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Academic offer and demand for advanced profiles in the EU

Artificial Intelligence, High Performance Computing and Cybersecurity

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Foreword

The PREDICT project focuses on analysing the supply of Information and Communications Technologies (ICT) and Research and Development (R&D) in ICT in Europe, in comparison with major competitors worldwide. ICTs are indeed the technologies underpinning the digital transformation of the economy and of society. This research aims at supporting the policy making process by providing the evidence needed to analyse strengths and weaknesses of the European ICT industry and of technological take-up in comparison with that of its most important trading partners, over a range of several years and to a significant level of detail. The PREDICT project has been producing comparable statistics and analyses on ICT industries and their R&D in Europe since 2006, covering major world competitors including 40 advanced and emerging countries – the EU28 plus Norway, Russia and Switzerland in Europe, Canada, the United States and Brazil in the Americas, China, India, Japan, South Korea and Taiwan in Asia, and Australia.

Examples of topics PREDICT addressed in a decade of research activity are: the shift of the ICT industry, and ICT demand, from manufacturing to services; the rise of the ICT industry in Asia; the international geography of ICT R&D and innovation; the growing problems of the IPR system; the importance of mobile internet, as driving rationale of supply and demand; the deployment of ICT supply-side activities within all sectors of the economy.

PREDICT is presently expanding by analysing techno-economic segments (TES) in the economy, describing the dynamics of their ecosystems with factual data from non-official heterogeneous sources, with the overall objective of contributing to measuring the digital transformation of the economy and providing policy recommendations.

Presently PREDICT is also supporting the work towards the first Digital Europe programme for increasing EU's international competitiveness and developing and reinforcing Europe's strategic digital capacities, by providing evidence about the availability in EU Member States (MSs) of adequate advanced digital skills in a number of IT domains. Moreover, the TES analytical approach has been applied to target Artificial Intelligence and map its landscape in the EC AI Watch.

PREDICT is a collaboration between the Digital Economy Unit of European Commission (EC) Joint Research Centre (JRC) and the Digital Economy and Skills Unit of the EC Communications Networks, Content and Technology (CNECT) Directorate General.

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Abstract

The JRC Report "Academic offer and demand for advanced profiles in the EU. Artificial Intelligence, High Performance Computing and Cybersecurity" aims at supporting policy initiatives to ensure the availability in EC Member States of adequate advanced digital skills in a number of IT domains including Artificial Intelligence (AI), High Performance Computing (HPC) and Cybersecurity (CS).

The report opens reviewing a few existing initiatives aimed at monitoring skill mismatch in view of the accelerating technological progress, which reveals insufficient in addressing dynamic, transversal and very specific techno-economic segments such as AI, HPC or CS. By making use of the Techno-Economic Segments (TES) analytical approach developed under the PREDICT3 project, the study collects data and builds quantitative indicators to provide a mapping of digital skills in the mentioned technological domains from two complementary perspectives: the existing academic offer of bachelor and master programmes, and the industry activity in the referred fields (giving indications about the type of profile specialisation the industry may need).

The results show that the educational offer targeting the analysed domains is more concentrated in the master level, with 60% of all programmes considered. One fourth of the programmes is specialised in the technological domain under study, while the rest are touching upon it within a wider programme or as a part of a programme specialised in a different discipline. Specialised masters represent 18% of the whole educational offer in these domains.

Section 1 introduces the research project objective, reviews related initiatives and presents the methodology developed to address the aim of the study. The methodology consists on a first step where the domain boundaries are identified, followed by data collection, to finally cluster the education programmes and enterprises into domain areas for the analysis. Sections 2 to 4 analyse the education offer and industry activity on each of the three techno-economic segments (AI, HPC, CS) for the EU28 aggregate and its Member States; further details on specialised masters are provided; and the education offer and industry activity (giving an idea about a potential demand for specific profiles) are clustered by domain specific fields. Section 5 summarises the findings, includes some concluding remarks and presents perspectives for further development of the project.

The conclusions emerging from this first round of analysis show that demand for skills in emerging highly specific technological domains may need to find solution in specialised programmes. Almost all Member States are facing shortages of ICT professionals, including in the area of AI. The current offer of specialised higher education programmes is limited and not equally available in all Member States.

1. Introduction

1.1. The research project and the present study

The achievement of a Digital Single Market remains amongst the key priorities for the European Commission (EC). Other challenges, such as those targeted by the Communication "Artificial intelligence for Europe" in April 2018, are setting the need of measuring the digital transformation of the economy and its impacts on industry, employment and society on the top of the agenda. However, it will need as well a deep understanding of the emerging technological segments and of the changes they are bringing about in the industrial and R&D landscape, in order to adequately prepare both industry and society to anticipate forthcoming evolutionary scenarios.

Since 2005, the EC Joint Research Centre (JRC), in close collaboration with the Directorate General for Communications Networks, Content & Technology of the EC (DG CNECT), has developed a long-lasting undertaking to provide metrics, data and analysis of the EU Information and Communication Technology (ICT) sector and its Research and Development (R&D) investments, and more recently of the digital transformation[1]. In the context of the Digital Europe programme[2], aimed at increasing EU's international competitiveness and reinforcing strategic digital capacities, this study is a first attempt to provide evidence to frame policy initiatives targeting the availability of adequate advanced digital skills, in the following IT domains:

- Artificial Intelligence (AI)

- High Performance Computing (HPC)

- Cybersecurity (CS).

By making use of the Techno-Economic Segments (TESs) analytical approach[3], the JRC is mapping the existing offer of academic programmes and the demand of profiles by industry, in the mentioned technological domains (AI, HPC and Cybersecurity), to frame decisions on how to improve the availability of academic education and training in the mentioned domains, so to be ready to feed the increasing industry demand and avoid to the extent possible the lack of suitable workforce.

The study behind the present report constitutes a comprehensive exercise involving the collection and analysis of multiple data sources for the quantification of the current educational offer targeting digital skills in the EU in specialised areas. It also provides an overview of the activity of an industry which is increasingly plunged into the digital transformation. A suitable coverage of the most demanded profiles by education institutions' offer is key in order to face the growing demand of specialised professionals by the industry and to facilitate socio-economic growth.

This report offers a first overview of the results of this research activity, and sets the basis for further in depth developments, planned for the next years, among which a reinforced multilingual approach, aiming at guaranteeing a more uniform and complete coverage of both demand and supply of advanced digital profiles in EU MS.

When considering which academic level is the most relevant for building profiles suitable to match the increasing industrial demand in digital highly specialised domains, the master level is the one generally perceived as the most appropriate. However, aspects such us corporations' internal training (very relevant for example in the case of cybersecurity) and other factors suggest to consider also the bachelor academic level for

[1] See the PREDICT project (https://ec.europa.eu/jrc/en/predict)

[2] Proposal for a Regulation of the European Parliament and of the Council establishing the Digital Europe programme for the period 2021-2027; COM(2018) 434 final.

[3] While some details on the methodological aspects of the TES analytical approach developed by JRC are offered in the present report, details on the TES methodology will be available in a separated dedicated forthcoming report.

their different impacts on advanced skills development. The PhD level, presenting different schemas and access conditions in different countries, is not systematically targeted by the study. Short term commercial training such as bootcamps and MOOCs are not addressed at this stage either.

In synthesis, the study addresses:

I. The mapping of the existing academic offer in the mentioned technological domains (AI, HPC and CS), including bachelor and master programs.

II. The mapping of the demand by the industry, proxied by analysing the companies active in the technological domains.

1.2. Some framework information from other initiatives

The digital transformation of economy and society is expected to have a strong and unprecedented impact in Europe, with a particular focus on the labour market. The EC is active with several initiatives[4] targeting from different angles the risk of a skill mismatch in view of the accelerating technological progress. Nevertheless, targeting specific and rapidly evolving technological domains is in general still work in progress.

CEDEFOP work on skills and future employment needs

Indeed, the issue of skills evolution, ICTs and job demand is addressed by *Cedefop*[5] from different perspectives, having as part of its mandate since 2010 to forecast trends in skill supply and demand for Europe every two years[6]. Cedefop expects a large increase in the use of ICT skills in the near future, also accompanied by some increase in autonomy and a reduction in routinized tasks (Cedefop, Eurofound (2018). In fact, a few economic sectors intensive in the use of ICT sector are identified as affected by genuine skill shortages, with strong demand for software and application developers, Cedefop (2015). An *online tool*[7] allows for visualisation of future trends of various indicators (labour force, employment and job openings) with focus by occupation, country and economic sector. The main limitation trying to address the research question tackled by the present study is the level of granularity used for occupations, which corresponds to labour market investigation needs but is not suitable to investigate the penetration of specific technological domains into professional profiles and skills. Cedefop's occupation classification is based on the International Standard Classification of Occupations[8] (ISCO); the classification groupings of ISCO are meant for statistical and analysis purposes, and may help for instance in matching job seekers with vacancies. Cedefop provides results up to the two digit level of detail, that is, for the 9 major groups and the 40 submajor groups. Such granularity corresponds to labour market investigation needs, but this level is not suitable to be applied to investigate the professional profiles and skills needed for specific technological domains.

In an attempt to cover ICT occupations more in depth, Cedefop's *Skills Panorama*[9] analyses two groups of occupations:

- The ICT professionals, or ISCO submajor group 25 (Information and Communications Technology Professionals), defined by Cedefop as professionals who "conduct research, plan, design, provide advice and improve information

4 See DG CNECT, Digital Skills and Jobs (https://ec.europa.eu/digital-single-market/en/policies/digital-skills)

5 European Centre for the Development of Vocational Training (http://www.cedefop.europa.eu/) is a EU decentralized agency founded in 1975 and based in Greece since 1995.

6 See the Council conclusions on “New skills for new jobs: the way forward” (http://www.consilium.europa.eu/uedocs/cms_Data/docs/pressdata/en/lsa/114962.pdf)

7 http://www.cedefop.europa.eu/en/publications-and-resources/data-visualisations/skills-forecast

8 http://www.ilo.org/public/english/bureau/stat/isco/index.htm. The ISCO lists 432 occupations, coded at 4 digit level, and are grouped, according to the tasks and duties undertaken in the job, into: 9 major groups (1 digit code), 40 submajor groups (2 digits code), and 127 minor groups (3 digits code).

9 http://skillspanorama.cedefop.europa.eu/en/analytical_highlights/information-and-communication-technology-professionals-skills-opportunities

technology systems, hardware, software and related concepts for specific applications; develop associated documentation including principles, policies and procedures; and design, develop, control, maintain and support databases and other information systems to ensure optimal performance and data integrity and security. […]Typically people in this occupation will have completed between three and six years of higher education."

- The ICT technicians,[10] or ISCO submajor group 35 (Information and Communications Technicians), defined as professionals who "support the design, development, installation, operation, testing, and problem solving of hardware and software. They regard a wide set of sub-occupations that range from network system technicians to telecommunications engineering technicians. Due to the wide penetration of information technologies (IT) across the economy, they work in a wide range of sectors, from IT to manufacturing and telecommunications and number of other service sectors."

Cedefop reports that between 2005 and 2015, employment in ICT occupations (ICT technicians and ICT professionals) grew by about 23%, with ICT technicians contributing by around 8%. The expected growth in both groups of occupations is positive, while it is expected to impact with a higher growth rate the ICT professionals group (10%) than to ICT technicians (5%). Some 400 thousands new jobs are expected to be created for ICT professionals, plus another 1.5 million jobs filled due to replacement demand. Only 20% of total job openings in the ICT occupations between 2015 and 2025, is projected to be for ICT technicians, while their share within ICT occupations is mildly declining. Currently, there is a shortage of ICT professionals in 24 EU Member States, and a shortage of ICT technicians in 12 countries. The five key skills required for ICT professionals are advanced ICT skills, problem solving, moderate ICT skills, learning and job-specific skills. The same five, while in different order apply for ICT technicians.

Cedefop also reports that a common driver for employment growth in ICT occupations is the uptake of ICT and related technologies by the economy, as well as the development of new business models and processes. Cedefop's analysis also warns about the vulnerability of this occupation groups, in particular the ICT technicians, due to the swift and constant technological advancements across sectors.

Cedefop *Forecasting skill demand and supply*[11] provides "comprehensive information on the future labour market trends in Europe. The forecasts act as an early warning mechanism to help to alleviate potential labour market imbalances and support different labour market actors in making informed decisions." Indeed, even if not addressing the need of the present study, the initiative *Assisting EU countries in skills matching*[12] (also by Cedefop) contributes by providing support to the governance of skill anticipation and matching, and offers several interesting lines of analysis.

Moreover, Cedefop runs *Skillsnet*[13], which is a network welcoming "researchers and experts active in early identification of skill needs and forecasting or in the transfer of research results on future skill requirements into policy and practice. Skillsnet members are involved in Cedefop activities related to identification of skill needs (forecasting, employer surveys, and sectoral analysis) and receive privileged access to information." Skillsnet "provides a forum for generation of new activities and projects in the early identification of skill needs by bringing in a multidisciplinary cross country perspective."

[10] Defined by Cedefop as professionals who "support the design, development, installation, operation, testing, and problem solving of hardware and software. They regard a wide set of sub-occupations that range from network system technicians to telecommunications engineering technicians. Due to the wide penetration of information technologies (IT) across the economy, they work in a wide range of sectors, from IT to manufacturing and telecommunications and number of other service sectors."

[11] http://www.cedefop.europa.eu/en/events-and-projects/projects/forecasting-skill-demand-and-supply

[12] http://www.cedefop.europa.eu/en/events-and-projects/projects/assisting-eu-countries-skills-matching

[13] http://www.cedefop.europa.eu/en/events-and-projects/networks/skillsnet

Cedefop approach suffers from two main limitations with regard to the mapping of the technological domains under study. First, if the analysis of the ICT occupations was enough to approach the objective of this report, these two occupation groups would need to be complemented, since they do not entirely cover what is identified as ICT specialists occupations by the Eurostat-OECD definition of ICT specialists (OECD, 2015). The latter additionally includes some 3 digit and 4 digit specific occupations not covered by Cedefop[14]. According to JRC estimations[15], about one third of all professionals working on ICT related occupations are not covered by the submajor groups 25 and 35. In 2016, 8.6 million ICT specialists were in employment, 3.8 of them, or 45% of all ICT specialists, under the ICT professionals ISCO group 25, 1.8 million (21%) as ICT technicians (ISCO group 35), and 2.9 million (34%) as ICT specialists in any of the other occupations covered by the Eurostat-OECD definition. The ICT specialists in the EU account for 3.8% of all labour force between 15 and 74 years old. This share shows a steady increase from 3.2% in 2011, meaning that the amount of ICT specialists needed and employed in Europe is increasing at a higher speed than total employment is. The countries employing in 2016 higher numbers of ICT specialists are United Kingdom (1.7 million persons), Germany (1.5 million), France (1.0 million), Italy (721 thousands) and Spain (632 thousands). The second limitation lies in the fact that measuring the future trends of the ICT specialists occupations would only provide an overall view of the context in which emerging technological domains operate.

An alternative approach is, hence, needed to better target skills mismatch in dynamic, transversal and very specific techno-economic segments such as artificial intelligence, cybersecurity or high performance computing.

The ESCO framework for skills, competences, qualifications and occupations

In order to provide insights on profiles needed by emerging technological domains, the present study is called to identify what academia offers in terms of study programmes. A next logical step would be to check if such offer is in line with what needed by the labour market. This suggests to link to the concept of skills. The European Skills, Competences, Qualifications and Occupations[16] (ESCO) definitions are reviewed for reference.

The ESCO classification is based on the three pillars of occupations, skills:

1. *Occupations*[17]: 2942 occupations, structured with hierarchical relationships between them, and mapping to the ISCO; each occupation comes with an occupational profile, containing a description of the occupation, scope note and definition, listing the knowledge, skills and competences that experts considered relevant terminology for this occupation on a European scale.

2. *Skills*: 13.485 skills/competences, not containing a full hierarchical structure, but rather structured along with 4 approaches[18]. The skill/competence concept is

[14] In particular, the Eurostat-OECD definition of ICT specialists considers the following ISCO codes: 133 (ICT managers), 2152 (Electronics engineers), 2153 (Telecommunications engineers), 2166 (Graphic and multimedia designers), 2356 (Information technology trainers), 2434 (ICT sales professionals), 25 (ICT professionals), 35 (ICT technicians), and 742 (Electronics and telecommunications installers and repairers).

[15] The JRC has developed a methodology to estimate the number of ICT specialists under the Eurostat-OECD definition. Imputation is needed due to missing values reported by one third of Member States in some of the 4 digit ISCO codes included in the definition of ICT specialists. The method applied by the JRC provides more accurate results than the one put in place by Eurostat until the current moment. See details in the technical report (López-Cobo M., and Rohman I.K., (forthcoming). *ICT specialists in employment. Methodological note*, JRC Technical Report, European Commission, Joint Research Centre, Seville, Spain.) describing the method and comparing results and performance measures with respect to the Eurostat method.

[16] From the ESCO site (https://ec.europa.eu/esco/portal/home): "ESCO is the multilingual classification of European Skills, Competences, Qualifications and Occupations. ESCO is part of the Europe 2020 strategy. The ESCO classification identifies and categorizes skills, competences, qualifications and occupations relevant for the EU labour market and education and training. It systematically shows the relationships between the different concepts."

[17] https://ec.europa.eu/esco/portal/occupation

[18] From ESCO site: "Through their relationship with occupations, i.e. by using occupational profiles as entry point; in the part of the transversal knowledge, skills and competences through a skills hierarchy; through relationships indicating

distinguished by the knowledge concept, even if the distinction is only represented by the skill type.

3. *Qualifications*: 2444 qualifications, being "the formal outcome of an assessment and validation process which is obtained when a competent body determines that an individual has achieved learning outcomes to given standards. Qualifications displayed in ESCO come from databases of national qualifications that are owned and managed by the European Member States"[19]. Member States provide this information to ESCO on a voluntary basis. It therefore depends on each Member State to ensure information availability. The Commission also envisages integrating private, international and sectorial qualifications from other sources into ESCO in the near future. It is piloting this approach and discussing it with the Member States.

