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# Academic Offer of Advanced Digital Skills in 2019-20. International Comparison

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

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## Contents

## Abstract

This work aims at supporting policy initiatives to ensure the availability in the EU27 of an adequate education offer of advanced digital skills in the domains of artificial intelligence (AI), high performance computing (HPC), cybersecurity (CS) and data science (DS). The study investigates the education offer provided in the EU27 and six additional countries: the United Kingdom, Norway, and Switzerland in Europe, Canada and United States in America, and Australia, with a focus on the characteristics of the detected programmes. It analyses the number of programmes offered in these domains, considering the distinction based on programme's scope or depth with which education programmes address the technological domain (broad and specialised), programme's level (bachelor programmes, master programmes and short courses), as long as the education fields in which these programmes are taught (e.g. Information and communication technologies, Engineering, manufacturing and construction, Business, administration and law), and the content areas covered by the programmes. The analysis is conducted for each technological domain separately, first addressing the features of the overall education offer detected in the countries covered by the study, and followed by an in-depth analysis of the situation in the EU27. Among the many results that this work provides, those associated to the most relevant insights can be listed as follows. First of all, the main role in the offer of advanced technological skills is held by the US, which leads in terms of number of programs provided in almost all combinations of technological domain, scope and level. Secondly, another important player is the UK, with a very consistent offer of bachelor and master degree programs (in both cases, the UK's share is around 25% of the total offer detected). The consequences of the Brexit have, therefore, to be considered and faced also in terms of the education offer of advanced technological skills in the EU27. Thirdly, the role of the EU27 is notable but more varying (depending on the combination of domain, scope and level of programmes) than that of the UK. Regarding more specific aspects related to the EU27 offer, we detect a good amount of programmes offered in the domain of DS. As this domain is found out to be remarkably associated to the field of education of *Business, Administration and Law*, this is a positive finding suggesting a good supply of competences that are suitable to economic activities of various types. Therefore, what observed for the EU27 suggests a good alignment between the offer and the demand of DS-related skills. In the EU27 we observe a large share of programmes belonging simultaneously to both DS and AI. Considering the relatively high offer in DS, and the fact that AI is currently a techno-economic domain that is attracting a lot of attention and of private and public resources, a consistent connection between these two domains can be considered as an important key to favour synergies and future economic growth. Additionally, we find DS programmes quite widespread among the fields of education, which may facilitate the role of DS as a vehicle to further introduce AI, HPC and CS in the fields of education barely addressing these technological domains. We also observe a relatively large offer of AI master degree programmes in the EU27, which is an important finding given the role of this education level in the provision of competences for the workforce. Finally, it is important to note that we detect potential elements of weakness in the EU27's education offer related to CS. These competences are increasingly crucial to prevent and fight cyber-related incidents, concerning both private and public spheres. Therefore, the detection of a relatively modest CS education offer (in comparison to other geographic areas) is a point that deserves attention. Many other findings are described throughout this report, but what discussed in this abstract has to be retained as the most relevant content aimed at supporting EU policies.

**Keywords**: digital skills, higher education, education supply, artificial intelligence, high-performance computing, cybersecurity, data science, digital transformation

## 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 of society. This research aims at supporting the policy making process by providing the evidence needed to analyse strengths and weaknesses of the European ICT industry and of technological take-up in comparison with that of its most important trading partners, over a range of several years and to a significant level of detail. The PREDICT project has been producing comparable statistics and analyses on ICT industries and their R&D in Europe since 2006, covering major world competitors including 40 advanced and emerging countries – the EU27 plus 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.

Examples of topics 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 their ecosystems with factual data from non-official heterogeneous sources, with the overall objective of contributing to measuring the digital transformation of the economy and providing policy recommendations.

Presently PREDICT is also supporting the work towards the first Digital Europe programme and the Digital Education Action Plan for increasing EU's international competitiveness and developing and reinforcing Europe's strategic digital capacities. PREDICT provides evidence about the availability in the EU27 Member States and six additional countries of adequate advanced digital skills in a number of IT domains. Moreover, the TES analytical approach has been applied to target artificial intelligence and map its worldwide landscape in the EC AI Watch.

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

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## Executive summary

### Policy context

The sustain and promotion of the digital transformation in Europe is one of the key objectives of the European Commission (EC). *A Europe fit for the digital age*[1], one of the six political priorities of the Von der Leyen Commission[2], aims at benefiting from digitalisation in a safe an ethical way. This priority is being developed through three actions: Excellence and trust in the artificial intelligence, European data strategy, and European industrial strategy, which establish a number of objectives, including 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, among others. Some of these objectives have been pursued in the recent years by addressing the development of a Digital Single Market and by targeting specific emerging technologies in, for instance, the European Strategy on Artificial intelligence (Communication "Artificial intelligence for Europe" European Commission (2018c)), the Coordinated Plan on AI (European Commission (2018e)), the White paper on AI - A European approach to excellence and trust (European Commission (2020a)), the European Cybersecurity Act (Regulation (EU) 2019/881), the European High Performance Computing Joint Undertaking (Council Regulation (EU) 2018/1488), and the European strategy for data (European Commission (2020b)). The achievement of these political goals is linked to a strong commitment to boost investments in digital skills. In fact, the proposed Digital Europe programme (proposal, European Commission (2018d), legislative resolution, European Parliament (2019)) aims at increasing EU27's international competitiveness and reinforcing strategic digital capacities, and identifies artificial intelligence (AI), high performance computing (HPC), and cybersecurity (CS) as key advanced digital skills for a competitive Europe in the digital race. In addition, the Digital Education Action Plan[3] includes a number of actions to support the development of digital competences in education, including specific measures on AI, CS, programming skills and entrepreneurship. The updated Digital Education Action Plan, expected to be adopted in the third quarter of 2020, tackles digital skills in education in a comprehensive way, from basic to advanced levels, including AI, data literacy, HPC and CS. Also, a number of actions of the Digital Skills and Jobs Coalition[4] aim at spreading coding skills and increasing the number of experts in digital, taking action to tackle the lack of digital skills in Europe. Summarising, while digital economy is a leading driver of the European economy, digital skills are becoming further demanded and their prevalence in society needs to be monitored and further developed.

### Overview of results

This study provides evidence related to the availability of advanced digital skills in the education offer provided in the EU27 and six additional countries: the United Kingdom, Norway, and Switzerland in Europe, Canada and United States in America, and Australia. The study addresses the following technological domains: AI, HPC, CS and Data Science (DS). It analyses the number of programmes offered in these domains, considering the distinction based on programme's scope or depth with which education programmes address the technological domain (broad and specialised), programme's level (bachelor programmes, master programmes and short courses), as well as the education fields in which these programmes are taught and the content areas covered.

We detect that among the considered geographic areas, the major role is played by **the US, as it leads in terms of number of programmes in almost all combinations of technological domains, scope and level**. The other two most relevant geographic areas are the EU27 and the UK. Regarding **the EU27**, we see a persistent finding in all the technological domains: **a modest offer of bachelor degree programmes, and a much more prominent offer in the most advanced degrees (masters) and business-related programmes (short courses).** As the data source of this study is exclusively based on English-taught programmes, the low number of detected bachelor degrees can also reflect the propensity to teach bachelor's degree programmes in native language in the EU27 Member States. Therefore, the study would be showing a partial picture in what respects bachelor degrees with technological content in the EU27, and the same caveat affects other non-English-speaking countries included in the study (Switzerland and Norway).

The four technological domains are taught primarily independently of each other, as **almost two thirds of programmes can be associated to a single domain** (in all countries considered, we have 24% of

1 https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age_en
2 https://ec.europa.eu/commission/files/political-guidelines-new-commission_en
3 https://ec.europa.eu/education/education-in-the-eu/digital-education-action-plan_en
4 https://ec.europa.eu/digital-single-market/en/digital-skills-jobs-coalition

programmes exclusively belonging to DS, 21% exclusively belonging to AI, and 20% exclusively belonging to CS). **A major overlap is detected: the one determined by programmes that can be referred to both AI and DS** (12% of all detected programmes). This deserves attention since both domains involve the extraction of information from complex data: while AI focuses more on the development of algorithms and procedures allowing computers to self-learn and automatise processes, in DS the focus is on the knowledge of methodologies and algorithms to process and model large quantity of data and investigate specific research questions. Therefore, an overlap between the two seems to be the confirmation of a well-shaped structure of the education offer of advanced digital skills. This overlap derives from the use of several common keywords to detect the related education offer, since both domains share techniques and applications.

When considering the programmes taught in the EU27 in comparison with the rest of the countries analysed, two main differences appear. First, the **EU27 presents a negative gap of more than 10 percentage points in the offer of "pure" CS** (programmes exclusively belonging to CS). This finding raises certain concern, due to the crucial role that CS has in the prevention and fight of cyber attacks and preservation of privacy. Second, **the percentage of programmes belonging to both AI and DS is** much **larger in the EU27** (18%) than for the remaining countries (11%). This may open the floor for cross-fertilisations between both domains.

The **field of education of *Information and communication technologies(ICT)* is the one offering most programmes in all the technological domains analysed**. The share of ICT over all fields of education varies considerably depending on the domain and geographic area: 59% of all HPC offer in both the EU27 and other countries, 52% of all CS offer in the EU27 and 54% in other countries, 41% of AI offer in the EU27 and 43% in other countries, and 37% in DS in the EU27 and 40% in other countries. The **second education field** mostly implicated in the offer of advanced digital skills is ***Engineering, manufacturing and construction***, which has a **remarkable share in AI** (27% in the EU27 and 29% in other countries), while in other technological domains its presence is less intense (in the EU27, 18% in HPC, 15% in CS and 11% in DS; in other countries, 16% in HPC, 8% in CS and 8% in DS). ***Business, administration and law***, which is the third major field of education detected, **has a relevant role especially in DS** (28% of the programmes in the EU27 and 27% in the rest of the considered countries) **and in CS** (17% in the EU27 and 20% in the other countries).

