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Academic Offer of Advanced Digital Skills in 2020-21: International Comparison

Focus on Artificial Intelligence, High Performance Computing, Cybersecurity and Data Science

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Contents

Abstract

The European Commission, as part of its policy to foster digital transformation and succeed in the digital decade, promotes digital skills as a key factor to improve economic competitiveness and social justice. This report provides evidence about the availability of higher education offer in Artificial intelligence, High performance computing, Cybersecurity, and Data science in the academic year 2020-2021, so as to anticipate possible gaps (or abundance) in their offer. Following a keyword-based query methodology that captures the inclusion of advanced digital skills in the programmes' syllabus, we monitor the availability of masters' programmes and study their characteristics, such as the scope (broad and specialised), education fields in which digital skills are taught (e.g., Information and communication technologies; Business, administration and law), and the content areas covered by the programmes. The EU's offer of AI-related specialised master's programmes is higher than that of the US. Even if the field of education dominating the offer of AI master's programmes is Information and communication technologies, noticeable shares are also observed for Engineering, manufacturing and construction. In Cybersecurity, the EU is the only area presenting a positive trend during the last year, involving both broad and specialised masters. Despite this, still the EU's related offer is lower than that of the US and that of the UK. Regarding Data science masters, the US keeps the leading position, among the areas considered for the study, in terms of number of programmes offered.

Foreword

The PREDICT project (Prospective Insights on R&D in ICT) 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 the society. This research aims at supporting the policy making process by providing essential evidence to analyse the strengths and weaknesses of the European ICT industry and the technological take-up in comparison with the most important trading partners, over a range of several years. 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 EU as well as the United Kingdom, 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.

Some topics that PREDICT addressed in over 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 the landscape with factual data from non-official heterogeneous sources. Overall, the objective is the contribution on measuring the digital transformation of the economy and providing policy recommendations.

Currently PREDICT is also supporting the Digital Europe programme and the Digital Education Action Plan for increasing EU's international competitiveness as well as developing and reinforcing Europe's strategic digital capacities. PREDICT provides insights about the availability in the EU Member States and six additional countries of adequate advanced digital skills in a number of Information Technology (IT) domains. Moreover, the TES analytical approach has been applied to target artificial intelligence and map the AI worldwide landscape under the EC AI Watch project.

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

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Executive summary

Over the last decades, the fields of Artificial Intelligence (AI), High Performance Computing (HPC), Cybersecurity (CS) and Data Science (DS) have experienced a significant technological development due to the rapid increase of computer processing power and data availability, as well as the development of new algorithms and methods. The digital transformation, supported by these and other technologies, has triggered what is considered the "Fourth industrial revolution". To succeed in the digital transformation, the European Commission (EC) supports actions to build an adequate economic infrastructure that allows to increase competitiveness and foster growth. At the same time, it has to be ensured that everyone benefits from the digital transition, so as to leave no one behind. As highlighted by the Digital Decade communication, not only Europeans must increase their basic digital skills – to allow them to benefit from the welfare and progress brought by a digital society – but the EU is also in need of more ICT specialists able to develop, deploy and use digital technologies, in respect of EU values. In fact, the Digital Decade communication proposes that by 2030 80% of citizens aged 16-74 should have at least basic digital skills, and that by the same date the EU should have 20 million ICT specialists in employment, and reducing its gender gap. EU and MS need to deliver on this together. Hence, the development of a digitally qualified population is a key factor to drive this transformation and to compete in the global race for digital talents. Under this prism, this report continues the work started in 2019 by the JRC (López-Cobo et al., 2019; Righi et al., 2020) providing updated evidence about the higher education offer of advanced digital skills, so as to anticipate possible gaps (or abundance) of certain key skills. The study is based on a dataset of education programmes related to AI, HPC, CS and DS, taught in English, in the EU and six additional countries: the United Kingdom, Norway, Switzerland, Canada, the United States and Australia. This collection of education programmes aims to represent the overall education offer on these advanced digital technologies in the referred countries. Although the number of programmes analysed constitutes only a subset of the whole digital education offer in these countries – as programmes taught in national language are not considered – it is assumed that their characteristics are representative of the entire education offer in these digital domains.

This work analyses the education offer by taking into consideration the number of education programmes provided, the scope with which education programmes are taught (broad and specialised programmes), the field of education in which programmes are offered (e.g. *Information and communication technologies*; *Engineering, manufacturing and construction*; *Business, administration and law*), and the content areas that are taught (specific to each technological domain). We also study the overlap in the offer of the technological domains (i.e., programmes belonging to multiple domains). Unlike previous studies, this report focuses on the master level to address the acquisition of the most work-related skills (and not the more basic notions provided at the bachelor level). Additionally, the Annex presents results also for bachelor degrees and short professional courses to provide the full picture and allow comparability with the previous reports.

The EU increases its education offer in masters in all four domains analysed, unlike other geographic areas. This may be already reflecting the commitment between the EC and Member States in the AI Coordinated plan to invest in AI-related skills, as well as the proactive support given by the Digital Education Action Plan to advanced digital skills. Germany, the Netherlands, France, Sweden, Ireland and Italy are among the top EU Member States in the four domains. The overall penetration rates, or proportion of masters with advanced digital skills over all masters offered are higher for the EU than for the US and the UK in all four technological domains. The EU Member States with highest penetration rates are Finland, Denmark, France and Austria.

Regarding the educational offer related to AI, we observe an increase of 9% in the offer of specialised masters' programmes by the EU and 11% in the UK offer, together with a contraction of 12% the US's offer specialised masters. As a result, the EU's offer of specialised masters surpasses that of the US, while the UK remains in the third position. The US anyway remains in the lead if we also consider the increase in broad programmes: the US has a total offer of 1,022 AI masters' programmes, 24% higher than that of the EU27 (825). The share of EU's AI programmes (both specialised and broad) in the education field of *Business, administration and law* has slightly increased from past year, and the correspondence between the field of *Engineering, manufacturing and construction* and the contents related to *Robotics & Automation* is remarkable. *ICT* appears to be the field of education most able to cover, in a more balanced way, the multitude of content areas of AI. A consistent share of contents related to *Machine Learning* is detected in the EU in the field of *Business, administration and law*. The teaching of this content in business-oriented educational paths is crucial to avoid a black-box effect (i.e., the use of algorithms without a clear understanding of the process leading to the resulting outputs) and to provide business students with necessary background information for a conscious discussion about ethical aspects of AI and for the application of regulatory provisions. Among EU Member States, Germany leads the offer, with 103 masters, still very far from that of the UK (697). The evolution of

France is remarkable, as it registers an overall increase of 36% of AI-related masters' programmes from 2020 to 2021, with a very balanced increase between broad and specialised master's degrees (+38% and + 33%, respectively). Also, the Netherlands, Spain and Finland improve their offer of both broad and specialised masters since last year. Germany, Italy, Austria and Portugal present a different trend, with a decrease in the offer of broad master's programmes, but an increase in the offer of specialised ones.

HPC is the domain with the lowest proportion of specialised masters, a fact that could be related to the instrumental nature -while at the same time specialised- of the domain, which makes it suitable to be taught in broad technical programmes in informatics. The US leads in the offer of HPC masters' programmes, with 405, followed by the EU (260) and the UK (233). In the EU's HPC programmes included in the field of education *Business, administration and law*, we observe a high correlation with the content related to *Cloud*. The two EU Member states offering the highest number of HPC masters', i.e., Germany and France (37 and 31 programmes, respectively) show a significant increase in their offer (almost one fourth higher than in 2019-20).

In the education offer of CS, the EU presents a positive trend, for both broad and specialised programmes, but remaining behind the UK. Among the fields of education in which EU's CS masters' programmes are taught, *Business, administration and law* presents a very uniform distribution of its four main areas of content covered: *Network & Distributed Systems Security*, *Data Security and Privacy*, *Cybersecurity*, and *Software and Hardware Security Engineering*. This multiplicity of topics in the syllabus is a characteristic observed in business-oriented studies, which aim at providing the student with a number of tools to apply in actual business scenarios. Among EU Member States, Germany leads with 14% of the total EU's offer, followed by the Netherlands (12%). France, Sweden, Italy, Ireland and Finland follow, each of them representing between 9% and 6% of EU's offer of CS masters. Germany, France and Finland, which already provided a consistent offer of CS programmes in 2020, substantially increase their offer of both broad and specialised masters.

In the geographical distribution of the DS-related masters' programmes, the US keeps its leading position with a share of 40% of the analysed programmes, although the number of US's specialised masters remains stable with respect to the previous year. The EU shows a balanced increase of 7% of both broad and specialised masters, which consolidates its second position in the domain. Broad masters' programmes are mostly taught in the education field of *Business, administration and law*. This finding supports the argument of the usefulness of broad DS skills in business-oriented working contexts. In particular, the content areas of *Big data*, *Business intelligence*, and *Data analytics* are widely present in *Business, administration and law* programmes, while the content area of *Machine learning & Statistical modelling* is less taught in this field of education. This indicates that business-oriented DS educational paths provide less technical and hard skills and they rely on a variety of contents focused on the analysis of data. EU Member States' DS-related educational offer presents a positive remarkable increase for several countries. These are Czechia (67%), Austria (23%), France (19%), Hungary (17%), Finland (16%), Lithuania (14%), the Netherlands (10%), and Germany (10%). In terms of levels, the Netherlands is by far the leading country (18% of the EU's offer), and it is followed by Germany and France (12% each), the two latter having above average shares of specialised master programmes (41%).

As the programmes analysed may be attributed to more than one digital domain, we study the overlap between the four domains. We detect a significant intersection between AI and DS (17% of all masters belong to both domains simultaneously), which highlights the degree of complementarity that exists between the two domains. While programmes in AI are mainly addressed to computer scientists and engineers, DS ones are targeted to computer scientists and business students. The EU presents an even higher overlap between AI and DS (21%), and this is likely to enhance the students' employment opportunities, as they will be able to fit in both AI-related and DS-related job vacancies.

Regarding the field of education in which advanced digital skills are taught in the EU, *ICT* is the main field for all four domains, with very large shares for HPC and CS (around 60% and 54%, respectively), and lower for AI and DS: 42% and 38% respectively. DS is the only domain in which almost three out of ten programmes are offered in the field of *Business, administration and law*. This evidence, along with the consistent presence of contents such as *Business intelligence* or *Data analytics*, shows that DS is a less technical domain, and that it is preferably considered in educational contexts that are more business-oriented. Therefore, the DS profile seems to require IT specific hard-skills and more business applications-related skills. In this respect, DS graduates seem to represent a valuable resource for small enterprises that desire to take advantage of the potential of data and digital technologies, whose employees are required to carry out assignments and tasks of multiple nature.

1 Introduction

1.1 Policy context

Over the last decades, the fields of AI, HPC, CS and DS have developed significantly due to the rapid increase of processing power and data availability, as well as the development of new algorithms and methods. These new technologies have triggered what is considered the "Fourth industrial revolution".

European Union priorities in the new era of digital technological developments

President Von der Leyen has set the priorities of the EC including "A Europe fit for the digital age", aiming at benefiting from digitalisation in a safe and ethical way in these days of rapid technological changes. The envisaged digital transformation is based on three main pillars, namely "Excellence and trust in the artificial intelligence", "European data strategy", and "European industrial strategy", setting a number of objectives, such as the achievement of technological sovereignty by boosting investment in areas such as artificial intelligence, blockchain, supercomputing, quantum computing; reinforcing cybersecurity capacity; supporting education and digital skills. In its conclusions of 25 March 2021, the European Council stressed the importance of the digital transformation for the Union recovery, prosperity, security and competitiveness and for the well-being of our societies, and invited the Commission to use all available policy tools to facilitate the digital transformation. In this respect, several steps have been taken in recent years so as to achieve these objectives. The Digital Compass Communication (European Commission, 2021a) presents a vision, targets and avenues for a successful digital transformation of the European Union by 2030, addressing vulnerabilities and dependencies as well as accelerating investment. It develops along four cardinal points, one of which is digital skills, which unfolds in two specific targets relating basic digital skills of the population and highly-skilled digital professionals. Another push to the digital transition is given by the Recovery and Resilience Facility[1] which requests Member States to earmark 20% of the funds for digital transition. A number of budget instruments have been put in place to make the digital transition a reality, among which: the InvestEU Programme, a major element of the European Union's Recovery Plan for Europe (Regulation (EU) 2021/523); the Digital Europe Programme (DIGITAL), a new EU funding programme which supports projects in AI, HPC, CS and advanced digital skills (Regulation (EU) 2021/694); or Horizon Europe, the EU's key funding programme for research and innovation (Regulation (EU) 2021/695).

Specifically, regarding AI, the 'European Strategy on Artificial intelligence' (Communication "Artificial intelligence for Europe" European Commission, 2018a) aims at boosting technological and industrial capacity and AI uptake, preparing for socioeconomic changes brought about by AI, and ensuring an appropriate ethical and legal framework. The "Coordinated Plan on AI" and its 2021 review (European Commission, 2018b, 2021b) set out specific objectives for a coordinated effort of the EC and Member States to foster European competitiveness in research and development, and tackling social, economic, legal and ethical aspects regarding AI. The "White paper on AI – A European approach to excellence and trust" (European Commission, 2020a) proposes policy options to promote uptake of trustworthy AI and addresses the associated risks of misuse of AI. In 2021, the proposal of a regulatory framework on AI (the Artificial Intelligence Act) (European Commission, 2021c) addresses the potential high risks that AI poses to safety and fundamental rights equally.

The "European strategy for data" (European Commission, 2020b) aims at facilitating data flows within the EU and across sectors, while personal data and consumer protection are fully respected, and clear and trustworthy data governance mechanisms are put in place. It has materialised through the Data Governance Act (European Commission, 2020d), the Digital Services Act (European Commission, 2020e) and the Digital Markets Act (European Commission, 2020f).

Additionally, the "European Cybersecurity Act" (Regulation (EU) 2019/881) lays down a framework for the establishment of European cybersecurity certification schemes for the purpose of ensuring an adequate level of cybersecurity in the Union. Furthermore, on 16 December 2020, the EC and the High Representative of the Union for Foreign Affairs and Security Policy introduced the EU Cybersecurity Strategy for the Digital Decade (JOIN(2020) 18 final) that sets out the action needed from the EU so as to: (a) protect its people, businesses and institutions from cyberattacks and threats, and (b) increase the international cooperation in order to ensure a secure, global and open internet. Finally, the EU Agency for Cybersecurity (ENISA) created a

[1] Regulation (EU) 2021/241 of the European Parliament and of the Council of 12 February.

multidisciplinary Ad Hoc Expert Group on cybersecurity related issues to tackle certain AI-related cybersecurity risks (European Commission, 2021b).

The European High Performance Computing Joint Undertaking (EuroHPC JU) (Council Regulation (EU) 2018/1488) is set to implement a public-private partnership on HPC, and to deploy and maintain an integrated world-class supercomputing and data infrastructure, and a competitive and innovative high-performance computing ecosystem. The EuroHPC JU plays a key role in the development of HPC capabilities in Europe, as it coordinates the efforts and pools resources among 32 participating countries to develop and deploy a world-class supercomputing infrastructure, easily and securely accessible from anywhere in Europe (European Commission, 2021b).

The need of qualified skills to match technological progress

Along with the aforementioned policy provisions, mainly targeting economic competitiveness, over the last years the EC has put the focus also on human capital aspects, so highlighting the need of qualified skills to benefit from technological progress. In September 2020, the EC introduced a new Digital Education Action Plan for the period 2021-2027 (European Commission, 2020c), which includes a set of actions to improve and integrate AI skills as part of a wider promotion of advanced digital skills. In addition, the EC has also taken action in supporting the access of computational thinking, coding, robotics, tinkering with hardware, computer science, AI and digital skills to a wider audience through the EU Code Week[2] (European Commission, 2021b). The EC also granted four networks of universities, SMEs and top researchers for delivering excellent master's programmes, with a specific focus on human-centric AI, AI for the public administration and AI explainable for healthcare[3] (European Commission, 2021b). Within the Digital Europe Programme, funding will be available for the design and development of specialised courses in key digital technologies, such as masters' programmes for students and professionals. Finally, it is also important to recall that under the indication of the Commission (2018 Coordinated Plan), EU Member States have been encouraged to adopt national AI strategies integrating the skills dimension, which mainly has taken the form of reforms of the formal education systems, computing and AI foundations at primary or secondary school, initiatives to adapt lifelong learning and reskilling policies (European Commission, 2018b; 2021b).

Contribution of the study

Under this prism, this report continues the work started in 2019 by the JRC (López-Cobo et al., 2019; Righi et al., 2020) providing evidence about the education offer related to AI, HPC, CS and DS. Given the strategic importance of acquiring such skills for future economic productivity, but also for social justice and well-being, we investigate the availability of education offer in advanced digital skills, to keep track of its evolution and identify possible gaps (or abundance). In the present work, we monitor the academic offer of master's programmes in the four aforementioned technological domains. The report supports policy makers' by giving insights on the availability and composition of education offer in advanced digital skills, as this plays a critical role in the development of significant competencies for current and future industrial growth and social fairness.

In particular, we present the number of education programmes offered in the EU and six additional countries: the United Kingdom, Norway, Switzerland, Canada, United States and Australia, and analyse their scope or depth with which digital competencies are taught in the syllabus (broad and specialised), the fields of education in which programmes are offered (e.g. *Information and communication technologies*, *Engineering, manufacturing and construction*, *Business, administration and law*), the content areas that are taught (these are specific to each technological domain), and also the overlap in the offer of the technological domains (programmes that belong to multiple domains).

As mentioned before, on this study we focus only on the master level, with the goal to investigate and extract insights on the acquisition of specific and (in many cases) work-related skills within each specific domain, rather than the basic notions provided at the bachelor level. Data about bachelor's degrees and short professional courses are also presented in Annex 1.

The structure of this report is as follows. Section 2 is devoted to the methodology, briefly describing the identification of the technological domain's boundaries; the data source, providing a discussion about its advantages and limitations; and a note about comparability with the 2020 study. Sections 3 to 6 discuss the results about the education offer of AI, HPC, CS and DS respectively. Section 7 focuses on the overlap of the

[2] https://codeweek.eu/

[3] These are funded by the Connecting Europe Facility Telecom.

four technological domains and, how they are offered across fields of education. The report ends with some concluding remarks in Section 8.

1.2 Main characteristics of the study

As in the 2020 edition, this report analyses formal education programmes. Even if other types of education exist, i.e., informal and non-formal[4], only formal education leads to the achievement of official degrees and certificates. Indeed, non-formal learning can play an important role in creating additional set of skills that can be very relevant for the completion of working activities and, even before, that can work as key signals during the job search and recruitment processes. Nevertheless, formal education provides the main characterisation of individual curriculum vitae, and thus this is what mostly matters for the new cohorts of students that, once they finished their studies, have to find an occupation[5]. The report focuses on the master's level of higher education. The choice of this education level lies in the fact that, after the Bologna process (started in the early 2000s), master's degrees have become the cornerstone of higher education. In fact, while the bachelor's degree represents the entry-point to university and provide the basic notions that will be the baseline in students' educational path, it is only with the master's degree that the acquisition of specific and (in many cases) work-related skills occurs. We should recall that the third education cycle structured by the Bologna process, i.e., PhD, is usually undertaken by students who want to embrace a research-oriented path, which can lead either to very technical and specialised working careers in private companies, or to working in the field of research and education. However, since PhDs are usually done by a limited number of individuals, master's degrees represent the educational stage that consistently allows the formation of qualified skills' offer. Clearly, the acquisition of such skills is key for the sustainment of future generations' living standards. Data about bachelor's degrees and short professional courses are also reported in the Annex, and briefly in some elaborations in the body of the report.

Box 1 outlines the main characteristics of the study and of the programmes analysed, as they have been adopted already in last year's report, and highlights the elements of novelty.

As this report mirrors the previous year version (Righi and López-Cobo et al. (2020)), both in terms of data sources and methodological aspects, the detected values are often compared to what observed in 2020 for the academic year 2019-20.

[4] Formal, non-formal and informal education are complementary and mutually reinforcing elements of a lifelong learning process. Below their definition according to the Council of Europe (retrieved 4 March 2022, from https://www.coe.int/en/web/european-youth-foundation/definitions).

- Formal education refers to the structured education system that runs from primary (and in some countries from nursery) school to university, and includes specialised programmes for vocational, technical and professional training. Formal education often comprises an assessment of the learners' acquired learning or competences and is based on a programme or curriculum which can be more or less closed to adaptation to individual needs and preferences. Formal education usually leads to recognition and certification.
- Non-formal education refers to planned, structured programmes and processes of personal and social education for young people designed to improve a range of skills and competences, outside the formal educational curriculum. Non-formal education is what happens in places such as youth organisations, sports clubs and drama and community groups where young people meet, for example, to undertake projects together, play games, discuss, go camping, or make music and drama. Non-formal education achievements are usually difficult to certify, even if their social recognition is increasing. Non-formal education should also be: voluntary, accessible to everyone (ideally), an organised process with educational objectives, participatory, learner-centred, about learning life skills and preparing for active citizenship, based on involving both individual and group learning with a collective approach, holistic and process-oriented, based on experience and action, organised on the basis of the needs of the participants.
- Informal education refers to a lifelong learning process, whereby each individual acquires attitudes, values, skills and knowledge from the educational influences and resources in his or her own environment and from daily experience. People learn from family and neighbours, in the market place, at the library, at art exhibitions, at work and through playing, reading and sports activities. The mass media are a very important medium for informal education, for instance through plays and film, music and songs, televised debates and documentaries. Learning in this way is often unplanned and unstructured.

[5] Degrees and certificates provide the most clear and undisputed signalling in the labour market, i.e., they are an instrument through which individuals can officially demonstrate their skill level in order to apply for a job. Then, other type of education can be demonstrated and reported, but usually in addition to the official university degrees. As the goal of this work is to gain insights on the level of advanced skills of the future workforce, the analysis needs to address the type of education that is mostly related to the future working position of current students.

Box 1. Main characteristics of the study and of the education programmes analysed

Technological domain: As in the previous edition, this study provides details on the higher education studies where AI, HPC, CS and DS are taught. An education programme may be considered in more than one technological domain due to the existing overlap between these domains (e.g., a programme on "Parallel computing" may belong to HPC and DS simultaneously). While it could be assumed that most of AI programmes belong to the ICT or engineering fields, it is relevant to uncover that within Arts and humanities there are some programmes that include programmes on AI, for instance in the narrow field of Audio-visual techniques and media production or in Philosophy and ethics.

Education level: The study collects data on three education levels: master, bachelor and short professional courses. The report, however, focuses on master's degrees, and some results on bachelor degrees and short courses are added in Annex. This choice, which is a novelty with respect to the previous reports, allows us to deepen the analysis on the educational level that, for the reasons explained at the beginning of this section, is considered as the most relevant to draw conclusions on the academic offer of advanced skills.

Geographical coverage: In order to provide comparisons with other competing economies, the present study covers the EU Member States and six additional countries: the United Kingdom, Norway, Switzerland, Canada, the United States, and Australia.

Time frame: The data analysed in this report refers to the academic year 2020-2021. This allows comparability over time with the previous study, which analysed the academic year 2019-2020. It must be taken into account that small deviations of the observed data over time might be explained by multiple factors apart from actual change, such as those attributable to the data source (e.g., frequency of update of universities' websites, frequency of data collection), or to the methodology (e.g., inability to capture relevant programmes with the methodology used).

Programme's Scope: Education programmes are classified into specialised and broad[6], according to the depth with which they address the technological domain under study. Specialised programmes are those with a strong focus in the domain, like for instance, in AI "Automation and Computer Vision" or "Advanced Computer Science (Computational Intelligence)". Broad programmes target the addressed domain, but in a more generic way, usually aiming at building wider profiles or referring to the domain in the framework of a programme specialised in a different discipline (e.g., a course on image classification in a biomedical engineering degree). While a programme has exclusively one scope in a certain technological domain, it is possible that it presents different scopes when appearing in multiple domains: for instance, it may be considered as a specialised programme in one domain and as a broad programme in another.

Programme's Field of education: This variable of analysis refers to the field of education or discipline in which the programme is taught, according to the *Fields of education and training 2013* (ISCED-F 2013) classification[7] (e.g., *Engineering, manufacturing and construction*; *Business administration and Law*, etc.). A programme may be taught in several fields of education, sometimes because it is a joint or double degree, or just because the programme addresses topics that are of interest of more than one field (e.g., an AI programme taught in the fields of *Information and Communication Technologies* (ICT) and of *Engineering, manufacturing and construction*. In those cases, the programme is weighted using fractional count to avoid double counting (for instance, a programme that appears both in the field of *ICT* and *Engineering* is weighted 0.5 in each of them). The field of education is presented following the ISCED-F 2013 classification, with two levels of detail: broad field or two digits (e.g., *Engineering, manufacturing and construction* (code 07)), which is the level mainly considered throughout the report; and narrow field or three digits (e.g., *Engineering and engineering trades* (code 071)), which is considered in Section 7.

[6] A programme is considered specialised in a technological domain (e.g. AI) if its title or short description include at least one keyword representative of the technological domain, or with at least three different keywords present in any text field of the programme description (López-Cobo et al., 2019).

[7] The International Standard Classification of Education (ISCED) is a framework for assembling, compiling and analysing cross-nationally comparable statistics on education. The 2013 revision focused on the fields of education and training (ISCED-F).

Programme's Content areas: These refer to the technological subdomains covered by the programmes' syllabus. They have been delineated following existing taxonomies or analysing programmes' descriptions. A programme may cover several content areas of each technological domain. In those cases, the programme is weighted using fractional count to avoid double counting; the weights are computed based on the frequency of the keywords present in the programme's description. For each domain, the related content areas are presented in a box at the beginning of the corresponding section.

2 Methodology

This work follows the methodology developed by Righi and López-Cobo et al. (2020). This section presents a summary of the main methodological steps adopted.

2.1 Identification of domain boundaries and categories for the analysis

Since official classifications lack to identify transversal technological domains such as the ones examined in this study, we use lists of representative keywords (one list per domain, see Annex 2) in order to query the data sources containing the information on education offer. The selection of keywords follows a semi-automatic process aimed to identify a representative list of terms present in specialised scientific publications. The first selection is performed as detailed in López-Cobo et al., 2019 for each of the four domains separately. In a second step, the programmes identified as specialised during the 2019 study have been analysed to detect additional keywords that are able to appropriately identify relevant programmes.

After the identification of pertinent programmes related to the technological domains under study, we classify the programmes into broad and specialised. A programme is considered as "specialised" in a technological domain (e.g., AI) if either its title or its short description includes at least one keyword representative of the technological domain, or at least three different keywords are present in any text field of the programme description (López-Cobo et al., 2019). If neither these conditions are met, the detected programme is considered as "broad". If the keywords detected are few (i.e., less than three) and exclusively located in the long description of the programme (and not in more relevant parts, like the title or the short description), the corresponding programme is considered as belonging to the technological domain but without a strong focus on it.

The keywords are also used to classify the programmes according to the content areas taught. In general, the categorisation of content areas is derived following the methodology proposed in the 2019 study, and refined with the analysis of the syllabus of the most specialised programmes in the data source. When available, existing taxonomies have also been used. For AI, we consider the AI taxonomy developed by JRC in the framework of AI Watch, the EC knowledge service to monitor the development, uptake and impact of Artificial Intelligence for Europe (Samoili & López-Cobo et al., 2020)[8]. Since the taxonomy and keywords represent both core AI technical domains and transversal topics, we are able to capture the education of AI from different and complementary angles: from development of algorithms to applications and ethical aspects. For CS, we use a JRC report aimed at aligning the cybersecurity terminologies, definitions and domains into a coherent and comprehensive taxonomy to facilitate the categorisation of cybersecurity capabilities in the EU (Nai-Fovino et al., 2018) to enrich the categorisation of content areas. For HPC and DS, the taxonomy is developed by the authors, based on the review of several specialised masters in the field. The four lists of keywords are reported in Annex 2.