Academic offer (Eurostat)

Eurostat publishes annual statistics on participation in education and training, in particular on *Students enrolments and new entrants in education and training* by level. There is information on tertiary education, covering four level subcategories: short-cycle, bachelor, master and doctoral studies; and by field of education. The closest fields of education[20] covering the mentioned technological domains are under the ICT field 06: Computer use; Database and network design and administration; and Software and applications development and analysis; as well as subfield Electronics and automation in Engineering, manufacturing and construction.

The classification of fields of education does not seem pertinent to address the objective of the current study. Furthermore, the penetration of the techno-economic segments such as AI into many different study fields, make it also insufficient in that sense, since AI courses are taught across different disciplines. Again, as in employment and skills, the official statistics do not suffice to capture the education offer in these domains.

Other initiatives

Other works, such as the report *Informatics education in Europe: Institutions, Degrees, Students, Positions, Salaries. Key Data 2012-2017 (*Informatics Europe, 2018) suffers from the same type of weaknesses, since it follows the referred classification of fields of education, which does not focus on the specific skills or education contents needed to address the labour shortage in the technological domains under study.

1.3. Methodological notes and data collection

From the picture sketched above, the questions addressed by the present study don't find a complete answer in any of the available works. This study addresses the mapping of academic offer and industry activity in three emerging, transversal and disruptive technological domains. In an attempt to consider the topic from different perspectives, it takes into account a varied set of sources, providing an initial set of indications for policy development.

The first step is represented by the identification of education programmes and industrial activities related to the technological domains on which the study is focusing.

The ESCO classification will be taken in consideration for the next phases, when an effort will be devoted to connect back to occupations, skills and qualifications the findings in terms of academic (and commercial) study programmes and in terms of industrial activities and demand for job profiles.

how knowledge, skills and competences are relevant to other knowledge, skills and competences (in particular in cases of skill contextualization); through functional collections that allow to select subsets of the skills pillar".

19 On a voluntary basis, therefore depending on each Member State to ensure information on its qualifications in ESCO is available, complete, correct and up-to-date.

20 ISCED-F 2013 - ISCED Fields of Education and Training 2013 is a classification of fields of education, which accompanies the International Standard Classification of Education 2011 (ISCED).

1.3.1. Identification of domain boundaries and categories for the analysis

As discussed in the previous section, the main limitation of existing initiatives is the fact that official classifications are not sufficient to map the techno-economic segments under study. As a consequence, the newly developed TES analytical approach is used in order to identify suitable boundaries of the addressed technological domains of interest (AI, HPC, CS). This is done by generating, in a semi-automatic way, a sufficiently representative set of *keywords* for each domain, corresponding to a suitable dictionary covering all the relevant terms intended as fundamental keywords in the considered domain. Once the list of representative keywords is established, it is used to query the data sources for the identification of the education offer and the companies focused in the technological domains. The length of the final list of keywords is such that the marginal increase of retrieved documents when querying the data sources sharply decreases to zero. In particular, a list of 35 to 50 terms has been considered for each domain under study (see Annex 1).

The keywords representing the technological domain are obtained in a three-step process:

(a) Selection of a seed subset of scientific articles where the characteristic keyword of the technology (e.g. "artificial intelligence") is present in the title, keywords or abstract of the publication[21]. This first step is run on all articles published in two different years (2009 and 2017), in order to capture both consolidated terms and neologisms, plausible to appear, given the constant technological developments in the domains. In view of expanding the set of investigated documents, and not examining only the papers containing the keyword, the journals in which these articles have been published are considered, and only those directly related to the technology are selected in this second step. Generalist journals or the ones centred in other scientific fields are ignored. For instance, the journal "Engineering Applications of Artificial Intelligence" would be selected, while "Physics of Life Reviews" would not, even if the latter has published some AI related articles. All papers published, during the two referred time periods, in the selected journals which are strongly representative of the scientific advancements in the technological domain, are analysed, and the most frequent author keywords considered.

(b) Given the fact that the study is also centred in the industrial dimension of the technological domain, also terms relevant for the industry need to be introduced. To that end, a similar approach leads to the selection of the most common technological terms in companies' activities descriptions.

(c) The list of candidate terms, sorted by relevance based on their frequency of occurrence, is then reviewed by experts and a short selection is made.

Then, the keywords have been grouped into categories based on multiple proximity criteria: technological, semantic, purpose-based and distance or co-occurrence in the analysed text (terms appearing together in the descriptions of education programmes or companies' activities).[22] Indeed, the identification of keywords and their clustering is an interesting result per se, as it may be considered a first step towards the construction of possible profiles as meaningful aggregation of fundamental skills. Finally, these results have been applied to categorise industrial activities and programmes, so to identify how academic training is suited to generate such potential profiles, and how such profiles are

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[21] This has been performed by analysing a vast amount of literature coming from the Scopus repository.

[22] For the keyword co-occurrence, a hierarchical agglomerative analysis for binary data has been so implemented. The similarity coefficient Phi of Pearson, appropriate for this type of binary data (presence vs non-presence), is used as a similarity measure between keywords. Using this coefficient, two keywords frequently appearing together in the programme descriptions will belong to the same cluster. The clusters are formed using the complete linkage criterion, and then, after the identification of the optimal number of clusters, they are manually labelled with the help of expert opinions. This exploratory phase therefore identified clusters for each domain.

visible in the industry activity. This can be regarded as a first exploration leading at the identification of front-end occupations and of the skills and knowledge required to supply adequate competences.

1.3.2. Assumptions and aspects to be considered

Being the present study a pilot which has been running for a very short period of time, it is affected by several assumptions and limitations. With regard to programmes, only academic programmes (not commercial ones, no MOOCs) have been considered.

The automatic identification of programmes by Machine Learning algorithms is complex and results are bound to be affected by algorithmic choices (different algorithm choices may therefore lead to other results). The same order of considerations stands for the analysis of the industrial activities and for clustering algorithms.

The overall weight of the English language is very high, even if this is expected to affect only moderately the overall results. Also, the analysis of industrial activities has been run in English language only, thou on sources with global coverage.

The clustering process is representing a first attempt, and it is identifying categories based on multiple proximity criteria. This shows a few limitations. At a later stage algorithms based on advanced topic modelling may be put in place to improve these issues.

The analysis is run by country, however several factors should be taken into account before drawing a line to connect industrial activities and academic programmes at country level, since several factors facilitate or hamper inter and intra country labour force mobility.

Nevertheless, the proposed figures and analysis provide:

— An overview of the whole EU28 panorama of academic offer in terms of bachelor and master programmes (resulting from an automatic classification process, so possibly affected by the choice of algorithms).

— A snapshot of the European industry in the selected technological domains, representing a relatively good coverage of the overall situation.

The clustering effort and the application of keyword clustering to the two sets of data aims at allowing for a first comparison between the side of demand for advanced professional profiles in the investigated domains, and the side of offer of academic formation.

1.3.3. Education offer in Europe in 2018

In a first exploratory trial, all the universities across Europe having a website have been considered (as listed by the Webometrics initiative) and, by applying text mining and machine learning techniques, the content related to study programmes addressing the report's domains has been extracted. The aim was manifold: to collect independently a first set of results, to have therefore a suitable term of comparison when considering third party sources, and to be able to measure strengths and weaknesses of a (semi)automatic classification system for programmes' content in view of a systematisation of the exercise. The identification of programmes related to AI, HPC and CS from web pages has several challenges: (a) inconsistence in terminology used by universities to refer to study programmes (e.g. a "course" may refer both to a part of a study programme, or the whole programme); (b) troublesome identification of individual programmes in the entire webpage (header, footer, menu items), especially in webpages showing lists with the whole education offer. Additionally, only English language content has been selected, due to limited resources to undergo a multilingual approach in data harvesting and text mining (mainly related to the amount of data to treat). The basic assumption, tested on randomly selected pages, is that the majority of master programmes are announced in English, while it is not the rule with undergraduate studies. Under these assumptions, the final product was a list of universities potentially focusing on AI, HPC and CS by announcing their bachelor and master studies. However, the identification of individual study programmes did not provide trustworthy data. As a consequence, another source to study education offer has been investigated.

In the current phase of the study, in order to rely on a validated source and have access to more detailed information, StudyPortals data on bachelor and master studies has been collected. Worldwide, StudyPortals covers over 170,000 programmes at 3,050 educational institutes across 110 countries[23], out of which over 50,000 correspond to programmes taught in European universities (Table 1). Programme information is collected by StudyPortals from institutions' websites[24]; their database is kept updated, with new programmes added at least once a year. The consideration of this source increases the precision and the coverage of academic programmes by EU universities with respect to what offered by the approach followed in the previous exploratory phase (in more than 90% of countries, the exploratory approach based on text mining Universities' websites resulted in lower university coverage than that provided by the selected source[25]). Moreover, the selected source proved to be the one offering the widest coverage among all those identified and consulted (it is in fact the one powering most of the currently running websites offering orientation to students). However, it still suffers from some lack of coverage, mostly due to the fact that national language programmes are not tracked, and that Universities may publish their programmes only at a specific time of the year (and not when programmes are already started and enrolment is not anymore possible).

The source aims to cover English-taught programmes. As this fact was considered as a possible limiting factor and it was feared that a significant number of programmes could have been left out, some case studies have been run in order to verify manually the degree of coverage of the actual offer by StudyPortals, which gave proof that a considerably high percentage of the targeted programmes is captured by the source (see Box 1 for details). In particular, the impact of the teaching language, although not negligible, is somehow limited and not strongly affecting the validity of the source. Universitiy's web presence is another factor affecting the coverage[26], since StudyPortals is fed with content placed at the universities' websites. Overall University coverage is also acceptable; universities not covered by the source are frequently concentrated among those with low Excellence ranking or low Web presence ranking. Considering these caveats, it can be confirmed that the coverage of the StudyPortals original dataset is sufficiently good. However, it is the case that a number of programmes and universities are not covered. Further validation came from the analysis of the exploratory activity based on webscraping and machine learning, which provided interesting results about the language independency of a sufficient pool of the most important keywords.[27]

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23 https://www.studyportals.com/

24 Institutions have the possibility to update information themselves.

25 The final results from the exploratory trial showed that 509 universities in the 28 EU Member States include pages referring to bachelor or master programmes, and to at least one of the technological domain keywords used for the searches. It is considered that 328 of them have a high probability of actually offering study programmes on artificial intelligence, high performance computing or cybersecurity at bachelor or master levels (this reduction is based on the number of keywords present in the pages; pages with too low number of keywords are considered as non-relevant, with its content indirectly referring to programmes, or showing the intention of offering programmes in the future).The fact that the number of identified universities is quite lower than the one offered by StudyPortals reflects the result of algorithm and parameter choices that could be revisited. In particular, the universities that have been marked as non-relevant might be actually offering programmes in the selected domains.

26 This rank is one of the criteria used by StudyPortals to include universities in the database.

27 Investigating the representativeness of the resulting dataset, it was found that language has certain but not total impact on identification of the related study programmes. Certain words are commonplace and are found in English in all countries (e.g. artificial intelligence, machine learning, cybersecurity…), while more complex strings (e.g. automated machine learning) were found in UK web pages only. Yet, the overall results show that a cluster of 21 keywords, including some of the most important keywords from all three domains, is rather language independent.

Besides, the programmes have been selected by means of the keywords identified following the methodology described in Paragraph 1.3.1. The information made available by the source allowed for searching at different levels of detail. This made it possible to group identified programmes into two categories, one gathering "specialised" programmes and another for more "general" ones. After testing this approach on a significant number of results, it has deemed useful to distinguish as specialised those programmes which hold particularly meaningful keywords in their titles or short descriptions, or with at least three different keywords present in any text field of the programme description[28], as they normally are programmes deeply focused on the mentioned topic, technique or application field. On the contrary, many programmes make reference to only one or two of the targeted keywords in more generic summary texts describing the programme. Those cases revealed to be associated with programmes targeting to some extent the addressed domain, but almost in all cases in a more generic way, aiming at building wider profiles, or making reference to it in the framework of a programme specialised in a different discipline (e.g. Photonics, Biomedical engineering, Finance and banking…). Therefore, the selected programmes have been classified into "specialised" and "broad" according to the degree and depth with which they focus on the domain. Examples of broad and specialised masters include:

- AI-specialised: "Artificial Intelligence - Cognitive Science", "Automation and Computer Vision", "Advanced Computer Science (Computational Intelligence)", " Applied Image and Signal Processing", etc.
- AI-broad: "Internet Science and Technology", "Applied Mathematics", "Life Science Informatics", "Biofluid Mechanics", "Finance and Banking", etc.
- HPC-specialised: "Big Data and High Performance Computing", "High-Performance Computer Systems", "Advanced Distributed Systems", "Distributed Systems and Web Technologies", "Computer Networking", etc.
- HPC-broad: "Information Systems and Computer Engineering", "Telecommunications Engineering", "Renewable Energy Systems", "Sport, Health and Exercise Sciences", " Visual Computing", etc.
- CS-specialised: "Computer Forensics", "Security in Computer Systems and Communications", "IT Security Management", "Cyber Technology", "Advanced Control Systems", etc.
- CS-broad: "Criminology", "Computer Science for Autonomous Systems", "Business Information Systems", "IT Management", "Governance and Law in Digital Society", etc.

BOX 1. CASE STUDIES: ASSESSMENT OF THE COVERAGE OF THE SELECTED SOURCE

Evidence has been collected by means of different sources and involving native language experts on the academic offer at master level in the domain of AI for the countries of Spain and France. The choice of these countries has been made on the basis of: (a) the language (different and not belonging to the same group of English), (b) expected medium to high level of development of an AI industry in the country, and (c) expected relative lower level of attractiveness of English-taught programmes for part of the local population.

In the case of **Spain**, jointly considering StudyPortals and desk research undergone, 67 masters have been identified from 37 universities. Forty percent of the masters (27) are specialised in AI and 60% (40) are classified as broad. Two thirds of these 67 masters are identified by StudyPortals, while one third (23 masters) has been detected with ad hoc searches in university websites but not covered by the referred source. Out of the 37 universities, 11 are not covered by StudyPortals. The latter are concentrated among the low-medium ranking universities, while 2

[28] The good performance of the methodology applied in order to classify programmes into specialised and broad has also been successfully tested. Tests run on 10% of the total number of identified programmes confirmed that considering at least 3 keywords was minimising the amount of misclassification.

universities among the top 500 universities according to the Excellence rank in Webometrics[29] are not covered by the source. This might be due to several reasons, including an explicit request of the university to withdraw from StudyPortals[30], language and details of the study programmes' information in the website, among others.

The detailed analysis of the masters not captured by StudyPortals can also help assessing the impact of the lack of coverage of the source. The characteristics of these masters, according to the teaching language, ranking of the university and other programme specificities shows the following results:

- Master's scope: The coverage of the source is 56% for specialised masters and 73% for broad masters.
- Master's University ranking: the coverage of StudyPortals reaches 82% of the masters when the university offering the program has a high ranking.
- Master's language: only 1 master is taught in English language in its entirety; 70% (16 masters) are taught in Spanish or the teaching language is not available in the website (hence can be assumed that it's Spanish); while 24% are taught in a combination of English and Spanish: 6 masters, for which a percentage of the content is offered in English language and the rest in national language, with a predominance of the latter in most of the cases analysed.
- Other programme specificities: a few of the programmes not captured by StudyPortals are "master propio" a type of non-official master targeted to acquire skills needed for the labour market, but not giving access to doctoral studies. In some cases, the master is being offered for the first time in the course 2018-2019; hence the absence might be well caused by the date of last data collection.

In the case of **France**, 102 masters have been identified from 49 universities. Following the criteria of depth of specialisation of the programme in the domain under study, 71% of the masters are considered as broad and 29% specialised in AI. StudyPortals includes 70% of them, and 30% of the programmes are not covered by the source and have been manually identified by web searches in universities' sites. Out of the 49 universities, 8 are not covered by StudyPortals, out of which 5 are high ranking universities according to the Webometrics Excellence rank. However, it's worthwhile noticing that the Webometrics' web Presence rank is quite low for French universities in general. In fact, there are no French universities among the top 1000 worldwide by web presence, compared to 24 Spanish universities. This fact has a strong impact in the coverage by StudyPortals. The characteristics of the 31 masters not covered by the source are as follows:

- Master's scope: as in the case of Spain, the coverage by the selected source of French masters is higher for broad studies (69%) than for specialised ones (59%).
- Master's language: 65% of the masters are taught in French or the teaching language is not stated in the website; 19% of the masters are taught in English language (6 masters), and 16% (5 masters) are taught in French with some content in English.
- Master's University ranking: in the French case study, the coverage of StudyPortals is lower for highly ranking universities. Only 47% of masters offered by high ranking universities is covered by the source, 53% for medium ranking, and 88% for low ranking universities.

Table 1 presents the data about academic programmes collected and associated to each technological domain. Programmes have been classified, depending on the level, into bachelors and masters. Even if not 100% exhaustive, the selected source proved to offer a rather precise idea of the percentage of academic offer targeting the selected domains in EU28. The table shows that currently tracked academic programmes.

[29] This rank is one of the criteria used by StudyPortals to include universities in the database.

[30] Even if it seems it applies only to a few cases, universities may retract information about their programmes from the portal while waiting for updating their education offer.

TABLE 1. OVERVIEW OF ACADEMIC OFFER IN THE EU, 2018

Domain	Number of tracked programmes			% of each domain over total programmes in any domain
	All levels	Bachelor	Master	
AI	2,054	765	1,289	3.9%
HPC	1,102	369	733	2.1%
CS	1,179	532	647	2.3%
Total nr of programmes in AI, HPC and CS	3,472	1,339	2,133	
Total nr of programmes tracked by StudyPortals in any domain in the EU	52,001	23,556	28,445	
% of AI, HPC and CS over StudyPortals Total	6.7%	5.7%	7.5%	

Note: The total number of programmes in the selected domains does not correspond to the sum of programmes in each domain due to the fact that a programme may correspond to more than one domain.