***Artificial intelligence***

AI plays a key role in the digital transformation and is affecting many spheres of our life. AI is behind many improvements in efficiency (e.g. in predictive maintenance, optimising manufacturing processes), social robots, smart mobility, assisted healthcare, computer vision based diagnosis, etc. However, it also entails risks related to e.g. unethical uses, lack of transparency in decision making, algorithmic bias. A coordinated and comprehensive education offer in AI is crucial for the future development of our society and economic growth.

In the AI domain, we observe a **very low gap between the EU27, the UK and US in the offer of master degree programmes**. Given the role of these programmes in providing the latest stage of skills training for the workforce (bachelor's degrees are only the initial part of the academic training, and short courses generally address specific and technical aspects or provide a general introduction to a topic), this finding is undoubtedly relevant to assess **the good position of the EU27 in the education offer related to AI**.

Regarding the content areas of the **AI education offer**, ***Robotics & Automation*** is definitely the area covered by the highest number of programmes, with only Switzerland and Norway not having it in the first position. A relevant role is played by ***Machine learning***, which was expected to be one of the most taught subjects as it constitutes a large part of AI theoretical foundations. In addition, ***AI Applications*** and ***AI Ethics*** have also relevant roles. When considering the programme's level, some differences emerge. ***Robotics & Automation*** is the area **most frequently taught in the academic entry-level** (bachelor): almost half of the bachelor programmes detected include notions of robotics and human-AI interaction. However, when moving to one **higher level in the academic education path** (master degrees), the content related to ***Robotics & Automation* intensively reduces its presence** (from 45% in bachelor's degrees to 30%), especially **in favour of *Machine learning***. This suggests that Machine learning may not be considered appropriate, because requires additional skills, for bachelor students (only around 5% of bachelor curriculum focuses on *Machine learning*). However, in the second part of the academic path it is definitely relevant (around 20% of master' content). This pattern, along with the detection of large shares of ***Machine learning*** in specialised short courses, suggests that it is **one of the key competences in the professional development and implementation of AI**.

For the two fields of education in which the AI offer is mostly concentrated, namely ***ICT*** and ***Engineering, manufacturing and construction***, two very **different patterns emerge in the EU27**. While the **training in *ICT* is based on a balanced multiplicity of contents** (*Robotics & Automation*, *Machine learning*, *AI Applications*, and *AI Ethics* have a similar share, around 20% each), ***Engineering, manufacturing and construction*** studies including AI **mostly concentrate on *Robotics & Automation*** content (more than 50%).

Finally, regarding the **AI master degrees offer by the EU27 Member States**, we detect that **Germany**, **Netherlands**, and **Sweden** are the major players, as each of them accounts for more than 10% of the entire EU27 offer of AI master degree programmes.

***High performance computing***

By HPC we refer to the use of supercomputers and parallel computing techniques to solve complex and demanding computational tasks, and to efficiently manage vast amounts of data. The offer of advanced digital skills related to HPC appears as **worldwide dominated by the US**. We detect different patterns in the composition of the programmes' content, depending on the geographic area. First, ***System architecture*** is the most frequently taught **content area** in general. ***Cloud*** and ***Parallel computing*** also present good shares. Although *Cloud* is relatively unimportant in Switzerland, it is very relevant in the content of HPC programmes in UK (35%) and in Australia (42%). *Parallel computing* has its largest presence in the EU27 (25%), in the US (28%) and in Canada (29%). The analysis of the **EU27 HPC** education offer by scope, level and content areas reveals an interesting point: almost 50% of the content of the **most specialised education**, i.e., specialised master degrees, relates to ***Parallel Computing***.

When combining the field of education and content areas in HPC programmes in the EU27, a strong characterisation emerges: ***ICT,*** which is the field of education offering most HPC programmes, **is associated with a balanced distribution of content**, since three areas hold relevant shares: ***System architecture***, ***Cloud*** and ***Parallel Computing***. This seems to suggest that, as observed for AI, the **education offer** taught in the **field of *ICT* is structured to cover a large variety of topics**.

The analysis of the **offer of HPC master programmes in the EU27 Member States** shows that **Germany** holds the first position (12% of total master programmes offered in the EU27), with **France**, **Sweden** and **Ireland** following (around 10% of the total EU27 offer each). It is relevant to observe that the ratio between specialised and broad programmes is generally low, since only very modest number of specialised programmes are detected. Nevertheless, noteworthy shares are detected in Netherlands (specialised HPC master degree programmes represent nearly one half of broad programmes), in Romania (the number of specialised HPC programmes is larger than the corresponding number of broad programmes), and in Lithuania (specialised master's programmes are nearly half of the broad ones).

**Cybersecurity**

By CS we usually refer to the set of technologies and procedures allowing the safe transmission and storage of information. Violations of privacy rights related to personal information, or lapses in the control and protection of private and businesses data, are examples of raising concerns for our private and public lives that have recently become increasingly relevant. The analysis of CS education offer shows interesting results. The first striking result is the reduced presence of the EU27 education offer in the international context. In fact, the results show a **modest EU27's share in the bachelor level, combined with an even lower EU27's share in what concerns specialised programmes of all levels (bachelor, master and short courses).** More specifically, the EU27's share of CS specialised offer is systematically 5 percentage points lower than the EU27's share in the offer of broad programmes. While for AI and HPC a modest position of the EU27 in bachelor degrees is counterbalanced by a better position in the offer of masters and short courses in the international landscape, the role of the EU27 in CS is overall limited. This finding is of upmost relevance, considering the increasing need to fight and prevent cyber threats and cyber attacks, and to reinforce a culture of cybersecurity in enterprises and public services.

Regarding the **contents** that are taught in **broad bachelor** CS programmes, in the EU27 we find that ***Data Security and Privacy*** and ***Network & Distributed Systems Security*** **are the most proposed content areas** (both around 30% of the offer's content), showing a substantial gap with other content areas. An

**increase in the specialisation**, either in the sense of the scope (specialised bachelor's degrees) or in the sense of the level (master degrees), **is associated with a larger proposal of contents related to *Network & Distributed Systems Security*** (nearly 10 percentage points larger than *Data Security and Privacy* in both cases). Finally, when considering the **most advanced type of programmes**, i.e., specialised master degrees, the content areas of ***Data Security and Privacy*** and of ***Network & Distributed Systems Security*** are again equally taught, but with shares smaller than in the case of broad bachelor programmes. In addition, a third content area becomes of major relevance: ***Cryptology (Cryptography and Cryptanalysis)***.

Finally, about the **offer of CS master's programmes in EU27 Member States**, **Germany** leads, with 14% of all EU27 offer of CS master programmes, followed by Netherlands (12%). Then, in decreasing order, we detect Sweden (9%), France, Ireland and Italy (7%), and Finland and Spain (5%). Interestingly, when focusing on specialised programmes, these eight countries offer nearly the same amount of specialised CS masters, which is around 2.5% of the entire offer of CS master degree programmes of each country.

**Data science**

DS deals with the study of approaches and methodologies to treat and disentangle vast amounts of data, and to transform it into knowledge. The first result of the analysis of education offer in DS is the **good positioning of the EU27 in the international context in the offer of master degree programmes**, showing a very **small gap with the other leading countries, the US and the UK**. This fact, also identified in the AI domain, is very relevant, since the master's level represents the final stage of formal education, giving access to the labour market.

**After *ICT*, the field of education of *Business, Administration and Law* is the second one offering most DS programmes** in all considered countries. This finding suggests a **good connection between DS and the competences that are demanded in a working context**. We also detect a remarkable presence of ***Natural sciences, mathematics and statistics*** in **the US and Canada**.

**In the EU27**, **the most prevalent areas of content are *Big data*** and ***Machine learning & Statistical modelling*** (both around 25% of the domains' content offered), and with **a secondary role** we find ***Business Intelligence*** and ***Data analytics (generic)*** (both around 15%). Similarly, the UK also presents as most important content areas the ones of *Big data* and *Machine learning & Statistical modelling*. However, **in the UK the generic area *Data analytics* holds a more relevant position in the curriculum (18%).**

The combination of field of education and content areas shows a sort of complementarity between the two fields of education covering the largest shares of programmes. While the field of education of ***ICT*** mainly focuses its AI programmes on ***Machine learning & Statistical modelling***, the field of ***Business, administration and law*** prefers ***Big data*** and ***Business intelligence***. Therefore, the offer of DS in the EU27 appears to be well structured and **able to tackle both the need of specific competences in technical fields**, **as well as the need of broader and less specialised DS competences in business-related applications**. This is a **promising sign of integration between the existing education offer and the demand of advanced skills**.

We observe that in the **EU27,** the distribution of the DS domain education offer by field of education is relatively uniform (apart from the large presence in *ICT*, as expected). This means that DS is quite widespread among the fields of education, which may be key to promote a progressive expansion of the other advanced technological domains. **DS**, which has overlaps with AI, HPC and CS, **may therefore be seen as a facilitator to further introduce** AI, HPC and CS **in the fields of education barely addressed by these technological domains.**

Finally, regarding the **offer of DS master degree programmes in the EU27 MSs**, the first position is held by **Netherlands**, which accounts for 17% of the entire EU27 offer. Germany and France represent 12% and 11%, of the EU27 offer of DS master's programmes, respectively. Then, with shares between 8% and 7%, Sweden, Ireland, Italy and Spain.

# 1 Introduction

The sustain and promotion of the digital transformation in Europe is one of the key objectives of the European Commission (EC) in recent years. *A Europe fit for the digital age*[5], one of the six political priorities of the Von der Leyen Commission[6], aims at benefiting from digitalisation in a safe an ethical way. This priority is being developed through three actions: *Excellence and trust in the artificial intelligence*, *European data strategy*, and *European industrial strategy*, which establish a number of objectives, including 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, among others. Some of these objectives have been pursued in the recent years by addressing the development of a Digital Single Market and by targeting specific emerging technologies. In particular, the European Strategy on Artificial intelligence (Communication "Artificial intelligence for Europe" European Commission (2018c)) 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 (European Commission (2018e)) sets 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. 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, clear and trustworthy data governance mechanisms are put in place. 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. The European High Performance Computing Joint Undertaking (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.