2.2 Data source: strengths and caveats

As in the previous study, the data source is the Studyportals' database, which includes programmes from 3,700 universities in over 120 countries. Studyportals[9] is a platform offering worldwide information on global study choice. Out of the seven dedicated Studyportals' websites, this study analyses data from the three of them. These are the ones focused on master's and bachelor's degrees and short professional courses, and they overall account for more than 150,000 programmes, out of which 50,000 correspond to programmes taught in European universities or study centres (Table 1). Studyportals collects information from institutions' websites and their database is updated at a regular pace, with new programmes added at least once a year.

This source is the one offering the widest coverage among all those identified and consulted. However, it still suffers from some lack of coverage, mostly due to the fact that national language programmes are not tracked. This poses a comparability issue between English-native speaking countries and the rest, but also between countries with differing levels of incorporation of English as a teaching language in higher education. Bachelor level studies are expected to be more affected by this concern, as in many cases the offer is taught in native language. Masters tend to have a more international audience, and therefore the set of masters taught in English seem to better represent the overall offer at this level. This is another component supporting our choice to focus on masters' degrees. The main assumption of the study is that, even if the education

[8] This report provides an operational definition of AI in the form of a taxonomy and a list of keywords that characterise the core domains of AI, but also covering transversal topics such as applications of the former and ethical considerations.
[9] studyportals.com

programmes captured by the source are only a part of the entire education offer of advanced digital skills in each country, and cannot be used to quantify the offer in a precise way, they are representative of the entire education offer of the studied countries, and the attributes of the programmes captured by our study can be extrapolated to the whole education offer. This assumption is considered valid, as it resulted from a previous study that verified the existence of bias due to considering only the courses taught in English[10]. In addition, the focus on English language has also to be considered as pertinent in view of the highly-technological and computer-related domains that are addressed by this study, and by the fact that English-taught courses are a key factor for workers' employability and inter-country mobility. As a consequence of the above-mentioned points, the analysis presented in this report focuses on the investigation of the characteristics of the programmes taught, in terms of their content areas, scope, and field of education.

Another strong advantage of the data source is the amount of program-related information available, which makes possible the analysis of the characteristics of the programmes covered. In particular, some of the most interesting attributes for our analysis relate to the programmes' content (title of the programme, short and long description, and programme outline). We use them to first identify a programme as related to AI, HPC, CS or DS, but also to categorise the technological subdomains taught in the programme. The field of education in which the programme is taught is also a very valuable piece of information, which entitles us to explore the diversification or concentration of the provision of advanced digital skills offer across disciplines.

Table 1. Listed programmes by level of education and continent, 2020-21

		On-campus	Other delivery methods	Total
Bachelor	North America	49,898	2,016	51,914
	Europe	19,738	817	20,555
	Oceania	2,691	922	3,613
	Asia	2,480	10	2,490
	Africa	837	35	872
	South America	4	0	4
	Total	**75,648**	**3,800**	**79,448**
Master	North America	24,958	5,491	30,449
	Europe	24,099	2,753	26,852
	Oceania	2,424	1,232	3,656
	Asia	3,184	32	3,216
	Africa	1,186	8	1,194
	South America	41	0	41
	Total	**55,892**	**9,516**	**65,408**
Short programmes	North America	374	2,465	2,839
	Europe	1,667	1,777	3,444
	Oceania	26	348	374
	Asia	122	20	142
	Africa	1	0	1
	South America	2	1	3
	Total	**2,192**	**4,611**	**6,803**
Total		**133,732**	**17,927**	**151,659**

Source: Studyportals

[10] In fact, as this was considered as a potentially limiting factor for the validity of the study, it was therefore scrutinised in the first report of the series together with other characteristics of the data source used (López Cobo et al., 2019, pp. 14-16). The impact of the teaching language was found not negligible but limited and not substantially affecting the validity of the results, especially when these are presented to characterise the education offer and not as an absolute quantification of the programmes offered.

3 Artificial Intelligence

AI has recently become one of the most disruptive technologies and opened the path for multiple and very different implementations such as virtual assistants, smart factories, and autonomous robots. Started back in the 80s with the large-scale diffusion of microchips, the digital transformation is now experiencing a tremendous boost thanks to AI. The impact of AI on digital technologies is so vast and pervasive that scholars talk already about a fourth industrial revolution, in which the digital technologies developed in the last 30 years are now supported by a new form of intelligence, which does not directly originate from humans. To be more explicit, indeed humans build and test the algorithms making AI possible, but at the same time these algorithms are mainly oriented towards a self-learning process allowing less supervision and more autonomy. A debate is currently open on the level of trust that not-human forms of intelligence should be allowed to.

The significance of AI for the economic growth has been stressed in several ways by the EC. We recall that in the Introduction of the Communication "Artificial Intelligence for Europe" (European Commission, 2018a) it is stated that "AI is helping us to solve some of the world's biggest challenges: from treating chronic diseases or reducing fatality rates in traffic accidents to fighting climate change or anticipating cybersecurity threats" and that "like the steam engine or electricity in the past, AI is transforming our world, our society and our industry. Growth in computing power, availability of data and progress in algorithms have turned AI into one of the most strategic technologies of the 21st century". Following this Communication, the Coordinated Plan on Artificial Intelligence (European Commission, 2018b) set out specific objectives for a coordinated effort of the EC and Member States regarding the technological and industrial development of AI in the Union and its Member States. More recently, the Communication "Fostering a European approach to Artificial Intelligence", which includes the 2021 review of the Coordinated Plan on AI, sets joint actions to promote the "EU global leadership on trustworthy AI"[11] (European Commission, 2021b), and the AI Act proposes a set of harmonised rules applicable to the design, development and use of certain high-risk AI systems (European Commission, 2021c).

The education offer mapped in this section refers to programmes related to at least one of the AI-related subdomains presented in Box 2. This list of content areas is derived from the AI taxonomy proposed by Samoili et al. (2020). Some of the subdomains have been merged as soon as the low number of programmes deemed it advisable.

Box 2. AI content areas and most frequent keywords

Robotics and Automation: robotics, human-computer interaction, control theory, robot systems, industrial robot, sensor network.

Machine learning: machine learning, data mining, neural network, deep learning, pattern recognition, reinforcement learning.

AI applications: big data, data analytics, intelligent systems, predictive analytics, business intelligence, internet of things, virtual reality, distributed computing, decision support.

AI ethics: security, accountability, safety, explainability, fairness, privacy, transparency.

Computer vision: image processing, computer vision, face/facial recognition, image recognition, object recognition.

Natural language processing: computational linguistics, natural language processing, machine/automated translation, text mining, information retrieval, chatbot.

Knowledge representation and reasoning; Planning; Searching; Optimisation: inductive programming, knowledge representation, expert systems, uncertainty in AI, information theory, knowledge reasoning, semantic web, graphic models, fuzzy logic, causal inference, genetic/evolutionary algorithms.

Connected and Automated vehicles: autonomous/automated vehicles, autonomous systems, self-driving car, unmanned vehicle, autonomous driving.

[11] "The European Commission together with Member States and private actors need to: accelerate investments in AI technologies to drive resilient economic and social recovery facilitated by the uptake of new digital solutions; act on AI strategies and programmes by implementing them fully and in a timely manner to ensure that the EU reaps the full benefits of first-mover adopter advantages; and align AI policy to remove fragmentation and address global challenges" (COM(2021)205).

Philosophy of AI: cognitive science in AI.

Multi-agent systems: cyber-physic systems, intelligent agents, game theory, agent-based models, q-learning.

Audio processing: speech recognition, speech processing, voice recognition, speech synthesis.

AI (generic): this area is allocated to programmes that refer to AI without further details on content areas.

Source: Adapted from Samoili et al. (2020)

3.1 AI education offer in the international context

Table 2. AI master's programmes by scope and geographic area, 2019-20 and 2020-21

	EU	United Kingdom	Norway	Switzerland	Canada	United States	Australia	Total
				Academic year 2020-21				
Broad	542	446	24	23	82	765	106	**1,988**
Specialised	283	251	11	11	40	257	23	**876**
Total	**825**	**697**	**35**	**34**	**122**	**1,022**	**129**	**2,864**
				Academic year 2019-20				
Broad	535	430	22	19	78	685	96	**1,865**
Specialised	259	227	11	8	38	293	24	**860**
Total	**794**	**657**	**33**	**27**	**116**	**978**	**120**	**2,725**
				Percentage change (%)				
Broad	1%	4%	9%	21%	5%	12%	10%	**7%**
Specialised	9%	11%	0%	38%	5%	-12%	-4%	**2%**
Total	**4%**	**6%**	**6%**	**26%**	**5%**	**4%**	**8%**	**5%**

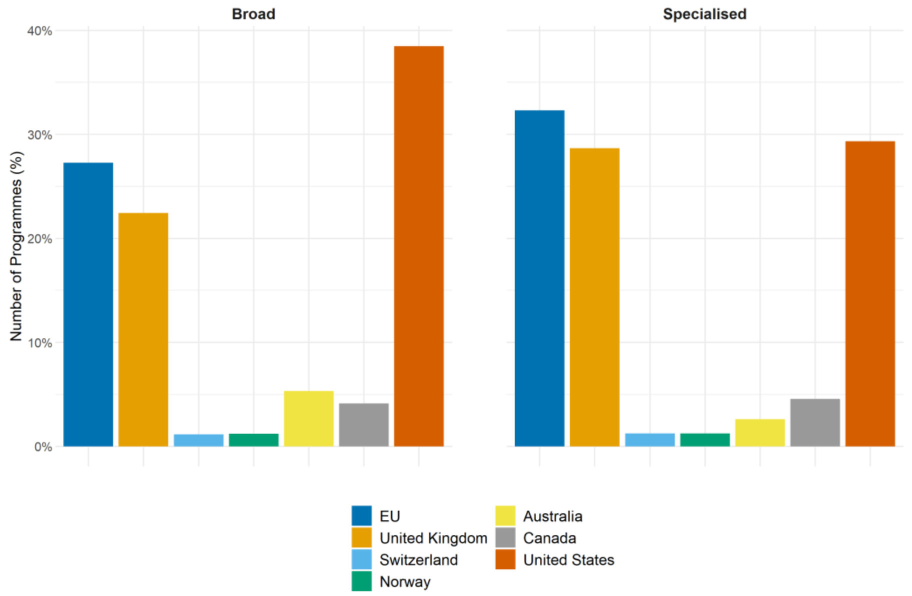
The variation observed with respect to the previous academic year is low for the domain of AI (Table 2). In general, we observe a slight increase, higher for Switzerland, with only the United States' and Australia's specialised masters showing lower values this year than the previous one.

Opposite trends seem to appear from the two sides of the Atlantic. In the EU and the UK, we observe an almost unvaried value in broad masters (plus 1% and 4%, respectively) and a remarkable increase in specialised masters (plus 9% and 11%, respectively).

In the US, on the other hand, the situation appears consistently different, with a good increase in broad masters (+12%) and a strong fall in specialised masters (-12%). Australia, which in general terms offers a high number of master's programmes in AI, also presents a similar trend.

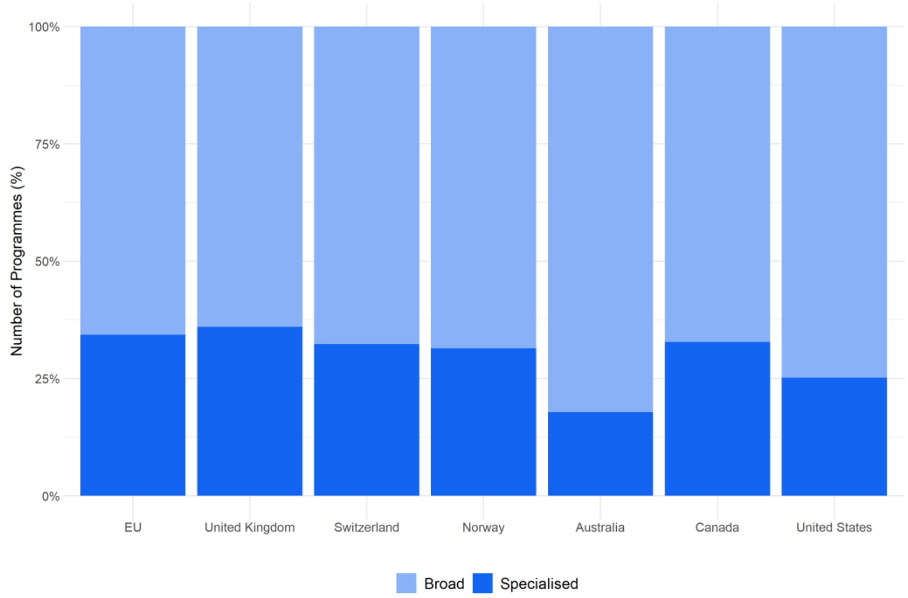
Figure 1 shows that the highest amount of specialised masters is offered by the EU, surpassing the US, which last year was leading in this indicator. The UK also improves its position in specialised masters, showing a share of masters substantially equal to the one of the US. **On broad masters, the US keeps its leading position**, accounting for almost 40% of AI-related programmes. Canada and Australia, whose AI educational offer is considerable (more than 100 programmes both in 2020 and in 2021), present opposite distribution by scope: while Australia has a wider offer in broad masters (more than 5% of all the broad masters considered), Canada provides more options for specialised masters (almost 5% of the specialised masters considered).

Figure 1. Geographical distribution of AI masters by scope (%). All geographic areas, 2020-21



Note: The percentages are based on the total number of programmes within each scope (broad and specialised)

Figure 2. AI masters by geographic area and scope (%). All geographic areas, 2020-21



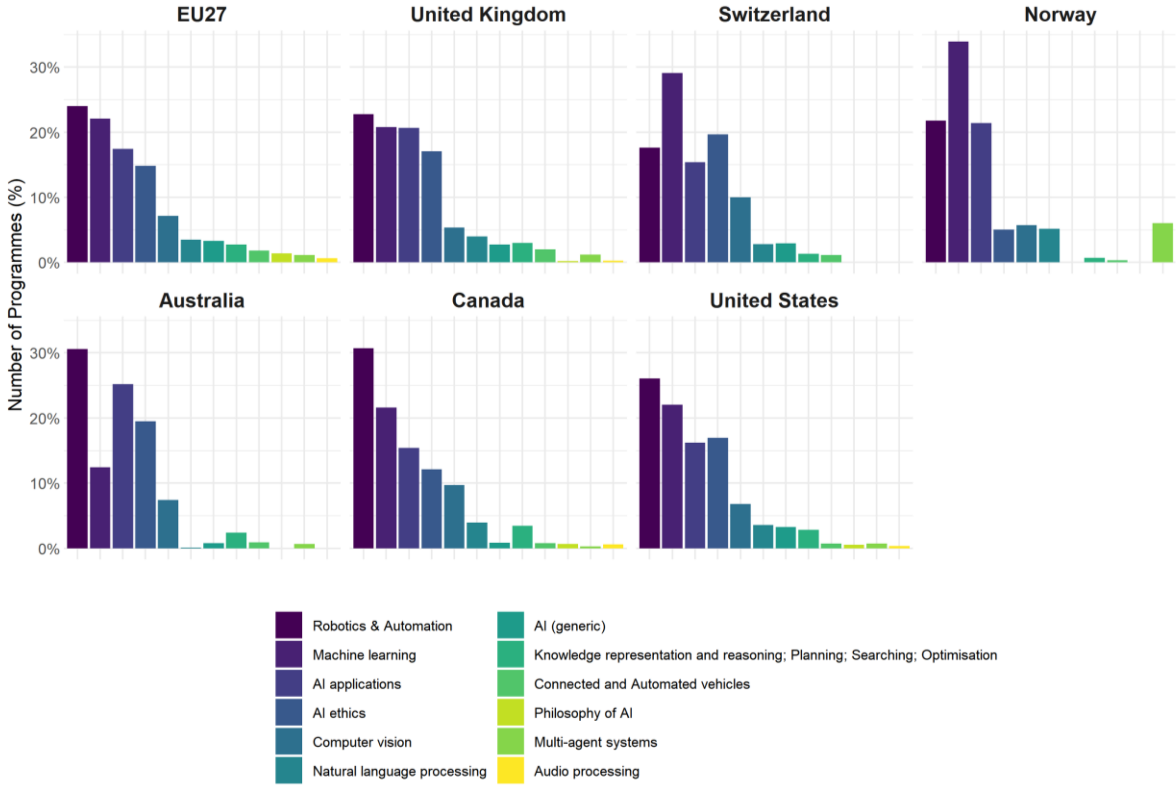
Note: The percentages are based on the total number of programmes within each geographic area.

Regarding the share between broad and specialised masters by geographical area (Figure 2), we observe that in general the values range around 70% for broad vs. 30% for specialized masters. **Australia and, to a lesser extent, the US are the areas showing the highest proportion of broad master's programmes related to AI**: 82% and 75% respectively, while the average for all the countries analysed is 68%. This point, already emerging from last year's data -with 80% of broad masters for Australia, 70% for the US and 68% for the average- is even more noticeable this year. Having a **high proportion of AI-related broad masters** indicates the design of master's programmes which are not specifically addressing AI but that include some notions of AI. This **may reflect either a different approach to the way of teaching the domain**, **or a**

different stage of integration in the educational system. However, we do not observe a wider expansion of AI across education fields in the countries with higher shares of broad masters (see Table A 6 in Annex 1).

For what concerns the **contents taught in AI-related master's programmes** (Figure 3), ***Robotics & Automation*** **appears to be the prevalent topic** in all considered geographical areas apart from Switzerland and Norway. **The second one in decreasing order is *Machine Learning***, which presents high shares in all areas except Australia. Then, **also *AI Applications* and *AI Ethics* appear to have a noticeable role, especially in the UK**. **The EU presents a distribution of content areas which is very similar to the one of the US**. The only difference is the slightly larger share of *AI Applications* in the EU, an area that, being related to big-data, data analytics and intelligence systems management, appears less technology specific and more business oriented.

Figure 3. AI masters by geographic area and content taught (%). All geographic areas, 2020-21



Note: The percentages are based on the total number of masters within each geographic area.

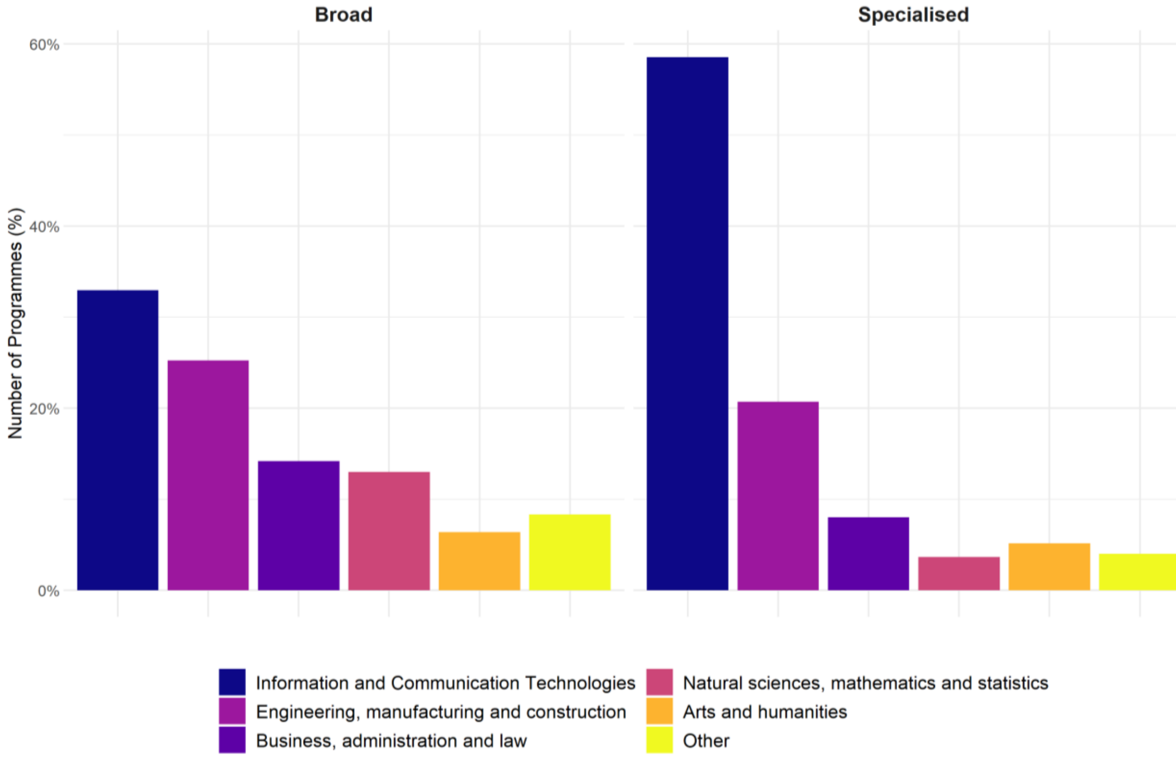
3.2 Focus on the EU

For a more in-depth analysis of the EU, we study the distribution of master's by field of education and scope. Figure 4 shows a very high share of AI-related specialised masters in the field of education *Information and Communication Technologies* (ICT). This finding is not surprising, given the strong connection between AI and the considered field of education. At the same time, it is relevant to observe that the share of ICT among AI masters has substantially increased from last year (from around 50% in the academic year 2019-20, to almost 60% in 2020-21), highlighting an increasing concentration of AI masters in this field.

In broad masters there is a more balanced distribution across fields of education, with relatively high shares for *Engineering, manufacturing and construction*, *Business, administration and law* and *Natural sciences, mathematics and statistics*. In addition, we report that **the share of programmes (both specialised and broad) in the field of *Business, administration and law* has slightly increased from**

past year. This indicates that disciplines providing more job opportunities in the private sector are incorporating AI contents at a larger scale.

Figure 4. AI masters by scope and field of education (%). EU, 2020-21

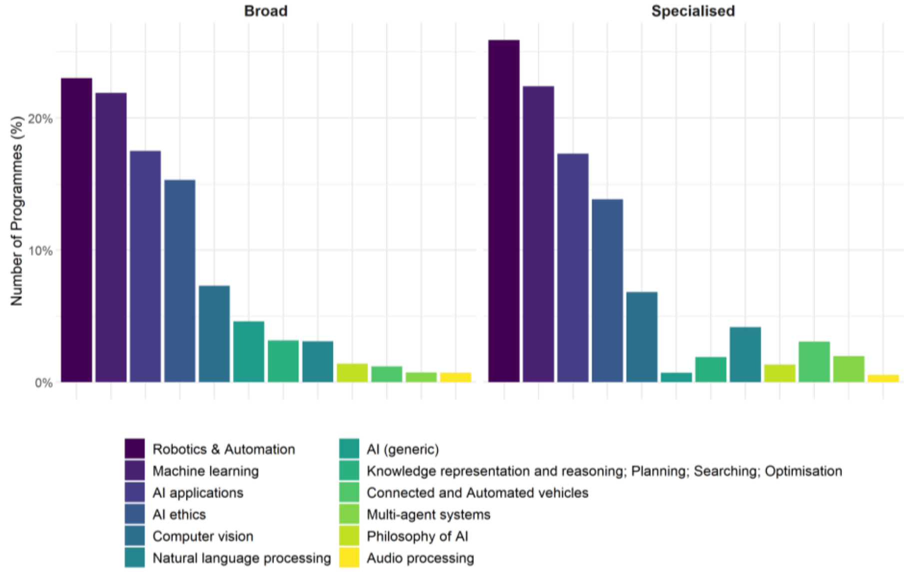


Note: The percentages are based on the total number of programmes within each scope.

About the AI content areas taught in the EU (Figure 5), no big differences are observed between broad masters and specialised masters. As expected, given its strong technical characterisation, **the content *Robotics & Automation* shows a larger share in specialised masters**. The only mentionable difference with respect to last year is that the share of the content area *Robotics & Automation* in specialised masters has slightly decreased (from 30% in 2020, to around 25% in 2021), in particular in favour of *Machine Learning* (which passed from less than 20% to 22% this year). This may be either just a normal fluctuation in the dynamics of education offer, or a mild shift towards the algorithmic development of AI through machine learning, which is transversal to AI and has multiple applications.

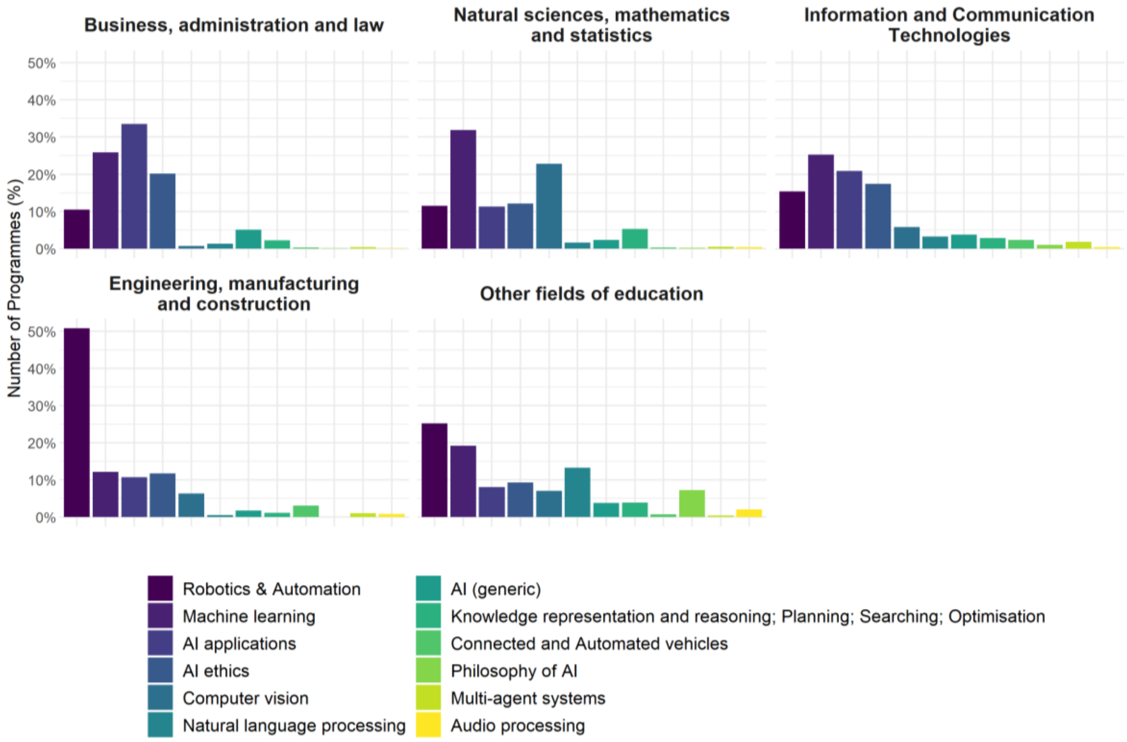
The cross-computation of number of masters by field of education and content areas (Figure 6) reveals some interesting points. First, the **correspondence between the field of *Engineering, manufacturing and construction* and the contents related to *Robotics & Automation* is outstanding**, as all the other content areas have minimal shares in this field of education. Second, the field of *ICT* appears to be the one able to cover in a more balanced way the multitude of content areas, with *Machine Learning* on top, followed by *AI Applications*, *AI ethics* and *Robotics & Automation*. Finally, regarding the field of *Business, administration and law*, interestingly we observe a high share of contents related to *Machine Learning*. In fact, although students on this field are not supposed to need strong machine learning skills for their future career, the fact that this content is taught in a business-oriented educational paths is important, as it should guarantee a minimum level of awareness about the functioning of AI algorithms. This is crucial to avoid the black-box effect, namely the use of algorithms without a clear understanding of the process leading to the resulting outputs. It is also valuable to remark that the understanding of basic mechanisms underlying computational processes constitutes the necessary background skills for a conscious discussion about ethical aspects of AI. These skills are also needed for the application of regulatory principles, as the ones proposed under the AI Act for the design, development and use of certain high-risk AI systems.