1.3.4. Industry activity: company profiles

The industry activity perspective of the study is proxied by analysing the profiles of the companies that are active in the technological domains. In the future it will also be applied a complementary approach, which was tested in the exploratory phase, by studying job offers where skills related to the technological domains are requested.

A direct comparison between number of companies and programmes does not provide insights about the skill gap, nor on the number of professionals needed to guarantee competitiveness in the uptake of disruptive technologies. However, this figure provides a tentative idea on country disparities in these two dimensions.

Company profiles

Companies active in an economic segment describe their activities based on their primary and sometimes also their secondary activity. The basic assumption to consider this source as suitable is that the companies active in a technological domain tend to look for skills very much related to those technologies that describe their activity.

The *JRC TES HOrizontal DAtabase (TESHODA)* includes several data sources collecting companies' microdata[31]. Such well known company databases incorporate up to date company descriptions and other textual data very useful for the purpose of the present study. The referred sources have been queried using the domain specific keyword lists. The number of companies identified as active in the technological domains is 5,400.

Interestingly, a much reduced number of keywords, less than 15 per domain, is enough for capturing more than 95% of all the detected companies, each of the additional keyword being able to retrieve only a residual and decreasing number of firms. Similarly, the number of keywords sufficient to represent 95% of all academic offer is also very low, and the match between the relevant keywords for both offer and demand is almost perfect. This result reinforces the usability of the selected list of keywords.

[31] Among them, those utilized in the study are BvD Orbis, Dowjones and Crunchbase.

Box 2. Exploratory Activity: A snapshot of job vacancies

To proxy industry needs, in a first exploratory data collection exercise, online vacancies from four private job portals (Monster, Indeed, EuroJobs, and Jobsite) have been screened, in order to classify them and extract the relevant information ensuring as much as possible a uniform coverage of all the EU countries, and coverage of qualified professionals and not only basic workers. A total of 9,461 vacancies was harvested, covering the entire month of June 2018 for the above listed job offer sites.

EURES, the European Job mobility Portal, has been also explored. In line with the data collection undergone in private job portals, the consideration of this portal aimed at offering a wider and more complete view of the industry activity of the selected technologies. As a relevant extension, EURES screening has been conducted in all EU languages, in order to retrieve the job offers posted in national languages, and thence amplify the country coverage. All job offers posted during the month of June 2018 were considered in the analysis.

The collected job offers have undergone a data treatment process in order to identify false positives, that is, cases initially identified as related to the technology during the collection stage, but that might not be referring to the selected technological domains in spite of some characteristics pointing in the direction of the inclusion. Consequently, cases suspected to be false positives have been identified and removed.

The number of job offers collected from each source, after the removal of false positives and after having grouped them with respect to the addressed domains according to the targeted profiles as emerging form the job description, was distributed by technological domain as follows:

Figure 1 Job offer from private portals and Eures

Domain¤	Nr·of·vacancies·from·private·job·portals¤	Nr·of·vacancies·in·Eures¤	Share·on·total·vacancies·in·Eures¤
AI¤	2,279¤	1,221¤	0.18%¤
HPC¤	678¤	101¤	0.01%¤
CS¤	1,038¤	494¤	0.07%¤
Total·analysed¤	n.a.¤	694,395¤	¤

The results of such an exploratory investigation confirmed that vacancies may be a suitable source to have a detailed view of the current industry demand. Therefore, a systematic exploration of job vacancies is planned to combine it with the overview provided by companies' activities.

2. AI technological domain

2.1. Mapping of the existing academic offer

The programmes offered by EU universities have been classified in specialised and broad, according to the degree and depth with which they focus on the technological domain. This facilitates the distinction between programmes whose entire content or most part of it concerns the domain, and those that include some specific course within a programme of a wider scope. Among the latter, general Computer science programmes can be included, but also programmes on other disciplines, e.g. Biomedical engineering, covering courses or modules on AI techniques such as signal processing or artificial neural networks.

This study identifies a total number of 2 054 programmes covering the domain of Artificial intelligence to a different extent. The vast majority of AI academic offer in Europe is taught at master level, the one generally perceived as the most appropriate to acquire the needed advanced skills, followed by bachelor studies (Figure 2). Table 2 shows that there are 197 European universities offering a total of 406 specialised masters in AI; 84 of the universities, or 43%, offer at least 2 specialised masters in AI.

Annex 2 presents a list of the European universities offering specialised masters by domain. The distribution of programmes by level and scope varies among countries (see Table A 1 in Annex 2), the highest proportion of specialised masters over the total offer per country is found in Slovakia, Finland, Czechia, France, Poland, and Estonia, with at least one third of their total AI academic offer in all levels and scopes concentrated in specialised masters. However, to have a rough idea on how well the education offer matches with industry needs in Europe, it is worthwhile considering the total amount of masters offered: about two thirds of the EU Member States have less than 10 master's programmes strongly focusing on AI. Only 11 Member States have more than 20 Master's programmes including at least one AI module, considering both specialised and broad programmes.

FIGURE 2. AI ACADEMIC OFFER: NUMBER OF PROGRAMMES BY PROGRAMME LEVEL AND SCOPE. EUROPEAN UNION, 2018

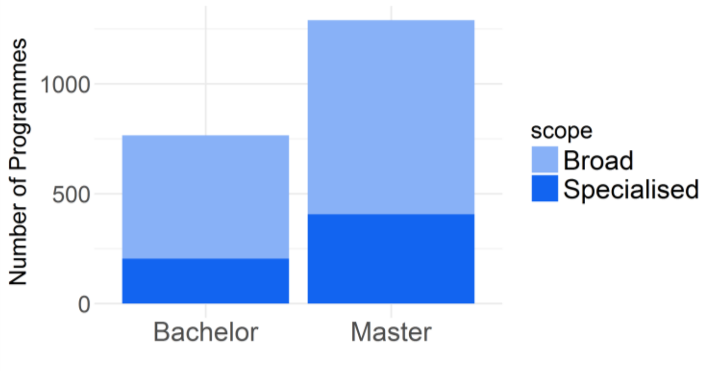


TABLE 2. AI ACADEMIC OFFER: NUMBER OF UNIVERSITIES OFFERING SPECIALISED MASTERS AND NUMBER OF MASTERS OFFERED. EU MEMBER STATES, 2018

	Number of universities offering Specialised Masters	Number of Specialised Masters
Belgium	3	3
Bulgaria	0	0
Czechia	1	3
Denmark	4	10
Germany	21	28
Estonia	3	3
Ireland	5	7
Greece	0	0
Spain	8	20
France	17	26
Croatia	0	0
Italy	15	19
Cyprus	2	4
Latvia	1	3
Lithuania	3	3
Luxembourg	0	0
Hungary	4	6
Malta	0	0
Netherlands	10	27
Austria	4	4
Poland	6	9
Portugal	4	5
Romania	6	6
Slovenia	0	0
Slovakia	2	4
Finland	9	17
Sweden	11	17
United Kingdom	58	182
European Union	**197**	**406**

Figure 3 shows the academic offer by thematic field in each level in the European Union.[32] The area of *Robotics & Autonomous systems* is covered by 35% of programmes offered by the European universities, when jointly considering bachelor and master studies. Programmes including courses on *Machine learning methods* constitute 21%, general aspects of *AI and Intelligent systems*, make 19%, *Image Recognition & Processing* is taught in 13% of programmes, and 3% are centred in *Speech Recognition & Natural Language Processing*. Another 8% of the programmes includes contents pertaining to the miscellaneous group *Other AI* areas. By programme level, *Robotics & Autonomous systems* is the most frequent topic in both bachelor and master programmes, while *Machine learning methods* ranks second in masters and fourth in bachelors. The most specialised areas of *Image Recognition & Processing* and *Speech*

[32] Similarly to what done for the classification of industrial activity, the programmes are classified into fields by considering the programme's description. Programmes are classified in all the fields covered by the programme's description. Fractional counting is considered to avoid double counting, so that the total number of programmes offered in the techno-economic segment can be computed as the sum of programmes in all fields.

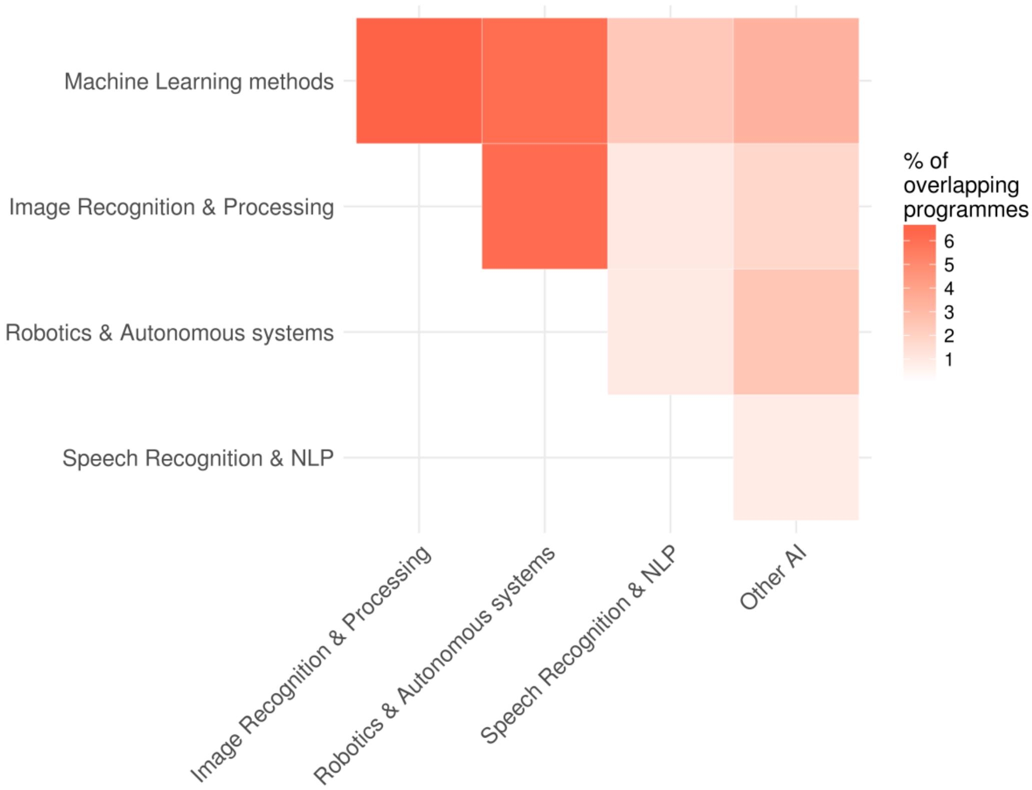
Recognition & Natural Language Processing are more likely to appear in the master level. Expectedly, the bachelor level has the highest share of generic AI studies, with 28% of all bachelor programmes in AI. When focusing on specialised masters, 35% cover the field of *Robotics & Autonomous systems*, 28% include *Machine learning methods*, 15% focus on *Image Recognition & Processing*, 11% on *Other AI areas*, 7% on generic AI, that is covering several aspect of AI with no specific focus on any particular subject, and 5% include modules or are completely focused on *Speech Recognition & Natural Language Processing*.

FIGURE 3. AI ACADEMIC OFFER: NUMBER OF PROGRAMMES BY PROGRAMME LEVEL AND FIELD (%). EUROPEAN UNION, 2018

Some specialised masters cover more than one field simultaneously. Figure 4 shows the percentage of programmes covering overlapping fields in pairs. For AI, one every four programmes cover at least two fields. The most frequent combinations appear between *Machine learning methods*, *Image Recognition & Processing* and *Robotics & Autonomous systems*.

Figure 5 shows the academic offer by thematic field (bachelor and master levels aggregated) in the EU Member States. The preference for programmes focused on *Robotics & Autonomous systems* seems quite generalized across countries, but still a few countries have another field as the main topic on interest in their academic offer: that is the case of *Machine learning* in Croatia, Finland, Italy, France, Greece, and Romania; or *Image Recognition & Processing* in Cyprus.

FIGURE 4 – NUMBER OF AI SPECIALISED MASTERS COVERING SEVERAL FIELDS (%). EUROPEAN UNION, 2018



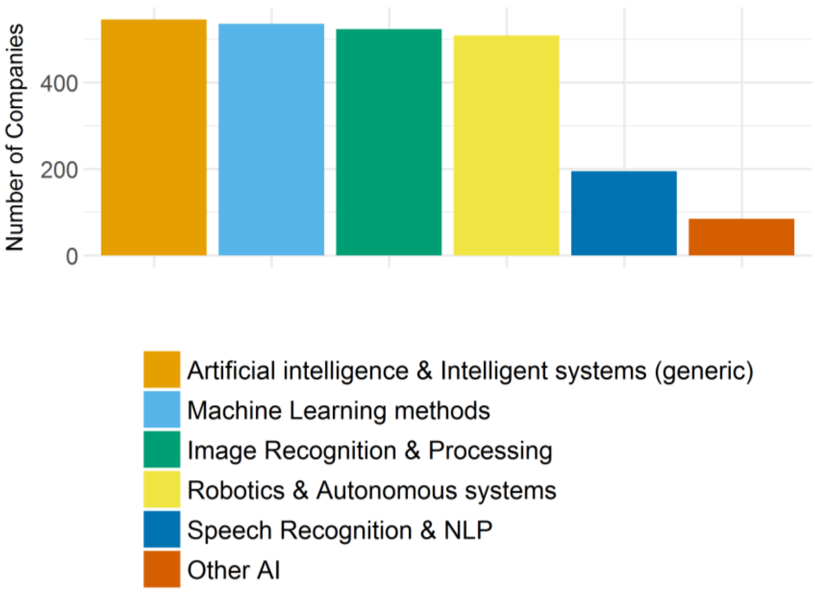
Note: The generic field does not ovelap with any other since, by definition, it is allocated only when no specialised field is present.

FIGURE 5. AI ACADEMIC OFFER BY PROGRAMME FIELD. EU MEMBER STATES, 2018

2.2. Mapping of industry activity in Europe

The European companies detected as involved in Artificial intelligence are classified by areas of activity[33], as shown in Figure 6. These areas of activity of the EU industry will be contrasted in the next section with the academic offer in the same fields.

FIGURE 6. AI INDUSTRY AREAS OF ACTIVITY. EUROPEAN UNION, 2018



Four big clusters encompass more than 88% of the European AI industry, with more than 500 companies each. The companies that refer to AI in general terms when describing their activities, or that are engaged in the broad field of Intelligent Systems, belong to the most numerous cluster of companies: *Artificial Intelligence & Intelligent Systems*. The next one is the group of companies making use of *Machine learning* in their daily activities, which includes companies providing AI as a service. The development and utilization of neural networks, deep learning, and other pattern recognition algorithms is a key skill in companies grouped in this cluster. The next group of companies develops its activity in the subfield of *Image Recognition & Processing*, a specialised field involving the use of machine learning methods for image recognition and processing, computer vision, face detection and recognition, etc. Specific education and training in the application of the mentioned methods to treat images is required in this AI domain. *Robotics & Autonomous systems* are the core business of 21% of the EU AI companies; while language related technologies are the main activity of another 8% of the detected companies. The latter covers the subfields of computational linguistics, natural language processing, understanding and generation, both in oral and written text formats, as well as applications of sentiment analysis. A smaller group of companies have their activity in a miscellaneous cluster including less common areas such as cognitive science or knowledge representation, and applications in predictive analytics or using computer simulation. Summarising, the wide range of activities in which AI companies are active requires specialised professionals in both basic use and development of algorithms, as well as in their application to specific subfields.

[33] This is done by considering the company's activity description, type of products developed or services offered, as collected from the explored data sources. In view of avoiding double counting, a company immersed in more than one area is considered by means of fractional counting, so that the total number of companies in the techno-economic segment can be computed as the sum of companies in all the clusters.

2.3. Academic offer and Industry profile

Figure 7 shows the relative position of European countries in AI industry and education, presenting the number of companies active in the techno-economic segment, and the number of programmes offered by universities, in percentage with respect to the European Union total. A direct comparison between number of companies and programmes does not provide insights about the skill gap, nor on the number of professionals needed in this technological domain. However, this figure gives a tentative idea on country disparities in these two dimensions. United Kingdom leads both in number of companies and of programmes offered by universities, hosting one third of AI companies and more than half of AI programmes. Other countries with relatively high number of companies are Germany, France, Spain, Netherlands and Sweden, while the education offer is also high in Italy and Ireland. In order to be able to compare the educational offer of different countries, it would be necessary to further qualify the analysis by introducing information regarding the quality of the universities, as well as the number of students graduated from these studies. On the industry side, the number of vacancies offered by the companies for specialists with advanced digital skills would also be needed in order to draw conclusions about the skills match. This report does not cover these types of considerations.