Investments in skills are a cornerstone for the achievement of technological sovereignty of the EU. In fact, the proposed Digital Europe programme (proposal, European Commission (2018d), legislative resolution, European Parliament (2019)) aims at increasing EU27's international competitiveness and reinforcing strategic digital capacities, and identifies artificial intelligence (AI), high performance computing (HPC), and cybersecurity (CS) as key advanced digital skills for a competitive Europe in the digital race. In addition, the Digital Education Action Plan (European Commission (2018a)) includes a number of actions to support the development of digital competences in education, including specific measures on AI, CS, programming skills and entrepreneurship. The forthcoming updated Digital Education Action Plan, expected to be adopted in the third quarter of 2020, tackles digital skills in education in a comprehensive way, from basic to advanced levels, including AI, data literacy, HPC and CS. In particular, for AI it proposes the design on an EU-wide curricula on AI, the development of an AI framework for self-assessment of individuals, of ethical guidelines on AI for teachers, and of AI learning resources for schools. It also foresees the boost of digital skills through a second edition of Digital Opportunity Traineeships[7], supporting cross-border traineeships aimed at acquiring digital skills in fields with labour market demand, extended to teachers and trainers. Also, a number of actions of the Digital Skills and Jobs Coalition[8] aim at spreading coding skills and increasing the number of experts in digital, taking action to tackle the lack of digital skills in Europe. Summarising, as digital economy is a leading driver of European economy, digital skills are becoming further demanded and their prevalence in society needs to be monitored and further developed.

Measuring digital transformation, and quantifying and analysing its impacts on industry, employment and society stay among the most pressing needs. Clearly, in this perspective, different insights may provide useful information to anticipate forthcoming scenarios in economy and society. In this respect, AI Watch[9], the Commission knowledge service to monitor the development, uptake and impact of artificial intelligence for Europe, provides useful insights on industrial, technological and research capacity, policy initiatives in Member States, uptake and technical developments of artificial intelligence and its impact in the economy, society and public services. Since 2005, the EC Joint Research Centre (JRC), in close collaboration with the EC Directorate

5 https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age_en
6 https://ec.europa.eu/commission/files/political-guidelines-new-commission_en
7 https://ec.europa.eu/digital-single-market/en/digital-opportunity-traineeships-boosting-digital-skills-job
8 https://ec.europa.eu/digital-single-market/en/digital-skills-jobs-coalition
9 https://ec.europa.eu/knowledge4policy/ai-watch_en

General for Communications Networks, Content and Technology (DG CNECT), has developed a long-lasting undertaking to provide metrics, data and analysis regarding the EU27 Information and communication technology (ICT) sector and its Research and Development (R&D) investments, and the digital transformation[10]. More recently, since 2019, the project also involved the quantification and analysis of supply of education offer in advanced digital skills.

In this policy context, this study provides evidence related to the availability of advanced digital skills in artificial intelligence (AI), high-performance computing (HPC), cybersecurity (CS) and data science (DS). This report updates and expands another JRC report published in 2019 (López-Cobo et al. (2019)), and is complementary to another JRC study aimed at estimating the number of available university places at bachelors' and masters' levels in AI, HPC, CS and DS (Gómez-Losada & López-Cobo et al., 2020). In the present work, we map the offer of academic programmes in the four mentioned technological domains, so to provide relevant evidences and insights in view of supporting policy decision. As the education offer analysed is associated with advanced technological skills, its role in the development of key competences for the ongoing and future industrial development is crucial. More specifically, we discuss the technological domains' education offer by considering the **number of education programmes** provided, the **geographic area** in which they are provided (EU27 and six additional countries: the United Kingdom, Norway, Switzerland, Canada, United States and Australia), their **scope** or extent to which education programmes are taught in the syllabus (broad and specialised), their **education level** (bachelor, master and short professional courses), 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).

The report contains a section for each technological domain, i.e., AI, HPC, CS and DS, following the same structure. Each section is divided in two parts: the first one is dedicated to the analysis of the technological domain's education offer in all the considered geographic areas, while the second one considers only the EU27, a solution that allows us to more deeply investigate specific aspects. The report is structured as follows. The remaining of this introductory section presents the definitions of the variables of analysis and highlights the novelties introduced with respect to the previous study conducted in 2019. Section 2 is devoted to the methodology, 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 2019 study. Section 3 discusses the results about the education offer of AI. Section 4 is dedicated to HPC. In Section 5 we discuss the findings related to CS. Section 6 shows the results for the technological domain of DS. Section 7 focuses on the overlap of the four technological domains considered and, in addition, it compares how each technological domain is offered in the fields of education. The report ends with some concluding remarks in Section 8.

## 1.1 Definitions

As previously mentioned, this report analyses education programmes including: (a) formal education belonging to the higher education levels of master and bachelor degrees; and (b) short professional courses, including online courses, not necessarily giving access to a formal education degree or official certificate. The programme's characteristics analysed in this study are presented in Box 1.

Box 1. Definition of main characteristics of the education programmes analysed

**Technological domain**: the four technological domains representing the advanced digital skills of interest for the study are AI, HPC, CS and DS. 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).

**Level**: three types of education programmes are covered by the study: bachelor's degree, masters' degree, and short professional courses. Each program exclusively belongs to one education level.

10 See the PREDICT project (ec.europa.eu/jrc/en/predict)

Short professional courses are short training programmes targeted to professionals or graduated students who want to broaden their knowledge on specific areas and increase their skills portfolio. They are becoming progressively more demanded due to the ease of access to MOOCs (massive open online courses). They are usually offered through online platforms, that display courses provided by universities and wider teaching collectives, such as Coursera, edX, or Udemy. Short courses are also directly offered by universities, academies and Summer schools, like Stanford Summer, Harvard or MIT in the US, Utrecht Summer School or TU Delft in Netherlands, TU Berlin in Germany, Audencia Business School in France, etc. The length of short courses varies between a few days to several months, and three out of four of the courses tracked for this study have a duration of up to a month.

**Scope**: education programmes are classified into specialised and broad[11], according to the depth with which they address the technological domain under study. Specialised programmes are those with a strong focus in the domain, e.g. "Automation and Computer Vision" or "Advanced Computer Science (Computational Intelligence)" in AI. Broad programmes target the addressed domain, but in a more generic way, usually aiming at building wider profiles or making reference to the domain in the framework of a programme specialised in a different discipline (e.g. Biomedical engineering). 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.

**Field of education**: it 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[12] (e.g. Engineering, manufacturing and construction, Business administration and Law, etc.). A programme may be taught in several fields of education, because it is a joint or double degree, or just because this programme addresses more than one field's interests (e.g. an AI program taught in the fields of ICT and Engineering). 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)), the one used preferably throughout the report; and narrow field or three digits (e.g. *Engineering and engineering trades* (code 071)), used for a deeper analysis in Section 7.

**Content areas**: these refer to the technological subdomains covered by the programmes' syllabus. They have been grouped following existing taxonomies or analysing programmes' descriptions. A programme may cover several content areas of each technological domain.

Within each technological domain, programmes that belong to different categories of each variable of analysis (field of education, content areas) are weighted to avoid double counting. For instance, a programme on AI taught in the ICT field and in Engineering is weighted 0.5 in each of these fields. The weights of the multiple content areas covered by a programme are computed based on the frequency of the keywords present on the programme description.

## 1.2 Extensions of this study

The main novelties incorporated by this edition of the study are the following:

- **Education level**: Apart from the levels of bachelor's degrees and master degrees examined by the previous study, this report also includes short professional courses. The latter aim at capturing short training programmes targeted to professionals or graduated students who want to broaden their knowledge on specific areas and increase their skills portfolio.
- **Technological domains**: Besides AI, HPC and CS, this study covers Data Science (DS), a domain that has experienced a surge in the last decade, and that is very much demanded in the labour market. This field has some overlap with AI and HPC, and can be considered as an applied field where data collection, data wrangling, modelling and visualisation are the core tasks.

11 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).

12 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).

- **Geographical coverage**: In order to provide comparisons with other competing economies, the present study covers the EU27 Member States and six additional countries: the United Kingdom, Norway, and Switzerland in Europe, Canada and United States in America, and Australia. The 2019 study provided results for the EU28 (current EU27 plus UK).
- **Time frame**: The data analysed in this report refers to education offer in the period 2019-2020. This in principle allows comparability over time with the previous study, which analysed the period 2018-2019. However, small deviations of the observed data might be explained by multiple factors others than actual change, such as data availability, frequency of update of universities' websites and data collection, inability to capture relevant programmes with the methodology used[13], etc. Furthermore, the methodological improvements included in this edition (see Subsection 2.1) pose some constraints to comparability over time. As a consequence, the focus of the analysis presented in this report is on the characteristics of the education offered, rather than on the number of programmes and its comparison with the previous study.
- **Dimensions of analysis**: In addition to the programmes' features covered by the 2019 study – i.e., the level of the programme (bachelor, master, and this year also short courses), the scope of the study (broad or specialised), and the different content areas covered by the program (e.g. Machine learning or Robotics for AI) – this study incorporates an interesting addition, as it provides details on the fields of education where AI, HPC, CS and DS are taught. This information enables the investigation of which fields of education are more intense in the teaching of advanced digital skills. While one expects that most AI programmes belong to the ICT or engineering fields, it is interesting to uncover that within *Arts and humanities* some programmes include courses on AI, for instance in the narrow field of *Audio-visual techniques and media production* or in *Philosophy and ethics*.

13 For instance, a new program described using terms not included in our keyword list will not be captured, although being relevant to the study.

# 2 Methodology

This work essentially follows the methodology developed in López-Cobo et al. (2019). This section presents a summary of the methodological steps, and focuses on the differences introduced in this edition of the study.