Figure 5. AI masters by scope and content area (%). EU, 2020-21



Note: The percentages are based on the number of programmes within each scope.

Figure 6. AI masters by field of education and content area (%). EU, 2020-21



Note: The percentages are based on the total number of programmes within each field of education.

Table 3. AI masters in the EU Member States, 2019-20 and 2020-21

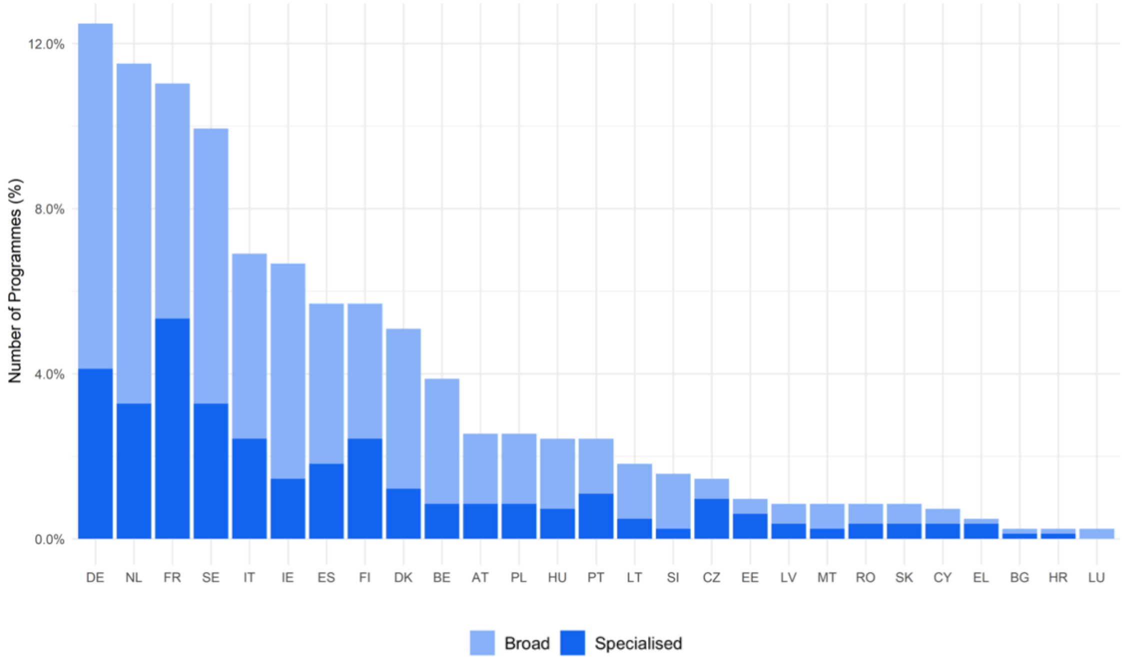
	Academic year 2020-21			Academic year 2019-20			Percentage change* (%)		
	Broad	**Specialised**	**Total**	**Broad**	**Specialised**	**Total**	**Broad**	**Specialised**	**Total**
BE	25	7	**32**	22	12	**34**	*14%*	*-42%*	***-6%***
BG	1	1	**2**	1	0	**1**			
CZ	4	8	**12**	4	6	**10**	*0%*	*33%*	***20%***
DK	32	10	**42**	38	13	**51**	*-16%*	*-23%*	***-18%***
DE	69	34	**103**	75	31	**106**	*-8%*	*10%*	***-3%***
EE	3	5	**8**	4	4	**8**			
IE	43	12	**55**	44	12	**56**	*-2%*	*0%*	***-2%***
EL	1	3	**4**	4	2	**6**			
ES	32	15	**47**	29	14	**43**	*10%*	*7%*	***9%***
FR	47	44	**91**	34	33	**67**	*38%*	*33%*	***36%***
HR	1	1	**2**	0	1	**1**			
IT	37	20	**57**	44	17	**61**	*-16%*	*18%*	***-7%***
CY	3	3	**6**	6	3	**9**			
LV	4	3	**7**	5	3	**8**			
LT	11	4	**15**	14	1	**15**	*-21%*	*300%*	***0%***
LU	2	0	**2**	2	0	**2**			
HU	14	6	**20**	8	6	**14**	*75%*	*0%*	***43%***
MT	5	2	**7**	2	1	**3**			
NL	68	27	**95**	65	24	**89**	*5%*	*13%*	***7%***
AT	14	7	**21**	15	6	**21**	*-7%*	*17%*	***0%***
PL	14	7	**21**	13	8	**21**	*8%*	*-13%*	***0%***
PT	11	9	**20**	14	6	**20**	*-21%*	*50%*	***0%***
RO	4	3	**7**	9	4	**13**	*-56%*	*-25%*	***-46%***
SI	11	2	**13**	3	2	**5**	*267%*	*0%*	***160%***
SK	4	3	**7**	0	3	**3**			
FI	27	20	**47**	24	19	**43**	*13%*	*5%*	***9%***
SE	55	27	**82**	56	28	**84**	*-2%*	*-4%*	***-2%***
EU	**542**	**283**	**825**	**535**	**259**	**794**	***1%***	***9%***	***4%***

Note: (*) The percentage variation is computed only for countries offering at least 10 programmes in one of the academic years.

The EU Member States offering the highest amount of AI master's programmes are Germany (103 masters), the Netherlands (95), France (91) and Sweden (82) **(**

Table 3). The only two countries showing a simultaneous decrease in the offer of both broad and specialised masters are Denmark (-16% and -23%, respectively) and Sweden (-2% and -4%, respectively). Even though the decrease in the AI-related offer of Denmark is substantial, the country is still offering a high number of masters. Therefore, this observation should not be considered as such a negative element, but just as an indicator to be monitored. **The performance of France is the most outstanding**, as it registers an overall variation of + 36% of AI-related programmes from 2019-20 to 2020-21, with a very balanced increase between broad and specialised masters (+38% and + 33%, respectively). The Netherlands, Spain and Finland, as France, improve their already large offer of both broad and specialised masters. In total terms, for the Netherlands we observe 95 programmes in 2020-21 and a variation of +7% with respect to 2019-20. For both Spain and Finland, 47 programmes each in 2020-21 and a variation of +9% with respect to the previous academic year. Finally, we observe a group of countries, namely Germany, Italy, Austria and Portugal, experiencing diverging trends. They all present a decrease in the offer of broad masters (-8%, -16%, -7% and -21%, respectively), combined with an increase in the offer of specialised masters (+10%, +18%, +17% and +50%, respectively). This might be the result of a process of focusing resources in the creation of more technical skills.

Figure 7. AI masters by EU Member State and scope (%). 2020-21



Note: The percentages are based on the total number of masters in the EU.

In Figure 7, it is possible to observe that, as expected, most of the countries present a share of broad masters that is larger than the one of specialised masters. Only four countries among those with at least 10 master's programmes in both academic years (**France, Finland, Portugal** and **Czechia**) **show a proportion of specialised masters higher than 40%** (against 34% in the EU). In the case of **France**, considering also the high number of programmes in absolute value and the growth of 33% in specialised masters in one year, **this seems to suggest a strong attention directed towards the formation of the most specialised AI-skills**. This might be also reflecting specificities of local labour demand.

4 High Performance Computing

HPC refers to the essential physical supports and computer architecture allowing the execution of advanced computations. Parallel computing, system architecture, cloud computing are just some examples of features that depend on both hardware elements and functional design properties. Thanks to these solutions, the computational power of machines is increasing, and hence they can sustain more demanding processes, like those based on AI, or complex simulations. The ability to rapidly process a large amount of information is exactly what makes HPC strategic. In addition, advancements in this field are also focused on the efficiency of computing processes from an energetic point of view, an increasingly important aspect in the twin –green and digital- transition.

In 2021 the EC has highlighted the "strategic nature of High-Performance Computing (HPC) as a crucial asset for the EU's innovation capacity" (European Commission, 2021b). In the European Cloud Initiative (European Commission, 2016), HPC is identified as one of the foundations for maximizing the growth potential of the European digital economy. This vision was also corroborated in the Mid-Term Review on the implementation of the Digital Single Market Strategy "A Connected Digital Single Market for All" (European Commission, 2017). Recently, the Communication "Fostering a European approach to Artificial Intelligence" encourages Member States to continue the development of national integrated large-scale data management and HPC infrastructure, to improve its accessibility by businesses, administrations and research institutions, and to strengthen Europe's position in processors and semiconductor technologies production to reduce European strategic dependencies. (European Commission, 2021b). The Digital Compass 2030, which proposes targets for the digital transition for a stronger and more resilient Europe in 2030, identifies secure and performant sustainable digital infrastructures as one of its four pillars. It proposes targets on the production of cutting-edge semiconductors, the deployment of secure edge nodes to guarantee low-latency access to data, and the development of the first European computer with quantum acceleration. To increase efficiency for the achievement of the targets, the Digital Compass calls for the joint pool of resources by the EU and its Member States through multi-country projects, such as the one to acquire supercomputers and quantum computers, connected with the EuroHPC (European Commission, 2021b).

The education offer mapped in this section refers to programmes related to at least one of the HPC-related subdomains presented in Box 3.

Box 3. HPC content areas and most frequent keywords

System architecture: distributed systems, computer architecture, distributed computing, computer clusters.

Cloud: cloud computing, data centre.

Parallel Computing: parallelization, scalability, parallel computation/programming/processing, energy efficiency, hadoop, mapreduce.

Processors: multi-core processors, graphics processing unit (GPU), field programmable gate array (FPGA).

HPC (generic): this area is allocated to programmes that refer to HPC without further details on content areas.

Source: Authors' elaboration.

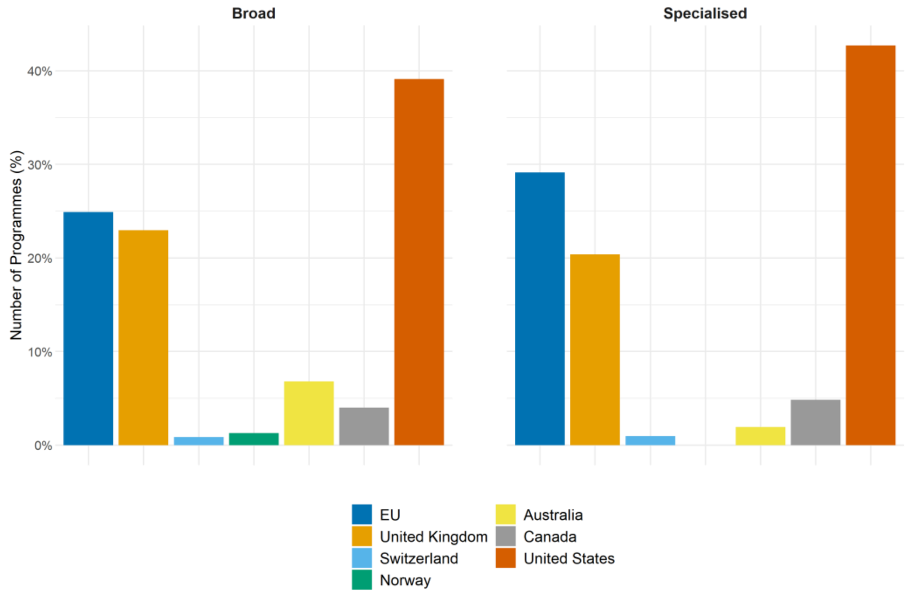
4.1 HPC education offer in the international context

The comparison with last year (Table 4) reveals a small overall decrease in the number of HPC-related masters offered (-3%). In contrast, the EU shows an increase of 7% in both broad and specialised masters. The US decreases in both broad and specialised masters (-5% and -4%, respectively), as in the UK (-11% and -16%, respectively).

Table 4. HPC masters by scope and geographic area, 2019-20 and 2020-21

	EU	United Kingdom	Norway	Switzerland	Canada	United States	Australia	Total
				Academic year 2020-21				
Broad	230	212	12	8	37	361	63	**923**
Specialised	30	21	0	1	5	44	2	**102**
Total	**260**	**233**	**12**	**9**	**42**	**405**	**65**	**1,026**
				Academic year 2019-20				
Broad	214	239	11	10	37	381	55	**947**
Specialised	28	25	0	0	5	46	2	**106**
Total	**242**	**264**	**11**	**10**	**42**	**427**	**57**	**1,053**
				Percentage change (%)				
Broad	7%	-11%	9%	-20%	0%	-5%	15%	**-3%**
Specialised	7%	-16%		-	0%	-4%	0%	**-4%**
Total	**7%**	**-12%**	**9%**	**-20%**	**0%**	**-5%**	**14%**	**-3%**

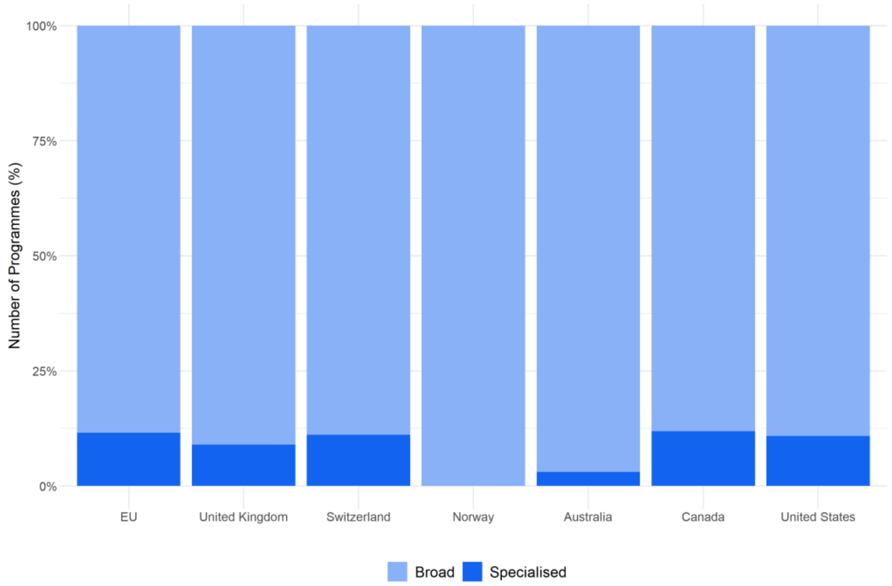
Figure 8. Geographical distribution of HPC programmes by scope (%). All geographic areas, 2020-21



Note: The percentages are based on the total number of masters within each scope (broad and specialised)

The US dominates the HPC-related educational offer of masters, as it presents around 40% of the broad and specialised masters considered. The EU accounts for 25% of broad masters and almost 30% of specialised masters. The opposite trend followed by the UK and the EU during the last academic year, leaves the EU in a better position in the international comparison (Figure 8). In fact, for 2020-21 **the EU presents a higher offer of both broad and specialised masters than the UK** (in 2020, the UK had more broad masters than the EU). Australia and Canada, which are leading areas in digitalisation, show here a structure similar to the one observed for AI: **Australia presents a relatively high offer of HPC broad masters, but a much lower share of specialised masters**. Conversely, **Canada is stronger in HPC specialised masters, surpassing Australia**.

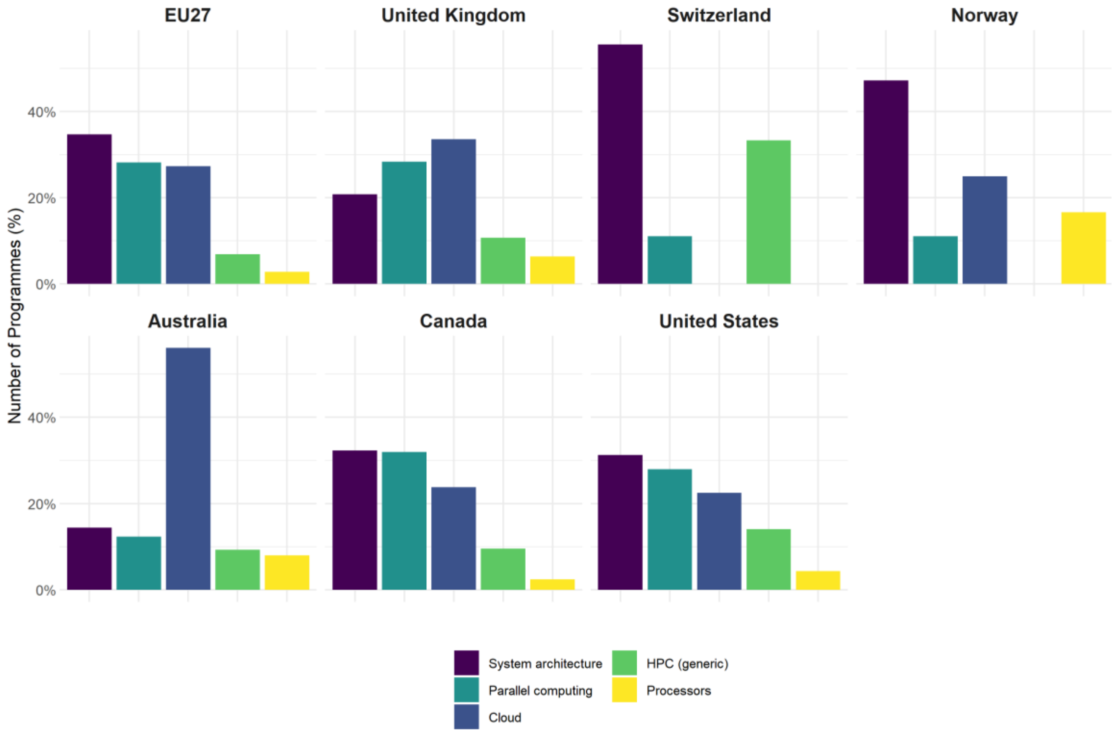
Figure 9. HPC programmes by geographic area and scope (%). All geographic areas, 2020-21



Note: The percentages are based on the total number of programmes within each geographic area.

HPC presents the lowest share of specialised masters of the four domains analysed: only one in ten masters is specialised (Figure 9), compared to an average of one in three in the domains of AI, CS or DS (Figure 2, Figure 16, Figure 23). This could be related to the instrumental nature -while at the same time specialised- of the domain, since it has multiple applications in computing intensive activities. HPC is generally taught in ICT as a cross-sectional topic, in studies where students acquire a wide range of technical skills, as having basic skills in HPC seems to be a very useful asset in the labour market.

Figure 10. HPC programmes by geographic area and content taught (%). All geographic areas, 2020-21

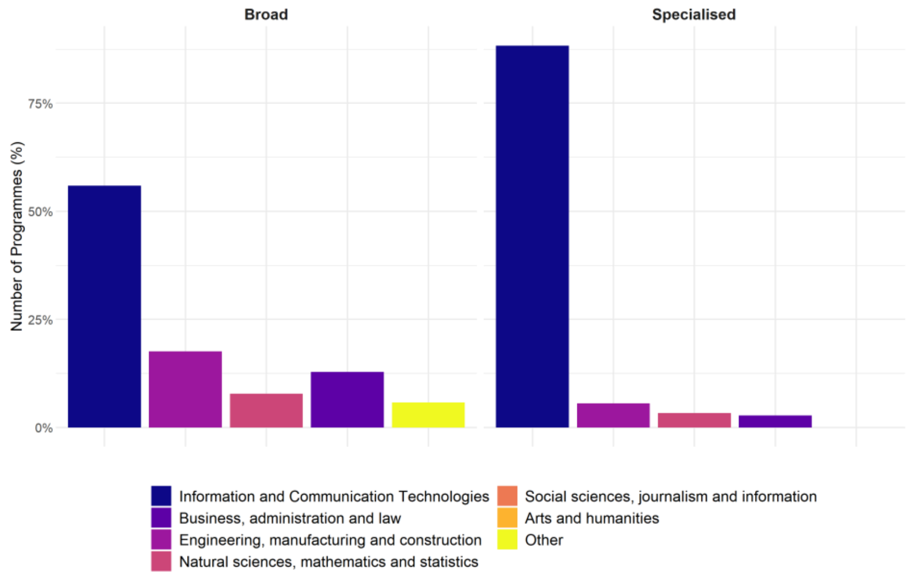


Note: The percentages are based on the total number of masters within each geographic area.

For what concerns the content areas taught in HPC (Figure 10), we observe a good balance among *System architecture*, *Parallel computing* and *Cloud* in the three most important geographical areas, i.e., the US, the EU, and the UK. The UK shows a slightly different distribution, it presents a lower share of contents related to *System architecture* (around 20% in the UK, vs. 35% in the EU and 30% in the US), while a stronger focus in *Cloud* (around 35% in the UK, vs. 27% in the EU and 22% in the US). Australia shows a large share of *Cloud*-related content (over 50%) that would almost induce to think about a specialisation of the country. This may be the result of specific policies, like the Australian Government Cloud Computing Policy, which is running since 2014 (Australian Government, 2014).

4.2 Focus on the EU

Figure 11. HPC master programmes by scope and field of education (%). EU, 2020-21



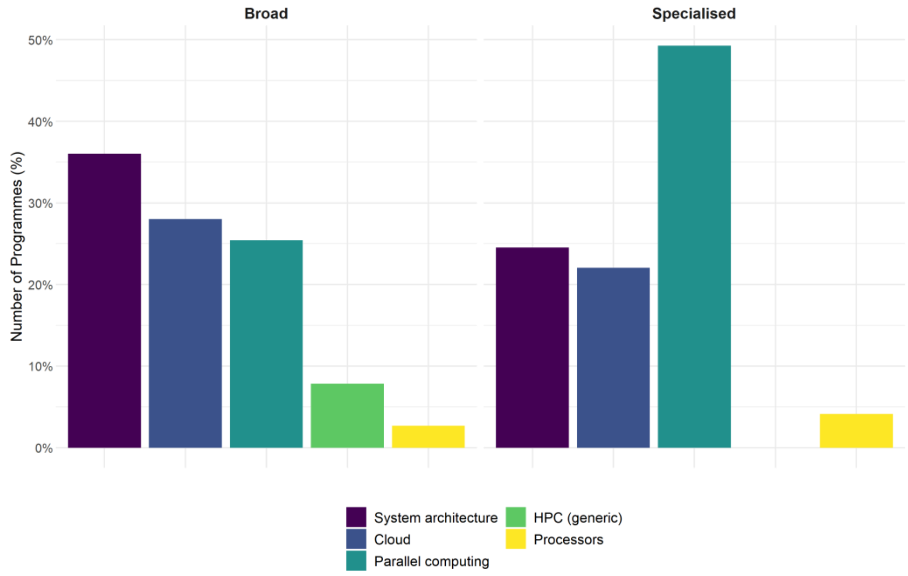
Note: The percentages are based on the total number of masters within each scope.

Figure 11 reveals a strong predominance of *ICT* as the main field of education in which HPC-related masters are taught. In line with expectations, more than 90% of specialised masters belong to this education field.

Regarding the main **content areas** that are taught in **EU's HPC masters**, **we find a different characterisation based on the scope of the programme**. While for broad masters we observe a high share of content related to *System Architecture* (around 35%), followed by *Cloud* and *Parallel Computing* (both over 25%), **for the specialised masters *Parallel computing* presents an outstanding share of almost 50%** (Figure 12). To a certain extent, this is expected, since parallel computing can be considered as the core functioning principle of HPC[12].

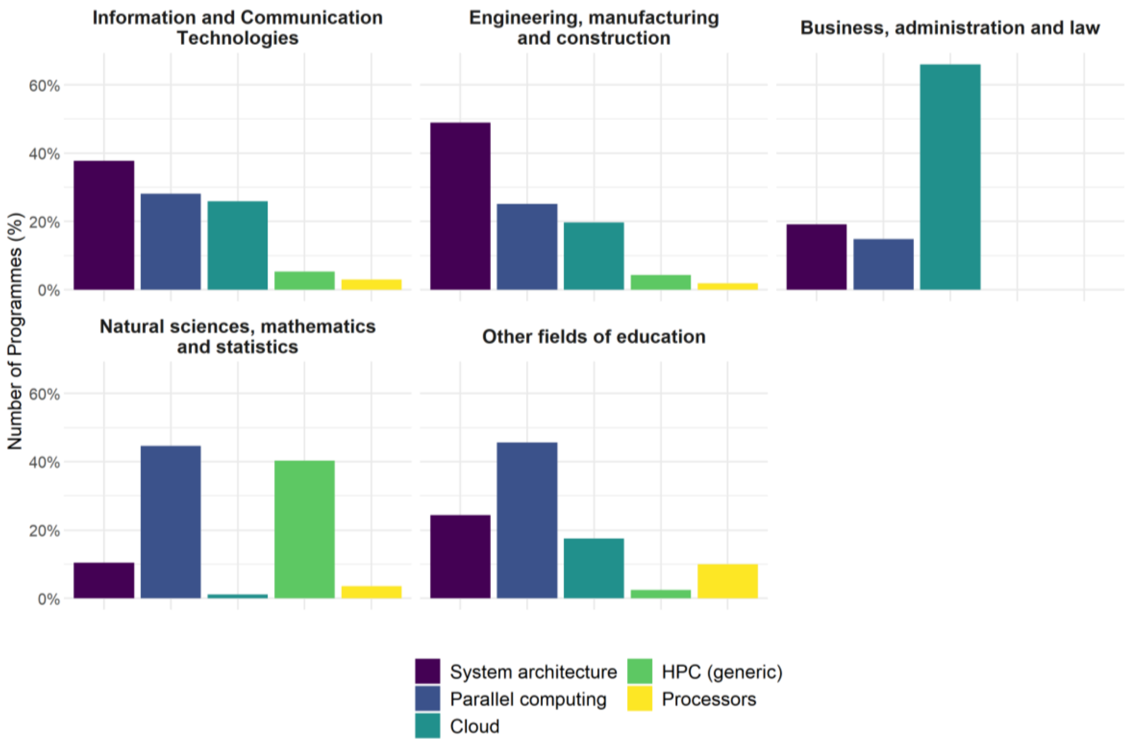
[12] Large problems can often be divided into smaller ones, which can then be solved at the same time (in parallel). This is the core idea of parallel computing, which is very much linked with computers' architecture and the functioning of operative systems.

Figure 12. HPC master programmes by scope and content area (%). EU, 2020-21



Note: The percentages are based on the total number of masters within each scope.

Figure 13. HPC master programmes by field of education and content area (%). EU, 2020-21



Note: The percentages are based on the total number of masters within each field of education.

Figure 13 reveals some interesting elements on the content areas taught by education field. First of all, **in the EU's offer we observe a strong correlation between the field of *Business, administration and law* and the content related to *Cloud***. This probably reflects the increasing use by enterprises of IT systems and services (e.g., performing computations from a centralized server) over the internet (the cloud)[13]. In the context of the digital transformation of European enterprises, this correspondence seems to be a signal of company's uptake of HPC. Figure 13 also shows that *Parallel computing* is the content area most frequently taught in the educational field of *Natural sciences, mathematics and statistics* (more than 40% of the contents). This is to some extent expected given the theoretical elements that are considered in this content area. Also, in line with expectations, a large share of *System architecture* contents is taught in the *Engineering, manufacturing and construction* field.