FIGURE 7. AI INDUSTRY (NB OF COMPANIES) VS AI ACADEMIC OFFER (NB OF PROGRAMMES) (%), 2018

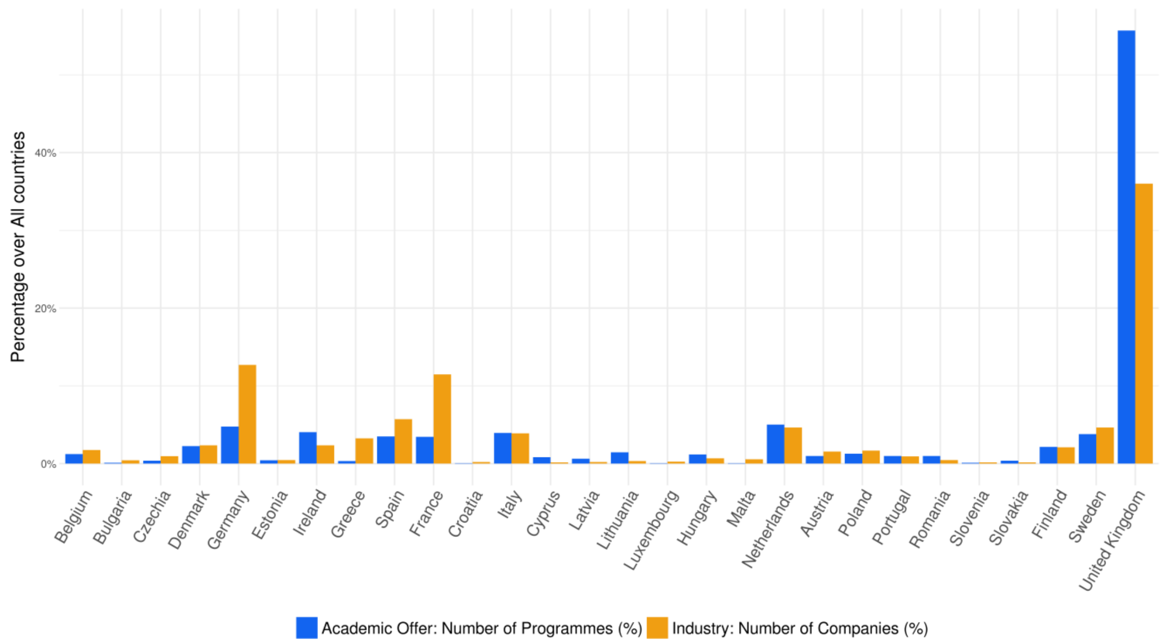
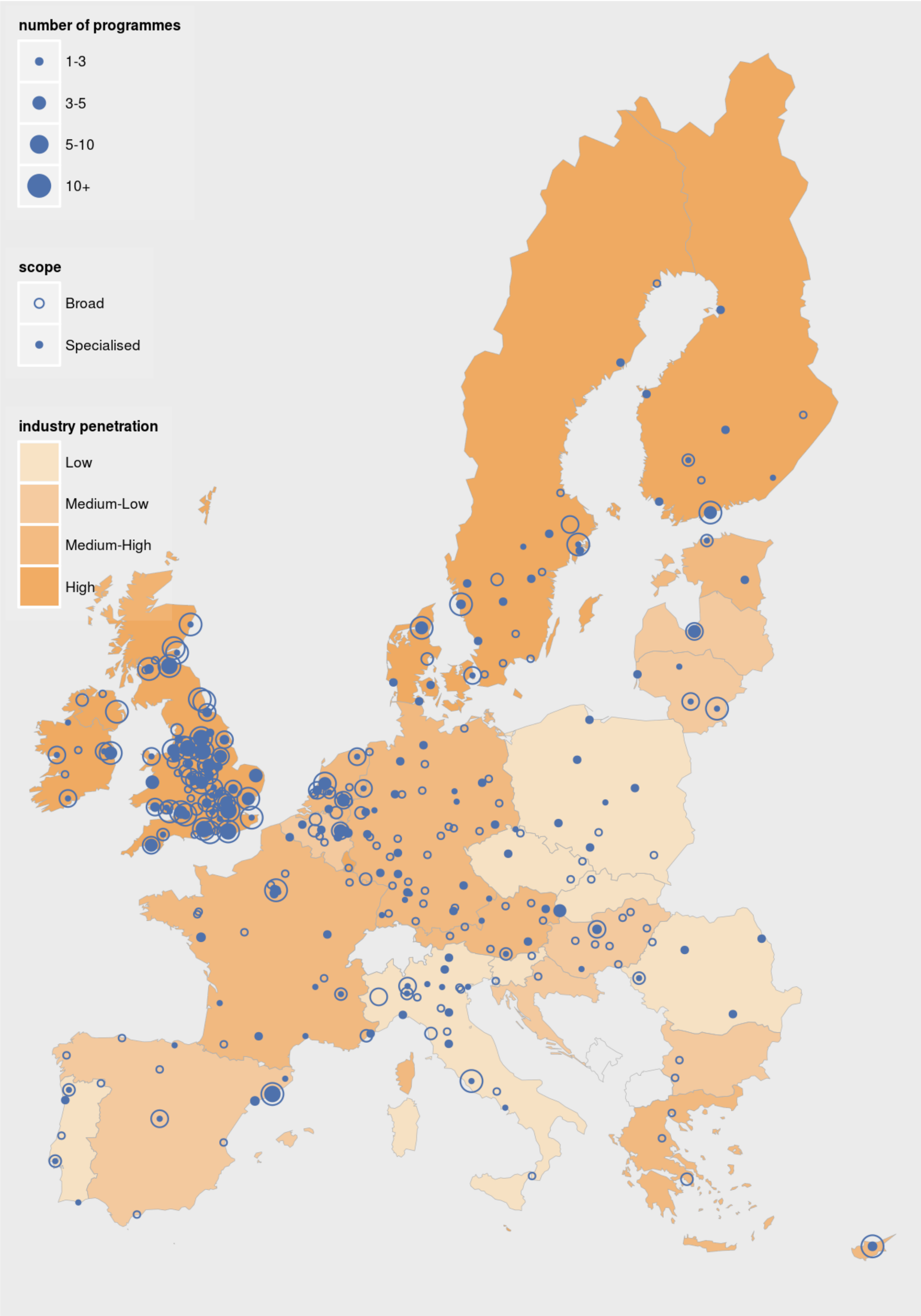


Figure 8 presents in a concise way the size of the AI industry by country and the academic offer by programme level and scope. The number of AI enterprises[34] over total number of enterprises[35] shows the industry penetration of AI in the country. The countries where the AI industry is most developed in this sense are Malta, United Kingdom, Denmark, Ireland, Finland, Luxembourg, and Sweden, with the highest penetration rates ranging from 4.5 AI companies every 10,000 companies in Malta to 1.6 in Sweden. As seen in the previous section, the academic offer is very much concentrated in the United Kingdom. The top five European cities by number of specialised programmes on AI of any level are London, Southampton, Edinburgh, Barcelona, and Manchester.

[34] As detected in the JRC TES HOrizontal DAtabase, see Paragraph 1.3.4.

[35] Total number of companies refers to 2016 data for the aggregate *Total business economy except financial and insurance activities*, as provided by Eurostat's Structural Business Statistics "Annual enterprise statistics for special aggregates of activities (NACE Rev. 2) [sbs_na_sca_r2]", last updated 21 December 2018.

FIGURE 8. AI ACADEMIC OFFER AND INDUSTRY: NUMBER OF PROGRAMMES BY SCOPE AND INDUSTRY PENETRATION PER COUNTRY. EUROPEAN UNION, 2018

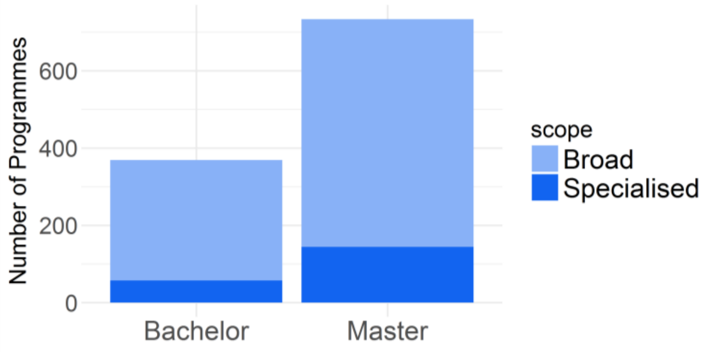


3. HPC technological domain

3.1. Mapping of the existing academic offer

This study has identified a total number of 1 102 programmes involving the HPC domain, considering both specialised and broad programmes, the latter covering the domain only in some courses or modules into a wider scope programme. Over two thirds of the academic offer in HPC in Europe are taught at master level. Specialised programmes have a lower share with respect to the total offer in the domain as compared with AI. At master level, specialised programmes constitute 20% of all masters on HPC, and 15% in bachelors (Figure 9). Table 3 shows that there are 88 European universities offering a total of 144 specialised masters in HPC; 28 out of the universities, or 32%, offer at least 2 specialised masters in HPC. Annex 2 presents a list of the European universities offering specialised masters by domain.

FIGURE 9. HPC ACADEMIC OFFER: NUMBER OF PROGRAMMES BY PROGRAMME LEVEL AND SCOPE. EUROPEAN UNION, 2018



The distribution of programmes by level and scope varies among countries (see Table A 2 in Annex 2).In Romania, Czechia, Finland and Netherlands at least one third of programmes is a specialised master. In 13 countries, the educational offer in HPC is only taught at master level.

Figure 10 shows the academic offer by thematic field in each level in the European Union. As expected, all levels are mostly focused on the field of *HPC Architectures & Technologies*, constituting the building blocks of the services to be offered by companies. This pattern is repeated in almost all countries (Figure 12). In specialised masters, 75% include courses on *HPC Architectures & Technologies*, 19% on Cloud Computing and the rest equally split between generic and other HPC contents, 3% each.

Figure 11 show the overlap in the fields covered by some specialised masters in HPC. For HPC, one every five programmes cover at least two fields. The most frequent combinations appears between *Cloud computing* and *HPC Architectures & Technologies*.

TABLE 3. HPC ACADEMIC OFFER: NUMBER OF UNIVERSITIES OFFERING SPECIALISED MASTERS AND NUMBER OF MASTERS OFFERED. EU MEMBER STATES, 2018

	Number of universities offering Specialised Masters	Number of Specialised Masters
Belgium	2	3
Bulgaria	0	0
Czechia	2	2
Denmark	3	5
Germany	11	13
Estonia	0	0
Ireland	4	5
Greece	0	0
Spain	3	5
France	5	5
Croatia	0	0
Italy	4	6
Cyprus	0	0
Latvia	0	0
Lithuania	2	2
Luxembourg	0	0
Hungary	0	0
Malta	0	0
Netherlands	4	12
Austria	0	0
Poland	2	2
Portugal	0	0
Romania	4	4
Slovenia	0	0
Slovakia	0	0
Finland	2	6
Sweden	7	10
United Kingdom	33	64
European Union	**88**	**144**

FIGURE 10. HPC ACADEMIC OFFER: NUMBER OF PROGRAMMES BY PROGRAMME LEVEL AND FIELD. EUROPEAN UNION, 2018

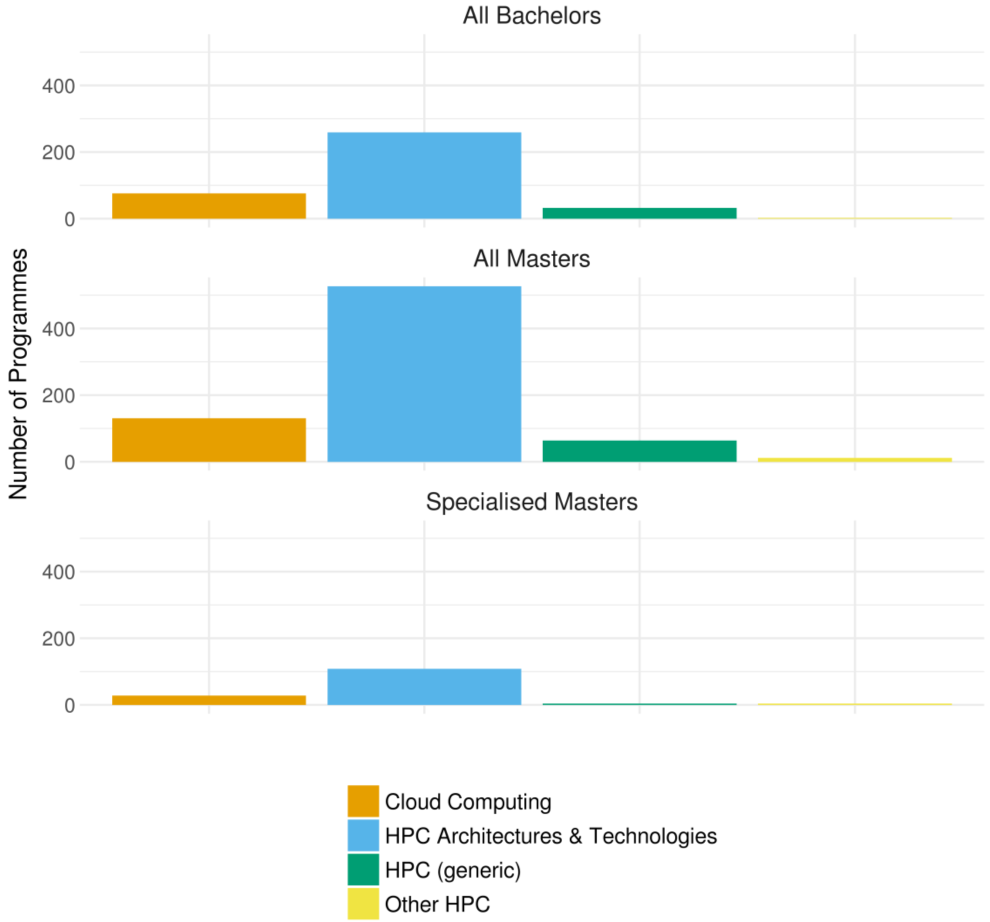


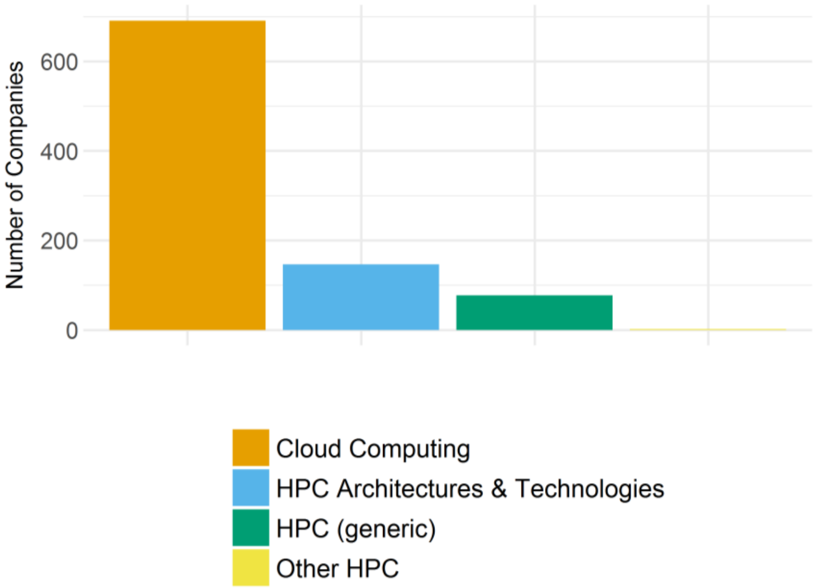
FIGURE 11 - NUMBER OF HPC SPECIALISED MASTERS COVERING SEVERAL FIELDS (%). EUROPEAN UNION, 2018

FIGURE 12. HPC ACADEMIC OFFER BY PROGRAMME FIELD. EU MEMBER STATES, 2018

3.2. Mapping of industry activity in Europe

In the HPC industry, Cloud computing is the main area of activity, involving 75 % of the detected companies (Figure 13). These companies offer cloud services, usually in combination with other related services such as virtualization and automation software, virtualization platforms, computing optimization for customers, etc. The second most relevant area, with 16% of companies, is that of HPC Architectures & Technologies, involving activities in massively accelerated computing solutions, software development tools for parallel programming, management of computer servers, optimization of algorithms, etc. Due to the fact that the services provided by cloud computing companies heavily rely on the technologies and algorithmic development grouped under the second cluster, it would be expectable to find the education offer very much concentrated in that area of activity.

FIGURE 13. HPC INDUSTRY AREAS OF ACTIVITY. EUROPEAN UNION, 2018



3.3. Academic offer and Industry profile

Figure 14 shows the relative position of European countries in HPC industry and education, presenting the number of companies active in the techno-economic segment, and the number of programmes offered by universities, in percentage with respect to the European Union total. As said before, although a direct comparison of companies and programmes is not fully meaningful, this figure gives a tentative idea on country disparities in these two dimensions.

As in AI, United Kingdom leads both in number of HPC companies (53% of the EU total) and number of HPC university programmes (62% of all EU HPC programmes). Other countries with relatively high number of companies are Germany (8.2%), France (7.3%), Spain (5.7%), Ireland (4.6%) and Netherlands (4.4%). In education offer, only Germany and Ireland offer more than 50 programmes in the domain, with 5.6% and 5.4% of all EU offer.