## 2.1 Identification of domain boundaries and categories for the analysis

Due to the fact that official classifications are not useful to identify transversal technological domains such as the ones examined in this study, we use a list of keywords representative of the domain in order to query the relevant data sources of education offer. This allow us to identify the programmes including the considered advanced digital technologies in their content. The keywords are then grouped into categories, which are used to analyse the content areas taught in the identified programmes. The fact that there is certain degree of overlap between the four technological domains analysed, is translated in the use of several keywords in more than one technological domain (e.g. machine learning in both AI and DS, or distributed computing in DS and HPC simultaneously). This causes the identification of overlaps in the education offer of the technological domains.

We have devoted efforts to improve the original list of keywords used in the 2019 study. We do so by (i) adding relevant terms, (ii) removing terms that proved not useful to capture relevant programmes, and (iii) considering additional sources and taxonomies for the grouping of keywords in categories. This has caused the expansion of the keyword list (see Annex 2), which now better captures the boundaries of the technological domains. It has made possible to have a more refined categorisation of the technological domains content areas. In particular, points (i) and (iii) have been reached as follows:

— For AI: we have considered the AI taxonomy and definition developed by JRC in the framework of AI Watch, the European Commission knowledge service to monitor the development, uptake and impact of Artificial Intelligence for Europe (Samoili & López-Cobo et al. (2020)). 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. This extension in the perspectives from which AI is considered allows us to capture the education of AI from these additional angles.

— For HPC: the programmes identified as specialised during the 2019 study have been analysed with a twofold objective: (i) to detect additional keywords that are able to appropriately identify relevant programmes, and (ii) to refine the categorisation of content areas.

— For CS: we have enriched the original keyword list and categorisation of content areas following 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 EU27 (Nai-Fovino et at. (2018)).

— For DS: besides following the methodology proposed in the 2019 study, the categorisation of content areas has been produced by analysing the content of the selected programmes.

Additionally, some terms have been identified as not useful because they didn't trigger the identification of pertinent programmes. These are very specialised terms that were not found in any of the programmes captured by the 2019 study. This is the case of, e.g. "natural language queries", which is not present in programmes descriptions, while relevant programmes are captured by the more generic keyword "natural language processing". These terms have been removed to increase efficiency by reducing computation time.

The removal of keywords and the addition of new ones prevent a strict comparison between the 2019 study and the present one. Still, more than 90% of all detected programmes in this edition are triggered by keywords present in the 2019 study. Only in the domain of HPC the effect of keyword treatment is slightly different. The cross-tabulation of field of education and keyword allowed a better identification and removal of false positives related to the keyword 'parallelisation'[14]. As a consequence, due to a different pre-processing with respect to that keyword, the programmes retrieved by it are not directly comparable, even if the keyword was used in both editions of the study. The fact that this is a very relevant keyword in the domain, makes that the pool of programmes that are directly comparable is 75% for the HPC domain. It is worth reminding that this potential comparison does not consider all the programmes detected due to the newly introduced keywords.

14 The information on the field of education in which the program is taught, which is available in this edition of the study for the first time, has been very useful to understand the interrelation between keywords and fields of education. It allows us to discern the content areas characterising each field.

## 2.2 Data source: strengths and caveats

As in the previous study, the data source is the Studyportals' database, which is made of over 207,000 programmes from 3,700 universities in over 120 countries. Studyportals[15] is a platform offering worldwide information on global study choice. Out of the seven dedicated Studyportals' websites, this study analyses data from three of them, the ones focused on master courses, bachelor degrees and short professional courses, and they overall account for more than 180,000 programmes, out of which 56,000 correspond to programmes taught in European universities (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 programmes taught in national languages other than English 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. Although this may hinder comparability in terms of absolute number of programmes offered at national level, the case studies conducted in the 2019 study to evaluate the coverage of specialised masters for Spain and France gave satisfactory results. It was concluded that Studyportals covers a high percentage of the targeted programmes and that the impact of the teaching language, although not negligible, is somehow limited and not strongly affecting the validity of the source. However, bachelor level studies are expected to be more affected by this concern, where the offer is mostly taught in native language, unlike masters, with more international audience and faculties. As a consequence, this study may be showing a partial picture of the level of inclusion of advanced digital skills in bachelor programmes.

Another of the identified strengths of the source is the amount of program-related information available in the database, which makes possible the analysis of the characteristics of the programmes covered. In particular, some of the most interesting ones for our analysis are the programme's content (technological categories or subdomains), and the field of education in which the programmes are taught. The main assumption of the study is that the attributes of the education offer captured by the source are representative of those of the entire education offer of the studied countries. As a consequence, the analysis presented in this report focuses on the investigation of the characteristics (or profile) of the programmes taught, in terms of their content (categories), level, scope, and field of education.

**Table 1. Listed programmes by level of education and continent, 2019-20**

| | | On-campus | Other delivery methods | Total |
|---|---|---|---|---|
| **Bachelor** | North America | 63,954 | 2,319 | 66,273 |
| | Europe | 21,605 | 754 | 22,359 |
| | Oceania | 3,639 | 648 | 4,287 |
| | Asia | 2,945 | 59 | 3,004 |
| | Africa | 989 | 13 | 1,002 |
| | South America | 44 | 14 | 58 |
| | **Total** | **93,166** | **3,807** | **96,973** |
| **Master** | North America | 32,450 | 4,953 | 37,403 |
| | Europe | 27,724 | 2,742 | 30,466 |
| | Oceania | 3,173 | 1,132 | 4,305 |
| | Asia | 3,721 | 53 | 3,774 |
| | Africa | 1,417 | 9 | 1,426 |
| | South America | 42 | 18 | 60 |
| | **Total** | **68,518** | **8,905** | **77,423** |
| **Short courses** | North America | 800 | 1,454 | 2,254 |
| | Europe | 2,341 | 916 | 3,257 |
| | Oceania | 22 | 344 | 366 |
| | Asia | 143 | 69 | 212 |
| | Africa | | 10 | 10 |
| | South America | 1 | | 1 |
| | **Total** | **3,307** | **2,778** | **6,085** |
| **Total** | | **164,991** | **15,490** | **180,481** |

15 studyportals.com

# 3 Artificial Intelligence

AI is one of the most disruptive technologies that are now leading the worldwide digital industry. Starting in the 1950s, AI has gone through several alternate seasons and only recently has established itself as one of the main drivers of the digital economy. Under the large umbrella of the AI technological domain, many interdisciplinary subdomains are found and, in addition, many fields of application are also detected. In order to match the increasing shift towards a larger supply of AI-related products and services, it is crucial to map the education offer of skills that are associated with these technologies. In fact, the interest by industry in hiring digitally competent employees is increasing, as these competences are fundamental for the production and development of the same AI products.

In recent years the relevance of AI for the economic growth has been stressed in several ways by the European Commission. In the Introduction of the Communication “Artificial Intelligence for Europe” (European Commission (2018c)) it is possible to read 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. The stakes could not be higher. The way we approach AI will define the world we live in. Amid fierce global competition, a solid European framework is needed”. Following this Communication, the “Coordinated Plan on Artificial Intelligence” (European Commission (2018e)) was adopted, setting 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. This has been followed by a number of studies developed, in the context of the AI Watch, to investigate the worldwide landscape of the AI domain and its pervasiveness in the economy and in the society (Righi & Samoili et al. 2020, Samoili & López-Cobo et al. 2020, Samoili & Righi et al. 2019, De Prato & López-Cobo et al. 2019, Craglia et al., 2018). In this section we target AI from the perspective of the education offer that is associated to it. The objective is to provide insightful and useful elements to map the provision of the skills related to this technological domain.

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

Box 2. AI content areas and most frequent keywords

***Knowledge representation and reasoning; Planning; Searching; Optimisation***: processes aiming at transferring/generating knowledge in a form that is processable by the computers, inductive programming, information theory, metaheuristics, genetic and evolutionary algorithms, semantic web, etc.

***Machine learning***: supervised and unsupervised learning, including neural networks, pattern recognition, etc.

***Natural language processing***: computational linguistics, information retrieval, text mining, machine translation, chatbot, etc.

***Computer vision***: image processing, face recognition, image recognition, etc.

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

***Multi-agent systems***: intelligent agents (any entity autonomously acting based on coded instructions and on information obtained from the context), agent-based models, game theory, etc.

***Robotics and Automation***: robot systems, control theory, human-computer-interaction, etc.

***Connected and Automated vehicles***: automated driving systems, autonomous vehicles, self-driving cars.

***AI applications***: applications of AI in big data, intelligent systems, data analytics, internet of things, business intelligence, virtual reality.

***AI ethics***: security, safety, accountability, explainability, fairness, and privacy.

***Philosophy of AI***: artificial general intelligence, strong AI, weak AI, narrow AI.

***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

As recently emerged (Righi & Samoili et al. 2020, Samoili & Righi et al. 2019, De Prato & López-Cobo et al. 2019), the most relevant areas in the AI worldwide techno-economic ecosystem are the US, China and EU27. In addition, the strength of UK, Canada and South Korea has been highlighted. These insights fundamentally match with what we detect here. The study revealed a total number of 5,297 AI programmes in all the countries considered, 1,032 (or 19%) of them correspond to the EU27 (Table 2). In Figure 1, in fact, it is possible to observe the geographical distribution of programmes offered in the geographic areas considered in the study, for each combination of programme scope (broad or specialised) and programme level (bachelor, master or short courses). In all the panels of Figure 1, **US appears as the area offering more programmes related to AI**. Sensible differences are present depending on the level considered: bachelor degrees, master degrees or short courses.