Table 5. HPC masters in the EU Member States, 2019-20 and 2020-21

	Academic year 2020-21			Academic year 2019-20			Percentage change* (%)		
	Broad	**Specialised**	**Total**	**Broad**	**Specialised**	**Total**	**Broad**	**Specialised**	**Total**
BE	10	0	**10**	9	0	**9**	*11%*	-	***11%***
BG	2	0	**2**	2	0	**2**			
CZ	3	2	**5**	3	1	**4**			
DK	15	1	**16**	17	1	**18**	*-12%*	*0%*	***-11%***
DE	34	3	**37**	28	2	**30**	*21%*	*50%*	***23%***
EE	2	0	**2**	2	0	**2**			
IE	20	1	**21**	22	1	**23**	*-9%*	*0%*	***-9%***
EL	1	0	**1**	4	0	**4**			
ES	16	0	**16**	16	0	**16**	*0%*	-	***0%***
FR	27	4	**31**	21	4	**25**	*29%*	*0%*	***24%***
HR	-	-	**-**	-	-	**-**	-	-	**-**
IT	11	2	**13**	10	2	**12**	*10%*	*0%*	***8%***
CY	2	0	**2**	3	0	**3**			
LV	1	0	**1**	2	0	**2**			
LT	6	1	**7**	3	2	**5**			
LU	1	0	**1**	1	0	**1**			
HU	7	0	**7**	6	0	**6**			
MT	1	0	**1**	1	0	**1**			
NL	12	6	**18**	9	5	**14**	*33%*	*20%*	***29%***
AT	10	0	**10**	10	0	**10**	*0%*	-	***0%***
PL	6	0	**6**	5	0	**5**			
PT	7	0	**7**	5	0	**5**			
RO	3	4	**7**	2	4	**6**			
SI	1	0	**1**	1	0	**1**			
SK	2	0	**2**	1	0	**1**			
FI	11	2	**13**	11	1	**12**	*0%*	*100%*	***8%***
SE	19	4	**23**	20	5	**25**	*-5%*	*-20%*	***-8%***
EU	**230**	**30**	**260**	**214**	**28**	**242**	***7%***	***7%***	***7%***

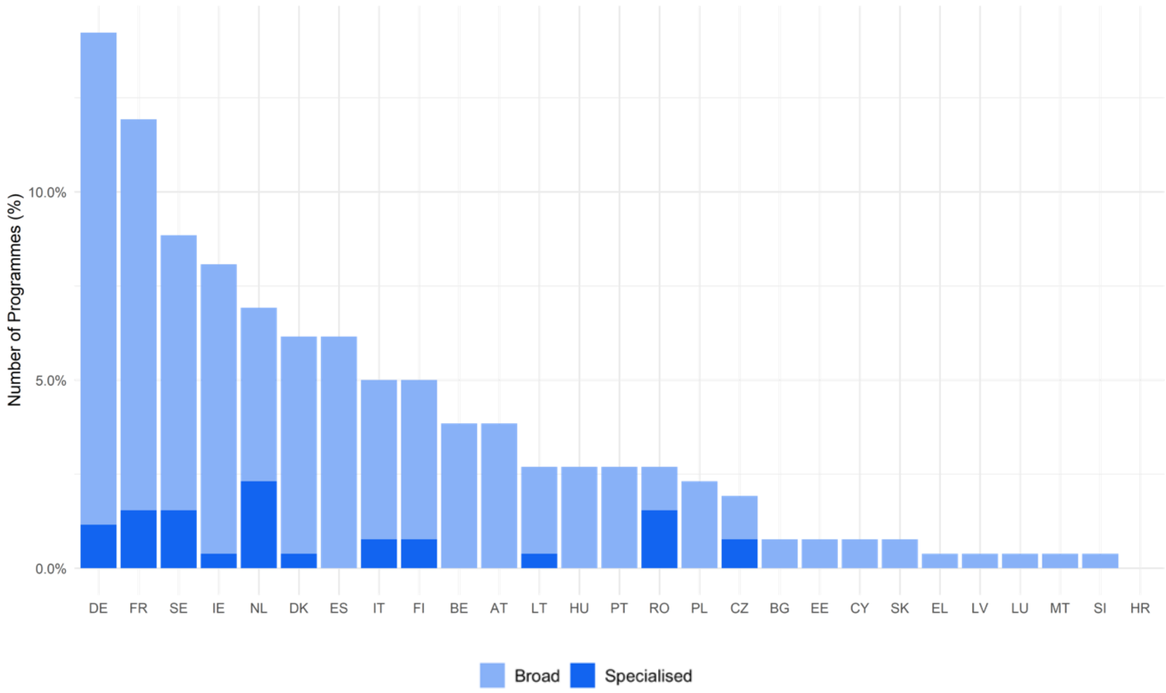
Note: (*) The percentage variation is computed only for countries offering at least 10 programmes in one of the academic years.

[13] In 2020, 36 % of EU enterprises used cloud computing, mostly for hosting their e-mail systems and storing files in electronic form, but also for accounting software applications, Customer Relations Management software and computing power. (Eurostat, 2021).

Regarding the observed variations since last year, the EU experienced **an overall increase of 7% in the offer of HPC master's programmes** (Table 5). Among the EU Member States providing a minimum number of 10 programmes in any of the two academic years, we observe a contraction in the HPC offer of Denmark (-11%), Ireland (-9%) and Sweden (-8%). However, it is important to recall that given the limited number of HPC programmes, small differences in the absolute values may produce large percentage variations.

Germany and France are the two leading countries in the EU's offer (Figure 14). Sweden, Ireland, the Netherlands, Denmark and Spain follow with shares larger than 5%. The only country –among those with at least 10 masters- presenting a high share of specialised masters is the Netherlands (6 masters, 33% of national offer). The two countries offering the largest number of HPC masters, i.e., Germany and France (37 and 31 programmes, respectively), show important increases in the last year (Table 5). In particular, the offer of broad masters raises by 21% and 29% in Germany and France, respectively. Considering the size of the variation, this seems to suggest the intention to strengthen the training of HPC as a transversal skill with multiple applications in professional contexts.

Figure 14. HPC master's programmes by Member State and scope (%). 2020-21



Note: The percentages are based on the total number of masters in the EU.

5 Cybersecurity

CS has recently become a major topic in the debate on the risks of a more digitalised world. The digital technologies that bring benefits to our economy and society may be also used to pursue criminal goals, and a number of risks need to be considered. Violations of privacy rights related to personal information, or security flaws in the control and protection of private and businesses data, are becoming issues of primary relevance. In addition, it is important to recall that, given the overwhelming role of digital technologies in our daily lives, digital violations and illegal behaviours not only constitute a threat for private users, but in some cases also for entire societies and institutions. This is the case of the use of fake news to influence the public opinion. Therefore, as the prevention and contrast of illegal digital behaviours is a priority for private and public interests, the formation of adequate CS skills is essential.

The first EU-wide law on cybersecurity, the NIS Directive, came into force in 2016 and helped to achieve a common high level of security of network and information systems across the EU. The EU Cybersecurity Act, that is in force since 2019, equipped Europe with a framework of cybersecurity certification of products, services and processes and reinforced the mandate of the EU Agency for Cybersecurity (ENISA). On 16 December 2020, the Commission and the High Representative of the Union for Foreign Affairs and Security Policy adopted the EU Cybersecurity Strategy for the Digital Decade that sets out how the EU will shield its people, businesses and institutions from cyber-threats, and how it will advance international cooperation and lead in securing a global and open internet. Furthermore, to address specific AI-related cybersecurity risks, the EU Agency for Cybersecurity (ENISA) established a multidisciplinary Ad Hoc Expert Group on cybersecurity topics related to AI.

The education offer mapped in this section refers to programmes related to at least one of the CS-related subdomains presented in Box 4.

Box 4. CS content areas and most frequent keywords

Data Security and Privacy: information security, network security, hacking/hacker, data security, anonymisation, firewalls.

Network & Distributed Systems Security: distributed systems, computer security, system security, security analysis, fault tolerance, security protocols.

Cryptology (Cryptography and Cryptanalysis): cryptography, cryptology, encryption, digital signature.

Software and Hardware Security Engineering: key management, malware, intrusion detection

Operational Incident Handling and Digital Forensics: digital forensics, digital evidence.

Security Management and Governance: penetration tests, cyber warfare, vulnerability assessment, counterintelligence, cyber risk, active monitoring.

Identity and Access Management (IAM): access management, access control, public key, identity management.

Critical Infrastructure Protection: (industrial) control systems.

Other: cybercrimes, information assurance.

Cybersecurity (generic): this area is allocated to programmes that refer to CS, cyber-attacks or cyber-threats without further details on content areas.

Source: Authors' elaboration.

5.1 CS education offer in the international context

Table 6 shows an overall decrease of 4% in the number of CS-related masters between the 2019-20 and 2020-21 academic years. In this context, the **EU is the only geographical area presenting a positive trend, which involves both broad and specialised masters**. Given the importance of CS, not only for private interests but also for public reasons, this modest increase seems to be a first positive signal of the EU's efforts in the reinforcement of training opportunities in this digital domain. **The UK shows a contraction**

of 6%. The highest decrease is observed for Australia, with 17% fewer masters in 2020-21 when compared to 2019-20 (-15% for broad masters and -23% for specialised ones).

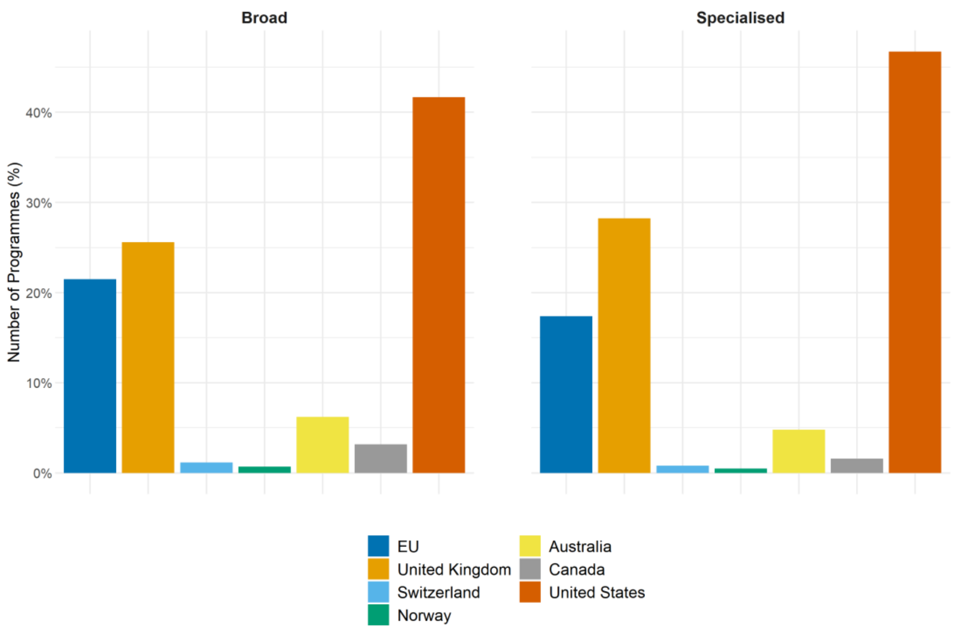
The international comparison presented in Figure 15 shows that despite the positive trend observed for the EU, still its CS-related offer of both broad and specialised masters is lower than the one of the US – with more than 40% of the collected broad and specialised masters- and the one of the UK –between 25% and 30%-.

The analysis of the distribution between broad and specialised masters (Figure 16) reveals that **the UK and the US,** apart from providing the largest number of programmes, **also structure the CS educational offer with a higher share of specialised programmes** (35% of their total offer, against 28% in the EU).

Table 6. CS master's programmes by scope and geographic area, 2019-20 and 2020-21

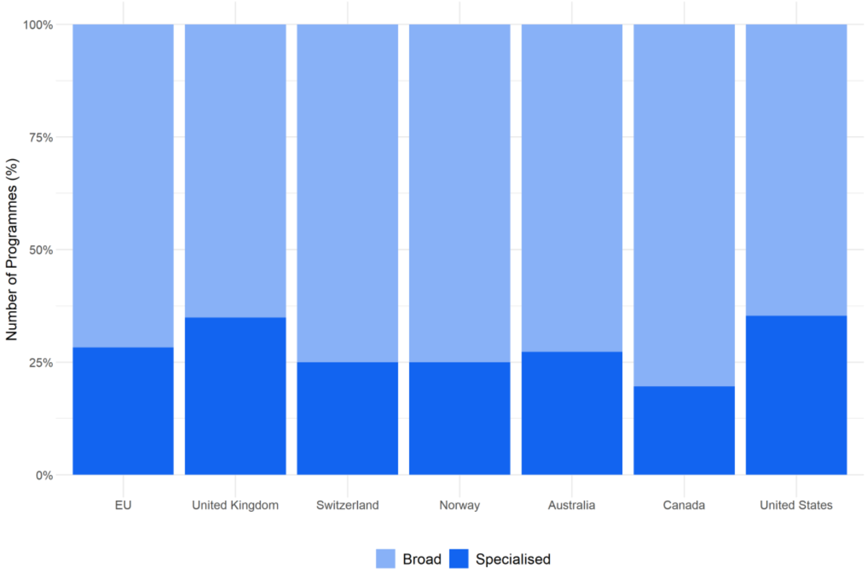
	EU	United Kingdom	Norway	Switzerland	Canada	United States	Australia	Total
				Academic year 2020-21				
Broad	277	330	9	15	41	537	80	**1,289**
Specialised	109	177	3	5	10	293	30	**627**
Total	**386**	**507**	**12**	**20**	**51**	**830**	**110**	**1,916**
				Academic year 2019-20				
Broad	269	341	10	13	41	563	94	**1,331**
Specialised	106	197	3	7	10	305	39	**667**
Total	**375**	**538**	**13**	**20**	**51**	**868**	**133**	**1,998**
				Percentage change (%)				
Broad	3%	-3%	-10%	15%	0%	-5%	-15%	**-3%**
Specialised	3%	-10%	0%	-29%	0%	-4%	-23%	**-6%**
Total	**3%**	**-6%**	**-8%**	**0%**	**0%**	**-4%**	**-17%**	**-4%**

Figure 15. Geographical distribution of CS programmes by scope (%). All geographic areas, 2020-21



Note: The percentages are based on the total number of programmes within each scope (broad and specialised)

Figure 16. CS programmes by geographic area and scope (%). All geographic areas, 2020-21



Note: The percentages are based on the number of programmes in the corresponding geographic areas.

The analysis of content areas (Figure 17) reveals *Network & Distributed Systems Security* as the most taught in the EU and Canada, followed in decreasing order by *Data Security and Privacy* and *Cryptology*. The UK and Australia propose a CS educational offer of masters' programmes centred on *Data Security and Privacy*, with *Network & Distributed Systems Security* and *Cybersecurity (generic)* as secondary content areas. **The US**, which leads in terms of number of CS masters' programmes offered, presents a structure of the content areas similar to that of the UK and Australia, but with ***Data Security and Privacy*** and ***Network & Distributed Systems Security* being the mostly taught**.

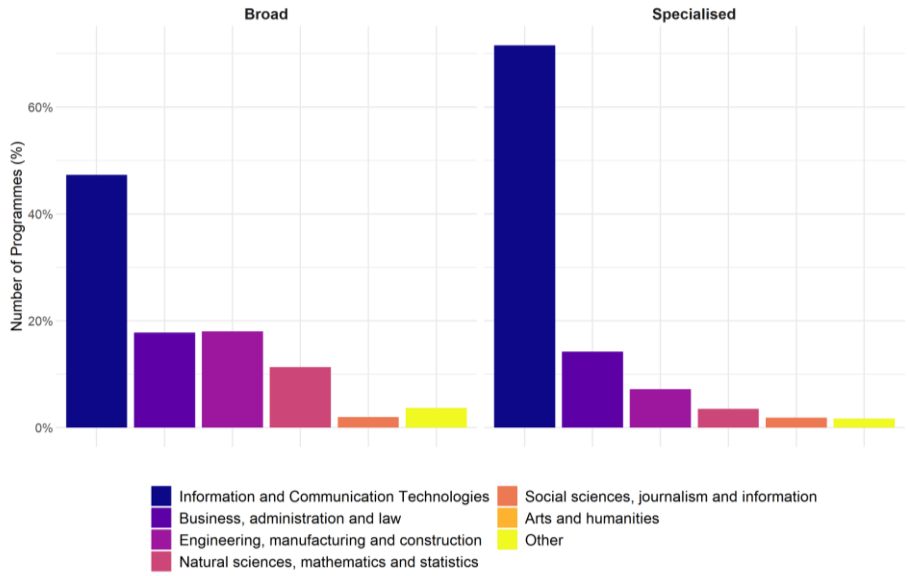
Figure 17. CS programmes by geographic area and content area (%). All geographic areas, 2020-21

Note: The percentages are based on the total number of masters within each geographic area.

5.2 Focus on the EU

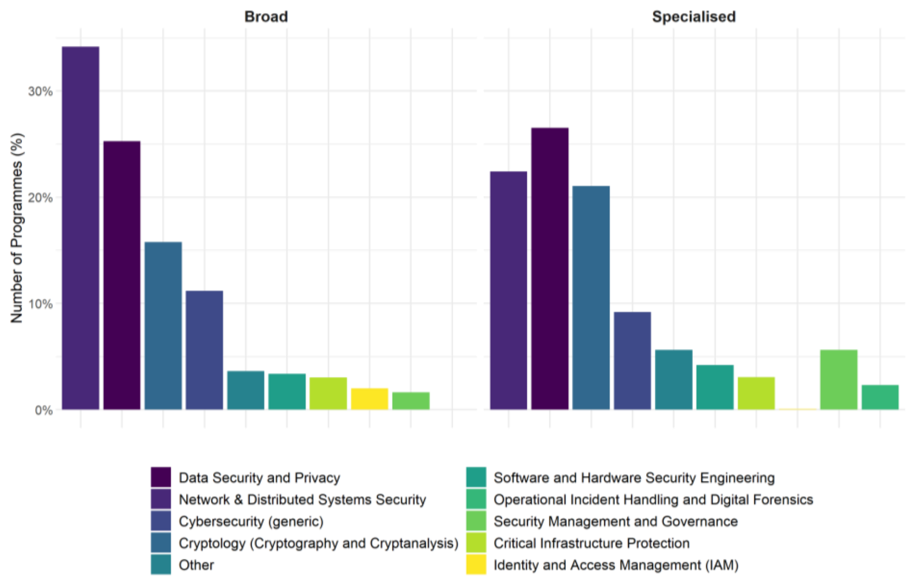
Focusing on the EU, Figure 18 reveals differences in the distribution of the offer of CS broad and specialised masters across fields of education. In fact, although the main field of education is *ICT* in both cases, **specialised masters are much more concentrated in this field**, with over 70% of masters being taught in this field. **Broad masters are more present in *Engineering, manufacturing and construction*, *Business, administration and law* and *Natural sciences, mathematics and statistics***. Table A 5 in Annex 1, which presents the distribution of masters by technological domain and narrow field of education (two-digits), shows that more than half (54.1%) CS masters (broad and specialised masters considered together) are taught in the field of *ICT*, but there are other narrow fields with a relatively important share: 14.5% of all CS masters are taught in *Engineering and engineering trades*; 13.2% are taught in *Business and administration*; 6.2% in *Mathematics and statistics*; and 3.4% in *Law* studies.

Figure 18. CS master programmes by scope and field of education (%). EU, 2020-21



Note: The percentages are based on the total number of masters within each scope.

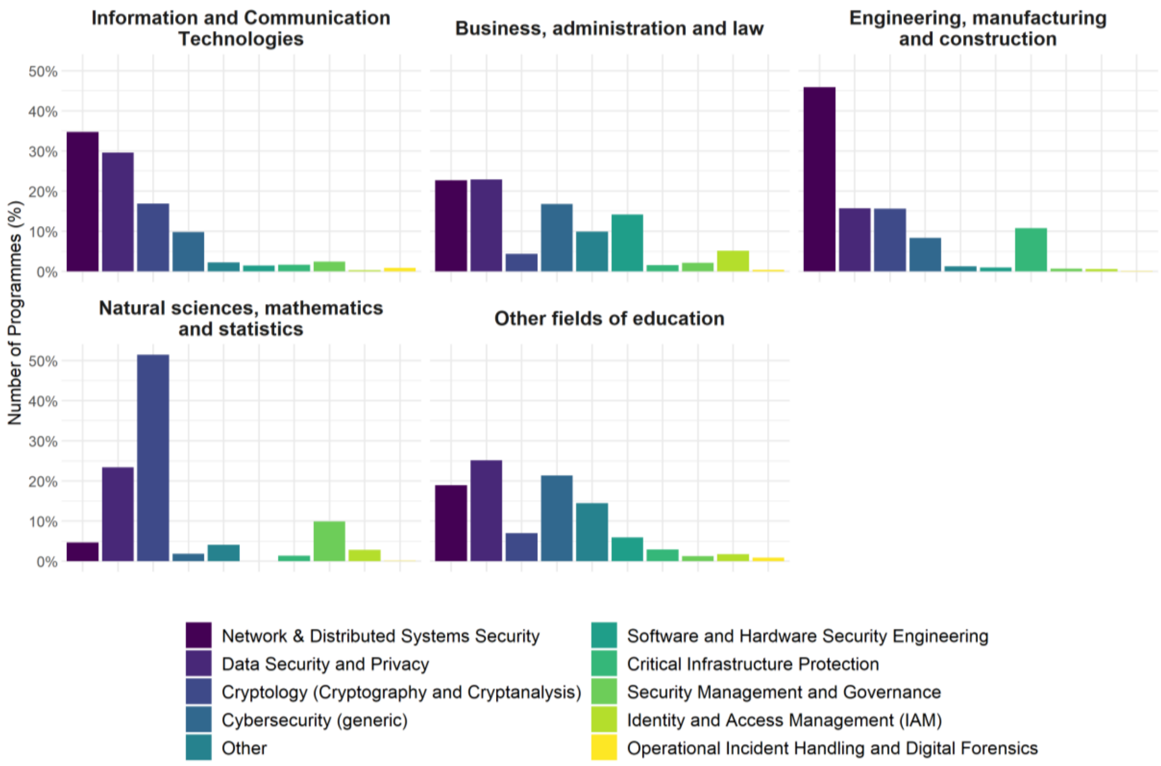
Figure 19. CS master programmes by scope and content area (%). EU, 2020-21



Note: The percentages are based on the total number of masters within each scope.

Figure 19 shows small differences between CS broad and specialised masters in their distribution by content area. While in the broad ones, the main focus is on *Network & Distributed Systems Security*, followed by *Data Security and Privacy*, and then *Cryptology*, specialised masters are more balanced as the three content areas present more similar shares (around 20-25% each).

Figure 20. CS master programmes by field of education and content area (%). EU, 2020-21



Note: The percentages are based on the total number of masters within each field of education.

Figure 20 shows that the distribution of content areas of CS masters varies across fields of education. For instance, we detect a **significant share of *Cryptology*** (over 50%) **taught in programmes of the *Natural sciences, mathematics and statistics* field**, explained by the theoretical nature of cryptology and its deep connections with abstract mathematics. We also observe that the **CS offer in the field of *Engineering, manufacturing and construction* is very focused on the *Network & Distributed Systems Security* content area**. It is relevant to notice that the education field of ***Business, administration and law* presents a very uniform distribution for what concerns its four main areas of content**. These are: *Network & Distributed Systems Security*, *Data Security and Privacy*, *Cybersecurity (generic)*, and *Software and Hardware Security Engineering*. In addition, the small share of *Cryptology* in this field of education indicates the limited importance of this area of content for the education background of students in this field, which is very business-oriented.

Among the countries offering at least 10 CS masters in the 2020-21 academic year or in the previous one, we observe different evolutions (Table 7.). **Germany, France** and **Finland**, which were already providing a high number of CS masters, substantially increase their offer in 2020-21 (increase of 8% for Germany, 30% for France and 20% for Finland). In particular, we see a significant jump of France's offer of specialised masters, from 9 in 2019-20 to 14 in 2020-21 (+56%) and an increase of broad masters in Finland, from 13 to 17 (+31%). For the **Netherlands** and **Italy there is almost no variation on their offer**, which remains stable at levels equal or very similar to those of 2020. Finally, it is important to remark that among the countries with at least 10 masters, **Spain**, **Denmark** and **Sweden** reduce their offer by more than 10%.

These variations do not appear as noteworthy, but it is important to keep track on the evolution in future academic years.

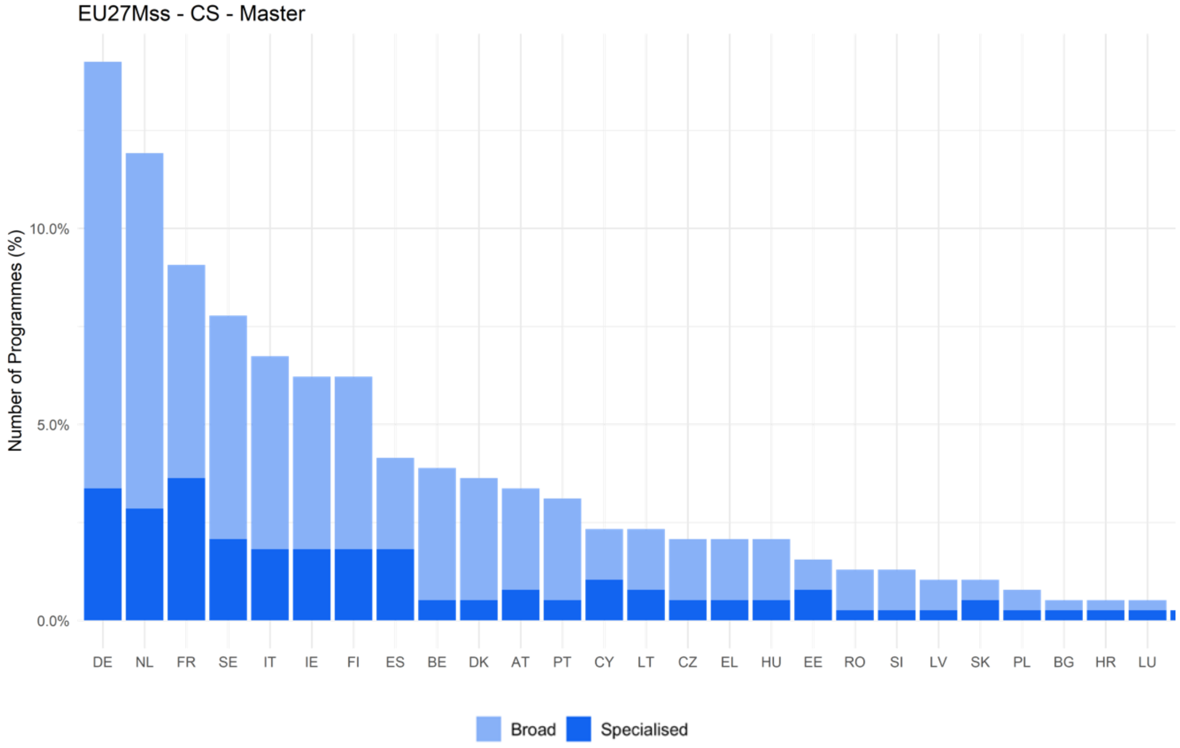
Table 7. CS masters in the EU Member States, 2019-20 and 2020-21

	Academic year 2020-21			Academic year 2019-20			Percentage change* (%)		
	Broad	**Specialised**	**Total**	**Broad**	**Specialised**	**Total**	**Broad**	**Specialised**	**Total**
BE	13	2	**15**	13	3	**16**	*0%*	*-33%*	***-6%***
BG	1	1	**2**	1	1	**2**			
CZ	6	2	**8**	5	2	**7**			
DK	12	2	**14**	15	1	**16**	*-20%*	*100%*	***-13%***
DE	42	13	**55**	40	11	**51**	*5%*	*18%*	***8%***
EE	3	3	**6**	4	3	**7**			
IE	17	7	**24**	19	7	**26**	*-11%*	*0%*	***-8%***
EL	6	2	**8**	6	3	**9**			
ES	9	7	**16**	11	8	**19**	*-18%*	*-13%*	***-16%***
FR	21	14	**35**	18	9	**27**	*17%*	*56%*	***30%***
HR	1	1	**2**	2	0	**2**			
IT	19	7	**26**	19	7	**26**	*0%*	*0%*	***0%***
CY	5	4	**9**	4	5	**9**			
LV	3	1	**4**	4	1	**5**			
LT	6	3	**9**	4	1	**5**			
LU	1	1	**2**	1	1	**2**			
HU	6	2	**8**	3	2	**5**			
MT	0	1	**1**	0	1	**1**			
NL	35	11	**46**	35	10	**45**	*0%*	*10%*	***2%***
AT	10	3	**13**	11	3	**14**	*-9%*	*0%*	***-7%***
PL	2	1	**3**	5	1	**6**			
PT	10	2	**12**	6	4	**10**	*67%*	*-50%*	***20%***
RO	4	1	**5**	3	1	**4**			
SI	4	1	**5**	4	1	**5**			
SK	2	2	**4**	0	2	**2**			
FI	17	7	**24**	13	7	**20**	*31%*	*0%*	***20%***
SE	22	8	**30**	23	11	**34**	*-4%*	*-27%*	***-12%***
EU	**277**	**109**	**386**	**269**	**106**	**375**	***3%***	***3%***	***3%***

Note: (*) The percentage variation is computed only for countries offering at least 10 programmes in one of the academic years.

