and only 0.97% of all ICT publications have been created in co-operation with the industry sector. Consequently, this will also be a major challenge for ICT research in the upcoming period, both in terms of developing research excellence and improving co-operation with the industry sector.

8 Research institutions in the ICT area

In Latvia, research competence and capacity in the area of ICT are concentrated in the following scientific institutions:

The research work of the **Institute of Electronics and Computer Science** is organised in five laboratories: discrete signal processing laboratory, time measurement laboratory, stroboscopy laboratory, embedded systems laboratory, cyber-physical systems laboratory. In the research programme for 2016–2021, IECS indicates the following priority research areas: ultra-high-resolution event time measurement, transformed time signal processing, ultra-broadband, super-high-frequency, ultra-high-frequency systems, video analysis for safe and smart cities, embedded and cyber-physical systems for mobility, Bio-medical and biometric signal and image processing, complex signal processing for industrial technologies, remote sensing and space data processing, development of wireless sensor network hardware and software platform (bio-economy, medicine, environmental monitoring, etc.).

At the Latvia University of Life Sciences and Technologies, research in the area of ICT is carried out by the Faculty of Information Technology and has an interdisciplinary orientation. Research directions include IT solutions, the application of mathematical modelling and statistics in agricultural, environmental and forestry sciences, development and evaluation of intercultural information systems, systems biology, modelling and optimisation of metabolic networks, Bioinformatics.

The University of Latvia has several research centres in the area of ICT – LU Faculty of Computing, LU Institute of Mathematics and Informatics (UL MII), LU Institute of Solid State Physics (ISSP UL).

The Faculty of Computing of the University of Latvia has a *Quantum Computer Science Centre* and a *Laboratory of Perception and Cognitive Systems*, as well as research work in computational linguistics is conducted; research and development of software tools and methods is performed. Quantum algorithms, quantum communication, quantum information theory and cryptography are studied at the Quantum Computer Science Centre.

The research work at LU MII takes place in six laboratories: system modelling and software technology laboratory, artificial intelligence laboratory, real-time systems laboratory, mathematical technology laboratory, ordinary differential equations laboratory and the academic network laboratory SigmaNet. The directions of research activity include mathematical foundations of computer science, methods and tools for complex systems design, graph theory and processing of visual information, semantic web technologies, machine learning and computational linguistics, bioinformatics, real-time and autonomous systems and high performance computing (HPC) infrastructure. Computer systems security research takes place at the Information Technology Security Incident Prevention Institution CERT.LV of LU MII and the Network Solutions Division NIC.

The research in the ICT sector at ISSP UL focuses on the areas of functional materials electronics and photonics,

where the research of materials for light emitters, materials for sensors, materials for photonics devices in information and communication technologies, prototyping of photonics and microelectronics devices is conducted.

ICT research at **Riga Technical University** takes place at RTU Faculty of Computer Science and Information Technology (RTU FCSI) and RTU Faculty of Electronics and Telecommunications (RTU ETF). Comprehensive intelligent computing for evolving digital companies, comprehensive data processing (communication, computing and management) in distributed complex environments, comprehensive intelligence for the development and integration of intelligent and autonomous systems, and mathematical modelling are the research areas of RTU FCSI.

Meanwhile, research directions of RTU ETF are: implementation of the latest generation fibre-optic transmission systems and constructions of their elements, complex approach to ensuring the autonomous operation of wireless sensor network nodes in environmental monitoring issues; mobile sensor network research and performance evaluation; development and evaluation of fibre-optic sensors and sensor networks; development, evaluation and usability of new generation microwave communication systems (LTE, 5G), planning and optimisation thereof; accuracy studies of global satellite navigation systems; mathematical modelling of telecommunication networks and systems, solutions of their resource and performance optimisation tasks and research and application of artificial intelligence methods in network management and administration tasks.

RTU Scientific Computing Centre – RTU HPC (High Performance Computing) provides access to modern computing infrastructure, creates a link with the European e-infrastructure and ensures the availability of scientific software for research and teaching.

At the Transport and Telecommunication Institute, ICT research areas include intelligent cyberphysical systems, Internet of Things, robotics, cybersecurity, big data and data mining, applications of virtual reality technologies. The research is carried out at the Telecommunications, Electronics and Robotics Centre, Applied Software Systems Laboratory, Multimedia Systems Laboratory, Materials and Machine Mechanisms Modelling Laboratory, Image Processing, Biometrics and Automated Border Control Systems Laboratory.

At Ventspils University College, research work in the area of ICT is carried out at the Ventspils International Radio Astronomy Centre (VIRC) and the Smart Technology Research Centre (STRC). The research areas of VIRC include high performance computing (HPC), satellite engineering, modern antenna technologies, cyberphysical and embedded systems, remote sensing – development of specialised methodologies for the transformation of remote sensing data into information products, research of remote sensing data processing methods, testing, software development. Meanwhile, the topics and directions of STRC research include signal and image processing technologies, ICT and electronics in applied sciences such as E-health, smart and language technologies, video, television and multimedia transmission technology quality research.

Socio-Technical Systems Engineering Institute of **Vidzeme University of Applied Sciences** implements the following sub-areas of ICT research: virtual reality technologies and visualisation, e-learning management and technologies, socio-technical system modelling technologies.

9 Annex

9.1. RIS3 IKT area by *NACE* code

This review defines the Latvian RIS3 ICT sector in the economy in accordance with the definition of the Organisation for Economic Co-operation and Development (OECD), which determines the inclusion of the following economic activities (in accordance with NACE Rev, 2):

- ICT manufacturing (NACE classes: 26.11; 26.12; 26.20; 26.30; 26.40; 26.80);
- Provision of ICT services:
- reproduction of computer software (NACE classes: 58.21; 58.29),

- telecommunications (NACE classes: 61.10; 61.20; 61.30; 61.90),
- computer programming, consultancy and related activities (NACE classes: 62.01; 62.02; 62.03; 62.09),
- data processing, hosting and related activities, operation of internet portals (NACE classes: 63.11; 63.12).

RIS3 ICT area does not include ICT wholesale (NACE classes: 46.51; 46.52) and repair of computers, peripherals and communication equipment (NACE classes: 95.11; 95.12).

9.2. Technological readiness levels

TRL – technological readiness levels:

- TRL 1 – Natural laws have been researched: the results of scientific research allow one to commence the work of applied research and technological development work.
- TRL 2 – The concept of practical application of the technology is formulated.
- TRL 3 – Experimental testing of the concept: research and development (analytical/laboratory studies) has been commenced with the purpose of confirming the predictions regarding technology components.
- TRL 4 – Validation of technology in laboratory environment: integration of key technological components has been performed to test their

interaction in the laboratory environment.
- TRL 5 – Validation of technology in an artificial environment: the technological components are integrated with relatively real support elements so that the technology can be tested in an artificially created environment.
- TRL 6 – Demonstration of technology in an artificial environment: a system model or prototype has been tested in an artificially created environment.
- TRL 7 – Demonstration of a system prototype in an operational environment: a system prototype that meets or only slightly differs from the planned system has been tested in a real operating environment.

- TRL 8 – The system has been completed and tested: the technology has been proven to work in its final form and under the intended conditions (latest level of technological development).
- TRL9 – the finished system has been tested in its operating environment.

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