The **EU27** and the **UK** appear as almost complementary. In fact, while the EU27 offers a small percentage of AI-related courses in bachelor degrees (Figure 1, panels 1 & 4), here UK presents a large offer. Then, when considering the master degrees (Figure 1, panels 2 & 5), the offer of the two areas is quantitatively very similar. Finally, when looking at the short courses provided (Figure 1, panels 3 & 6), the situation is reversed with EU27 leading. It has to be reminded, that this study covers only English taught programmes, which could partially explain this pattern of higher offer in UK in bachelor degrees, while most continental European countries usually teach in their native language. On the other hand, when it comes to master degrees, it is expected a more international offer, with higher proportion of programmes taught in English throughout Europe. In any case, even if the teaching language is somehow inflating the gap, the offer of the UK in bachelor degrees is high. New measures are advisable to compensate an increasing difficulty in the mobility of citizens due to the recent Brexit. **The first insight the study reveals is that the EU27 loses large amount of offer of AI-related bachelor programmes (the part provided by UK).**

It is important to highlight the **very low gap between the EU27, UK and US in the offer of AI master degree programmes**. Given the role of these programmes in providing the ultimate formation of competences for the workforce (bachelor degrees only constitute the initial part of the academic formation and short courses usually either address specific and technical aspects or provide a general introduction to a topic), this finding is certainly relevant to assess **the good position of the EU27 in the education offer related to this domain.**

The distinction between broad and specialised programmes does not change the picture. In fact, the geographic distribution of the offer is very similar between broad and specialised programmes for the three levels: bachelor degrees, master degrees and short courses.

**Table 2. AI programmes by geographic area, level and scope, 2019-20**

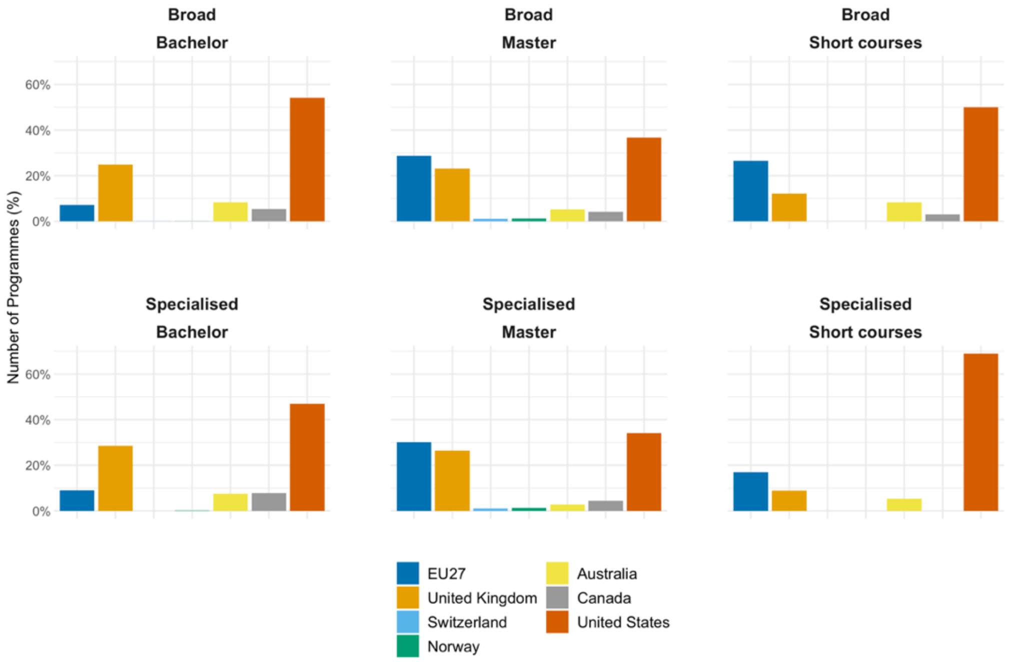
| | | Bachelor | | Master | | Short courses | | Total |
|---|---|---|---|---|---|---|---|---|
| | | Broad | Specialised | Broad | Specialised | Broad | Specialised | |
| | **EU27** | 116 | 58 | 535 | 259 | 35 | 29 | **1,032** |
| UK | United Kingdom | 402 | 185 | 430 | 227 | 16 | 15 | **1,275** |
| NO | Norway | 1 | 1 | 22 | 11 | | | **35** |
| CH | Switzerland | 1 | | 19 | 8 | | | **28** |
| CA | Canada | 88 | 51 | 78 | 38 | 4 | | **259** |
| US | United States | 878 | 305 | 685 | 293 | 66 | 118 | **2,345** |
| AU | Australia | 134 | 49 | 96 | 24 | 11 | 9 | **323** |
| | **TOTAL** | **1,620** | **649** | **1,865** | **860** | **132** | **171** | **5,297** |

What evidenced by Figure 1, is confirmed by Figure 2, which shows a large **gap between the EU27 offer of AI-related bachelor degrees and the EU27 offer of AI-related master degrees**, with **the latter being more than three times the former**. This is also observed in the continental European countries considered (Switzerland and Norway). On the other hand, this gap between bachelor degrees and master degrees is not shown for Anglo-Saxon countries. In fact, it is possible to observe a stronger balance between AI-bachelor degrees and AI-master degrees for the UK, Australia, Canada and the US. The lack of balance between AI-related bachelor degrees and master degrees in continental Europe may be explained by, at least, two nonexclusive factors. First of all, the finding may have revealed a structural property of the education offer promoted by the EU27. If this is true, it means that the EU27 concentrates the offer of high-technological skills (in this case AI) in the most advanced level, i.e. the master degrees. Second, a bias due to the teaching language may be present, showing in any case a limited offer of bachelor degrees taught in English in the EU27.

Regarding the **fields of education** in which AI is taught, as expected, the largest number of programmes is detected in ***ICT***, followed by ***Engineering, manufacturing and construction***. Very small differences are observed between countries, with these two fields of education on average covering nearly 40% and 30%, respectively, of all AI programmes offered (Figure A 1 in Annex 1).

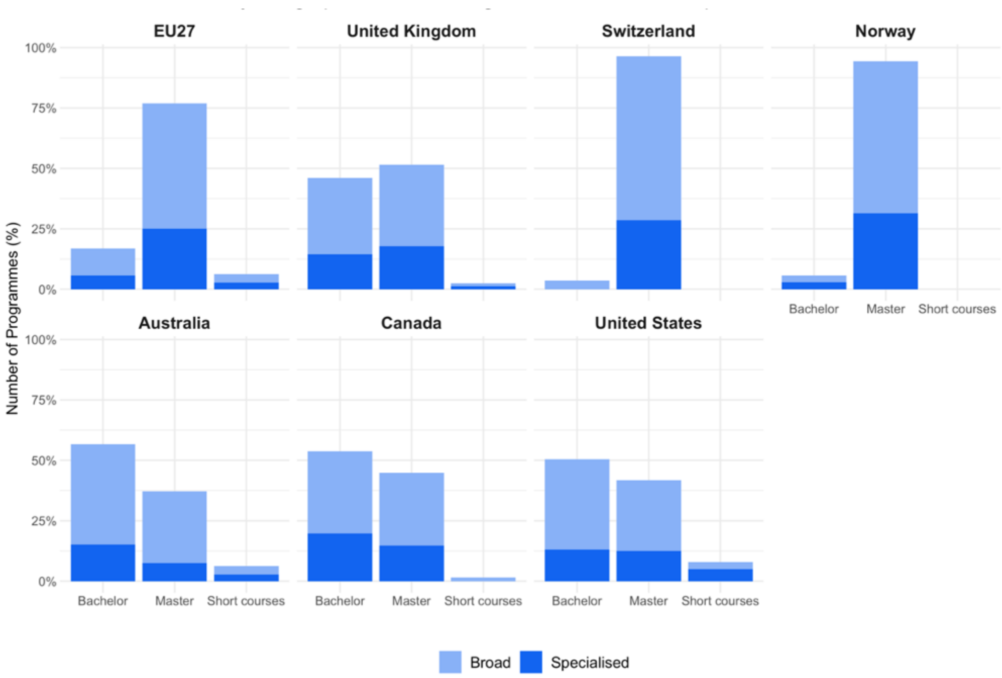
When analysing the **content of AI-related programmes** (Figure 3), geographical differences emerge. The area of ***Robotics & Automation*** is definitely the most frequently taught, with only Switzerland and Norway not having it in the first position. A relevant role is played by ***Machine learning***, expected to be one of the most taught subjects as it constitutes a large part of AI theoretical foundations and has multiple applications. In addition, ***AI applications*** and ***AI ethics*** also deserve attention: despite their presence is not constant in all countries, they both appear as relevant. While in the EU27, UK, Canada and the US these two content areas appear as taught in very similar quantity, in Switzerland and Australia, *AI ethics* (which mainly refers to security, safety, accountability, explainability, fairness, and privacy) is covered by almost double number of programmes than the area of *AI applications* (which covers applications of AI in e.g. big data, intelligent systems, internet of things, virtual reality). Finally, Norway presents a reversed situation with *AI applications* covering more than twice the programmes of *AI ethics*.