Figure 21 shows that the EU's educational offer of CS masters' programmes is led by Germany (14% of all EU's offer), followed by the Netherlands (12%). France, Sweden, Italy, Ireland and Finland follow, all representing between 9% and 6% of EU's offer. The EU's average of specialised CS masters is 28%. France and Spain are the countries with the largest share of specialised masters: 44% and 40% of their national offer, respectively.

Figure 21. CS master's programmes by Member State and scope (%). 2020-21



Note: The percentages are based on the total number of masters in the EU.

6 Data Science

Despite the ever-increasing claims about the new and amazing possibilities unleashed by AI, humans can still outmatch machines in reasoning and problem-solving. The same stands for data analytics as well. In fact, the distinction between the selection process of the optimal type of analysis on the one hand, and the implementation of the selected methodology on the other hand, is crucial. While the latter can be extremely automatized, and hence computer programmes can be extremely useful for it, the former is more complex and requires further considerations regarding, for instance, the theoretical adequacy of methodologies, the type of data to be used, the objectives, the set of available algorithms, the time constraints, the computational resources available, etc. Therefore, in recent years, the new field of DS was born to propose an educational path able to merge theoretical notions (statistical and mathematical), with their practical implementation on computing machines. As the abundance of digital information has almost led to the paradoxical situation in which too much information is no information, DS is needed in order to disentangle great amount of available data and obtain meaningful information out of them. What is at stake is the fact that the complexity (both in quantity and quality) of the available information, if not properly considered, can leave room for arbitrary analyses, conclusions based on partial or biased points of view, and misleading results. Furthermore, in case that AI is used to run unsupervised processes, some human action is always needed, at least in the very initial phase of setting and launching the procedure and making sure that the data sources and methods satisfy the principles of a fair and transparent use of the technology. Hence, a mix of hard and soft skills is required to handle the increasing availability of multi-dimensional data and new algorithms, treat structured and unstructured data, unveil emerging analytical results, and elaborate and communicate key insights.

The EC has identified a crucial driver for the economic competitiveness of the Union and for its social well-being in the usage of data. In the communication “A European strategy for data” (European Commission, 2020b), it is possible to read that “*Europe aims to capture the benefits of better use of data, including greater productivity and competitive markets, but also improvements in health and well-being, environment, transparent governance and convenient public services.*” (European Commission, 2020a), and that “*making more data available and improving the way in which data is used is essential for tackling societal, climate and environment-related challenges, contributing to healthier, more prosperous and more sustainable societies*”. In addition, in the latest communication “Fostering a European approach to Artificial Intelligence” (European Commission, 2021b), the significant role of data is highlighted in multiple contexts, and it is remarked the need to make a trustworthy use of it for the development and deployment of certain AI systems. At the same time, it is also acknowledged the importance of data-sharing, especially between companies, to foster competitiveness in the digital transition. Therefore, much of the potential related to the use of data is still unexpressed. And in addition to the elements reported, the skills that are needed to treat, process and elaborate data should not be taken secondarily. In fact, at the current state of the technology, machines are not able to automatically manage the input information with full autonomy. To really make the value of data emerge, factors like theoretical reasoning and computer programming skills are absolutely essential.

The education offer mapped in this section refers to programmes related to at least one of the DS-related subdomains presented in the Box 5.

Box 5. DS content areas and most frequent keywords

Machine learning & Statistical modelling: machine learning, neural networks, statistical learning, predictive analytics, deep learning, pattern recognition, classification/clustering/boosting algorithms, reinforcement learning, unstructured data, recommender system, decision tree, transfer learning.

Big data: big data, nosql.

Business intelligence: business intelligence, decision support, decision analytics.

Data mining: data mining.

Data science architectures: parallelisation, scalability, distributed computing, parallel computing, spark, hadoop, mapreduce.

Natural language processing: information retrieval, natural language processing/understanding, information extraction, sentiment analysis.

Other: data visualisation, semantic web, genetic/evolutionary algorithms, gradient descent, metaheuristic optimisation.

Data analytics (generic): this area is allocated to programmes that refer to DS and the main techniques to collect, process and analyse data, without further details on content areas.

Source: Authors' elaboration.

6.1 DS education offer in the international context

Table 8. DS master's programmes by scope and geographic area, 2019-20 and 2020-21

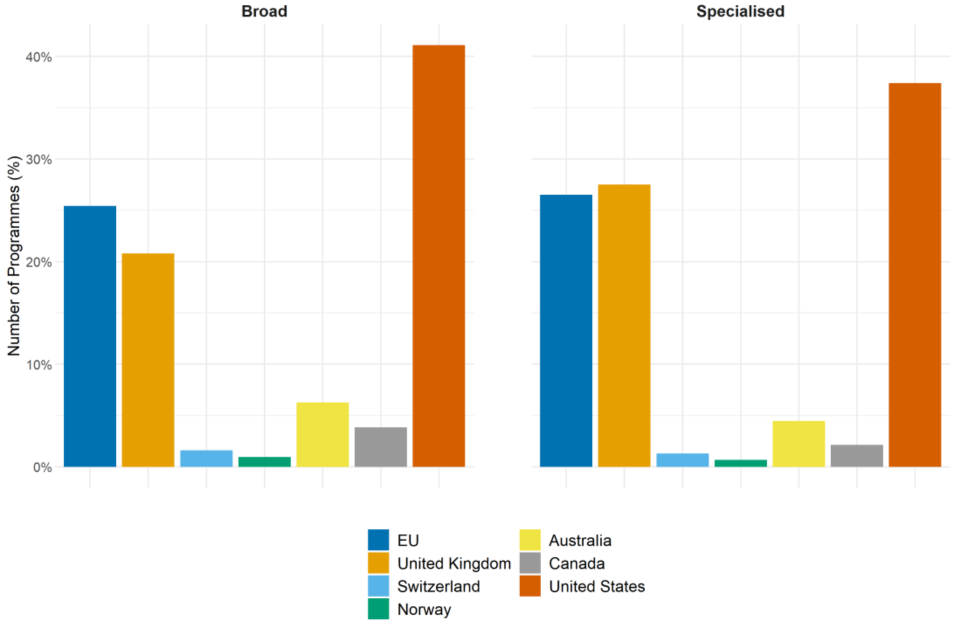
	EU	United Kingdom	Norway	Switzerland	Canada	United States	Australia	Total
				Academic year 2020-21				
Broad	646	528	24	41	98	1044	159	**2,540**
Specialised	349	362	9	17	28	492	59	**1316**
Total	**995**	**890**	**33**	**58**	**126**	**1,536**	**218**	**3,856**
				Academic year 2019-20				
Broad	605	515	20	36	94	946	153	**2,369**
Specialised	325	365	10	12	29	492	66	**1299**
Total	**930**	**880**	**30**	**48**	**123**	**1438**	**219**	**3,668**
				Percentage change (%)				
Broad	7%	3%	20%	14%	4%	10%	4%	**7%**
Specialised	7%	-1%	-10%	42%	-3%	0%	-11%	**1%**
Total	**7%**	**1%**	**10%**	**21%**	**2%**	**7%**	**0%**	**5%**

When comparing the evolution of DS-related education with respect to the previous academic year, we observe a **consistent and balanced increase in the EU (7%) of both broad and specialised masters' programmes** (Table 8). The overall addition of 65 masters confirms the second position of the EU in the domain. **The US**, which leads in number of programmes offered, **also faces an overall increase, but exclusively due to the increase of broad masters,** since the number of specialised masters remains unchanged with respect to 2019-20. The UK, the third geographical area in terms of number of DS programmes offered, does not show any significant change.

Small differences arise in the **geographical distribution of the DS-related broad and specialised masters** (Figure 22). The **US keeps its leading position**, with a share of 41% of broad masters, and 37% of specialised masters. Following the US, **the EU and the UK hold a very close position**, with shares between 20% and 30% of the DS educational offer depending on the scope of the programmes. In fact, while the **EU holds the second position in broad masters** (25% of the offer, against 21% for the UK), the UK appears to focus more on specialised masters, where a share of 28% can be observed (against 27% for the EU).

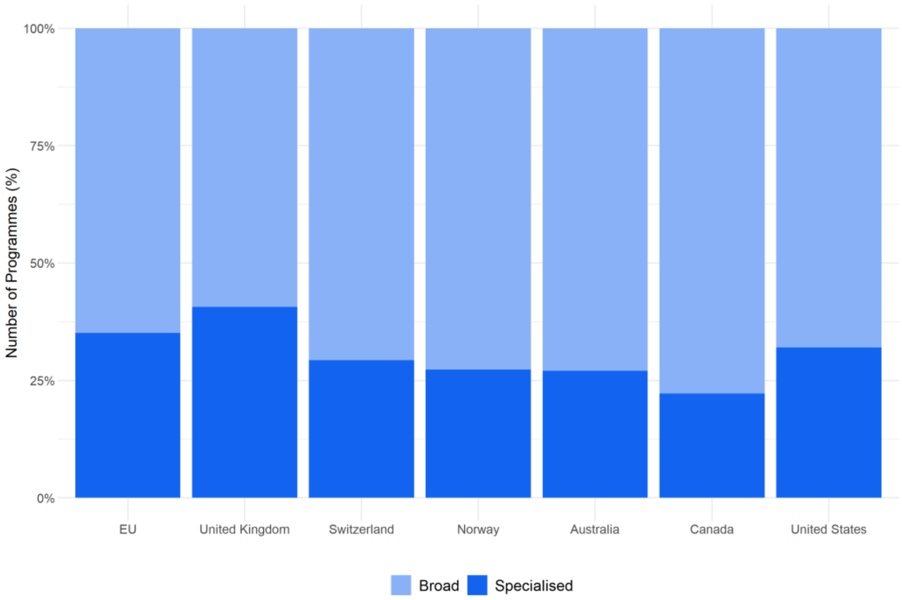
The overall offer of DS masters is split into 34% of specialised masters and 66% of broad masters. The **UK's offer presents a remarkable share of specialised masters (41%)** (Figure 23), while this share reaches 35% in the EU and 34% in the US. This, together with the fact that DS is the domain, out of the four analysed in this study, in which the UK concentrates the highest offer, **is likely to reflect a structural feature of the UK's economy** and **a stronger demand of such specific skills on the local labour market**. Indeed, the role of the UK in the AI landscape has been highlighted by several works (Samoili et al., 2018, p. 38). In particular, the presence of firms with a core business in AI but not oriented towards the development of the technology (by means of filing of patents for instance), i.e., firms that mostly provide AI-related services, is predominant in the UK. It is likely that these firms don't need highly-technical skills (like the ones related to pure AI, CS or HPC) and may be hiring profiles with skills that are related to the usage of data.

Figure 22. Geographical distribution of DS programmes by scope (%). All geographic areas, 2020-21



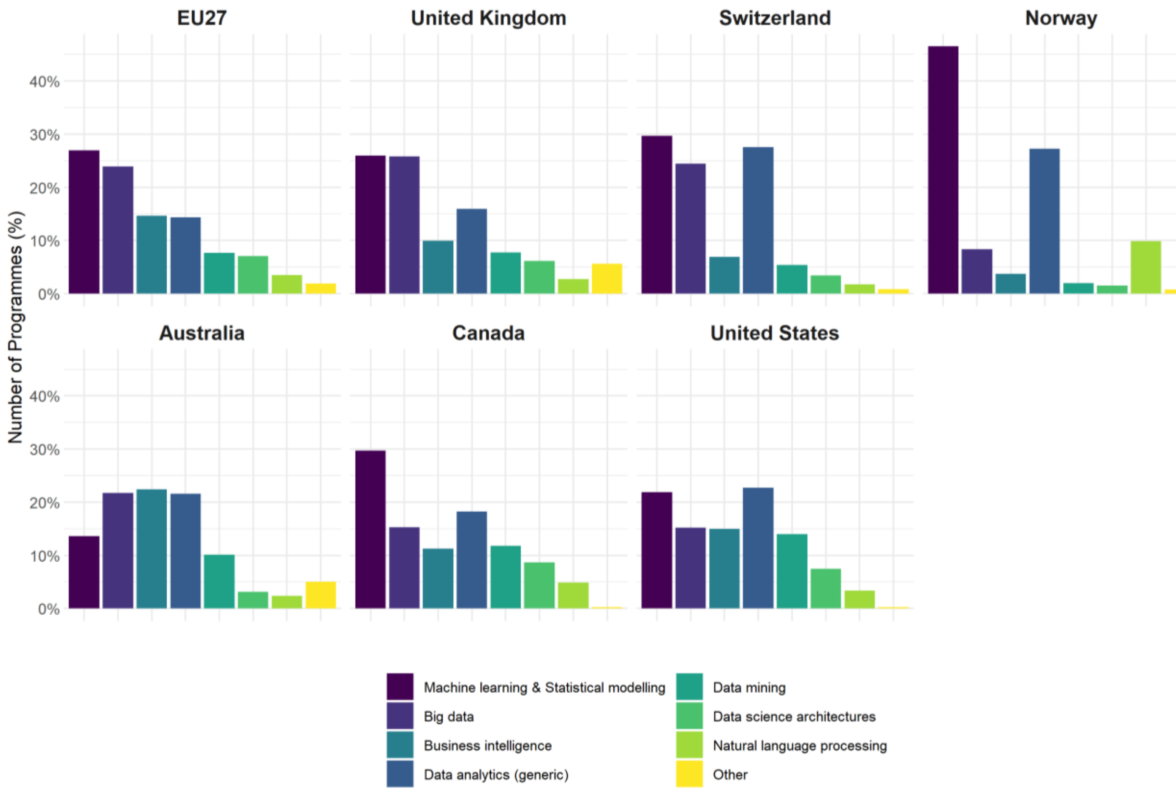
Note: The percentages are based on the number of programmes in the specific combination of scope (broad vs. specialised).

Figure 23. DS programmes by geographic area and scope (%). All geographic areas, 2020-21



Note: The percentages are based on the total number of programmes within each geographic area.

Figure 24. DS programmes by geographic area and content taught (%). All geographic areas, 2020-21



Note: The percentages are based on the total number of masters within each geographic area

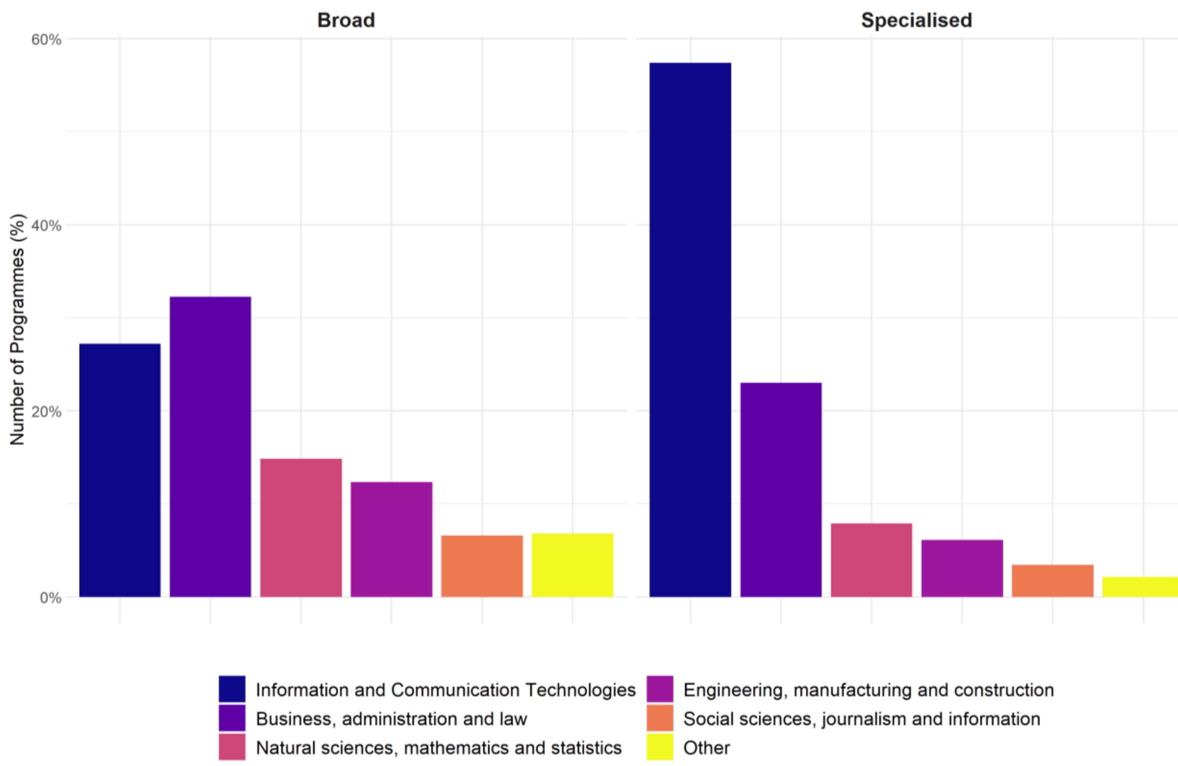
Machine learning & Statistical modelling is the main content area taught in DS masters in all considered areas, but Australia (Figure 24). The three main geographical areas considered by the size of their offer, i.e., the US, the EU, and the UK, present some differences in terms of main content areas. The **EU is very focused on *Machine learning & Statistical modelling* and *Big data*, and then it presents some considerable shares for both *Business intelligence* and *Data analytics***. The UK shows a similar pattern, but it presents a smaller share for *Business intelligence*. For the US, the two major areas of content are *Machine learning & Statistical modelling* and *Data analytics*.

6.2 Focus on the EU

In Figure 25 we observe a different distribution of EU's broad and specialised masters by education field. Interestingly, DS is the only domain -among the four considered- in which the largest share of broad masters is not taught in the *ICT* field, but in ***Business, administration and law*** instead. **This finding supports the idea of usefulness and applicability of DS-related skills in business contexts**. DS-skills are more focused on the broad capacity of data usage for multiple processes rather than on more technical aspects, like in the other domains considered. Therefore, they are intensively proposed in business-oriented educational paths. This is very likely to be the response to specific features of the labour market demand. DS-related specialised masters are mainly included in the educational field of *ICT*.

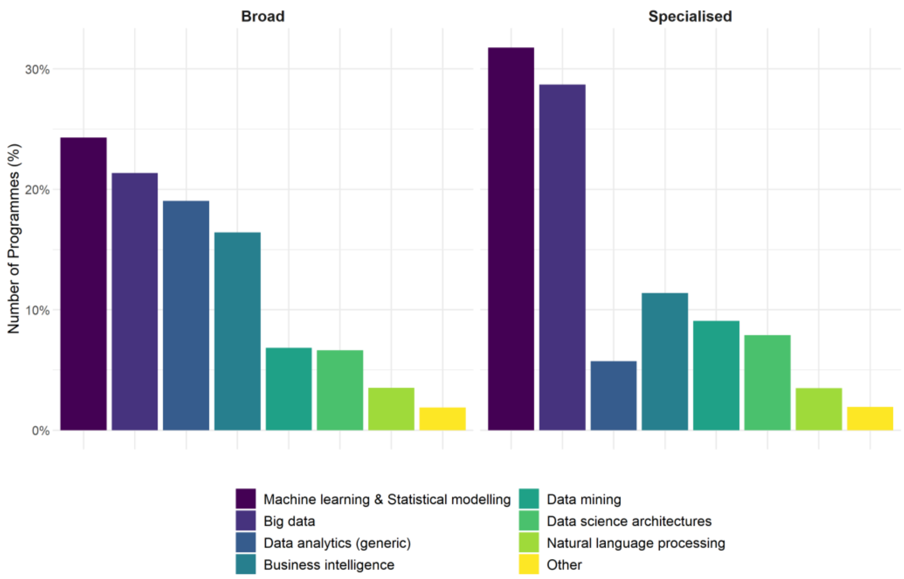
The **EU's broad masters present a very balanced set of content areas** (Figure 26). Four out of the eight content areas present shares between 15% to 25% (in decreasing order): ***Machine learning & Statistical modelling*, *Big data*, *Data analytics*, and *Business intelligence***. On the contrary, **specialised masters are very concentrated in *Machine learning & Statistical modelling* and *Big data***. Nonetheless, they also present good shares of secondary content areas, such as *Business intelligence* (12%), *Data mining* (9%) and *Data science architectures* (8%).

Figure 25. DS master programmes by scope and field of education (%). EU, 2020-21



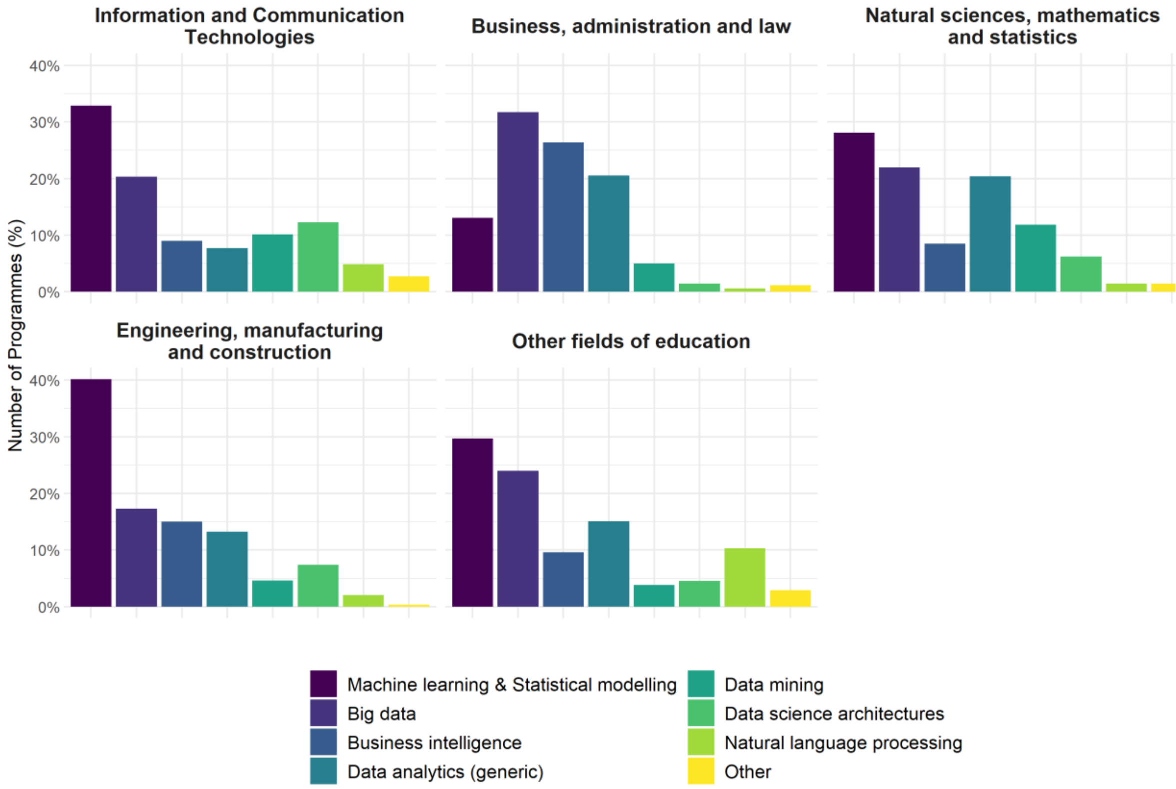
Note: The percentages are based on the total number of masters within each scope.

Figure 26. DS master programmes by scope and content area (%). EU, 2020-21



Note: The percentages are based on the total number of masters within each scope.

Figure 27. DS master programmes by field of education and content area (%). EU, 2020-21



Note: The percentages are based on the number of programmes in each field of education.

When we look at the distribution of content areas taught within each field of education, it is interesting to notice that **the most technical content area, i.e., *Machine learning & Statistical modelling* is not so widely taught in the field of *Business, administration and law*** (Figure 27). This fact should not be overlooked, given the role of DS in the referred education field *Data science architectures*, another highly-technical content area, is mainly taught in *ICT*, with minor presence in *Engineering, manufacturing and construction* and in *Natural sciences, mathematics and statistics*. The educational field of *Business, administration and law* is the one presenting the largest share for the content areas of *Big data*, *Business intelligence*, and *Data analytics*. These could be mirroring the most demanded skills by companies.

The analysis of the variation in the EU Member States' DS-related educational offer with respect to the previous academic year (Table 9.) shows a remarkable increase for several countries. These are Czechia (67%), Austria (23%), France (19%), Hungary (17%), Finland (16%), Lithuania (14%), the Netherlands (10%), and Germany (10%).

The highest decrease is observed for Romania and Cyprus (both -27%), Poland (-14%) and Spain (-10%); Denmark and Belgium also show smaller contractions in the offer. Although these variations are not ominous, it is important to further monitor the DS-related offer of these countries, especially taking into account their remarkable role in the AI landscape (Samoili et al., 2020, Righi et al., 2021).