FIGURE 14. HPC INDUSTRY (NB OF COMPANIES) VS HPC ACADEMIC OFFER (NB OF PROGRAMMES) (%), 2018

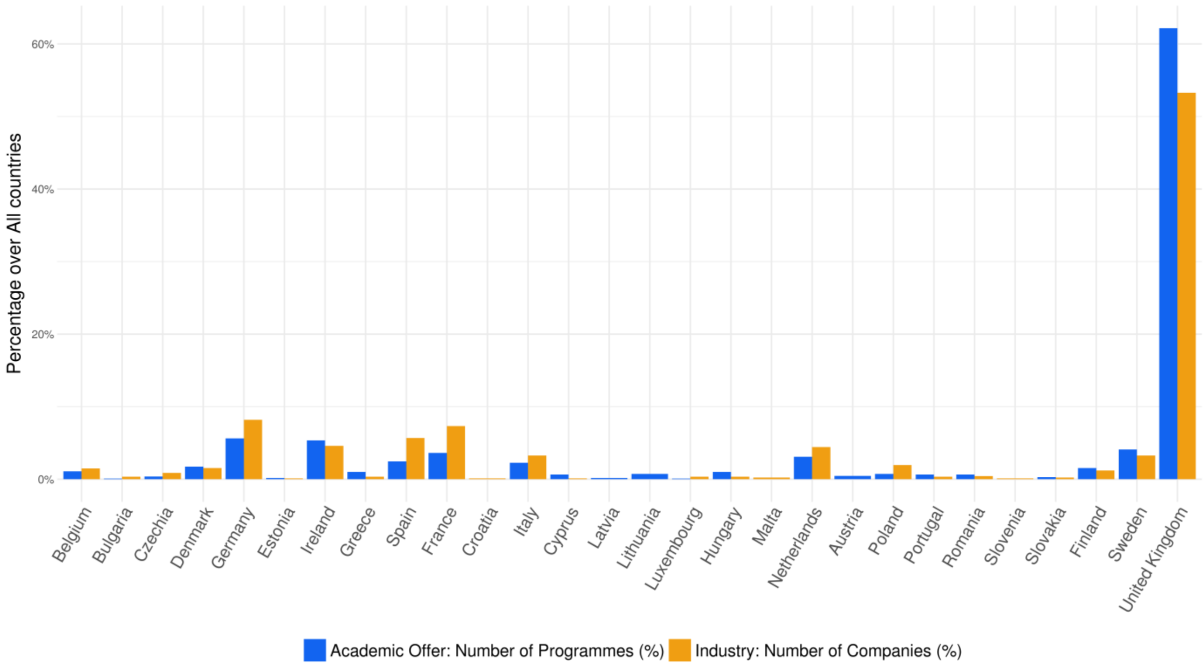
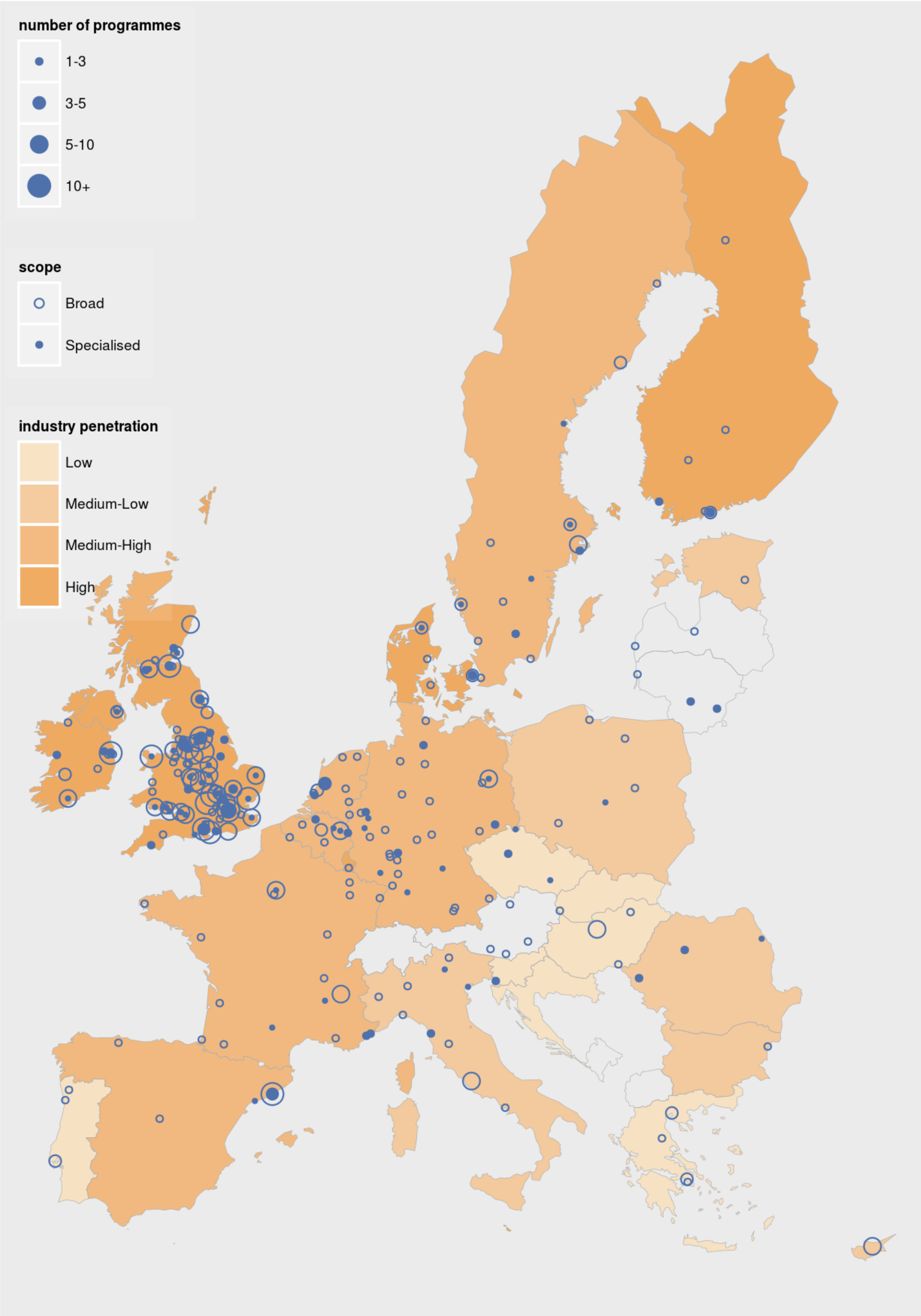


Figure 15 presents the size of the HPC industry by country and the academic offer by programme level and scope. The countries with highest industry penetration in the HPC domain are United Kingdom (2.3 HPC companies every 10,000 companies), Ireland (1.7), Luxembourg (0.9), Malta (0.7), Denmark (0.6) and Finland (0.5). The top five European cities by number of specialised programmes on HPC of any level are London, Amsterdam, Leeds, Bolton, and Southampton.

FIGURE 15. HPC ACADEMIC OFFER AND INDUSTRY: NUMBER OF PROGRAMMES BY SCOPE AND INDUSTRY PENETRATION PER COUNTRY. EUROPEAN UNION, 2018



4. CS technological domain

4.1. Mapping of the existing academic offer

Figure 16 show the number of programmes targeting CS in EU28 universities by programme level. Each bar in the figure is also further split to allow distinguishing broad from specialised programmes. This study identifies a total number of 1 179 programmes addressing to some extent the CS domain. Master programmes constitute 55% of all programmes in the domain, with 45% of bachelor studies covering cybersecurity aspects. Among the three domains analysed in this report, CS is the one with highest share of specialised programmes, with 36% of masters and 25% of bachelor degrees (Figure 9). Table 3 shows that there are 140 European universities offering specialised masters in CS; 53 out of the universities, or 38%, offer at least 2 specialised masters in CS. Table A 4 in Annex 2 presents a list of the European universities offering specialised masters by domain. The distribution of programmes by level and scope varies among countries (Table A 3).

Figure 17 shows the academic offer by thematic field in each level in the European Union. Network Security is the most repeated field both at bachelor level and master level, present in 29% of programmes, followed by Information Security and Cryptography, both with 17%. Risk Assessment & Prevention and Cybersecurity (generic) amount for 14% each, followed by Control Systems & Architectures and Other CS, with less than 5% each. The distribution among fields of specialised masters is as follows: Network Security: 28%, Information Security: 21%, Risk Assessment & Prevention: 19%, Cryptography: 17%, Other CS: 7%, Control Systems & Architectures: 5%, Cybersecurity (generic): 4%.

Figure 18 shows the percentage of specialised masters covering overlapping fields in pairs. For CS, one every three specialised masters covers at least two fields. The most frequent combinations appear between *Network Security*, *Information Security* and *Cryptography*.

FIGURE 16. CS ACADEMIC OFFER: NUMBER OF PROGRAMMES BY PROGRAMME LEVEL AND SCOPE. EUROPEAN UNION, 2018

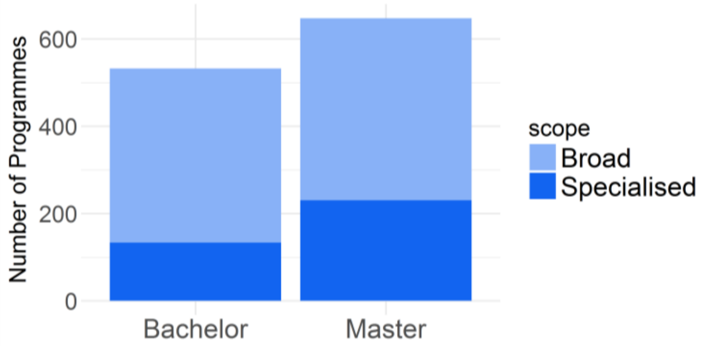
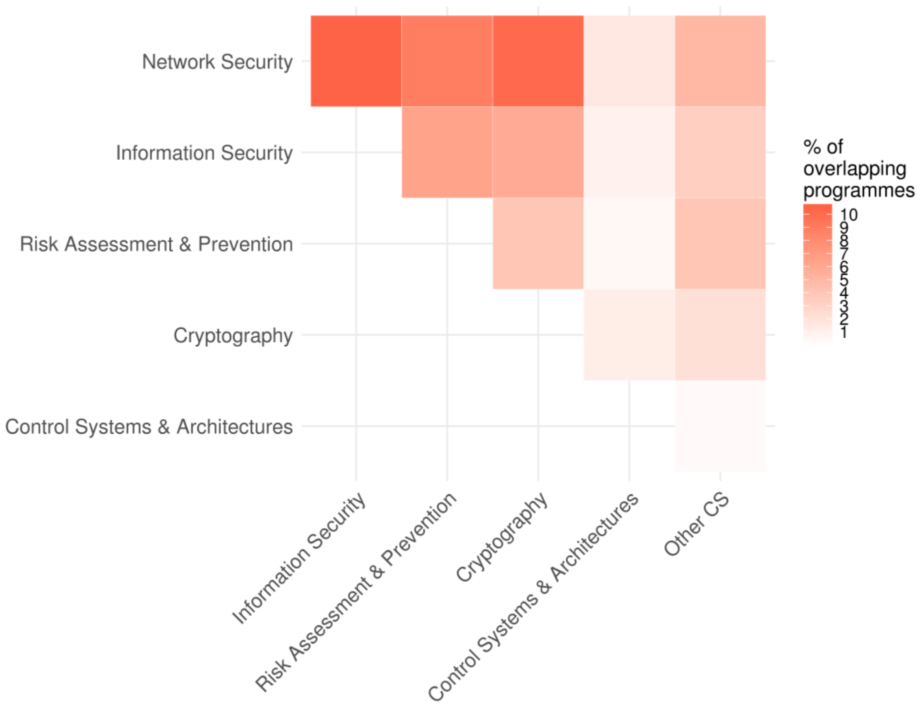


TABLE 4. CS ACADEMIC OFFER: NUMBER OF UNIVERSITIES OFFERING SPECIALISED MASTERS AND NUMBER OF MASTERS OFFERED. EU MEMBER STATES, 2018

	Number of universities offering Specialised Masters	Number of Specialised Masters
Belgium	1	2
Bulgaria	1	1
Czechia	1	2
Denmark	1	1
Germany	6	6
Estonia	3	4
Ireland	5	8
Greece	4	4
Spain	4	5
France	9	10
Croatia	0	0
Italy	6	6
Cyprus	2	3
Latvia	1	1
Lithuania	1	1
Luxembourg	1	1
Hungary	0	0
Malta	0	0
Netherlands	7	9
Austria	2	2
Poland	1	1
Portugal	0	0
Romania	0	0
Slovenia	0	0
Slovakia	1	1
Finland	5	10
Sweden	4	4
United Kingdom	74	148
European Union	**140**	**230**

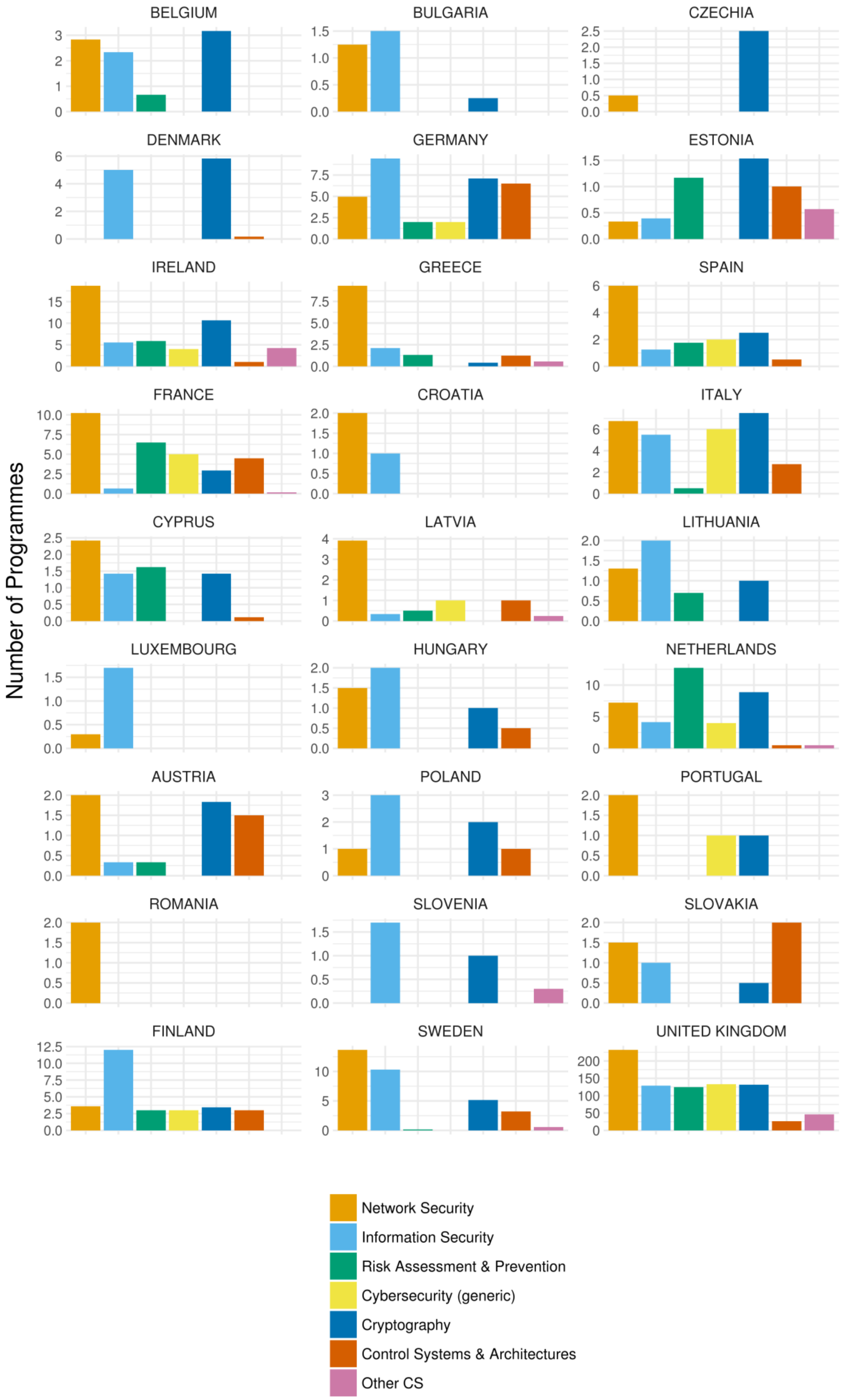
FIGURE 17. CS ACADEMIC OFFER: NUMBER OF PROGRAMMES BY PROGRAMME LEVEL AND FIELD. EUROPEAN UNION, 2018

FIGURE 18 - NUMBER OF CS SPECIALISED MASTERS COVERING SEVERAL FIELDS (%). EUROPEAN UNION, 2018



Note: The generic field does not ovelap with any other since, by definition, it is allocated only when no specialised field is present.

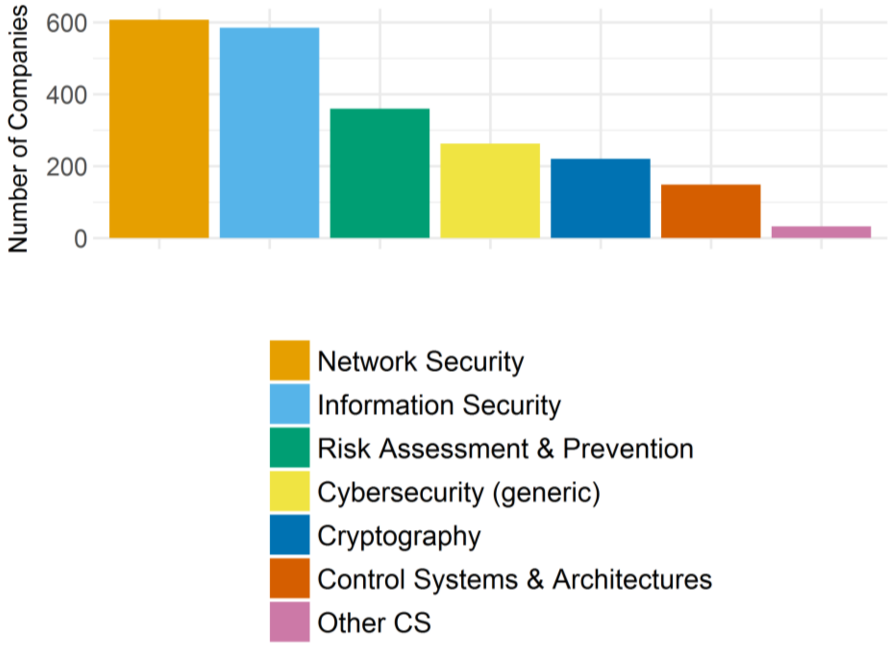
FIGURE 19. CS ACADEMIC OFFER BY PROGRAMME FIELD. EU MEMBER STATES, 2018



4.2. Mapping of industry activity in Europe

The European companies detected as involved in the CS domain are classified by specific areas of activity as shown in the following figure. The two big clusters of *Network Security* and *Information Security* ideally collect about half of the European CS industry. Still more than 10 % is covered by the following areas: *Risk assessment and prevention* and the less specialised *Cybersecurity*. *Cryptography* and *Control Systems and Architectures* shows lower percentages corresponding to more specialised subdomains.