**Figure 1. Geographical distribution of AI programmes by scope and level (%). All geographic areas, 2019-20**



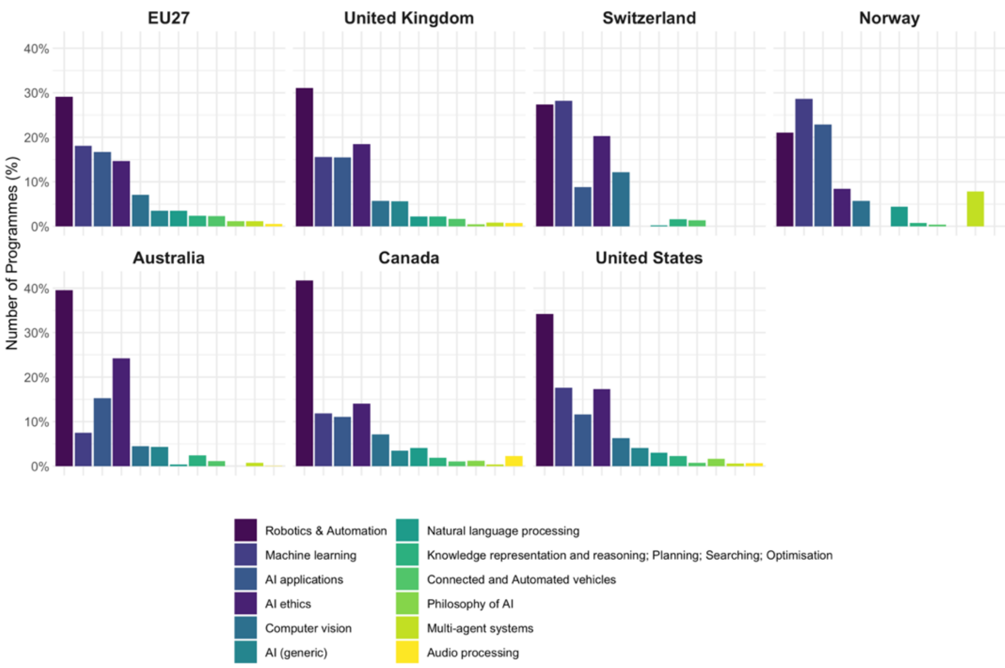

Note: The percentages are based on the number of courses in the specific combination of scope (broad vs. specialised) and level (bachelor vs. master vs. short courses)

**Figure 2. AI programmes by geographic area, level and scope (%). All geographic areas, 2019-20**




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

**Figure 3. AI programmes by geographic area and content taught (%). All geographic areas, 2019-20**




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

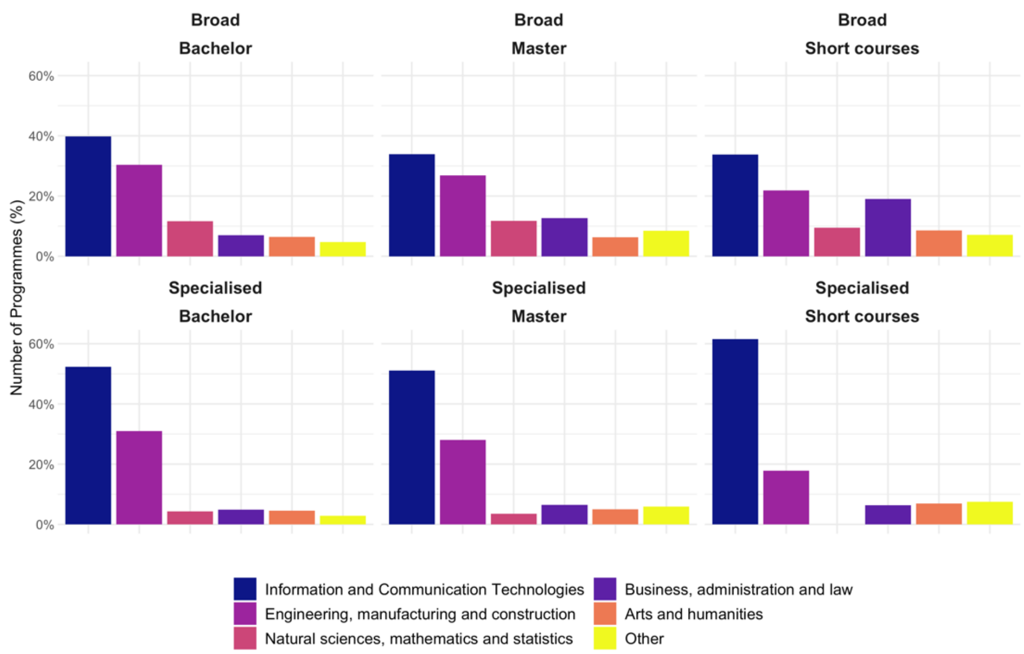
## 3.2 Focus on the EU27

In the EU27, the **fields of education** that most include AI-related content are ***ICT*** and ***Engineering, manufacturing and construction***, as observable in Figure 4. We can observe some differences when we consider the scope of the program: broad programmes, i.e., programmes that cover AI as part of a more generic field or as a course complementary to another specialised domain, versus specialised programmes, where AI is an intrinsic part of the curriculum.

In the context of **broad programmes**, we can observe that the proportion between the two fields of education of *ICT* and *Engineering, manufacturing and construction* is similar in all levels. Figure 4 shows that for broad programmes (bachelor, master or short courses), the field of ***ICT*** is always around 35-40%, while ***Engineering, manufacturing and construction*** reaches 20-30% of programmes.

On the other hand, when considering exclusively **specialised programmes**, a different pattern emerges. First of all, Figure 4 shows that the two aforementioned fields gain importance, therefore forcing the remaining fields to lower shares. Hence the higher specialisation of the programmes couples with a **more intense offer** in the fields of ***ICT*** and ***Engineering, manufacturing and construction***. Second, **when moving from bachelor or master degrees to short courses, a larger gap between *ICT* and other fields is observed**. This field of education seems, therefore, to be the one offering most AI-related content, especially when the specialisation of the programme increases and the length diminishes.

**Figure 4. AI programmes by scope, level and field of education (%). EU27, 2019-20**




Note: The percentages are based on the number of programmes in the combination of scope and level.

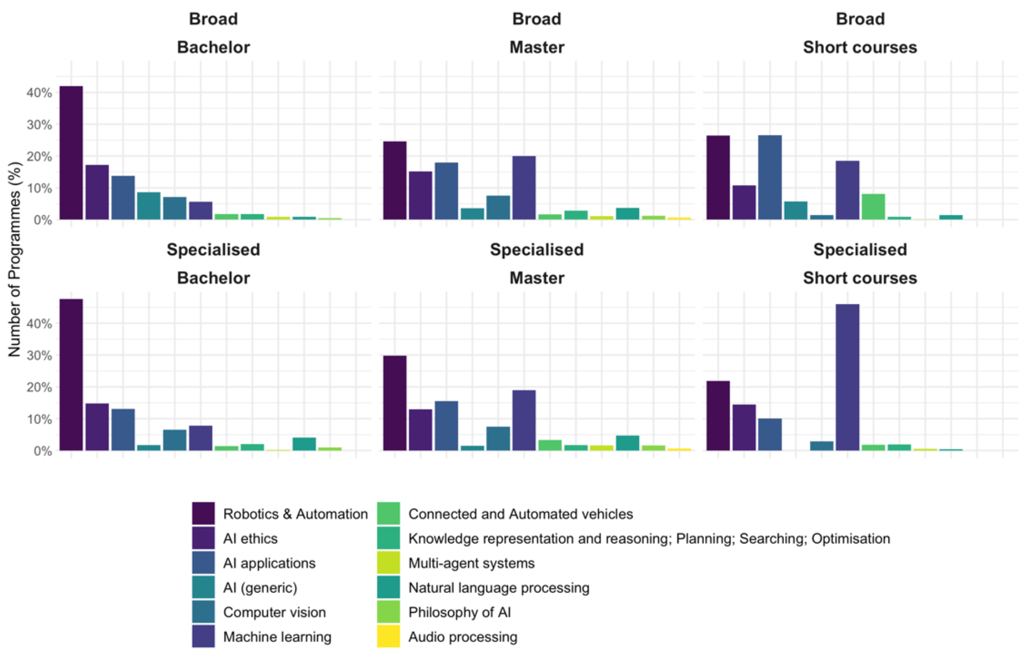
Regarding the **contents taught in AI-related courses** (Figure 5), no large differences are observed between broad and specialised programmes. This means that, substantially, the content areas selected to be taught are not influenced by the scope of the course. The only point worth mentioning is the large variation in the share of *Machine learning* between broad short courses and specialised short courses. While in the first ones, only 15% of the courses cover *Machine learning*, this percentage raises to almost 50% among specialised short courses. This is a clear evidence of the fact that the **education offer mainly oriented to professionals and specialists is largely focused on *Machine learning***.

***Robotics & Automation*** appear as undoubtedly the **content most frequently taught in the academic entry-level** (bachelor degrees), but not that much in master degrees. Almost half of the whole offer of bachelor programmes in the EU27 with AI content focus on notions of robotics and human-AI interaction, most probably mainly as an application area. However, when moving to a **higher level in the academic education** (master degrees), the content related to ***Robotics & Automation*** **intensively reduces its presence** (from 45% to 25-30% of the curriculum), especially **in favour of *Machine learning***. This may be interpreted as the latter being considered not appropriate and requiring additional skills for bachelor students (around 5% of the content of bachelor programmes is on Machine learning content). Nevertheless, the role of ***Machine learning* in the second part of the academic path is definitely relevant** (around 20% of master courses' content focuses on this area). This pattern, along with the evidence related to the dominance of *Machine learning* in specialised short courses, suggests that it is **one of the key competences in the professional development and implementation of AI**.

Finally, it is important to mention the role of ***AI ethics*** and ***AI applications*** as relevant contents that in any combination of program's scope and level get a **relevant share of the education offer**: on average, around 15% of the curriculum covers *AI ethics* (content for instance about security, safety, accountability, explainability), and the same proportion of curriculum focuses on business *applications of AI* in, for example, big data, internet of things, virtual reality.