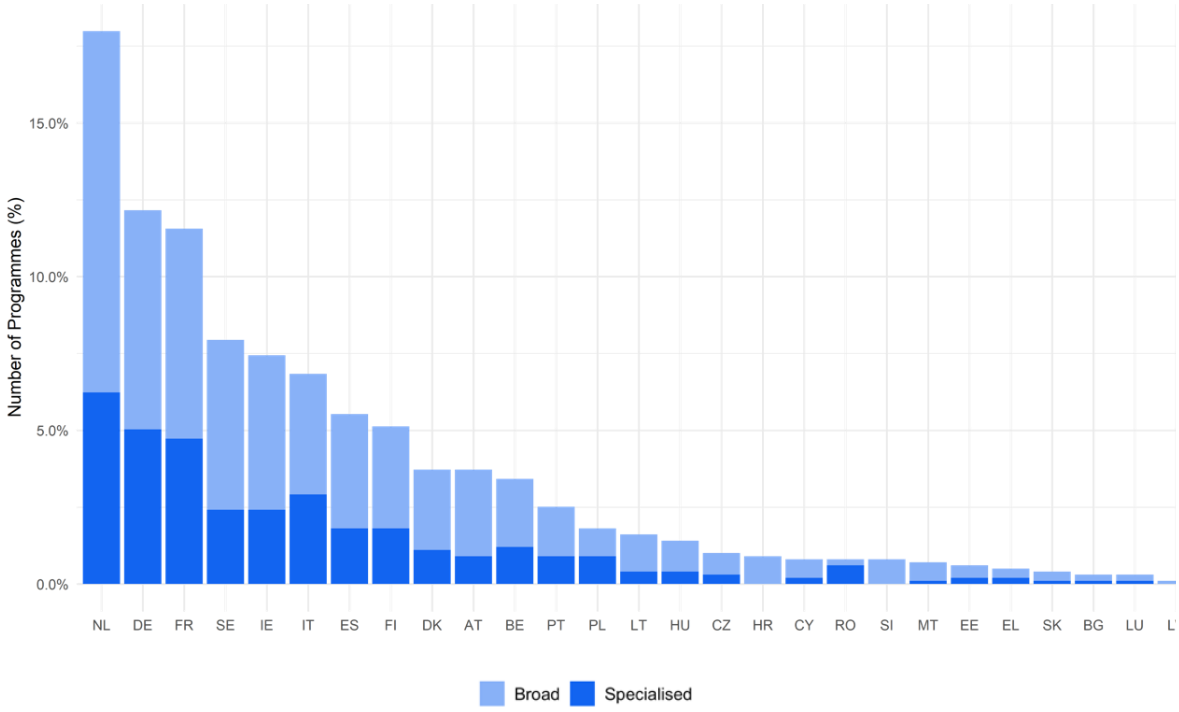
The **Netherlands is by far the leading EU Member State** in the number of **DS masters** (Figure 28), with its educational offer constituting 18% of the offer of the entire EU. In addition, it also presents a good share of specialised master programmes (34% of national offer). **Germany and France follow** (each of them represents 12% of the EU's offer) with **remarkable shares of specialised master programmes** (41% and 40% of national offer, respectively). Then, we observe the group made of Sweden, Ireland, Italy, Spain and Finland, each of them representing between 8% and 5% of the EU's DS education offer at master level. Among them, we highlight a **high share of specialised masters in Italy** (43% of the national offer).

Table 9. DS masters in the EU Member States, 2019-20 and 2020-21

	Academic year 2020-21			Academic year 2019-20			Percentage change* (%)		
	Broad	**Specialised**	**Total**	**Broad**	**Specialised**	**Total**	**Broad**	**Specialised**	**Total**
BE	22	12	**34**	20	15	**35**	*10%*	*-20%*	***-3%***
BG	2	1	**3**	1	1	**2**			
CZ	7	3	**10**	2	4	**6**	*250%*	*-25%*	***67%***
DK	26	11	**37**	28	12	**40**	*-7%*	*-8%*	***-8%***
DE	71	50	**121**	67	43	**110**	*6%*	*16%*	***10%***
EE	4	2	**6**	2	2	**4**			
IE	50	24	**74**	48	23	**71**	*4%*	*4%*	***4%***
EL	3	2	**5**	5	2	**7**			
ES	37	18	**55**	43	18	**61**	*-14%*	*0%*	***-10%***
FR	68	47	**115**	58	39	**97**	*17%*	*21%*	***19%***
HR	9	0	**9**	7	0	**7**			
IT	39	29	**68**	40	27	**67**	*-3%*	*7%*	***1%***
CY	6	2	**8**	9	2	**11**	*-33%*	*0%*	***-27%***
LV	1	0	**1**	1	0	**1**			
LT	12	4	**16**	10	4	**14**	*20%*	*0%*	***14%***
LU	2	1	**3**	2	1	**3**			
HU	10	4	**14**	9	3	**12**	*11%*	*33%*	***17%***
MT	6	1	**7**	3	0	**3**			
NL	117	62	**179**	107	55	**162**	*9%*	*13%*	***10%***
AT	28	9	**37**	24	6	**30**	*17%*	*50%*	***23%***
PL	9	9	**18**	12	9	**21**	*-25%*	*0%*	***-14%***
PT	16	9	**25**	17	7	**24**	*-6%*	*29%*	***4%***
RO	2	6	**8**	3	8	**11**	*-33%*	*-25%*	***-27%***
SI	8	0	**8**	8	0	**8**			
SK	3	1	**4**	2	0	**2**			
FI	33	18	**51**	26	18	**44**	*27%*	*0%*	***16%***
SE	55	24	**79**	51	26	**77**	*8%*	*-8%*	***3%***
EU	**646**	**349**	**995**	**605**	**325**	**930**	***7%***	***7%***	***7%***

Note: (*) The percentage variation is computed only for countries offering at least 10 programmes in one of the academic years.

Figure 28. DS master's programmes by Member State and scope (%). 2020-21

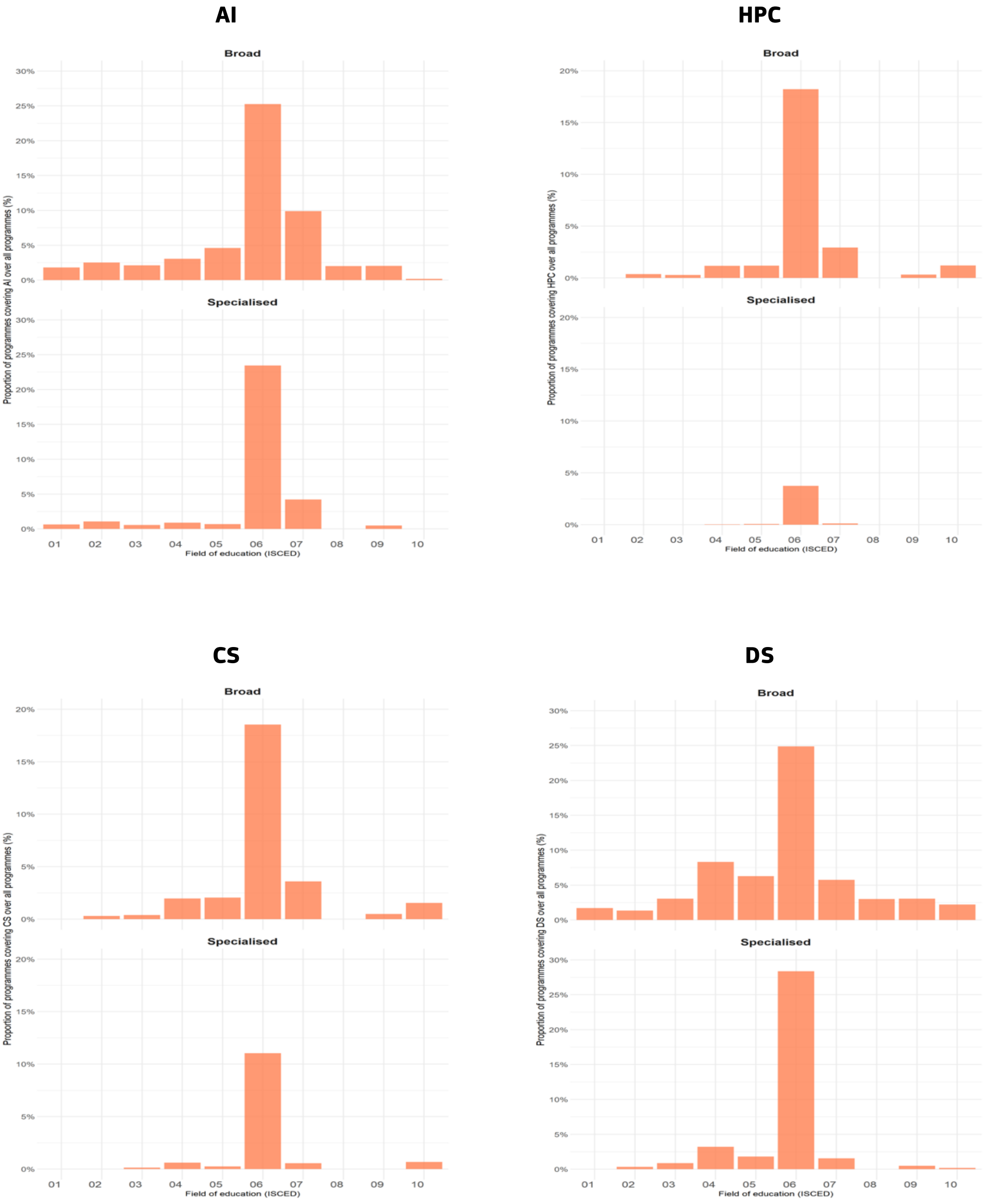


Note: The percentages are based on the number of programmes in each field of education in the EU.

7 Overall education offer in AI, HPC, CS and DS and overlap among domains

7.1 Advanced skills offer in the whole educational offer

Figure 29. Penetration rate of advanced digital skills in masters' programmes by field of education (% of masters in digital domains over total number of masters), 2020-21



Field of education

01 Education
02 Arts and humanities
03 Social sciences, journalism and information
04 Business, administration and law
05 Natural sciences, mathematics and statistics
06 Information and Communication Technologies
07 Engineering, manufacturing and construction
08 Agriculture, forestry, fisheries and veterinary
09 Health and welfare
10 Services

Note: The percentages are based on the total number of masters within each field of education.

As expected, the analysis of the penetration that advanced digital skills have in the whole education offer (by field of education) reveals that *ICT* is the field with highest share of masters related to the domains considered (Figure 29): 25% of masters in *ICT* are specialised in AI, and an additional 23% of *ICT* masters include AI contents in a broader way. Similarly, the penetration of DS in *ICT* reaches 28% and 25% respectively. AI masters are also relatively common in the field of *Engineering, manufacturing and construction*: 10% of masters in engineering are broad AI masters, and 4.2% are specialised AI masters; and in *Natural sciences, mathematics and statistics*: 4.6% of masters are broad AI masters and 0.7% are specialised AI masters. This pattern is repeated in the four domains that are considered in the study. It is worth noting that 8.3% of the masters in *Business, administration and law* are broad masters in DS, and 3.2% are specialised masters in DS.

Another interesting result is the higher pervasiveness of broad masters across fields of education, which reveals the inclusion of notions on advanced digital skills in masters of education, arts and humanities, social sciences, health, etc.

Table A 14 in Annex 1 presents the penetration rates of each technological domain by country, that is, the proportion of masters taught in each technological domain over all masters taught in the country. The overall penetration rates of the EU are 4.2%, 1.3%, 2.0% and 5.1% for AI, HPC, CS and DS respectively, in all cases above the rates of the US (1.8%, 0.7%, 1.5%, 2.8%) and the UK (2.2%, 0.7%, 1.6%, 2.8%). The EU Member States with at least 10 masters offered in 2020-21 that exceed the average EU rate by at least one fourth are, in AI: Slovenia (7.6%), Denmark (7.0%), Finland (6.7%) and France (5.7%); in HPC: Denmark (2.7%), France (1.9%), Finland (1.8%) and Austria (1.7%); in CS: Finland (3.4%); in DS: France and Finland (7.2%) and Austria (6.3%).

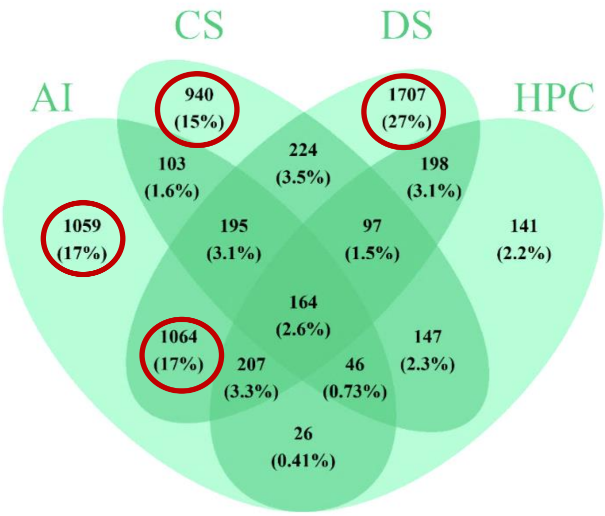
7.2 Technological domains' overlap

When considering all the masters' programmes detected in the study, the analysis of the degree of overlap among the different domains allows to determine the interconnections in the educational offer of the four digital domains[14]. In Figure 30, it is possible to observe three out of four masters' programmes are included in one of the following four subsets (red-rounded in Figure 30): **programmes that belong exclusively to AI (17%), programmes that belong exclusively to CS (15%), programmes that belong exclusively to DS (27%), and programmes that belong simultaneously to DS and AI (17%).** The fact that both AI and DS are present twice in this list highlights the predominant role they have in the design of training paths on advanced digital skills, in comparison to CS and HPC. **The only consistent intersection detected is between AI and DS**, and this remarks **the degree of continuity that exists between the two domains**. Considering the characterization of the educational offer of these domains in terms of the educational fields in which they're taught, we could interpret this overlap saying that even if many contents are shared between the two domains, **AI is mainly for computer scientists and engineers, while DS is more for computer scientists and students in the business track**.

Considering the single domains separately (Table 10) it is possible to observe a **very large overlap between HPC and the other domains**. While AI, CS and DS deal with some functions that can be implemented by means of computers, HPC is more related to the way most advanced computers are built and programmed to enhance computing power. Therefore, **HPC-related notions have indeed a very transversal role**. In addition, **a substantial part of HPC content is related to *Cloud*, which is becoming the new paradigm in terms of data sharing, platforms and distributed computation**. So, the fact that these skills are taught also in domains different from HPC should not surprise.

[14] It has to be recalled that the same masters' programme can be detected under multiple domains, depending on its textual description, and therefore, the set of keywords identifying it.

Figure 30. Overlap of technological domains. All geographic areas, 2020-21



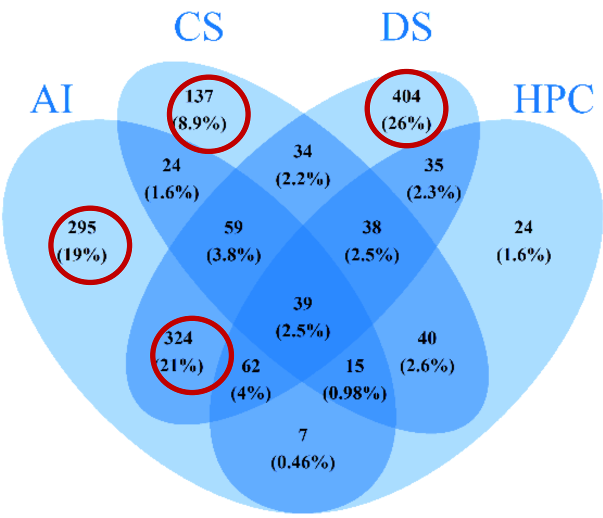
Note: The percentages are based on the total number of masters in all four domains.

Table 10. Percentage of overlap of technological domains. All geographic areas, 2020-21

	% of masters not shared with other domains	% of masters shared with other domains	Number of masters
AI	37%	63%	2,864
HPC	14%	86%	1,026
CS	49%	51%	1,916
DS	44%	56%	3,856
All 4 domains			**6,318**

Note: The percentages are based on the total number of masters within each domain. Given the overlaps between domains, the total number of masters does not equal the sum of number of masters by domain.

Figure 31. Overlap of technological domains. EU, 2020-21



Note: The percentages are based on the total number of masters in all four domains in the EU.

Table 11. Percentage of overlap of technological domains. EU, 2020-21

	% of masters not shared with other domains	% of masters shared with other domains	Number of masters
AI	36%	64%	825
HPC	9%	91%	260
CS	35%	65%	386
DS	41%	59%	995
All 4 domains			**1,537**

Note: The percentages are based on the total number of masters within each domain. Given the overlaps between domains, the total number of masters does not equal the sum of number of masters by domain.

When focusing on the EU, the overlap among domains presents some significant differences (Figure 31). First of all, we detected a smaller percentage of programmes belonging exclusively to CS (8.9% in the EU, vs. 15% overall). Secondly, it is also possible to observe a larger overlap between AI and DS (21% in the EU, vs. 17% overall). These points seem to indicate positive signals. In fact, the smaller percentage of programmes that exclusively belong to CS implies that EU's CS-related programmes present more common elements with the other digital domains. This is noteworthy, as CS skills are essential for privacy and protection issues, no matter in which specific technological domain the students have their main focus. With regards to AI and DS, also this finding appears to be a good signal, since there is a conceptual continuity between the two domains and the fact that their offer overlaps is likely to enhance the students' employment opportunities, as they will be more able to fit in both AI-related and DS-related positions.

For what concerns each single domain separately, in Table 11. we observe a very low percentage of HPC programmes not presenting overlaps with any other domain (9% in the EU, vs. 14% overall). In general, it should be noted that in any of the four domains considered, **the share of programmes overlapping with other domains is always larger when considering the EU**. This indicates that in **the EU, the educational offer of the four advanced technological domains is remarkably interconnected**.

7.3 Distribution of fields of education by technological domain

With regards to the education fields in which the advanced digital skills are taught, Table 12. shows that **for each domain the highest number of programmes comes from the educational field of *ICT***, which was expected given the nature of the domains considered. **The largest coverage is detected in HPC**, where programmes in this field account for almost 60%, **followed by CS** (54%). For these two domains, educational fields other than the aforementioned do not have any remarkable role. In AI and DS, *ICT* is also the education field accounting for the highest number of masters. However, the percentages are much smaller than those observed for HPC and CS: 42% of AI masters and 38% of DS masters.

AI masters are also covered by the educational field of *Engineering, manufacturing and construction* (24%). This is the highest share observed for any domain, and it reveals the strong technical context in which the AI skills are taught in most of the cases. Other significant shares observed for AI are for the fields of *Business, administration and law* (12%, in line with other domains), *Natural sciences, mathematics and statistics* (10%, also in line with other domains), and finally to the two educational fields of *Arts and humanities* and *Social sciences, journalism and information*. Despite the two latter do not present large shares (6% and 5%, respectively), we notice that in other domains their role is less notable. These AI masters are mostly present in the narrow fields of *Social and behavioural sciences* (3.3% of all AI masters), *Arts* (3.2%); *Languages* (2.3%); and *Journalism and information* (1.2%). This last finding highlights the **broader use of AI in artistic and societal contexts**.

For DS, an important finding should be highlighted: it is the only domain in which almost three out of ten masters are included in the education field of *Business, administration and law*. This result, along with the consistent presence of contents such as *Business intelligence* or *Data analytics* (Figure 26), shows that DS is a less technical domain, and that it is remarkably considered in educational contexts that are more business-oriented. Therefore, the DS profile appears to require less specific hard-skills and more with business acumen.

In this sense, DS seem to be more adaptable than AI, CS and HPC to a multiplicity of business contexts and tasks.

The previous insight should make DS students a valuable resource for businesses that (i) need support to take advantage of the potential of data, and that (ii) are usually characterised by the necessity to cover assignments of multiple nature by the same employee.

Table 12. Masters by broad field of education and technological domain. EU, 2020-21

		AI		HPC		CS		DS	
Broad field of educ. code	**Broad field of education**	N. of Prog.	%	N. of Prog.	%	N. of Prog.	%	N. of Prog.	%
00	Generic programmes and qualifications	0	0%	0	0%	1	0%	0	0%
01	Education	4	1%	0	0%	0	0%	3	0%
02	Arts and humanities	49	6%	5	2%	4	1%	23	2%
03	Social sciences, journalism and information	37	5%	4	2%	8	2%	55	6%
04	Business, administration and law	100	12%	30	12%	65	17%	289	29%
05	Natural sciences, mathematics and statistics	81	10%	19	7%	35	9%	123	12%
06	Information and Communication Technologies	344	42%	155	60%	209	54%	376	38%
07	Engineering, manufacturing and construction	195	24%	42	16%	58	15%	101	10%
08	Agriculture, forestry, fisheries and veterinary	2	0%	0	0%	0	0%	3	0%
09	Health and welfare	13	2%	2	1%	3	1%	18	2%
10	Services	0	0%	2	1%	4	1%	5	1%
	Total	**825**	**100%**	**260**	**100%**	**386**	**100%**	**995**	**100%**
	Total number of masters in any of the domains: 1,537								

8 Conclusions

Over the last decades, digital technologies have evolved and become pervasive in all spheres of our life. Emerging fields like Artificial Intelligence (AI), High Performance Computing (HPC), Computer Science (CS) and Data Science (DS) have experienced an unprecedented development thanks to the continuous increase of computing power and data availability. These new technologies have triggered what is considered the 'Fourth industrial revolution'. The EC is supporting the transition towards a competitive, fair, trustworthy and resilient digital economy and society that works for all and empowers its citizens. Among the most relevant provisions, we can mention the European Strategy on Artificial intelligence, aiming at boosting technological and industrial capacity and AI uptake; its Coordinated Plan on AI, setting out specific objectives for a coordinated effort of the EC and Member States; the White paper on AI, proposing policy options to promote uptake of trustworthy AI and addressing the associated risks of misuse of AI; the European strategy for data, aiming at facilitating data flows within the EU and across sectors; the Communication "Fostering a European approach to Artificial Intelligence", which presents a proposal for a regulatory framework on AI to promote the development of AI, and addresses the potential high risks that AI poses to safety and fundamental rights; the European Cybersecurity Act; and the European High Performance Computing Joint Undertaking. Along with these acts and strategies, the EC identifies the promotion of advanced digital skills as one of the pillars for the digital transition, as acknowledged by the Digital Compass Communication, which presents a vision, targets and avenues for a successful digital transformation of the European Union by 2030. The new Digital Education Action Plan for the period 2021-2027 includes a set of actions to improve and integrate AI skills for the citizens to interact with AI systems; the Digital Europe Programme provides funding for the design and development of specialised courses in key digital technologies, many Member States have adopted national strategies to develop advanced digital skills, as suggested in the 2018 Coordinated Plan on AI.

In this context, this report continues the work started in 2019 by the JRC providing evidence about the educational offer related to AI, HPC, CS and DS. Given the strategic importance of such skills for future economic productivity, we investigate the availability of higher education offer in advanced digital skills, so as to anticipate possible gaps (or abundance). In the present study, we monitor the academic offer of masters' programmes in the four mentioned technological domains and analyse its characteristics in the EU and six additional countries: the United Kingdom, Norway, Switzerland, Canada, the United States and Australia. We target master university programmes that are taught in English.

The most salient points of the analysis are reported below:

- In the academic year 2020-21, the EU has overall increased its higher education offer in advanced digital skills. In fact, the EU is the only one of the geographical areas analysed that shows an increase in the number of specialised masters in the four technological domains, however the overall number of broad and specialised masters remains below 1,000 in every domain, always below the number of masters in the US, and above the UK except for CS. This helps the EU to consolidate the second position, after the US, in AI, HPC and DS, and third after the UK in CS. In specialised AI masters, the EU surpasses the US and holds the first position.

- The US and the UK have an uneven evolution: the US increases its offer in AI (only in broad masters, and reducing the offer of specialised ones), and DS, and reduces it in HPC and CS (in both broad and specialised masters). The UK also experiences an increase of AI masters, decrease in HPC and CS, and remains stable in DS.

- Several Member States have a very strong position in the EU, occupying the first positions in the supply of advanced digital skills, and some of them showing a significant increase with respect to 2019-20. Germany, the Netherlands, France, Sweden, Ireland, Italy and Spain are among the top EU Member States in the four domains. We observe a significant overall increase with respect to the previous academic year, often exceeding 20%, in the number of masters provided by Germany (except in AI), the Netherlands and France. Finland also sees increases above 15% in CS and DS, Hungary increases by over 40% in AI, Austria increases its offer in DS by 23%.

- The overall penetration rates, or proportion of masters with advanced digital skills over all masters offered are higher for the EU than for the US and the UK in all four technological domains.

- We observe a differential pattern of distribution of broad and specialised masters across the fields of education. While the vast majority of specialised masters are taught in *ICT* (from 57% in DS to 88% in CS), broad masters have more presence in other fields of education like *Engineering, manufacturing and construction*, *Business, administration and law* and *Natural sciences, mathematics* *and statistics*. This concentration of specialised masters in *ICT*, although expected, seems to be a good signal as it indicates that specialised masters are concentrated in the field of education with which the theoretical connection is stronger.

- The field of education *Business, administration and law* gains importance in the EU's education offer, especially among broad masters. This field of education accumulates 14% of the broad masters offered in AI, 13% of HPC-related broad masters, 18% in CS, and 32% in DS. Also, studies in the field of *Business, administration and law* tend to have a more uniform distribution of areas of content in the syllabus than masters taught in more technical fields (i.e., informatics, engineering). This supports the argument of the usefulness of broad digital skills in business-oriented working contexts. Due to the wider coverage of less technical contents (e.g., *Big data*, *Business intelligence*, and *Data analytics* in DS) in comparison with specialised masters (which show a higher weight of *Machine learning & Statistical modelling*) indicates that business-oriented DS educational paths provide less technical and hard skills and instead rely on a variety of contents focused on the use of data. Still, the fact that *Machine learning* is one of the most frequent content areas in AI-related masters in *Business, administration and law* seems positive, as this would guarantee a minimum level of awareness of the core functioning of AI algorithms and therefore would help minimise the black-box effect in the application of AI by companies.
- Considering the relatively strong link observed between business studies and the teaching of the four digital domains, we can argue that the development of advanced digital skills can help to sustain the digital transition of business active in non-technological economic sectors. In particular, data scientists appear to be good candidates to support such a crucial transition for the economy of the EU.
- The low proportion of specialised masters in HPC (10% of all HPC masters) may be explained by the instrumental nature of HPC, which is taught embedded as a cross-sectional topic in syllabus providing students with a wide range of technical skills. In fact, we find a high percentage of overlap between HPC and the other domains under study: 91% of the EU's masters in HPC are considered at the same time masters in at least one of the other domains.
- We find that 21% of EU masters belong simultaneously to AI and DS, which highlights the degree of continuity that exists between the two domains. While AI is mainly for computer scientists and engineers, DS is targeted to computer scientists and business students.