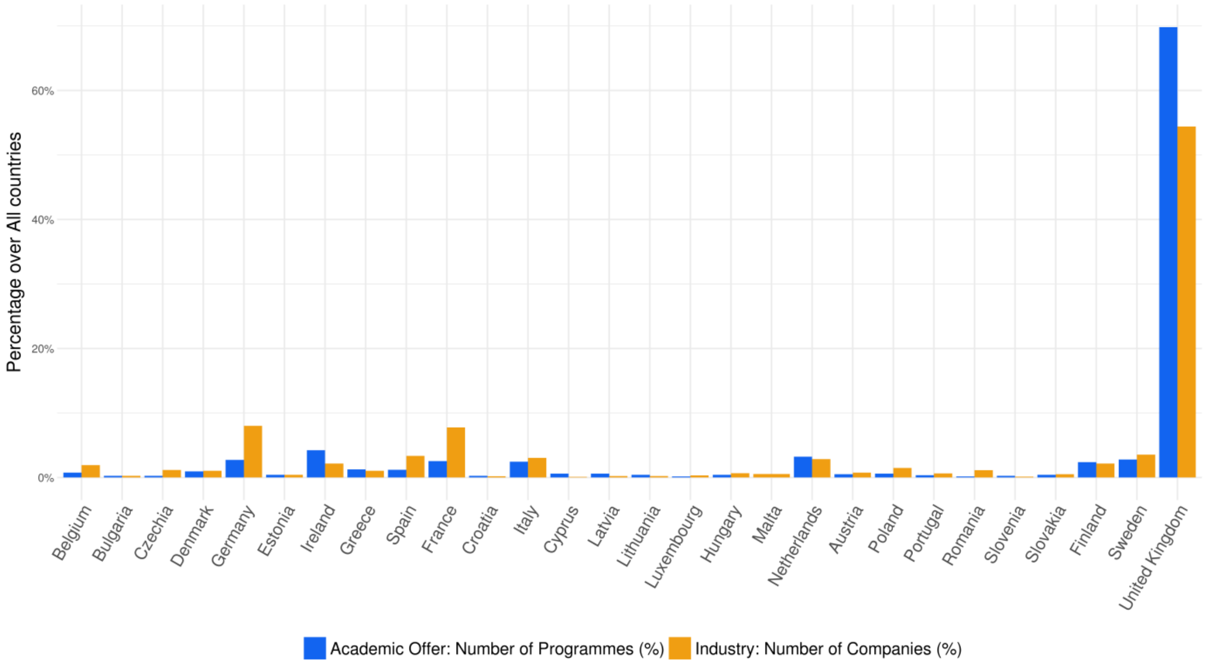
FIGURE 20. CS INDUSTRY AREAS OF ACTIVITY. EUROPEAN UNION, 2018



4.3. Academic offer and Industry profile

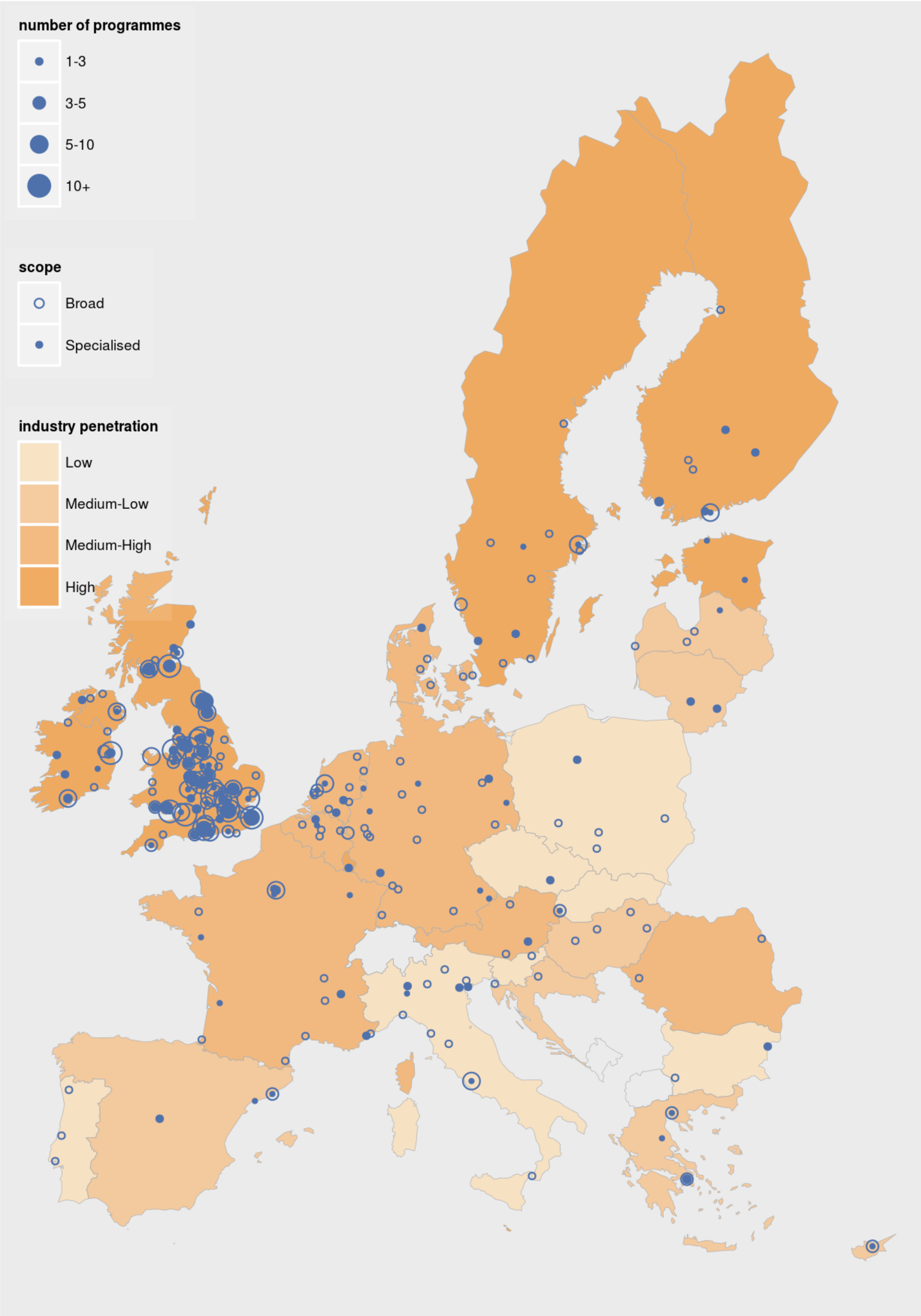
Also in the case of Cybersecurity, Figure 21 presents the relative position of European countries in CS industry and education, presenting the number of companies active in the techno-economic segment, and the number of programmes offered by universities, in percentage with respect to the European Union total. Still, it is not possible to draw a direct analysis of the potential skill gap. However, countries' current results can be roughly checked, and disparities can be spotted. Also in this case United Kingdom leads both in number of companies and number of programmes offered by universities. The cases of France, Germany and to a certain extent also Spain and Sweden show a relatively higher industrial activity not completely corresponded by matching academic programmes.

FIGURE 21. CS INDUSTRY (NB OF COMPANIES) VS CS ACADEMIC OFFER (NB OF PROGRAMMES) (%), 2018



The countries with highest industry penetration in the CS domain are United Kingdom (5.7 HPC companies every 10,000 companies), Malta (4.1), Luxembourg (2.2), Finland (2.1), Ireland (2.0), Estonia (1.3), and Sweden (1.1) (Figure 22). The top five European cities by number of specialised programmes on CS of any level are London, Canterbury, Sunderland, Southampton, and Cambridge.

FIGURE 22. CS ACADEMIC OFFER AND INDUSTRY: NUMBER OF PROGRAMMES BY SCOPE AND INDUSTRY PENETRATION PER COUNTRY. EUROPEAN UNION, 2018



5. Education offer in several domains

The three technological domains under study are not independent, since they share some underlying technologies, methods and fields of application. For instance, machine learning algorithms have become scalable and applicable to increasing amounts and streaming inflows of data thanks to supercomputers, parallelisation and distributed systems, and those algorithms are being used to fight cybercrime. The academic offer mirrors this overlap, by providing some programmes covering more than one technological domain. Figure 23 shows the overlap between the three technological domains in terms of education programmes addressing one of more of these. AI programmes constitute 59% of all academic offer in any of the three domains: 42% addressing only AI and 17 % addressing simultaneously also HPC or CS.

Figure 24 presents to what extent Member States cover the three technological domains in their education offer, at bachelor or master level, and Figure 25 provides the same information but restricting to specialised masters. Most countries offer at least one programme in the three domains. However, many countries do not cover all of them in specialised masters, with the HPC domain missing in 13 Member States.

Table 5 summarizes, for each Member State, the number of identified universities offering suitable academic programmes in each of the domains.

FIGURE 23. OVERLAP OF TECHNOLOGICAL DOMAINS IN ACADEMIC OFFER. PERCENTAGE OF ACADEMIC PROGRAMMES PER DOMAIN. EUROPEAN UNION, 2018

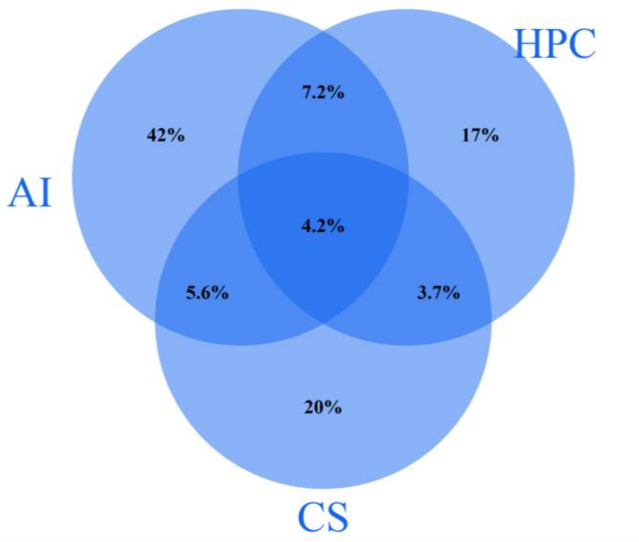


Figure 24. Number of Programmes by Domain. EU Member States, 2018

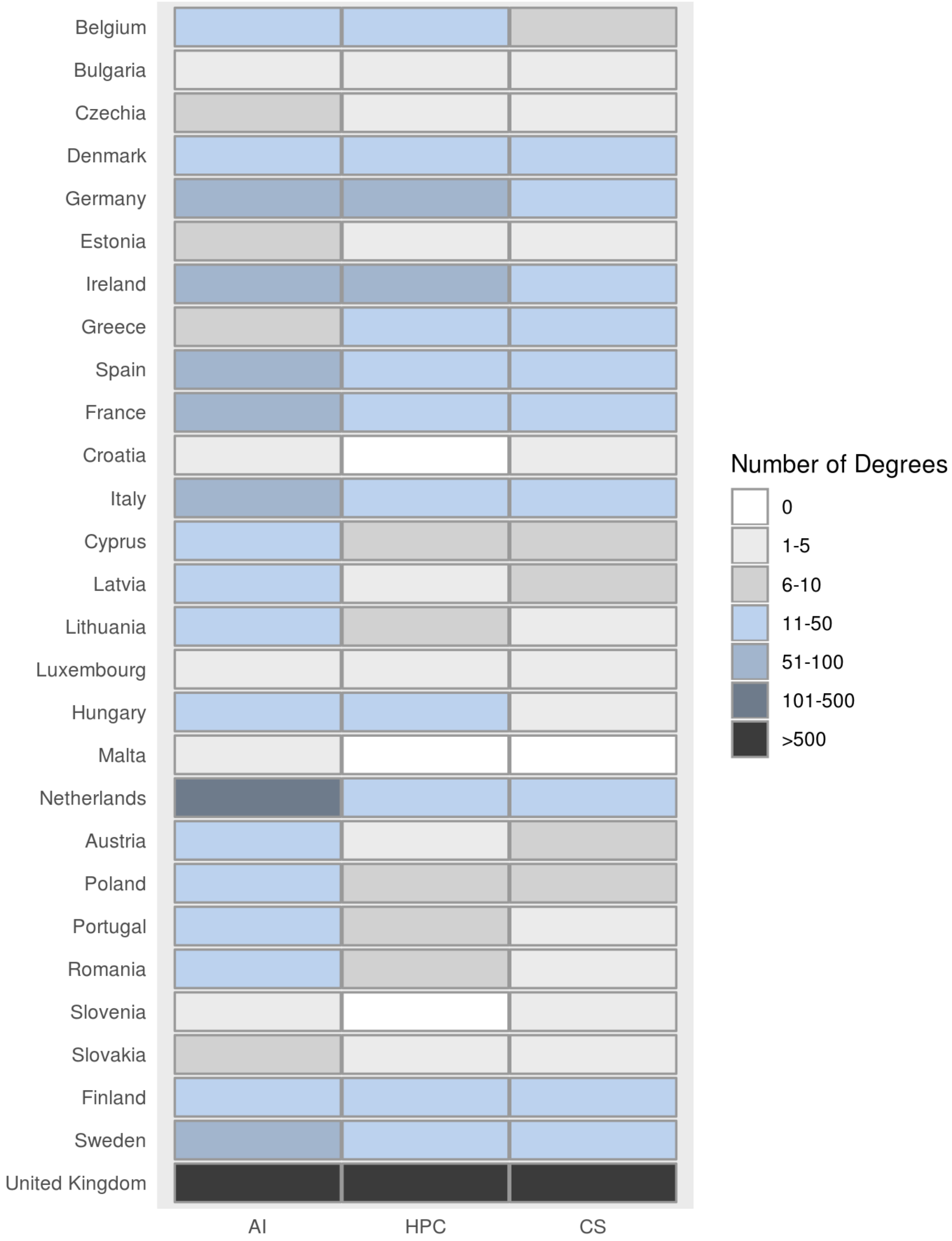


FIGURE 25. NUMBER OF SPECIALISED MASTERS BY DOMAIN. EU MEMBER STATES, 2018

TABLE 5. NUMBER OF IDENTIFIED UNIVERSITIES BY DOMAIN. EU MEMBER STATES, 2018

	AI	HPC	CS	Total universities in AI, HPC and CS domains
Belgium	9	5	5	11
Bulgaria	2	1	2	3
Czechia	5	2	1	6
Denmark	7	7	6	11
Germany	54	44	27	82
Estonia	3	1	3	4
Ireland	18	17	18	23
Greece	6	8	8	14
Spain	19	12	6	23
France	38	25	24	55
Croatia	1	0	2	2
Italy	30	16	18	34
Cyprus	6	4	3	6
Latvia	3	2	5	6
Lithuania	7	5	3	8
Luxembourg	1	1	1	1
Hungary	14	6	4	14
Malta	1	0	0	1
Netherlands	19	10	17	25
Austria	12	5	4	13
Poland	12	6	6	16
Portugal	9	4	3	10
Romania	9	4	2	9
Slovenia	1	0	2	2
Slovakia	3	1	1	3
Finland	15	10	13	22
Sweden	21	20	16	29
United Kingdom	116	124	125	145
European Union	441	340	325	578

Note: The total number of universities in the selected domains does not correspond to the sum of universities active in each domain universities normally cover more than one domain.

6. Conclusion

The main objective of this study is to present a methodology to provide a mapping of the academic offer in Artificial Intelligence, High Performance Computing and Cybersecurity and to apply it to the European Union and its Member States. Such an objective is reached by collecting and assessing the academic offer and the industry activity in these technological domains in 2018. The sources used to that end are proven fit for the purpose and the best available, although some lack of coverage is observed in the source to monitor academic offer.

The report provides an overview of the EU28 academic offer of bachelor and master programmes and a snapshot of the activities by European industry. Even if a direct comparison between number of companies and programmes is not enough to reach conclusions about the skill gap, or to speculate on the number of professionals needed to guarantee EU industry's competitiveness, it gives a tentative idea on country disparities in these two dimensions. In that sense, it is observed that the United Kingdom hosts more companies and educational programmes than any other EU Member State in the three technological domains studied.

Across the three considered technological domains, about 60% of education programmes are offered at master level and 40% at bachelor level. The share of specialised programmes is around one fourth of all programmes, with variations depending on the domain. The majority of broad programmes may mirror industry praxis of hiring employees with generic academic background in computer science or data science to then train internally. Specialised masters represent 18% of the whole educational offer in these domains.

Industry and education do not necessarily show the same distribution of activity areas and fields of study. There is some correspondence between those specialised skills that target the building blocks of the domain on the one hand, and the skills needed by companies to provide their services on the other. One example is provided by the good amount of programmes containing courses on *Machine learning methods*, teaching the advanced skills pool that may be applied to many industry areas such as those related with image, text, robotics, etc. Another example is provided in the High Performance Computing domain, where it can be observed a clear match between the field of study covering HPC Architectures & Technologies and its application in Cloud computing services, the main industry area in this domain.

Talent is one essential ingredient for disruptive technologies to be developed and used. AI and digitalisation are producing a strong impact in the European economy and society, affecting also the work environment and requested digital skills.

In Europe, there is a significant and persistent ICT skills gap. Demand for skills in emerging areas such as AI, HPC or CS are particularly acute and the problem is growing as the offer lags behind the market. Most Member States are facing shortages of ICT professionals and technicians, while the current education offer of specialised higher education programmes is limited and not equally available in all Member States. Also considering profiles, at country level disparities appear. Some countries do not present a sufficiently good correspondence between the fields covered by education offer and the areas where industry is active.