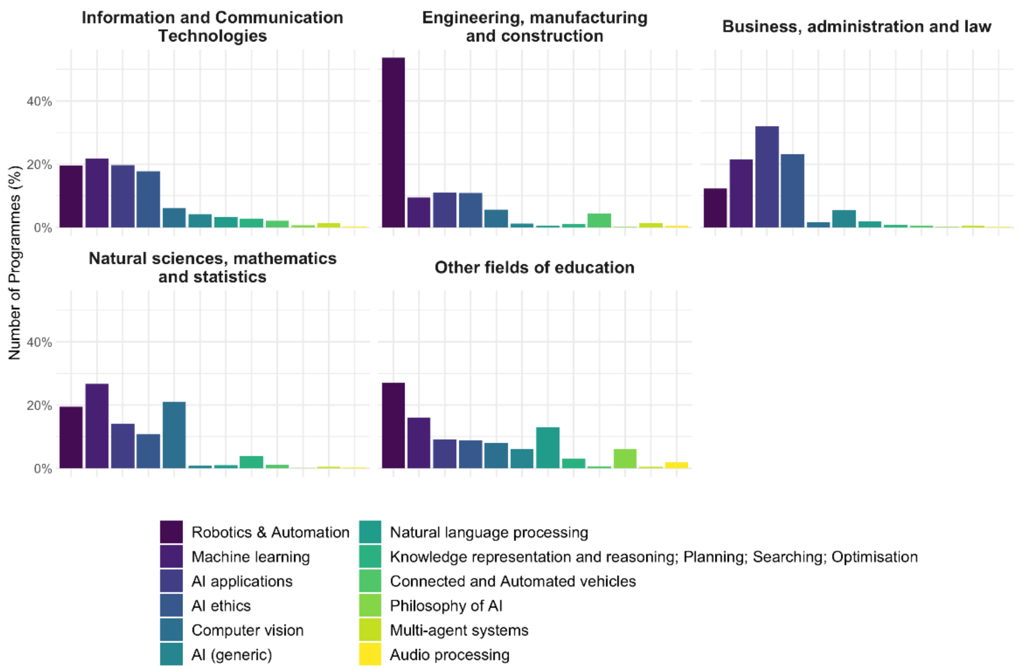
We, then, combine the fields of education in which AI is proposed as subject, and the type of AI-related content that is taught, as shown in Figure 6. Starting from the two fields of education which concentrate most offer (see Figure 4), namely ***ICT*** and ***Engineering, manufacturing and construction***, two very different patterns emerge. While the **training in *ICT* is based on a balanced multiplicity of contents** (*Robotics & Automation*, *Machine learning*, *AI applications*, and *AI ethics* have all almost the same share, around 20%), this is not the case for ***Engineering, manufacturing and construction***. The latter is in fact **almost entirely concentrated in *Robotics & Automation*** content (more than 50%). It seems therefore that on the one hand, the students in *Engineering, manufacturing and construction* face an educational path relatively poor in terms of variety of contents and very concentrated and specialised in only one of them. On the other hand, the academic offer in ***ICT* builds its strength on the multiplicity of contents**, and probably also in a larger degree of interdisciplinarity associated to them. We say "strength" as *ICT* is the field of education that concentrates the largest proportion of AI-related courses. The field of ***Business, administration and law*** deserves to be mentioned as it also collects a relatively good number of AI-programmes (Figure 4). As expected, here the role of *Robotics & Automation* is modest while the ones of ***AI applications, AI ethics*** and ***Machine learning*** (in decreasing order of relevance) are noteworthy.

**Figure 5. AI programmes by scope, level and content area (%). EU27, 2019-20**




Note: The percentages are based on the number of programmes in the combination of scope and level.

**Figure 6. AI programmes by field of education and content area (%). EU27, 2019-20**

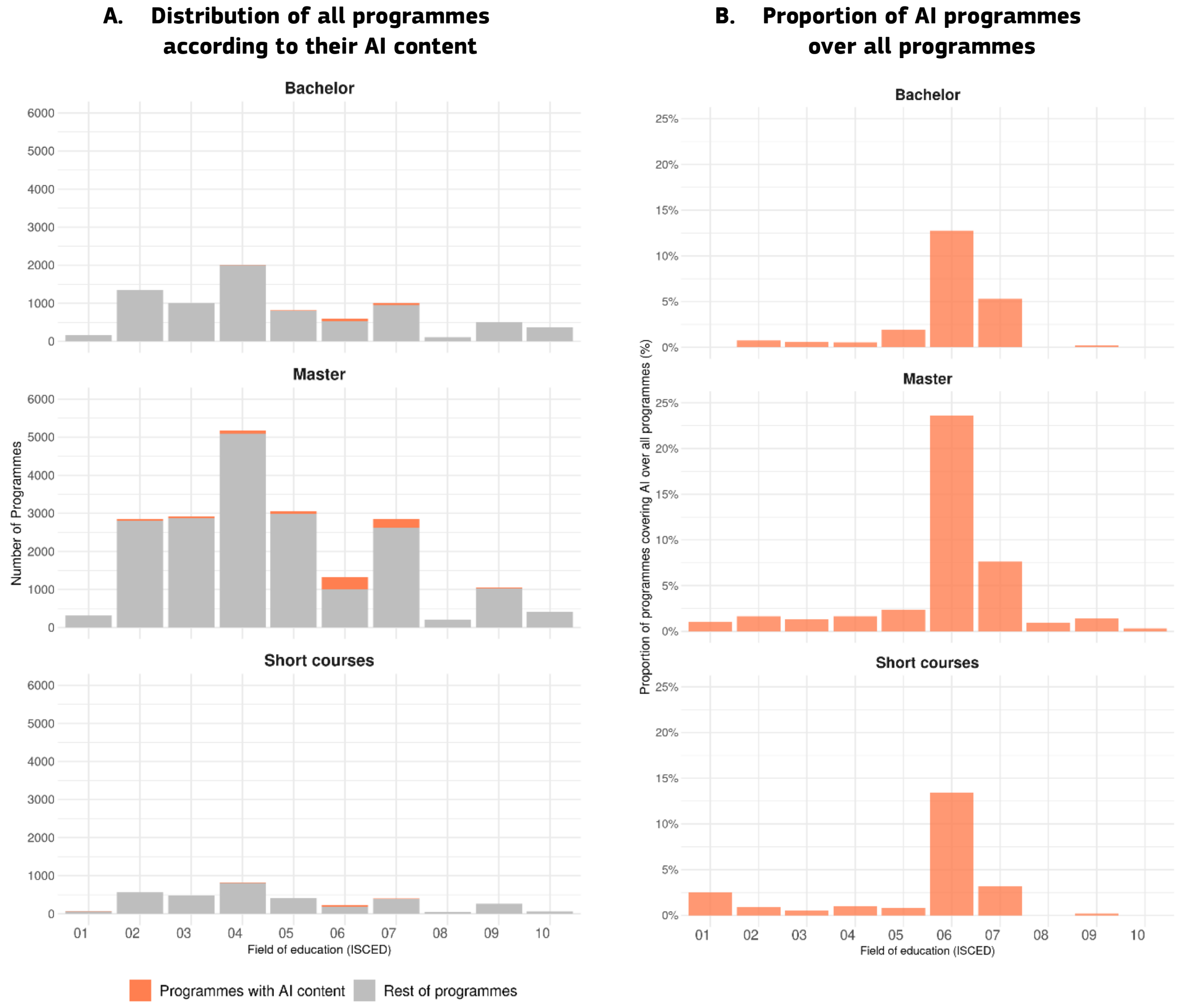



Note: The percentages are based on the number of programmes in each field of education.

For each level, we consider the distribution of the entire education offer by field of education (Figure 7A) with the distinction of the part including AI content (orange bars) and the rest of programmes (grey bars). In addition, in order to have a better view on the percentage of programmes addressing the AI domain, the ratio between the number of AI programmes by educational field and the total number of programmes by educational field has been computed and plotted in Figure 7B. Not surprisingly, *ICT* and *Engineering, manufacturing and construction* play the most relevant role in the offer of AI educational skills. In fact, the proportion that AI occupies in these two educational fields is much higher than what observed for the remaining educational fields. This asymmetry highlights the fact that AI is not taught in a way proportional to the existing structure of the whole education offer. On the contrary, it is a domain which is highly concentrated in very technical and specific fields of education. In fact, as shown in Figure 7B, the prevalence of AI in *ICT*, or proportion of programmes in the field of *ICT* that are related to AI, reaches 12% in bachelor's degrees, 22% in master's degrees and 13% in short courses. This prevalence is the highest of all fields of education. The field of *Engineering, manufacturing and construction* also has relevant prevalence of AI, with 5% of bachelor's degrees, 7% of master's and 3% of short courses.

The distribution observed in Figure 7 is expected, as AI is still a very technical domain. However, given the high level of digitalisation of our society, and so the potential pervasiveness of AI in close future years, the EU27 may benefit from a larger presence of AI programmes in less technological fields of education. A spread of the AI domain would favour a wider, richer and more inclusive discussion about this technology. In future years, AI could concern a larger spectrum of social actors, hence not exclusively including very technical profiles (as those that, at the moment, are mainly targeting the existing programmes). For this reason, an appropriate educational scheme should be structured and implemented.

**Figure 7. Distribution of all programmes according to their AI content (A) and Proportion of AI programmes over all programmes (B) by level and field of education. EU27, 2019-20**




**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

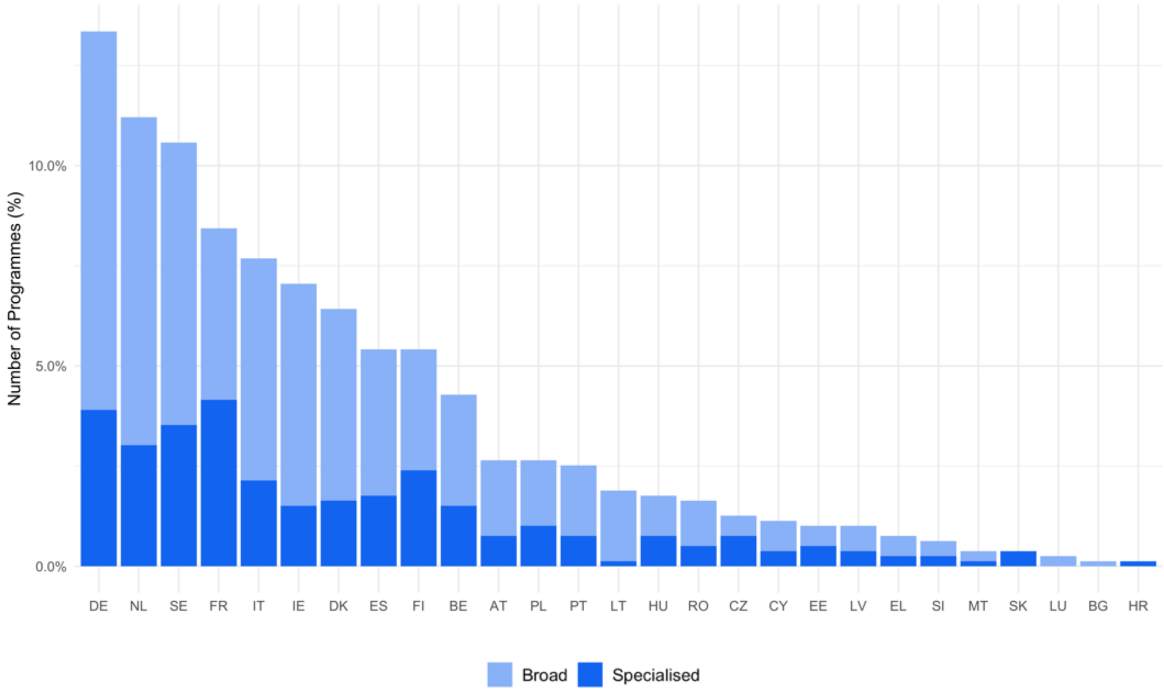
### 3.2.1 *AI master's programmes in the EU27 Member States*

Regarding the distribution of programmes by Member State, we focus our attention on master degrees. As these represent the ultimate formal educational stage, they have a key role in the development of work-related competences and skills. For this reason, they certainly deserve specific consideration at country level.