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List of abbreviations

AI	Artificial Intelligence
BAL	Business, administration and law
CS	Cybersecurity
DG CNECT	Directorate General for Communications Networks, Content and Technology
DS	Data Science
EC	European Commission
EMC	Engineering, manufacturing and construction
ENISA	European Union Agency for Network and Information Security
EU	European Union
GPU	Graphics processing unit
HPC	High performance computing
IAM	Identity and Access Management
ICT	Information and Communication Technology
IoT	Internet of Things
ISCED	International Standard Classification of Education
JRC	Joint Research Centre
OECD	Organisation for Economic Co-operation and Development
PREDICT	Prospective Insights on R&D in ICT
R&D	Research and development

List of country codes and names

EU Member States						***Non-EU countries***	
BE	Belgium	IT	Italy	RO	Romania	UK	United Kingdom
BG	Bulgaria	CY	Cyprus	SI	Slovenia	NO	Norway
CZ	Czechia	LV	Latvia	SK	Slovakia	CH	Switzerland
DK	Denmark	LT	Lithuania	FI	Finland	CA	Canada
DE	Germany	LU	Luxembourg	SE	Sweden	US	United States
EE	Estonia	HU	Hungary			AU	Australia
IE	Ireland	MT	Malta				
EL	Greece	NL	Netherlands				
ES	Spain	AT	Austria				
FR	France	PL	Poland				
HR	Croatia	PT	Portugal				

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Annex 1 Detailed results

Table A 1. AI programmes by country, level and scope. All countries, 2020-21

		Bachelor		Master		Short programmes		Total
		Broad	Specialised	Broad	Specialised	Broad	Specialised	
BE	Belgium	6	3	25	7	4	3	**48**
BG	Bulgaria	0	0	1	1	0	0	**2**
CZ	Czechia	2	0	4	8	0	0	**14**
DK	Denmark	2	3	32	10	2	3	**52**
DE	Germany	10	9	69	34	15	6	**143**
EE	Estonia	0	2	3	5	0	1	**11**
IE	Ireland	43	11	43	12	0	0	**109**
EL	Greece	1	0	1	3	1	0	**6**
ES	Spain	4	1	32	15	1	1	**54**
FR	France	3	1	47	44	3	1	**99**
HR	Croatia	0	0	1	1	2	0	**4**
IT	Italy	6	0	37	20	2	2	**67**
CY	Cyprus	5	0	3	3	0	0	**11**
LV	Latvia	2	4	4	3	0	0	**13**
LT	Lithuania	4	4	11	4	0	1	**24**
LU	Luxembourg	0	0	2	0	0	0	**2**
HU	Hungary	10	1	14	6	0	0	**31**
MT	Malta	1	0	5	2	0	0	**8**
NL	Netherlands	9	10	68	27	8	8	**130**
AT	Austria	2	1	14	7	0	0	**24**
PL	Poland	3	9	14	7	0	0	**33**
PT	Portugal	2	0	11	9	0	0	**22**
RO	Romania	1	0	4	3	0	0	**8**
SI	Slovenia	0	0	11	2	0	0	**13**
SK	Slovakia	1	1	4	3	0	0	**9**
FI	Finland	8	3	27	20	0	1	**59**
SE	Sweden	3	1	55	27	2	0	**88**
	EU	**128**	**64**	**542**	**283**	**40**	**27**	**1084**
UK	United Kingdom	402	198	446	251	22	14	**1333**
NO	Norway	1	1	24	11	0	0	**37**
CH	Switzerland	3	0	23	11	1	1	**39**
CA	Canada	88	55	82	40	6	2	**273**
US	United States	942	274	765	257	98	164	**2500**
AU	Australia	129	42	106	23	8	10	**318**
	TOTAL	**1821**	**698**	**2530**	**1159**	**215**	**245**	**6668**

Table A 2. HPC programmes by country, level and scope. All countries, 2020-21

		Bachelor		Master		Short programmes		Total
		Broad	Specialised	Broad	Specialised	Broad	Specialised	
BE	Belgium	3	0	10	0	2	0	**15**
BG	Bulgaria	0	0	2	0	0	0	**2**
CZ	Czechia	0	0	3	2	0	0	**5**
DK	Denmark	2	0	15	1	1	0	**19**
DE	Germany	8	0	34	3	4	0	**49**
EE	Estonia	0	0	2	0	0	0	**2**
IE	Ireland	28	0	20	1	0	0	**49**
EL	Greece	0	0	1	0	0	0	**1**
ES	Spain	3	0	16	0	3	0	**22**
FR	France	3	0	27	4	3	0	**37**
HR	Croatia	1	0	11	2	0	0	**14**
IT	Italy	1	0	2	0	0	0	**3**
CY	Cyprus	0	0	1	0	0	0	**1**
LV	Latvia	2	0	6	1	0	0	**9**
LT	Lithuania	0	0	1	0	0	0	**1**
LU	Luxembourg	1	0	7	0	0	0	**8**
HU	Hungary	0	0	1	0	0	0	**1**
MT	Malta	3	0	12	6	10	0	**31**
NL	Netherlands	0	0	10	0	0	0	**10**
AT	Austria	0	0	6	0	0	0	**6**
PL	Poland	0	0	7	0	0	0	**7**
PT	Portugal	0	1	3	4	0	0	**8**
RO	Romania	0	0	1	0	0	0	**1**
SI	Slovenia	0	0	2	0	0	0	**2**
SK	Slovakia	2	0	11	2	0	0	**15**
FI	Finland	2	0	19	4	1	0	**26**
SE	Sweden	138	1	212	21	7	0	**379**
	EU	**197**	**2**	**442**	**51**	**31**	**0**	**723**
UK	United Kingdom	0	0	12	0	0	0	**12**
NO	Norway	1	0	8	1	3	2	**15**
CH	Switzerland	43	1	37	5	2	0	**88**
CA	Canada	289	8	361	44	86	8	**796**
US	United States	43	0	63	2	26	1	**135**
AU	Australia	3	0	10	0	2	0	**15**
	TOTAL	**773**	**13**	**1375**	**154**	**181**	**11**	**2507**

Table A 3. CS programmes by country, level and scope. All countries, 2020-21

		Bachelor		Master		Short programmes		Total
		Broad	Specialised	Broad	Specialised	Broad	Specialised	
BE	Belgium	5	1	13	2	6	3	**30**
BG	Bulgaria	1	0	1	1	0	0	**3**
CZ	Czechia	2	0	6	2	1	0	**11**
DK	Denmark	1	0	12	2	1	1	**17**
DE	Germany	9	2	42	13	1	1	**68**
EE	Estonia	0	1	3	3	2	0	**9**
IE	Ireland	32	7	17	7	0	2	**65**
EL	Greece	3	1	6	2	1	0	**13**
ES	Spain	3	1	9	7	3	1	**24**
FR	France	3	2	21	14	1	0	**41**
HR	Croatia	1	0	1	1	2	0	**5**
IT	Italy	3	1	19	7	0	0	**30**
CY	Cyprus	2	0	5	4	1	0	**12**
LV	Latvia	3	1	3	1	0	0	**8**
LT	Lithuania	2	1	6	3	0	0	**12**
LU	Luxembourg	0	0	1	1	0	0	**2**
HU	Hungary	4	0	6	2	1	0	**13**
MT	Malta	1	0	0	1	0	0	**2**
NL	Netherlands	11	1	35	11	8	12	**78**
AT	Austria	1	0	10	3	1	0	**15**
PL	Poland	3	0	2	1	0	0	**6**
PT	Portugal	1	0	10	2	0	0	**13**
RO	Romania	1	0	4	1	0	0	**6**
SI	Slovenia	0	0	4	1	0	0	**5**
SK	Slovakia	1	0	2	2	0	0	**5**
FI	Finland	4	2	17	7	0	0	**30**
SE	Sweden	3	2	22	8	0	0	**35**
	EU	**100**	**23**	**277**	**109**	**29**	**20**	**558**
UK	United Kingdom	375	154	330	177	20	31	**1087**
NO	Norway	1	3	9	3	0	0	**16**
CH	Switzerland	2	2	15	5	2	2	**28**
CA	Canada	74	18	41	10	3	1	**147**
US	United States	957	276	537	293	76	53	**2192**
AU	Australia	83	21	80	30	25	6	**245**
	TOTAL	**1692**	**520**	**1566**	**736**	**184**	**133**	**4831**

Table A 4. DS programmes by country, level and scope. All countries, 2020-21

		Bachelor		Master		Short programmes		Total
		Broad	**Specialised**	**Broad**	**Specialised**	**Broad**	**Specialised**	
BE	Belgium	6	4	22	12	5	4	**53**
BG	Bulgaria	1	0	2	1	0	0	**4**
CZ	Czechia	0	1	7	3	0	0	**11**
DK	Denmark	1	2	26	11	3	4	**47**
DE	Germany	15	7	71	50	9	8	**160**
EE	Estonia	1	0	4	2	0	1	**8**
IE	Ireland	33	9	50	24	2	0	**118**
EL	Greece	3	0	3	2	0	2	**10**
ES	Spain	10	3	37	18	5	2	**75**
FR	France	3	2	68	47	25	3	**148**
HR	Croatia	0	0	9	0	1	0	**10**
IT	Italy	2	2	39	29	1	1	**74**
CY	Cyprus	2	0	6	2	0	0	**10**
LV	Latvia	3	0	1	0	0	0	**4**
LT	Lithuania	3	0	12	4	0	1	**20**
LU	Luxembourg	0	0	2	1	0	0	**3**
HU	Hungary	3	0	10	4	0	0	**17**
MT	Malta	0	0	6	1	0	0	**7**
NL	Netherlands	21	9	117	62	22	12	**243**
AT	Austria	1	1	28	9	0	1	**40**
PL	Poland	2	1	9	9	0	0	**21**
PT	Portugal	2	0	16	9	0	0	**27**
RO	Romania	1	0	2	6	0	0	**9**
SI	Slovenia	0	0	8	0	1	0	**9**
SK	Slovakia	1	0	3	1	0	0	**5**
FI	Finland	8	1	33	18	0	0	**60**
SE	Sweden	4	0	55	24	1	1	**85**
	EU	**126**	**42**	**646**	**349**	**75**	**40**	**1278**
UK	United Kingdom	417	93	528	362	20	28	**1448**
NO	Norway	0	2	24	9	0	0	**35**
CH	Switzerland	4	0	41	17	4	6	**72**
CA	Canada	71	12	98	28	3	1	**213**
US	United States	923	260	1,044	492	134	271	**3,124**
AU	Australia	117	29	159	59	5	12	**381**
	TOTAL	**1784**	**480**	**3,186**	**1665**	**316**	**398**	**7,829**

Table A 5. Masters by narrow field of education and technological domain. EU, 2020-21

			AI		HPC		CS		DS	
Broad field of educ. code	**Narrow field of educ. Code**	**Narrow field of education**	N. of Prog.	%	N. of Prog.	%	N. of Prog.	%	N. of Prog.	%
00	03	Personal skills and development	0	0.0%	0	0.0%	1	0.3%	0	0.0%
01	11	Education	4	0.5%	0	0.0%	0	0.0%	3	0.3%
02	21	Arts	26	3.2%	5	1.9%	3	0.8%	14	1.4%
02	22	Humanities (except languages)	5	0.6%	0	0.0%	0	0.0%	2	0.2%
03	23	Languages	19	2.3%	0	0.0%	1	0.3%	7	0.7%
03	31	Social and behavioural sciences	27	3.3%	1	0.4%	4	1.0%	46	4.6%
03	32	Journalism and information	10	1.2%	3	1.2%	3	0.8%	8	0.8%
04	41	Business and administration	94	11.4%	28	10.8%	51	13.2%	282	28.3%
04	42	Law	5	0.6%	2	0.8%	13	3.4%	6	0.6%
05	50	Natural sciences, mathematics and statistics n.f.d.	3	0.4%	0	0.0%	1	0.3%	4	0.4%
05	51	Biological and related sciences	26	3.2%	3	1.2%	5	1.3%	38	3.8%
05	52	Environment	1	0.1%	0	0.0%	3	0.8%	3	0.3%
05	53	Physical sciences	17	2.1%	6	2.3%	2	0.5%	30	3.0%
05	54	Mathematics and statistics	34	4.1%	10	3.8%	24	6.2%	48	4.8%
06	61	Information and Communication Technologies	344	41.7%	155	59.6%	209	54.1%	376	37.8%
07	71	Engineering and engineering trades	189	22.9%	39	15.0%	56	14.5%	94	9.4%
07	72	Manufacturing and processing	3	0.4%	1	0.4%	1	0.3%	3	0.3%
07	73	Architecture and construction	3	0.4%	2	0.8%	1	0.3%	4	0.4%
08	81	Agriculture	2	0.2%	0	0.0%	0	0.0%	2	0.2%
08	82	Forestry	0	0.0%	0	0.0%	0	0.0%	1	0.1%
08	83	Fisheries	0	0.0%	0	0.0%	0	0.0%	1	0.1%
09	91	Health	10	1.2%	1	0.4%	1	0.3%	10	1.0%
09	92	Welfare	0	0.0%	0	0.0%	1	0.3%	0	0.0%
09	98	Interdisciplinary programmes involving broad field 09	3	0.4%	1	0.4%	1	0.3%	8	0.8%
10	101	Personal services	0	0.0%	2	0.8%	1	0.3%	3	0.3%
10	103	Security services	0	0.0%	0	0.0%	3	0.8%	0	0.0%
10	104	Transport services	0	0.0%	1	0.4%	1	0.3%	2	0.2%
		Total	**825**	**100%**	**260**	**100%**	**386**	**100%**	**995**	**100%**
	Total number of masters in any of the domains: 1,537									

Table A 6. AI masters by country and field of education. All countries, 2020-21

		Generic programmes and qualifications	Education	Arts and humanities	Social sciences, journalism & information	Business, administration and law	Natural sciences, mathematics and statistics	Information and Communication Technologies	Engineering, manufacturing and construction	Agriculture, forestry, fisheries and veterinary	Health and welfare	Services
BE	Belgium	0.0	0.0	0.7	1.0	4.3	2.2	10.2	13.2	0.0	0.5	0.0
BG	Bulgaria	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CZ	Czechia	0.0	0.0	0.7	0.0	0.0	2.5	7.5	1.3	0.0	0.0	0.0
DK	Denmark	0.0	0.0	3.3	2.2	3.0	2.8	12.0	17.7	0.0	1.0	0.0
DE	Germany	0.0	0.3	3.3	6.8	10.5	13.5	44.2	21.3	1.0	2.0	0.0
EE	Estonia	0.0	0.0	0.3	0.3	0.7	1.0	3.0	2.7	0.0	0.0	0.0
IE	Ireland	0.0	0.5	6.0	4.0	7.5	3.5	18.8	13.2	0.0	1.5	0.0
EL	Greece	0.0	0.0	0.0	0.0	0.5	0.0	2.7	0.8	0.0	0.0	0.0
ES	Spain	0.0	0.0	4.3	3.3	8.0	5.5	18.2	7.2	0.0	0.5	0.0
FR	France	0.0	1.3	2.3	1.3	21.0	10.0	38.0	16.2	0.0	0.8	0.0
HR	Croatia	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0
IT	Italy	0.0	0.0	3.2	1.2	7.2	4.5	28.5	12.2	0.0	0.3	0.0
CY	Cyprus	0.0	0.0	0.5	0.3	1.0	0.0	4.2	0.0	0.0	0.0	0.0
LV	Latvia	0.0	0.0	0.3	0.0	0.7	0.0	5.0	1.0	0.0	0.0	0.0
LT	Lithuania	0.0	0.0	0.3	1.0	1.3	1.7	4.2	6.5	0.0	0.0	0.0
LU	Luxembourg	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0
HU	Hungary	0.0	0.0	1.0	0.3	0.0	1.0	9.7	7.7	0.0	0.3	0.0
MT	Malta	0.0	0.0	1.0	1.0	0.8	0.5	1.5	1.7	0.0	0.5	0.0
NL	Netherlands	0.0	0.3	7.2	10.5	14.2	11.7	37.2	9.7	0.0	4.3	0.0
AT	Austria	0.0	0.0	0.3	0.3	4.0	2.3	8.5	4.8	0.0	0.7	0.0
PL	Poland	0.0	0.0	0.0	0.0	1.8	0.3	11.8	6.7	0.0	0.0	0.3
PT	Portugal	0.0	0.0	1.5	0.0	3.8	1.7	6.8	6.2	0.0	0.0	0.0
RO	Romania	0.0	0.0	0.0	0.0	0.5	0.0	6.2	0.3	0.0	0.0	0.0
SI	Slovenia	0.0	1.0	3.0	0.3	0.3	0.0	3.8	4.5	0.0	0.0	0.0
SK	Slovakia	0.0	0.0	0.0	1.0	0.0	0.5	3.5	2.0	0.0	0.0	0.0
FI	Finland	0.0	0.3	2.0	1.3	4.0	5.2	20.8	12.3	1.0	0.0	0.0
SE	Sweden	0.0	0.0	5.7	1.0	4.3	9.3	36.0	25.3	0.0	0.3	0.0
	EU	**0.0**	**3.8**	**49.0**	**37.3**	**99.5**	**80.7**	**344.2**	**195.3**	**2.0**	**12.8**	**0.3**

		Generic programmes and qualifications	Education	Arts and humanities	Social sciences, journalism & information	Business, administration and law	Natural sciences, mathematics and statistics	Information and Communication Technologies	Engineering, manufacturing and construction	Agriculture, forestry, fisheries and veterinary	Health and welfare	Services
UK	United Kingdom	0.0	0.8	53.3	18.7	81.2	51.8	321.8	146.3	1.3	16.7	5.0
NO	Norway	0.0	0.7	4.7	0.5	3.3	4.3	16.0	5.5	0.0	0.0	0.0
CH	Switzerland	0.0	0.0	0.3	1.2	6.0	3.0	15.8	6.7	0.0	0.5	0.5
CA	Canada	0.0	0.0	3.2	2.3	6.0	15.7	51.2	39.8	0.5	3.3	0.0
US	United States	0.0	11.2	56.2	28.0	111.5	102.2	421.2	278.2	0.8	12.2	0.7
AU	Australia	0.0	0.0	3.5	0.7	20.3	10.8	47.8	36.8	0.0	5.7	3.3
	TOTAL	**0.0**	**16.5**	**170.2**	**88.7**	**327.8**	**268.5**	**1218.0**	**708.7**	**4.7**	**51.2**	**9.8**

Note: A programme may be taught in more than one field of education. In that case, the programme is weighted using fractional count to avoid double counting (for instance, a programme that appears both in the field of *ICT* and *Engineering* is weighted 0.5 in each of them).

Table A 7. HPC masters by country and field of education. All countries, 2020-21

		Generic programmes and qualifications	Education	Arts and humanities	Social sciences, journalism & information	Business, administration and law	Natural sciences, mathematics and statistics	Information and Communication Technologies	Engineering, manufacturing and construction	Agriculture, forestry, fisheries and veterinary	Health and welfare	Services
BE	Belgium	0.0	0.0	0.0	0.0	1.3	0.0	6.2	2.5	0.0	0.0	0.0
BG	Bulgaria	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0
CZ	Czechia	0.0	0.0	0.0	0.3	0.0	2.0	2.7	0.0	0.0	0.0	0.0
DK	Denmark	0.0	0.0	0.3	1.7	1.8	0.0	8.2	3.0	0.0	0.0	1.0
DE	Germany	0.0	0.0	0.0	0.3	6.8	1.3	17.2	10.2	0.0	0.5	0.7
EE	Estonia	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.7	0.0	0.0	0.0
IE	Ireland	0.0	0.0	0.5	0.0	8.2	1.0	9.7	1.7	0.0	0.0	0.0
EL	Greece	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.3	0.0	0.0	0.0
ES	Spain	0.0	0.0	0.0	0.7	4.2	0.5	7.2	2.5	0.0	0.3	0.7
FR	France	0.0	0.0	2.3	0.0	2.8	4.0	16.7	4.7	0.0	0.5	0.0
HR	Croatia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IT	Italy	0.0	0.0	0.0	0.0	2.0	0.0	10.7	0.3	0.0	0.0	0.0

		Generic programmes and qualifications	Education	Arts and humanities	Social sciences, journalism & information	Business, administration and law	Natural sciences, mathematics and statistics	Information and Communication Technologies	Engineering, manufacturing and construction	Agriculture, forestry, fisheries and veterinary	Health and welfare	Services
CY	Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0
LV	Latvia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
LT	Lithuania	0.0	0.0	0.3	0.0	0.0	0.7	4.7	1.3	0.0	0.0	0.0
LU	Luxembourg	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
HU	Hungary	0.0	0.0	0.0	0.0	0.0	1.0	5.2	0.8	0.0	0.0	0.0
MT	Malta	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
NL	Netherlands	0.0	0.0	0.8	1.2	0.0	4.0	9.7	2.0	0.0	0.3	0.0
AT	Austria	0.0	0.0	0.0	0.0	1.0	2.0	5.0	2.0	0.0	0.0	0.0
PL	Poland	0.0	0.0	0.0	0.0	0.0	0.0	5.5	0.5	0.0	0.0	0.0
PT	Portugal	0.0	0.0	0.5	0.0	1.7	1.0	2.8	1.0	0.0	0.0	0.0
RO	Romania	0.0	0.0	0.0	0.0	0.0	0.0	6.2	0.8	0.0	0.0	0.0
SI	Slovenia	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
SK	Slovakia	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0
FI	Finland	0.0	0.0	0.3	0.0	0.5	0.0	10.2	2.0	0.0	0.0	0.0
SE	Sweden	0.0	0.0	0.0	0.0	0.0	1.5	16.7	4.8	0.0	0.0	0.0
	EU	**0.0**	**0.0**	**5.2**	**4.2**	**30.3**	**19.0**	**155.2**	**42.2**	**0.0**	**1.7**	**2.3**
UK	United Kingdom	0.0	0.0	7.5	2.2	23.2	22.7	143.2	27.5	0.0	2.8	4.0
NO	Norway	0.0	0.0	0.0	0.5	1.5	0.0	7.8	2.2	0.0	0.0	0.0
CH	Switzerland	0.0	0.0	0.0	0.0	0.3	2.0	4.2	2.5	0.0	0.0	0.0
CA	Canada	0.0	0.0	0.0	0.3	1.8	7.2	27.7	3.3	0.0	1.3	0.3
US	United States	0.0	1.0	4.7	4.5	41.3	50.0	237.0	61.3	1.5	3.7	0.0
AU	Australia	0.0	0.5	5.5	1.2	9.2	8.2	31.0	8.0	0.0	0.8	0.7
	TOTAL	**0.0**	**1.5**	**22.8**	**12.8**	**107.7**	**109.0**	**606.0**	**147.0**	**1.5**	**10.3**	**7.3**

Note: A programme may be taught in more than one field of education. In that case, the programme is weighted using fractional count to avoid double counting (for instance, a programme that appears both in the field of *ICT* and *Engineering* is weighted 0.5 in each of them).

Table A 8. CS masters by country and field of education. All countries, 2020-21

		Generic programmes and qualifications	Education	Arts and humanities	Social sciences, journalism & information	Business, administration and law	Natural sciences, mathematics and statistics	Information and Communication Technologies	Engineering, manufacturing and construction	Agriculture, forestry, fisheries and veterinary	Health and welfare	Services
BE	Belgium	0.0	0.0	0.0	0.0	2.0	0.5	7.8	4.7	0.0	0.0	0.0
BG	Bulgaria	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0
CZ	Czechia	0.0	0.0	0.0	1.0	0.3	1.0	5.3	0.0	0.0	0.0	0.3
DK	Denmark	0.0	0.0	0.3	1.3	1.8	0.0	5.5	4.0	0.0	0.0	1.0
DE	Germany	0.0	0.0	1.5	1.2	11.8	5.0	26.3	8.2	0.0	0.5	0.5
EE	Estonia	0.0	0.0	0.0	0.0	1.0	0.0	3.7	1.3	0.0	0.0	0.0
IE	Ireland	0.0	0.0	0.5	1.0	3.7	0.5	12.5	5.5	0.0	0.0	0.3
EL	Greece	0.0	0.0	0.0	0.0	1.5	0.0	5.2	1.3	0.0	0.0	0.0
ES	Spain	0.0	0.0	0.0	0.0	2.5	1.2	8.0	4.3	0.0	0.0	0.0
FR	France	0.0	0.0	1.3	0.5	7.5	1.3	19.0	4.8	0.0	0.5	0.0
HR	Croatia	0.0	0.0	0.0	0.0	1.0	0.0	0.7	0.3	0.0	0.0	0.0
IT	Italy	0.0	0.0	0.5	0.5	2.5	4.0	17.2	1.3	0.0	0.0	0.0
CY	Cyprus	0.0	0.0	0.0	0.0	2.5	0.0	6.5	0.0	0.0	0.0	0.0
LV	Latvia	0.0	0.0	0.0	0.0	0.7	0.0	1.5	1.8	0.0	0.0	0.0
LT	Lithuania	0.0	0.0	0.0	0.0	1.3	0.3	4.8	2.5	0.0	0.0	0.0
LU	Luxembourg	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0
HU	Hungary	0.0	0.0	0.0	0.0	1.0	1.0	5.2	0.8	0.0	0.0	0.0
MT	Malta	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
NL	Netherlands	1.0	0.0	0.0	0.3	11.5	9.3	16.8	5.5	0.0	0.5	1.0
AT	Austria	0.0	0.0	0.0	0.0	3.0	3.3	5.5	1.2	0.0	0.0	0.0
PL	Poland	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0
PT	Portugal	0.0	0.0	0.0	1.0	3.2	1.0	6.0	0.5	0.0	0.0	0.3
RO	Romania	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.8	0.0	0.0	0.0
SI	Slovenia	0.0	0.0	0.0	0.3	1.8	1.0	1.5	0.0	0.0	0.0	0.3
SK	Slovakia	0.0	0.0	0.0	0.0	0.0	1.0	3.0	0.0	0.0	0.0	0.0
FI	Finland	0.0	0.0	0.0	0.3	1.0	0.3	16.8	4.0	0.0	1.0	0.5
SE	Sweden	0.0	0.0	0.0	0.0	2.0	3.3	21.0	3.7	0.0	0.0	0.0
	EU	**1.0**	**0.0**	**4.2**	**7.5**	**64.7**	**35.2**	**209.0**	**57.7**	**0.0**	**2.5**	**4.3**

		Generic programmes and qualifications	Education	Arts and humanities	Social sciences, journalism & information	Business, administration and law	Natural sciences, mathematics and statistics	Information and Communication Technologies	Engineering, manufacturing and construction	Agriculture, forestry, fisheries and veterinary	Health and welfare	Services
UK	United Kingdom	0.0	0.7	10.8	35.2	115.3	23.0	269.2	36.5	0.5	2.8	13.0
NO	Norway	0.0	0.0	0.0	0.5	2.0	1.0	7.0	1.5	0.0	0.0	0.0
CH	Switzerland	0.0	0.0	0.7	0.0	6.3	2.3	10.2	0.5	0.0	0.0	0.0
CA	Canada	0.0	0.0	0.0	1.8	7.8	8.0	28.0	4.8	0.0	0.0	0.5
US	United States	1.7	1.8	13.0	23.3	184.7	47.7	458.2	63.3	1.0	4.2	31.2
AU	Australia	0.0	2.0	1.5	4.5	25.8	4.2	53.3	16.3	0.0	0.7	1.7
	TOTAL	**2.7**	**4.5**	**30.2**	**72.8**	**406.7**	**121.3**	**1034.8**	**180.7**	**1.5**	**10.2**	**50.7**

Note: A programme may be taught in more than one field of education. In that case, the programme is weighted using fractional count to avoid double counting (for instance, a programme that appears both in the field of *ICT* and *Engineering* is weighted 0.5 in each of them).