However, inter-country labour force mobility should be also considered, as well as students' mobility to enrol in academic programmes throughout Europe.

Future extensions of the project might include the following:

— consideration of the number of students, as well as university quality indicators, to better assess the skill mismatch;

— analysis of other types of education offer, such as MOOCs, lifelong learning, vocational training;

— consideration of the number of vacancies offered by the companies for specialists with advanced digital skills, by scaling up the exploratory investigation addressing job search sites to better assess industrial needs;
— establishing a connection between industrial needs and education offer and occupations, skills and qualifications as reflected by the ESCO framework.

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Annex 1. List of domain specific keywords

Artificial intelligence	Cyber security	High performance computing
adaptive learning	computer security	cloud computing
applied intelligence	control system	computer modelling
artificial immune system	counter-intelligence	cuda
artificial intelligence	cryptography	data intensive computing
artificial neural network	cryptology	distributed computing
automated machine learning	cyber attack	distributed systems
autonomous systems	cyber counterintelligence	exascale
cognitive science	cyber crime	gpgpu
computational creativity	cyber defense	gpu
computational linguistics	cyber physical system	grid computing
computer analysis	cyber resilience	hadoop
computer simulation	cyber risk	high performance computing
computer vision	cyber security	high velocity data
convolutional neural network	cyber situational awareness	high veracity data
decision analytics	cyber terrorism	hpc
deep learning	cyber threat	hpc applications
distributed computing	cyber trust	hpcc
expert system	cyber war	in silico experiment
extreme learning machine	cyber warfare	infiniband
face detection	data security	large-scale observations
face recognition	data security and privacy	mapreduce
fraud and anomaly detection	digital forensics	massive parallelism
image processing	encryption	message passing interface
image recognition	exploitation techniques	parallel algorithm
intelligent systems	hackers	parallel architecture
knowledge representation	hacking	parallel computation
machine learning	identity and access management	parallel computing
metaheuristic optimisation	industrial control system	parallel processing
multiagent system	information assurance	parallel programming
natural language generation	information protection	parallelization
natural language interface	information security	scalability
natural language processing	intrusion detection	single instruction multiple data
natural language queries	malware	supercomputer technology
natural language understanding	network and distributed systems	supercomputing
neural network	network security	
pattern recognition	operational incident handling and digital forensics	
predictive analytic	penetration testing	
predictive data science	phishing	
recommender system	pre-emptive and strategic force operation	

Artificial intelligence	**Cyber security**	**High performance computing**
reinforcement learning	security analysis and design	
robotics	software and hardware security engineering	
semisupervised learning	stuxnet	
sentiment analysis	supervisory control and data acquisition	
speech recognition	system security	
statistical learning	theft intelligence	
supervised learning	trust management assurance and accountability	
swarm intelligence	vulnerability assessment	
transfer learning		
unsupervised learning		

Annex 2. Detailed results

Table A 1 - AI Academic Offer: Number Of Programmes By Programme Level And Programme Scope. EU Member States, 2018

	Bachelor		Master		Total
	Broad	Specialised	Broad	Specialised	
Belgium	0	0	22	3	25
Bulgaria	1	0	1	0	2
Czechia	0	0	5	3	8
Denmark	3	6	27	10	46
Germany	11	4	55	28	98
Estonia	2	1	3	3	9
Ireland	29	10	37	7	83
Greece	2	0	5	0	7
Spain	14	11	27	20	72
France	1	1	43	26	71
Croatia	0	0	1	0	1
Italy	5	0	57	19	81
Cyprus	4	1	8	4	17
Latvia	3	3	4	3	13
Lithuania	9	4	14	3	30
Luxembourg	0	0	1	0	1
Hungary	10	0	8	6	24
Malta	1	0	0	0	1
Netherlands	10	7	59	27	103
Austria	3	0	13	4	20
Poland	7	3	7	9	26
Portugal	3	0	12	5	20
Romania	4	1	9	6	20
Slovenia	0	0	2	0	2
Slovakia	0	2	2	4	8
Finland	2	1	24	17	44
Sweden	0	0	61	17	78
United Kingdom	437	149	376	182	1144
European Union	**561**	**204**	**883**	**406**	**2054**

Table A 2 - HPC Academic Offer: Number Of Programmes By Programme Level And Programme Scope. EU Member States, 2018

	Bachelor		Master		Total
	Broad	Specialised	Broad	Specialised	
Belgium	0	0	9	3	12
Bulgaria	0	0	1	0	1
Czechia	0	0	2	2	4
Denmark	7	1	6	5	19
Germany	8	2	39	13	62
Estonia	0	0	2	0	2
Ireland	21	4	29	5	59
Greece	2	0	9	0	11
Spain	5	2	15	5	27
France	3	0	32	5	40
Croatia	0	0	0	0	0
Italy	2	0	17	6	25
Cyprus	2	0	5	0	7
Latvia	0	0	2	0	2
Lithuania	3	0	3	2	8
Luxembourg	0	0	1	0	1
Hungary	2	0	9	0	11
Malta	0	0	0	0	0
Netherlands	7	1	14	12	34
Austria	0	0	5	0	5
Poland	0	0	6	2	8
Portugal	0	0	7	0	7
Romania	0	1	2	4	7
Slovenia	0	0	0	0	0
Slovakia	0	0	3	0	3
Finland	1	0	10	6	17
Sweden	2	0	33	10	45
United Kingdom	247	46	328	64	685
European Union	**312**	**57**	**589**	**144**	**1102**

TABLE A 3 - CS ACADEMIC OFFER: NUMBER OF PROGRAMMES BY PROGRAMME LEVEL AND PROGRAMME SCOPE. EU MEMBER STATES, 2018

	Bachelor		Master		Total
	Broad	Specialised	Broad	Specialised	
Belgium	0	1	6	2	9
Bulgaria	1	0	1	1	3
Czechia	0	0	1	2	3
Denmark	7	0	3	1	11
Germany	5	1	20	6	32
Estonia	0	1	0	4	5
Ireland	18	8	16	8	50
Greece	4	2	5	4	15
Spain	0	1	8	5	14
France	1	1	18	10	30
Croatia	1	0	2	0	3
Italy	1	1	21	6	29
Cyprus	2	0	2	3	7
Latvia	4	0	2	1	7
Lithuania	0	1	3	1	5
Luxembourg	0	0	1	1	2
Hungary	1	0	4	0	5
Malta	0	0	0	0	0
Netherlands	7	2	20	9	38
Austria	0	0	4	2	6
Poland	4	0	2	1	7
Portugal	0	0	4	0	4
Romania	1	0	1	0	2
Slovenia	1	0	2	0	3
Slovakia	2	0	2	1	5
Finland	6	0	12	10	28
Sweden	4	1	24	4	33
United Kingdom	329	113	233	148	823
European Union	**399**	**133**	**417**	**230**	**1179**

FIGURE A 1 - AI ACADEMIC OFFER: NUMBER OF PROGRAMMES BY COUNTRY, PROGRAMME LEVEL AND PROGRAMME SCOPE. EU MEMBER STATES, 2018

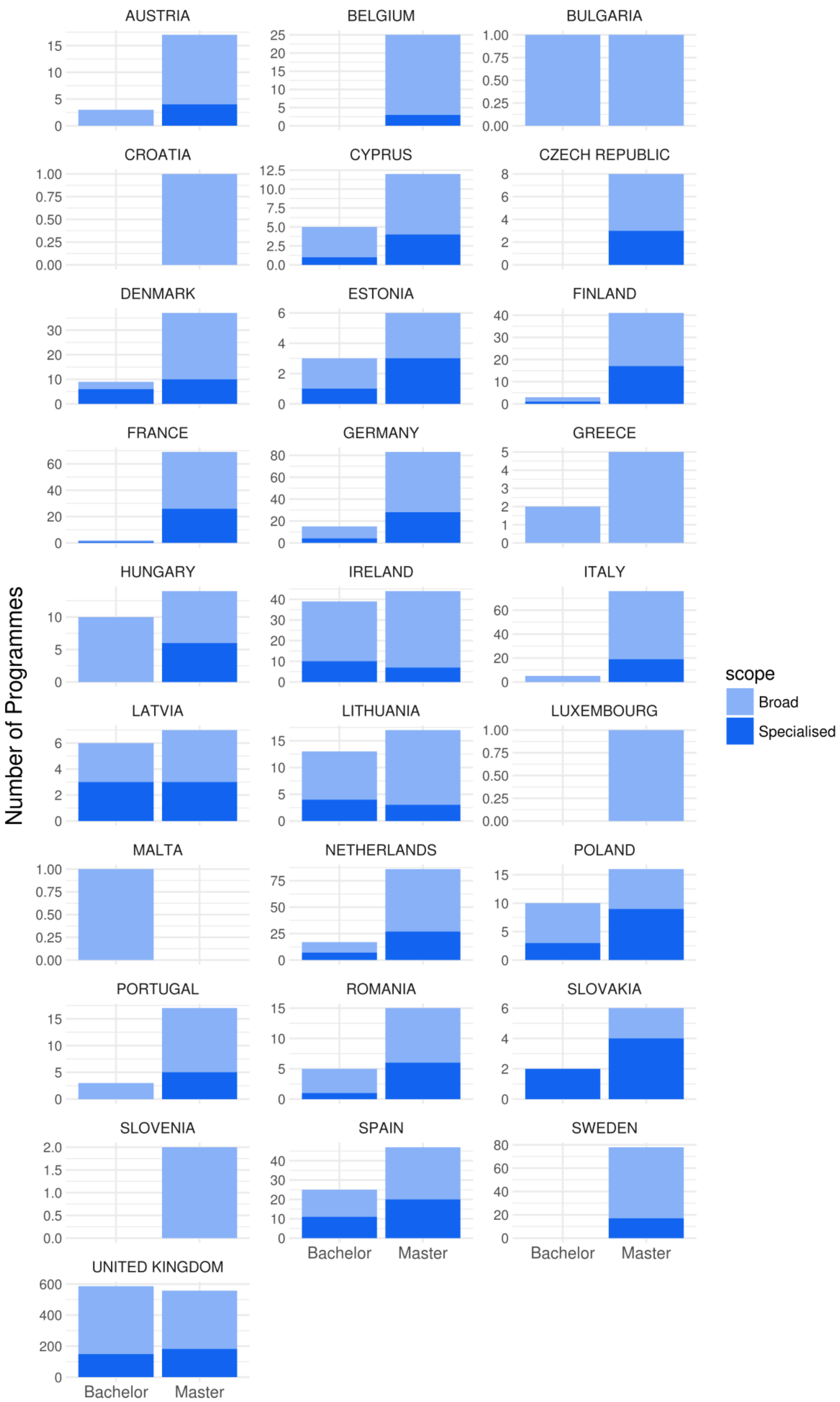

FIGURE A 2 - HPC ACADEMIC OFFER: NUMBER OF PROGRAMMES BY COUNTRY, PROGRAMME LEVEL AND PROGRAMME SCOPE. EU MEMBER STATES, 2018

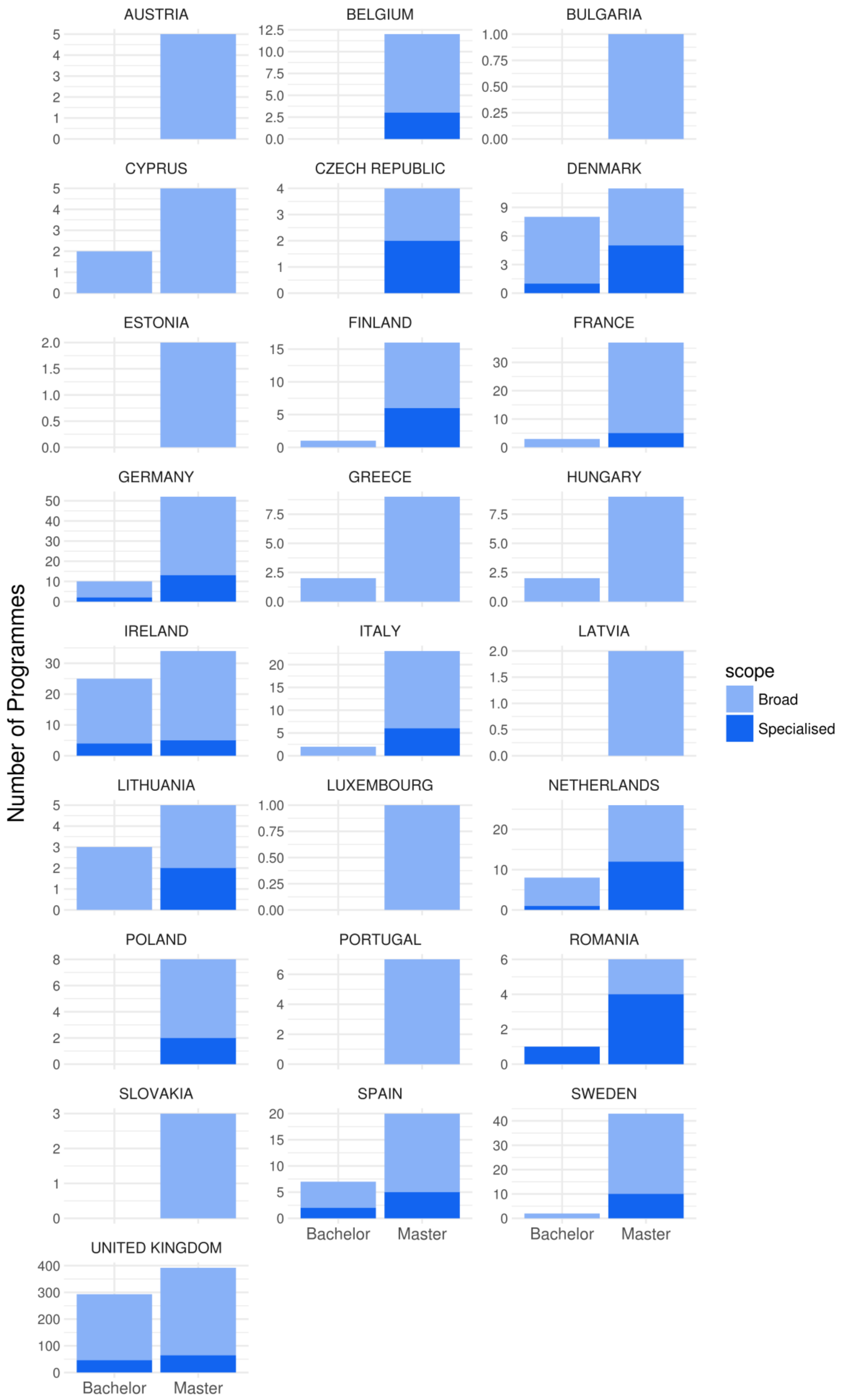

FIGURE A 3 - CS ACADEMIC OFFER: NUMBER OF PROGRAMMES BY COUNTRY, PROGRAMME LEVEL AND PROGRAMME SCOPE. EU MEMBER STATES, 2018