Table A 9. DS masters by country and field of education. All countries, 2020-21

		Generic programmes and qualifications	Education	Arts and humanities	Social sciences, journalism & information	Business, administration and law	Natural sciences, mathematics and statistics	Information and Communication Technologies	Engineering, manufacturing and construction	Agriculture, forestry, fisheries and veterinary	Health and welfare	Services
BE	Belgium	0.0	0.0	0.7	1.0	7.3	3.5	15.0	6.5	0.0	0.0	0.0
BG	Bulgaria	0.0	0.0	0.0	0.0	1.0	0.0	2.0	0.0	0.0	0.0	0.0
CZ	Czechia	0.0	0.0	0.3	0.7	1.0	2.0	6.0	0.0	0.0	0.0	0.0
DK	Denmark	0.0	0.0	1.8	4.2	10.5	4.8	8.7	4.5	0.5	1.5	0.5
DE	Germany	0.0	0.3	1.7	4.8	40.7	13.8	46.5	9.8	0.0	1.7	1.7
EE	Estonia	0.0	0.0	0.0	1.0	1.0	2.5	1.0	0.0	0.0	0.5	0.0
IE	Ireland	0.0	0.0	0.7	3.3	28.5	8.8	27.7	4.3	0.0	0.7	0.0
EL	Greece	0.0	0.0	0.0	0.0	2.5	0.0	2.2	0.3	0.0	0.0	0.0
ES	Spain	0.0	0.0	2.0	3.3	21.2	4.5	17.5	5.2	0.3	0.5	0.5
FR	France	0.0	1.3	1.7	4.7	41.0	12.2	41.5	9.5	0.7	2.2	0.3
HR	Croatia	0.0	0.0	0.0	0.0	4.0	0.5	2.7	1.8	0.0	0.0	0.0

		Generic programmes and qualifications	Education	Arts and humanities	Social sciences, journalism & information	Business, administration and law	Natural sciences, mathematics and statistics	Information and Communication Technologies	Engineering, manufacturing and construction	Agriculture, forestry, fisheries and veterinary	Health and welfare	Services
IT	Italy	0.0	0.0	2.0	1.2	18.0	7.8	31.0	6.8	0.5	0.7	0.0
CY	Cyprus	0.0	0.0	0.0	0.0	5.0	0.0	3.0	0.0	0.0	0.0	0.0
LV	Latvia	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
LT	Lithuania	0.0	0.0	0.3	0.3	2.2	3.7	5.0	4.2	0.0	0.3	0.0
LU	Luxembourg	0.0	0.0	0.0	0.0	2.0	0.0	1.0	0.0	0.0	0.0	0.0
HU	Hungary	0.0	0.0	0.0	0.3	4.7	0.0	7.2	1.8	0.0	0.0	0.0
MT	Malta	0.0	0.0	1.0	0.0	1.2	1.0	2.2	1.7	0.0	0.0	0.0
NL	Netherlands	0.0	0.3	4.7	20.8	50.3	30.3	50.3	12.3	0.0	9.0	0.8
AT	Austria	0.0	0.0	0.3	2.7	14.7	4.7	10.2	3.7	0.0	0.0	0.8
PL	Poland	0.0	0.0	1.0	0.5	4.7	0.0	10.3	1.5	0.0	0.0	0.0
PT	Portugal	0.0	0.0	1.0	0.7	8.5	3.7	7.7	2.5	1.0	0.0	0.0
RO	Romania	0.0	0.0	0.0	0.0	0.5	0.0	7.5	0.0	0.0	0.0	0.0
SI	Slovenia	0.0	0.3	0.0	0.3	2.0	0.0	3.3	2.0	0.0	0.0	0.0
SK	Slovakia	0.0	0.0	0.0	1.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0
FI	Finland	0.0	0.3	1.7	1.0	5.3	8.2	23.8	10.0	0.0	0.7	0.0
SE	Sweden	0.0	0.0	2.2	2.7	11.0	11.3	39.0	12.5	0.0	0.3	0.0
	EU	**0.0**	**2.7**	**23.0**	**54.5**	**288.7**	**123.3**	**376.2**	**101.0**	**3.0**	**18.0**	**4.7**
UK	United Kingdom	0.5	3.2	33.7	46.8	228.7	100.7	374.2	68.3	1.0	23.5	9.5
NO	Norway	0.0	0.7	2.5	1.8	8.0	3.8	15.0	1.2	0.0	0.0	0.0
CH	Switzerland	0.0	0.0	1.0	5.5	14.8	8.3	21.2	6.2	0.0	0.0	1.0
CA	Canada	0.0	0.5	2.2	5.8	24.3	24.3	49.3	12.0	0.0	6.5	1.0
US	United States	0.0	16.3	27.5	63.5	485.0	237.0	518.2	139.0	2.3	42.5	4.7
AU	Australia	0.0	2.2	7.2	8.3	76.0	28.7	76.0	14.5	0.0	1.7	3.5
	TOTAL	**0.5**	**25.5**	**97.0**	**186.3**	**1125.5**	**526.2**	**1430.0**	**342.2**	**6.3**	**92.2**	**24.3**

Note: A programme may be taught in more than one field of education. In that case, the programme is weighted using fractional count to avoid double counting (for instance, a programme that appears both in the field of *ICT* and *Engineering* is weighted 0.5 in each of them).

Table A 10. AI masters by country and content area. All countries, 2020-21

		AI applications	AI ethics	Audio processing	Computer vision	Connected and Automated vehicles	Knowledge representation and reasoning; Planning; Searching; Optimisation	Machine learning	Multi-agent systems	Natural language processing	Philosophy of AI	Robotics & Automation	AI (generic)
BE	Belgium	4.1	4.8	0.0	0.3	1.0	1.8	7.5	0.1	0.0	0.3	11.2	1.0
BG	Bulgaria	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CZ	Czechia	0.6	2.8	0.1	3.0	0.0	0.0	1.4	0.7	0.6	0.0	2.9	0.0
DK	Denmark	5.8	2.3	1.0	2.5	0.8	0.8	9.2	0.0	0.6	1.0	18.0	0.0
DE	Germany	21.3	10.4	0.2	12.4	2.7	1.5	19.5	0.9	4.0	0.5	26.6	3.0
EE	Estonia	0.6	0.7	0.0	0.1	0.0	0.0	1.3	0.5	0.3	0.0	4.6	0.0
IE	Ireland	11.0	7.4	1.4	5.1	0.7	2.9	10.0	0.0	1.3	1.5	13.6	0.0
EL	Greece	1.4	0.9	0.0	0.2	0.1	0.0	0.7	0.0	0.0	0.0	0.7	0.0
ES	Spain	10.3	7.1	0.5	3.5	0.1	1.8	9.6	0.3	4.2	1.1	5.6	3.0
FR	France	20.2	16.6	0.1	8.6	0.5	2.5	20.9	2.4	0.8	0.6	14.8	3.0
HR	Croatia	0.7	0.6	0.0	0.0	0.2	0.0	0.3	0.0	0.0	0.0	0.3	0.0
IT	Italy	11.9	9.9	0.0	1.5	0.2	1.3	12.9	0.9	1.7	0.9	14.8	1.0
CY	Cyprus	1.2	2.5	0.0	0.0	0.0	0.0	0.5	0.2	0.0	0.0	1.7	0.0
LV	Latvia	1.8	0.7	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	1.0	3.0
LT	Lithuania	2.4	3.9	0.1	1.5	0.0	0.0	3.0	0.0	0.0	0.0	4.2	0.0
LU	Luxembourg	0.6	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.3	0.0
HU	Hungary	1.3	4.9	0.0	2.8	1.3	0.5	1.4	0.1	0.4	1.0	5.1	1.0
MT	Malta	0.0	0.0	0.0	1.2	0.0	0.8	3.7	0.0	0.0	0.9	0.4	0.0
NL	Netherlands	12.1	13.6	1.2	2.3	0.7	3.2	30.5	1.3	7.4	1.8	15.9	5.0
AT	Austria	1.6	6.1	0.1	2.5	0.8	0.6	2.7	0.2	0.1	0.0	6.5	0.0
PL	Poland	4.6	1.3	0.4	1.5	1.5	1.3	4.9	0.0	0.3	0.0	4.1	1.0
PT	Portugal	4.3	5.1	0.0	2.3	0.5	0.0	2.5	0.0	1.0	0.0	3.3	1.0
RO	Romania	2.8	0.3	0.0	0.4	0.1	0.3	1.3	0.3	0.5	0.0	1.1	0.0
SI	Slovenia	1.3	4.5	0.2	0.5	0.0	0.4	1.2	0.0	1.0	0.0	3.9	0.0
SK	Slovakia	0.2	0.6	0.0	0.0	0.0	0.6	0.9	0.0	0.4	0.7	2.8	1.0
FI	Finland	11.5	4.9	0.1	2.1	1.6	0.8	13.6	0.1	0.1	1.0	10.1	1.0
SE	Sweden	10.2	8.5	0.1	3.8	2.6	1.6	22.3	1.5	3.8	0.0	24.5	3.0
	EU	**143.9**	**122.1**	**5.5**	**58.9**	**15.2**	**22.6**	**182.1**	**9.6**	**28.6**	**11.3**	**198.1**	**27.0**

		AI applications	AI ethics	Audio processing	Computer vision	Connected and Automated vehicles	Knowledge representation and reasoning; Planning; Searching; Optimisation	Machine learning	Multi-agent systems	Natural language processing	Philosophy of AI	Robotics & Automation	AI (generic)
UK	United Kingdom	144.2	118.8	1.7	37.3	14.0	21.0	144.9	8.5	27.7	1.2	158.6	19.0
NO	Norway	7.5	1.8	0.0	2.0	0.1	0.3	11.9	2.1	1.8	0.0	7.6	0.0
CH	Switzerland	5.2	6.7	0.0	3.4	0.4	0.5	9.9	0.0	1.0	0.0	6.0	1.0
CA	Canada	18.8	14.8	0.8	11.9	0.9	4.2	26.3	0.3	4.8	0.8	37.5	1.0
US	United States	165.8	173.4	3.6	69.1	7.0	29.1	225.3	7.2	36.6	5.6	266.3	33.0
AU	Australia	32.5	25.1	0.0	9.6	1.2	3.1	16.1	0.9	0.1	0.0	39.5	1.0
	TOTAL	**517.8**	**462.7**	**11.6**	**192.1**	**38.9**	**80.7**	**616.6**	**28.6**	**100.6**	**19.0**	**713.5**	**82.0**

Table A 11. HPC masters by country and content area. All countries, 2020-21

		Cloud	Parallel computing	Processors	System architecture	HPC (generic)
BE	Belgium	1.0	4.8	0.5	3.7	0.0
BG	Bulgaria	2.0	0.0	0.0	0.0	0.0
CZ	Czechia	0.2	2.9	1.0	0.9	0.0
DK	Denmark	2.0	4.8	0.0	9.3	0.0
DE	Germany	9.0	8.6	0.3	17.1	2.0
EE	Estonia	0.0	0.0	0.0	2.0	0.0
IE	Ireland	14.3	2.9	0.0	2.8	1.0
EL	Greece	0.0	0.5	0.5	0.0	0.0
ES	Spain	5.3	4.2	0.0	5.5	1.0
FR	France	4.6	9.3	4.0	10.1	3.0
HR	Croatia	0.0	0.0	0.0	0.0	0.0
IT	Italy	5.0	1.6	0.3	5.1	1.0
CY	Cyprus	0.0	0.0	0.0	2.0	0.0
LV	Latvia	0.0	0.0	0.0	1.0	0.0
LT	Lithuania	3.9	2.2	0.0	0.8	0.0
LU	Luxembourg	0.0	0.0	0.0	1.0	0.0
HU	Hungary	0.0	5.0	0.0	0.0	2.0
MT	Malta	0.0	0.5	0.0	0.5	0.0
NL	Netherlands	1.3	10.0	0.7	4.0	2.0
AT	Austria	4.0	2.0	0.0	3.0	1.0
PL	Poland	2.0	0.8	0.0	2.2	1.0
PT	Portugal	2.7	2.0	0.0	2.3	0.0
RO	Romania	0.8	2.1	0.1	4.0	0.0
SI	Slovenia	1.0	0.0	0.0	0.0	0.0
SK	Slovakia	0.0	0.0	0.0	2.0	0.0
FI	Finland	6.8	3.4	0.1	1.7	1.0
SE	Sweden	5.2	5.6	0.0	9.2	3.0
	EU	**71.1**	**73.3**	**7.4**	**90.2**	**18.0**
UK	United Kingdom	78.3	66.2	15.0	48.6	25.0
NO	Norway	3.0	1.3	2.0	5.7	0.0
CH	Switzerland	0.0	1.0	0.0	5.0	3.0
CA	Canada	10.0	13.4	1.0	13.6	4.0
US	United States	90.9	113.1	17.5	126.5	57.0
AU	Australia	36.5	8.0	5.2	9.4	6.0
	TOTAL	**289.8**	**276.3**	**48.0**	**298.9**	**113.0**

Table A 12. CS masters by country and content area. All countries, 2020-21

		Critical Infrastructure Protection	Cryptology (Cryptography and Cryptanalysis)	Data Security and Privacy	Identity and Access Management (IAM)	Network & Distributed Systems Security	Operational Incident Handling & Digital Forensics	Security Management and Governance	Software and Hardware Security Engineering	Cybersecurity (generic)	Other
BE	Belgium	0.2	2.9	5.4	1.5	4.0	0.0	0.0	1.0	0.0	0.3
BG	Bulgaria	0.0	0.7	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CZ	Czechia	0.0	2.0	1.5	0.0	3.5	0.0	0.0	0.0	1.0	0.0
DK	Denmark	0.7	1.0	0.8	1.0	10.6	0.0	0.0	0.0	0.0	1.0
DE	Germany	0.5	8.9	15.5	1.0	15.2	0.0	1.1	3.5	8.0	0.5
EE	Estonia	0.5	1.7	0.2	0.0	1.8	0.5	0.0	0.0	1.0	0.0
IE	Ireland	0.0	3.1	5.6	0.0	9.0	0.2	0.9	1.3	1.0	1.5
EL	Greece	0.5	0.6	3.2	0.0	3.1	0.1	0.0	0.1	0.0	0.0
ES	Spain	0.3	2.2	3.3	0.0	5.6	0.1	0.5	0.0	4.0	1.1
FR	France	0.0	5.2	10.8	0.0	9.3	0.3	0.2	1.8	7.0	0.6
HR	Croatia	0.0	0.0	0.5	0.0	1.5	0.0	0.0	0.0	0.0	0.0
IT	Italy	1.0	4.5	5.6	0.0	6.9	0.0	2.0	1.0	4.0	0.9
CY	Cyprus	0.0	1.3	2.5	0.0	1.0	0.1	1.1	2.1	1.0	0.0
LV	Latvia	1.2	0.0	1.6	0.0	0.5	0.3	0.3	0.3	0.0	0.0
LT	Lithuania	0.5	3.0	2.3	0.0	2.3	0.0	0.1	0.1	0.0	0.0
LU	Luxembourg	0.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
HU	Hungary	0.5	2.5	1.3	0.0	3.8	0.0	0.0	0.0	0.0	1.0
MT	Malta	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.9
NL	Netherlands	3.0	9.3	7.3	2.0	7.1	0.0	4.2	1.1	6.0	1.8
AT	Austria	0.3	2.1	5.2	0.0	4.0	0.0	0.2	1.2	0.0	0.0
PL	Poland	0.5	1.5	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
PT	Portugal	0.0	4.4	0.9	0.0	2.6	0.0	0.0	0.0	3.0	0.0
RO	Romania	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0
SI	Slovenia	0.0	1.0	1.7	0.0	0.0	0.3	0.0	0.0	1.0	0.0
SK	Slovakia	0.3	1.8	0.8	0.0	1.3	0.0	0.0	0.0	0.0	0.7
FI	Finland	1.8	2.7	10.9	0.1	4.0	0.0	0.1	0.5	4.0	1.0

		Critical Infrastructure Protection	Cryptology (Cryptography and Cryptanalysis)	Data Security and Privacy	Identity and Access Management (IAM)	Network & Distributed Systems Security	Operational Incident Handling & Digital Forensics	Security Management and Governance	Software and Hardware Security Engineering	Cybersecurity (generic)	Other
SE	Sweden	0.0	4.5	10.4	0.0	14.2	0.7	0.0	0.0	0.0	0.0
	EU	**11.7**	**66.6**	**98.9**	**5.6**	**119.0**	**2.5**	**10.6**	**13.9**	**41.0**	**11.3**
UK	United Kingdom	3.6	40.1	147.6	3.3	103.8	22.4	16.3	38.9	90.0	1.2
NO	Norway	0.0	2.0	5.6	0.0	3.9	0.2	0.0	0.1	0.0	0.0
CH	Switzerland	0.0	4.4	4.5	0.0	4.9	0.0	0.0	1.3	5.0	0.0
CA	Canada	0.0	11.0	13.6	0.1	15.2	0.3	0.2	2.6	4.0	0.8
US	United States	8.4	75.4	237.9	12.4	205.7	33.1	26.0	20.1	120.0	5.6
AU	Australia	0.0	4.4	43.4	1.2	23.2	5.1	2.0	2.1	21.0	0.0
	TOTAL	**23.7**	**204.0**	**551.5**	**22.6**	**475.7**	**63.6**	**55.1**	**79.0**	**281.0**	**19.0**

Table A 13. DS masters by country and content area. All countries, 2020-21

		Big data	Business intelligence	Data mining	Data science architectures	Machine learning & Statistical modelling	Natural language processing	Data analytics (generic)	Other
BE	Belgium	7.6	4.7	2.6	4.1	9.5	0.6	4.0	1.0
BG	Bulgaria	1.0	0.0	1.0	0.0	0.0	0.0	1.0	0.0
CZ	Czechia	0.7	0.0	1.8	3.5	2.4	0.6	1.0	0.0
DK	Denmark	9.1	6.4	0.8	3.2	12.4	2.5	2.0	0.4
DE	Germany	32.5	16.4	8.1	10.8	26.8	5.3	19.0	2.0
EE	Estonia	1.5	1.5	0.8	0.0	2.0	0.3	0.0	0.0
IE	Ireland	12.5	10.3	8.8	2.8	17.6	1.6	18.0	2.4
EL	Greece	0.7	1.4	0.1	1.0	0.7	0.0	1.0	0.0
ES	Spain	20.9	6.5	1.1	1.9	19.4	2.0	3.0	0.2
FR	France	25.4	12.5	6.3	9.6	35.7	2.1	19.0	4.3

		Big data	Business intelligence	Data mining	Data science architectures	Machine learning & Statistical modelling	Natural language processing	Data analytics (generic)	Other
HR	Croatia	0.0	5.0	0.0	0.0	1.0	0.0	3.0	0.0
IT	Italy	27.2	6.5	4.5	1.3	20.9	3.2	4.0	0.3
CY	Cyprus	0.0	3.4	0.8	0.0	1.7	0.0	2.0	0.2
LV	Latvia	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0
LT	Lithuania	4.5	1.0	3.8	1.7	3.0	0.0	2.0	0.0
LU	Luxembourg	0.0	0.0	0.0	0.0	0.0	1.0	2.0	0.0
HU	Hungary	1.8	5.0	0.9	3.3	2.8	0.2	0.0	0.0
MT	Malta	0.0	0.0	1.0	0.0	5.0	0.0	1.0	0.0
NL	Netherlands	46.4	21.4	13.4	8.3	38.6	6.0	41.0	3.9
AT	Austria	14.2	6.3	2.2	1.0	6.3	0.0	7.0	0.0
PL	Poland	3.6	3.8	3.0	1.1	4.7	0.2	0.0	1.8
PT	Portugal	3.1	11.5	3.8	3.3	2.3	1.0	0.0	0.0
RO	Romania	1.2	1.5	0.6	2.1	2.2	0.3	0.0	0.0
SI	Slovenia	1.0	2.5	1.5	0.0	2.0	0.0	1.0	0.0
SK	Slovakia	0.0	0.0	0.0	0.0	2.7	1.3	0.0	0.0
FI	Finland	11.1	6.2	1.6	4.5	19.4	3.1	5.0	0.1
SE	Sweden	12.3	12.0	6.4	6.7	28.7	3.6	7.0	2.3
	EU	**238.2**	**145.8**	**75.9**	**70.4**	**267.9**	**34.8**	**143.0**	**18.9**
UK	United Kingdom	230.0	88.3	69.1	54.8	230.9	24.6	142.0	50.2
NO	Norway	2.8	1.2	0.7	0.5	15.4	3.3	9.0	0.3
CH	Switzerland	14.2	4.0	3.1	2.0	17.2	1.0	16.0	0.5
CA	Canada	19.3	14.2	14.8	10.9	37.4	6.1	23.0	0.3
US	United States	234.0	230.5	215.5	114.6	336.8	52.0	349.0	3.6
AU	Australia	47.4	48.9	22.1	6.9	29.6	5.2	47.0	10.9
	TOTAL	**785.9**	**532.9**	**401.2**	**260.2**	**935.1**	**127.0**	**729.0**	**84.8**

Table A 14. Penetration rate of advanced digital skills in masters' programmes by country (% of masters in digital domains over total number of masters). All countries, 2020-21

		Number of masters by technological domain				All masters	Proportion of masters by technological domain over all masters			
		AI	HPC	CS	DS		AI	HPC	CS	DS
BE	Belgium	32	10	15	34	612	5.2%	1.6%	2.5%	5.6%
BG	Bulgaria	2	2	2	3	182	1.1%	1.1%	1.1%	1.6%
CZ	Czechia	12	5	8	10	322	3.7%	1.6%	2.5%	3.1%
DK	Denmark	42	16	14	37	600	7.0%	2.7%	2.3%	6.2%
DE	Germany	103	37	55	121	2560	4.0%	1.4%	2.1%	4.7%
EE	Estonia	8	2	6	6	134	6.0%	1.5%	4.5%	4.5%
IE	Ireland	55	21	24	74	2455	2.2%	0.9%	1.0%	3.0%
EL	Greece	4	1	8	5	207	1.9%	0.5%	3.9%	2.4%
ES	Spain	47	16	16	55	1220	3.9%	1.3%	1.3%	4.5%
FR	France	91	31	35	115	1604	5.7%	1.9%	2.2%	7.2%
HR	Croatia	2	0	2	9	45	4.4%	0.0%	4.4%	20.0%
IT	Italy	57	13	26	68	1138	5.0%	1.1%	2.3%	6.0%
CY	Cyprus	6	2	9	8	360	1.7%	0.6%	2.5%	2.2%
LV	Latvia	7	1	4	1	142	4.9%	0.7%	2.8%	0.7%
LT	Lithuania	15	7	9	16	300	5.0%	2.3%	3.0%	5.3%
LU	Luxembourg	2	1	2	3	86	2.3%	1.2%	2.3%	3.5%
HU	Hungary	20	7	8	14	454	4.4%	1.5%	1.8%	3.1%
MT	Malta	7	1	1	7	170	4.1%	0.6%	0.6%	4.1%
NL	Netherlands	95	18	46	179	2890	3.3%	0.6%	1.6%	6.2%
AT	Austria	21	10	13	37	584	3.6%	1.7%	2.2%	6.3%
PL	Poland	21	6	3	18	424	5.0%	1.4%	0.7%	4.2%
PT	Portugal	20	7	12	25	534	3.7%	1.3%	2.2%	4.7%
RO	Romania	7	7	5	8	102	6.9%	6.9%	4.9%	7.8%
SI	Slovenia	13	1	5	8	170	7.6%	0.6%	2.9%	4.7%
SK	Slovakia	7	2	4	4	46	15.2%	4.3%	8.7%	8.7%
FI	Finland	47	13	24	51	704	6.7%	1.8%	3.4%	7.2%
SE	Sweden	82	23	30	79	1642	5.0%	1.4%	1.8%	4.8%

		Number of masters by technological domain				All masters	Proportion of masters by technological domain over all masters			
		AI	**HPC**	**CS**	**DS**		**AI**	**HPC**	**CS**	**DS**
	EU	**825**	**260**	**386**	**995**	**19684**	**4.2%**	**1.3%**	**2.0%**	**5.1%**
UK	United Kingdom	697	233	507	890	31722	2.2%	0.7%	1.6%	2.8%
NO	Norway	35	12	12	33	600	5.8%	2.0%	2.0%	5.5%
CH	Switzerland	34	9	20	58	993	3.4%	0.9%	2.0%	5.8%
CA	Canada	122	42	51	126	4764	2.6%	0.9%	1.1%	2.6%
US	United States	1022	405	830	1536	55794	1.8%	0.7%	1.5%	2.8%
AU	Australia	129	65	110	218	5648	2.3%	1.2%	1.9%	3.9%
	TOTAL	**2864**	**1026**	**1916**	**3856**	**119205**	**2.4%**	**0.9%**	**1.6%**	**3.2%**

Annex 2 List of domain specific keywords

Artificial intelligence

accountability *	deep learning	machine translation	sound synthesis
adaptive learning	deep neural network	multi-agent system	speaker identification
ai application	ethics *	narrow artificial intelligence	speech processing *
anomaly detection	expert system	natural language generation	speech recognition
artificial general intelligence	explainability *	natural language processing	speech synthesis
artificial intelligence	face recognition	natural language understanding	strong artificial intelligence
audio processing *	fairness *	neural network	supervised learning
automated vehicle	human computer interaction	pattern recognition	support vector machine
automatic translation	human-ai interaction	predictive analytics	swarm intelligence
autonomous system *	image processing	recommender system *	text mining
autonomous vehicle	image recognition	reinforcement learning	transfer learning
business intelligence *	inductive programming	robot system *	transparency *
chatbot	intelligence software	robotics	trustworthy ai
computational creativity *	intelligent agent *	safety *	uncertainty *
computational linguistics	intelligent control	security *	unsupervised learning
computational neuroscience *	intelligent software development	semantic web *	voice recognition
computer vision	intelligent system	sentiment analysis *	weak artificial intelligence
control theory	knowledge representation and reasoning	service robot *	
cyber physical system	machine learning	social robot *	

* Terms that are queried in combination with domain's core terms.

High Performance Computing

accelerators *	distributed computing	hpc applications *	parallel programming *
cloud *	distributed systems *	hpcc	parallelisation *
cloud computing	energy efficiency	infiniband	performance analysis
cluster *	exascale *	manycore	performance evaluation
cluster computing *	field-programmable gate array	mapreduce *	performance modeling
compute unified device architecture *	fpga	massive parallelism *	performance optimisation
computer architecture *	gpgpu	message passing interface	reconfigurable computing *
computer modelling *	gpu	multi core	scalability
concurrent *	graphics processing unit	opencl	single instruction multiple data
cuda	grid computing	parallel algorithms *	supercomputer
data center	hadoop	parallel architectures *	supercomputer technology
data intensive computing	high performance computation	parallel computation *	

* Terms that are queried in combination with domain's core terms.

Cybersecurity

access control	cyber warfare	firewall *	phishing
access management	cybercrime	hacker	pseudonymity
activity monitoring	cybersecurity	hash function	public key
anonymity *	cybersecurity incident	identity access management	random number generation
anonymization	data anonymisation	identity management	security analysis
computer security	data sanitisation	information assurance	security protocol *
control system	data security	information protection	stuxnet
counterintelligence	digital evidence	information security	supervisory control data acquisition
cryptanalysis	digital forensics	intrusion detection	system security
cryptography	digital rights management	key management	vulnerability assessment
cryptology	digital signature	malware	web protocol
cyber attack	distributed systems	network attack	web protocol security
cyber risk	encryption	network security	
cyber threat	fault tolerance	penetration testing	

* Terms that are queried in combination with domain's core terms.

Data science

ant colony optimisation	distributed computing	metaheuristic optimisation	reinforcement learning
automated machine learning	distributed processing	multiagent system	scalability
big data	ensemble method	natural language processing	semantic web
business intelligence	evolutionary algorithm	natural language understanding	semi-supervised learning
data analytics	genetic algorithm	neural network	sentiment analysis
data mining	gradient descent	nosql	spark *
data science	hadoop	parallel computing *	statistical learning
data visualisation	information extraction	parallel processing *	supervised learning
decision analytics	information retrieval	parallelisation *	support vector machine
decision support	k-nearest-neighbour	pattern recognition	transfer learning
decision tree	machine learning	predictive analytics	unstructured data
deep learning	mapreduce	recommender system	unsupervised learning
ant colony optimisation	distributed computing	metaheuristic optimisation	reinforcement learning

* Terms that are queried in combination with domain's core terms.

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