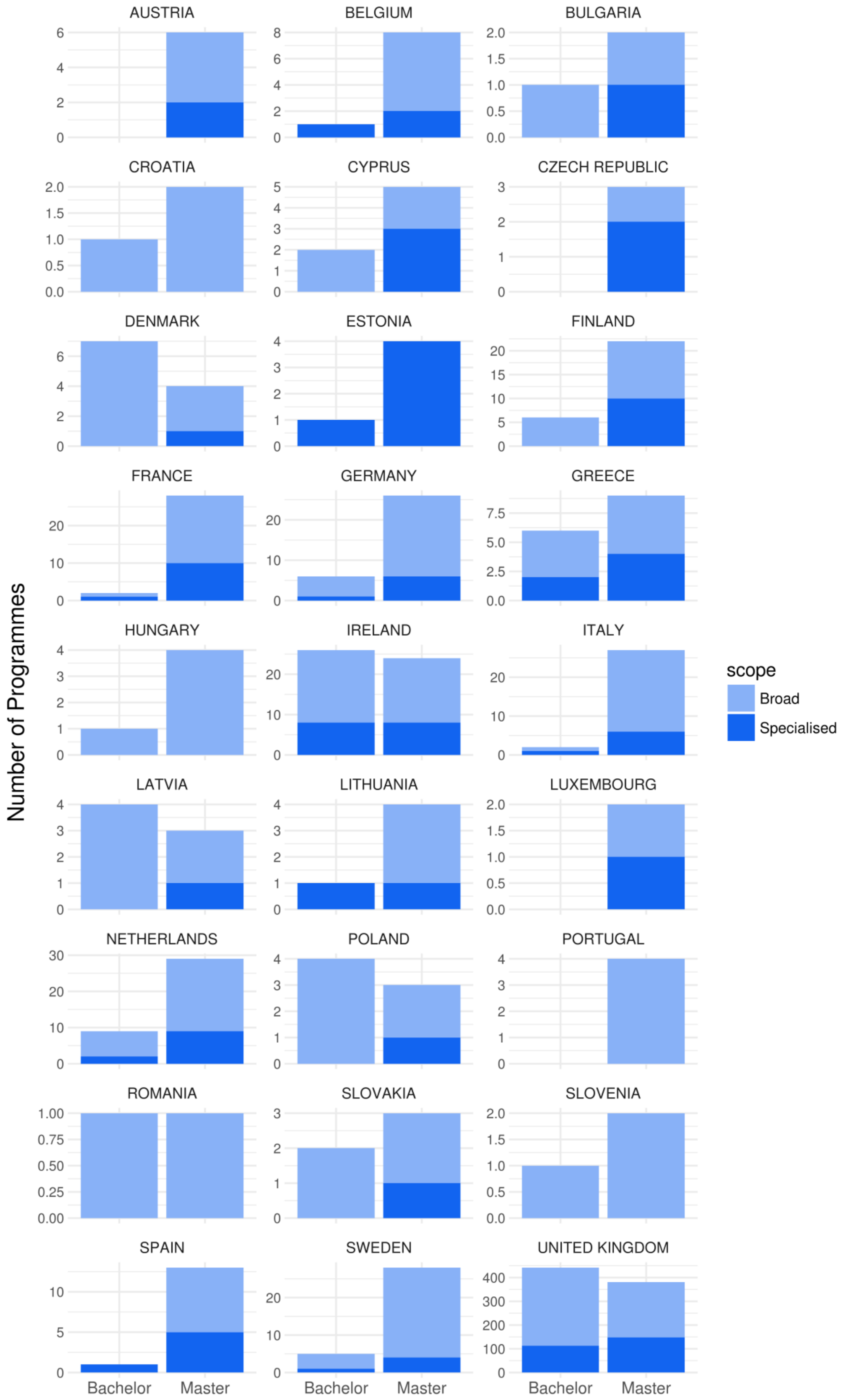

TABLE A 4 NUMBER OF SPECIALISED MASTERS OFFERED BY UNIVERSITY. EU MEMBER STATES, 2018

Country	University	Number of specialised masters			
		AI	CS	HPC	AI, HPC, CS
European Union		**406**	**230**	**144**	**714**
Belgium	Ghent University	1	0	0	1
Belgium	Hasselt University	0	1	0	1
Belgium	KU Leuven	1	0	0	1
Belgium	University of Antwerp	0	2	2	2
Belgium	University of Liège	1	0	0	1
Bulgaria	Varna Free University "Chernorizets Hrabar"	0	0	1	1
Czechia	Charles University	3	1	0	4
Czechia	Masaryk University	0	1	2	2
Denmark	Aalborg University	5	2	1	7
Denmark	IT University of Copenhagen	1	2	0	2
Denmark	University of Copenhagen	1	1	0	1
Denmark	University of Southern Denmark	3	0	0	3
Germany	Anhalt University of Applied Sciences	1	0	0	1
Germany	Bielefeld University	1	0	0	1
Germany	Brand Academy - University of Applied Sciences	0	2	0	2
Germany	Deggendorf Institute of Technology	0	0	1	1
Germany	Esslingen University of Applied Sciences	1	0	0	1
Germany	Frankfurt School of Finance & Management	1	1	0	2
Germany	Friedrich-Alexander-Universität Erlangen-Nürnberg (Erlangen Campus)	0	1	0	1
Germany	German Research School for Simulation Sciences	0	1	0	1
Germany	GISMA Business School	0	0	1	1
Germany	International Institute Zittau, Central Academic Unit of TU Dresden	1	1	0	2
Germany	International School of IT Security	0	0	1	1
Germany	Otto von Guericke University Magdeburg	1	0	0	1
Germany	RWTH Aachen University	3	0	0	3
Germany	Technical University of Munich	2	0	0	2
Germany	TH Köln (University of Applied Sciences)	0	2	0	2
Germany	The Bonn-Rhine-Sieg University of Applied Sciences	1	0	0	1
Germany	The Brandenburg University of Technology Cottbus - Senftenberg	0	0	1	1
Germany	TU Dortmund University	1	0	0	1
Germany	TU Dresden	1	1	0	2
Germany	University of Bonn	1	0	0	1
Germany	University of Bremen	1	0	0	1
Germany	University of Duisburg-Essen	1	1	0	1
Germany	University of Freiburg	1	0	0	1
Germany	University of Hamburg	1	0	0	1
Germany	University of Kaiserslautern	1	1	1	2
Germany	University of Passau	1	0	1	1
Germany	University of Potsdam	2	0	0	2
Germany	University of Stuttgart	3	1	0	3
Germany	University of Tübingen	2	0	0	2
Germany	University of Wuppertal	0	1	0	1
Estonia	ITMO University	1	0	0	1
Estonia	Tallinn University	0	0	1	1
Estonia	Tallinn University of Technology	1	0	1	2
Estonia	University of Tartu	1	0	2	3

Country	University	Number of specialised masters			
		AI	CS	HPC	AI, HPC, CS
Ireland	Cork Institute of Technology	1	1	2	4
Ireland	Dublin City University	0	1	1	2
Ireland	Dublin Institute Of Technology	0	0	1	1
Ireland	Institute of Technology, Sligo	1	0	0	1
Ireland	Maynooth University	1	0	0	1
Ireland	National University of Ireland, Galway	2	1	0	3
Ireland	Trinity College Dublin	0	2	0	2
Ireland	University College Dublin	2	0	2	4
Ireland	University of Limerick	0	0	2	2
Greece	Business College Athens (BCA)	0	0	1	1
Greece	Hellenic American College	0	0	1	1
Greece	International Hellenic University	0	0	1	1
Greece	TEI of Thessaly	0	0	1	1
Spain	Autonomous University of Barcelona	3	3	0	6
Spain	Carlos III University of Madrid	0	0	1	1
Spain	ISDE - Instituto Superior de Derecho y Economica	1	0	1	2
Spain	Pompeu Fabra University	1	0	0	1
Spain	Universitat Politècnica de Catalunya · BarcelonaTech (UPC)	4	1	1	6
Spain	Universitat Rovira I Virgili	5	1	2	5
Spain	University of Barcelona	2	0	0	2
Spain	University of Girona	2	0	0	2
Spain	University of the Basque Country	2	0	0	2
France	Centrale Lille	1	0	0	1
France	Data ScienceTech Institute	3	1	0	3
France	Ecole Centrale de Nantes	5	0	1	6
France	École Polytechnique	1	0	1	2
France	EDHEC Business School	1	0	0	1
France	EPITA Graduate School of Computer Science	0	0	1	1
France	ESIEE Paris	1	0	0	1
France	EURECOM - Graduate school and Research Center in Digital Science	0	1	2	2
France	Grenoble INP Institute of Engineering Univ. Grenoble Alpes	1	1	1	3
France	HEC Paris School of Management	1	0	0	1
France	IMT Mines Albi-Carmaux	0	1	0	1
France	INSA Toulouse - Institut National des Sciences Appliquées	1	0	0	1
France	Montpellier Business School	1	0	0	1
France	NEOMA Business School	1	0	0	1
France	Paris-Saclay University	2	1	0	2
France	Sciences Po	0	0	1	1
France	Toulouse Business School	0	0	1	1
France	Université Côte d'Azur	1	0	0	1
France	Université de Lorraine	0	0	1	1
France	University Jean Monnet (Saint-Étienne)	2	0	0	2
France	University of Bordeaux	1	0	1	2
France	University of Burgundy	2	0	0	2
France	UPEC - Université Paris-Est Créteil	1	0	0	1
Italy	Ca' Foscari University of Venice	3	3	1	3
Italy	EIT Digital Master School	1	1	0	2
Italy	Free University of Bozen-Bolzano	2	0	0	2

Country	University	Number of specialised masters			
		AI	CS	HPC	AI, HPC, CS
Italy	International School for Advanced Studies	0	1	0	1
Italy	MIP Politecnico Di Milano	1	0	0	1
Italy	Politecnico Di Milano	1	0	0	1
Italy	Sapienza University of Rome	2	0	1	3
Italy	Tor Vergata University of Rome	1	0	1	2
Italy	Università Commerciale Luigi Bocconi	0	0	1	1
Italy	University of Bologna	1	0	0	1
Italy	University of Brescia	1	0	0	1
Italy	University of Genova	1	0	0	1
Italy	University of Naples Federico II	1	0	0	1
Italy	University of Padova	0	0	1	1
Italy	University of Pavia	1	0	1	2
Italy	University of Pisa	0	1	0	1
Italy	University of Siena	1	0	0	1
Italy	University of Trento	1	0	0	1
Italy	University of Verona	1	0	0	1
Cyprus	European University Cyprus (EUC)	0	0	1	1
Cyprus	Open University of Cyprus	1	0	0	1
Cyprus	University of Cyprus	3	0	0	3
Cyprus	University of Nicosia	0	0	2	2
Latvia	Riga Technical University	3	0	0	3
Latvia	Vidzeme University of Applied Sciences	0	0	1	1
Lithuania	Kaunas University of Technology	0	1	0	1
Lithuania	Klaipeda University	1	0	0	1
Lithuania	Siauliai University	1	0	0	1
Lithuania	Vilnius Gediminas Technical University	1	0	1	2
Lithuania	Vilnius University	0	1	0	1
Luxembourg	University of Luxembourg	0	0	1	1
Hungary	Central European University (CEU)	1	0	0	1
Hungary	Eötvös Loránd University	2	0	0	2
Hungary	Pázmány Péter Catholic University	2	0	0	2
Hungary	University of Pécs	1	0	0	1
Netherlands	Delft University of Technology (TU Delft)	0	2	0	2
Netherlands	Eindhoven University of Technology (TU/e)	0	0	1	1
Netherlands	EIT Digital Master School	0	0	1	1
Netherlands	International Management Forum (IMF)	0	0	1	1
Netherlands	Leiden University	4	0	1	5
Netherlands	Maastricht University	2	0	0	2
Netherlands	Maastricht University - Center for European Studies	4	1	0	5
Netherlands	Radboud University	6	0	2	8
Netherlands	Tilburg University	2	0	0	2
Netherlands	University of Amsterdam	1	2	0	3
Netherlands	University of Groningen	1	0	0	1
Netherlands	University of Twente (UT)	1	0	2	3
Netherlands	Utrecht University	1	0	0	1
Netherlands	Vrije Universiteit Amsterdam	5	7	1	11
Austria	Alpen-Adria-Universität Klagenfurt	1	0	0	1
Austria	FH Joanneum University of Applied Sciences	0	0	1	1
Austria	Graz University of Technology (TU Graz)	1	0	1	2
Austria	Salzburg University of Applied Sciences	1	0	0	1

Country	University	Number of specialised masters			
		AI	CS	HPC	AI, HPC, CS
Austria	University of Vienna	1	0	0	1
Poland	Gdansk University of Technology	3	0	0	3
Poland	Kazimierz Wielki University Bydgoszcz	0	0	1	1
Poland	Lodz University of Technology	1	1	0	1
Poland	Silesian University of Technology	1	0	0	1
Poland	University of Economy in Bydgoszcz	1	0	0	1
Poland	University of Lodz	1	1	0	1
Poland	Wroclaw University of Technology	2	0	0	2
Portugal	Instituto Superior Técnico	2	0	0	2
Portugal	School of Engineering, Polytechnic of Porto	1	0	0	1
Portugal	University of Algarve	1	0	0	1
Portugal	University of Minho	1	0	0	1
Romania	Gheorghe Asachi Technical University of Iasi (TUIASI)	1	1	0	1
Romania	Politehnica University Timisoara	1	1	0	2
Romania	University Babes-Bolyai	1	1	0	2
Romania	University of Bucharest	1	0	0	1
Romania	University Politehnica of Bucharest	1	0	0	1
Romania	West University of Timisoara	1	1	0	1
Slovakia	Comenius University in Bratislava	1	0	0	1
Slovakia	Slovak University of Technology in Bratislava	3	0	1	3
Finland	Aalto University	5	5	2	10
Finland	Åbo Akademi University	1	1	0	1
Finland	EIT Digital Master School	1	0	0	1
Finland	ITMO University	0	0	1	1
Finland	JAMK University of Applied Sciences	0	0	1	1
Finland	LUT University	2	0	0	2
Finland	Metropolia University of Applied Sciences	2	0	0	2
Finland	Novia University of Applied Sciences	1	0	0	1
Finland	South-Eastern Finland University of Applied Sciences	0	0	1	1
Finland	Tampere Universities	3	0	0	3
Finland	University of Jyväskylä	1	0	0	1
Finland	University of Oulu	1	0	0	1
Finland	University of Turku	0	0	5	5
Sweden	Chalmers University of Technology	2	2	0	4
Sweden	Halmstad University	1	0	1	2
Sweden	Jönköping University	1	0	0	1
Sweden	KTH Royal Institute of Technology	3	2	0	5
Sweden	Linköping University	2	2	0	3
Sweden	Linnaeus University	0	1	1	2
Sweden	Mälardalen University	1	0	0	1
Sweden	Mid Sweden University	0	1	0	1
Sweden	Örebro University	1	0	1	2
Sweden	Stockholm University	0	0	1	1
Sweden	Umea University	1	0	0	1
Sweden	University of Gothenburg	2	1	0	3
Sweden	University of Gothenburg, Faculty of Science	1	0	0	1
Sweden	University West	2	0	0	2
Sweden	Uppsala University	0	1	0	1
United Kingdom	Abertay University	0	0	1	1
United Kingdom	Aberystwyth University	3	0	0	3

Country	University	Number of specialised masters			
		AI	CS	HPC	AI, HPC, CS
United Kingdom	Anglia Ruskin University	0	1	2	2
United Kingdom	Birmingham City University	1	0	2	3
United Kingdom	Bournemouth University	0	0	2	2
United Kingdom	Brunel University London	1	2	0	2
United Kingdom	Cardiff University	1	0	1	2
United Kingdom	City, University of London	2	0	2	4
United Kingdom	Coventry University	4	1	2	6
United Kingdom	Cranfield University	2	1	5	8
United Kingdom	De Montfort University	4	0	3	7
United Kingdom	Department of Computer Science, University of Liverpool	0	1	0	1
United Kingdom	Edge Hill University	0	1	2	2
United Kingdom	Edinburgh Napier University	0	0	3	3
United Kingdom	Glasgow Caledonian University	2	0	0	2
United Kingdom	Goldsmiths, University of London	2	0	0	2
United Kingdom	Heriot-Watt University	4	0	1	5
United Kingdom	Imperial College London	10	3	2	10
United Kingdom	King's College London	4	0	2	6
United Kingdom	Kingston University	1	0	4	5
United Kingdom	Lancaster University	0	0	1	1
United Kingdom	Leeds Beckett University	0	0	1	1
United Kingdom	Liverpool John Moores University	2	0	2	4
United Kingdom	London Metropolitan University	0	0	1	1
United Kingdom	London School of Economics and Political Science	0	1	0	1
United Kingdom	London South Bank University	5	0	1	6
United Kingdom	Loughborough University	1	0	2	3
United Kingdom	Loughborough University London	0	0	1	1
United Kingdom	Middlesex University	1	0	1	2
United Kingdom	Newcastle University	0	4	1	5
United Kingdom	Northumbria University	3	0	3	6
United Kingdom	Nottingham University Business School	1	0	0	1
United Kingdom	Oxford Brookes University	1	0	1	2
United Kingdom	Plymouth University	3	0	1	4
United Kingdom	QA?s Executive Master's	0	1	1	2
United Kingdom	Queen Mary University of London	9	4	0	12
United Kingdom	Queen's University Belfast	0	0	2	2
United Kingdom	Robert Gordon University	0	0	1	1
United Kingdom	Royal Holloway University of London	3	0	3	6
United Kingdom	Sheffield Hallam University	3	0	1	4
United Kingdom	Southampton Solent University	0	0	1	1
United Kingdom	Staffordshire University	0	0	2	2
United Kingdom	Swansea University	5	1	4	9
United Kingdom	The University of Edinburgh	9	5	3	17
United Kingdom	The University of Exeter	1	0	0	1
United Kingdom	The University of Hertfordshire	2	3	4	7
United Kingdom	The University of Hull	2	1	0	2
United Kingdom	The University of Manchester	7	2	2	10
United Kingdom	The University of Northampton	0	0	1	1
United Kingdom	The University of Winchester	0	0	2	2
United Kingdom	University College London (UCL)	2	1	0	3
United Kingdom	University of Aberdeen	1	0	0	1

Country	University	Number of specialised masters			
		AI	CS	HPC	AI, HPC, CS
United Kingdom	University of Bath	4	1	0	4
United Kingdom	University of Bedfordshire	0	6	5	9
United Kingdom	University of Birmingham	4	0	2	6
United Kingdom	University of Bolton	0	2	2	2
United Kingdom	University of Bradford	0	0	1	1
United Kingdom	University of Brighton	1	0	1	2
United Kingdom	University of Bristol	3	1	1	4
United Kingdom	University of Buckingham	1	0	0	1
United Kingdom	University of Cambridge	2	1	1	3
United Kingdom	University of Central Lancashire (UCLan)	0	0	1	1
United Kingdom	University of Chester	1	0	2	2
United Kingdom	University of Derby	0	0	1	1
United Kingdom	University of Dundee	0	1	0	1
United Kingdom	University of East Anglia	3	1	0	4
United Kingdom	University of East London	0	0	1	1
United Kingdom	University of Essex	6	0	0	6
United Kingdom	University of Glasgow	1	0	3	4
United Kingdom	University of Gloucestershire	0	0	2	2
United Kingdom	University of Greenwich	1	0	3	4
United Kingdom	University of Kent	1	1	8	9
United Kingdom	University of Leeds	6	5	0	6
United Kingdom	University of Leicester	1	3	1	5
United Kingdom	University of Lincoln	5	1	0	6
United Kingdom	University of London	0	0	2	2
United Kingdom	University of Nottingham	1	1	0	2
United Kingdom	University of Oxford	0	0	1	1
United Kingdom	University of Portsmouth	0	0	1	1
United Kingdom	University of Salford	2	0	2	4
United Kingdom	University of Sheffield	7	0	1	7
United Kingdom	University of South Wales	0	0	3	3
United Kingdom	University of Southampton	15	3	7	22
United Kingdom	University of St Andrews	1	1	1	2
United Kingdom	University of Sunderland	0	0	4	4
United Kingdom	University of Surrey	3	0	2	5
United Kingdom	University of Sussex	5	0	0	5
United Kingdom	University of the West of England (UWE Bristol)	4	0	1	5
United Kingdom	University of the West of Scotland	0	1	1	2
United Kingdom	University of Warwick	1	2	1	3
United Kingdom	University of West London	0	0	2	2
United Kingdom	University of Westminster	0	0	1	1
United Kingdom	University of Wolverhampton	0	0	3	3
United Kingdom	University of York	1	0	1	2
United Kingdom	WMG University of Warwick	0	0	2	2

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