It is possible to observe in Figure 8 that three Member States lead the offer of AI master degrees. These are Germany, Netherlands, and Sweden. Each of them individually accounts for more than 10% of the entire EU27 offer of AI master degree programmes. In addition, they all show a remarkable balance between the offer of broad programmes and the offer of specialised programmes, with the latter being approximatively half of the former. We can also observe a group of countries in an intermediate position, with shares varying in a relatively wide range (from 8% to 4%). These, in decreasing order of the share they represent, are: France, Italy, Ireland, Denmark, Spain, Finland and Belgium. It is relevant to highlight the large number of specialised AI master programmes offered by France and Finland. In both cases, this offer represents almost half of the national offer. Hence, in these two countries, the number of specialised AI master programmes is almost equal to the number of broad master programmes. In fact, France is the country offering the highest number of specialised AI masters in the EU27. The remaining countries have a marginal role in the entire EU27 offer of AI master's degrees (almost all below 3% of total number of programmes).

A more thorough analysis, not addressed in this work, may show a different picture when considering national characteristics that put these results in perspective. Indicators that consider the number of masters in relation to a national aggregate, such as gross domestic product, number of graduates in ICT, population, etc., may yield additional interesting results.

**Figure 8. AI master's programmes by Member State and scope (%). 2019-20**




Note: The percentages are based on the number of programmes in each field of education in the EU27.

# 4 High Performance Computing

High Performance Computing (HPC) is another key area in the landscape of digitalisation. While AI is mainly about the development of self-learning algorithms which are able to (semi-) autonomously process information (structured and unstructured data, images, sounds, etc.) and make decisions, HPC is about the physical support and the intra- and inter- machines' architecture sustaining very demanding computational processes. Some examples of relevant subjects related to HPC are the parallelization of CPU processes and the availability of large cluster/cloud structures made of multitudes of inter-connected computers serving together very complex tasks. These technological advancements have moved forward the previously existing computational limits, so making possible to process larger amounts of multi-dimensional data. Nowadays, the role of HPC is fundamental in physical simulations, prediction of natural phenomena (like weather forecasts), molecular modelling and cryptography, to name a few. In other cases, supercomputers are also key to enable the simultaneous access to platforms by a vast number of users.

The Communication on High-Performance Computing (European Commission (2012)) "highlights the strategic nature of High-Performance Computing (HPC) as a crucial asset for the EU's innovation capacity", and the European Cloud Initiative (European Commission (2016a)) addresses HPC as one of the basis on which to maximise the growth potential of the European digital economy. The Mid-Term Review on the implementation of the Digital Single Market Strategy "A Connected Digital Single Market for All" (European Commission (2017)) identifies HCP as a critical element for the digitisation of industry and the data economy. And more recently, the Council Regulation (EU) 2018/1488 specifically addresses the development of a public-private partnership in the domain of HPC with the establishment of the European High Performance Computing Joint Undertaking, entrusted with the deployment of an integrated world-class supercomputing and data infrastructure, and a competitive and innovative high-performance computing ecosystem. The role of HPC is, therefore, deemed as crucial and synergies between public institutions and private actors are sought. In the present section, we investigate which is the situation of the education offer related to this domain, with the goal to show how the skills related to HPC are provided and structured. A complete discussion about the development status of such a specific technological domain necessarily needs to consider the availability and the features of the related competences and skills.

Box 3. HPC content areas and most frequent keywords

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

***Cloud***: cloud computing, data centre.

***Parallel Computing***: process parallelization, parallel computation/programming, scalability, concurrent HPC.

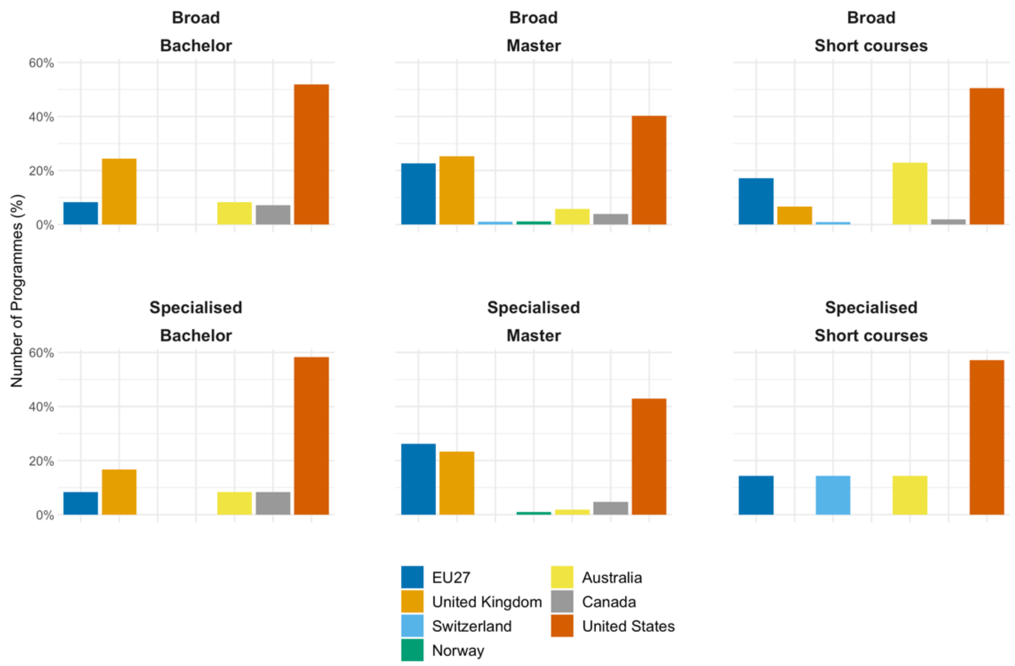
***Processors****: multi-core processors, graphics processing unit (GPU).*

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

## 4.1 HPC education offer in the international context

We have detected a total number of 1,768 HPC programmes in all the countries considered, out of which 311 (17%) are taught in the EU27 (Table 3). The offer of advanced digital skills related to HPC appears as **worldwide dominated by the US**, which always has the largest share in all the combinations by scope and level of the considered programmes (Figure 9). **UK is home to a high proportion of HPC-related bachelor** and **master degree** programmes (always around 25% of the detected offer, apart from the specialised bachelor programmes, in which the UK covers the 15% of the offer).

**Figure 9. Geographical distribution of HPC programmes by scope and level (%). All geographic areas, 2019-20**




Note: The percentages are based on the number of courses in the specific combination of scope (broad vs. specialised) and level (bachelor vs. master vs. short courses)

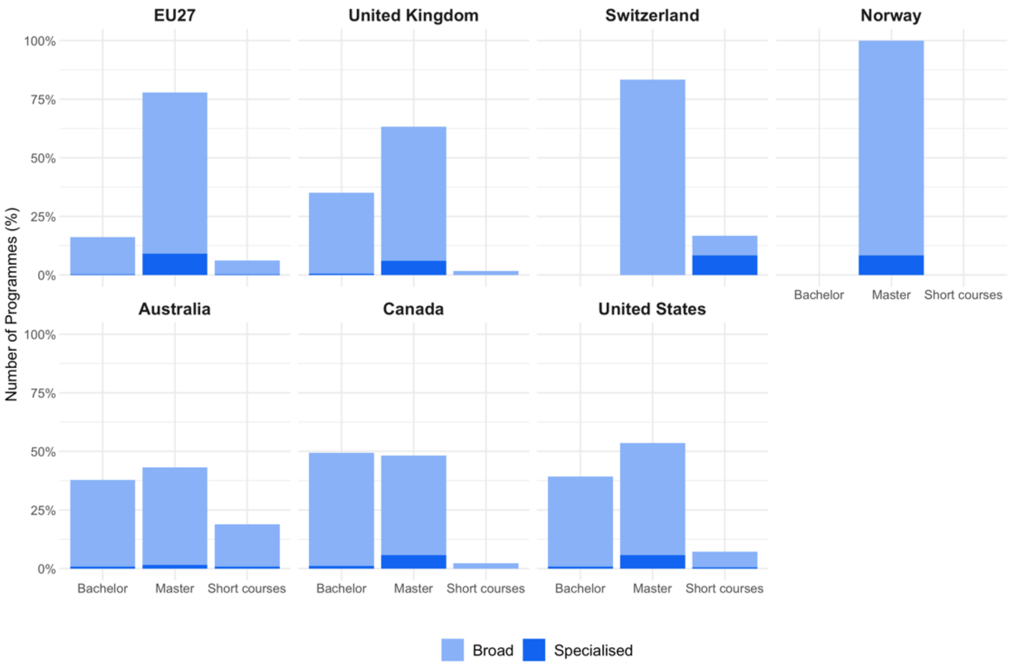
The **EU27** seems to host only a **modest share of HPC bachelor programmes** (around 10%), while the EU27's share **of master's level offer is higher**. This is confirmed by Figure 10, which shows a large gap between the two levels in the EU27. It is also possible to observe that the proportion of short courses is very modest in all the geographic areas apart from Australia.

In addition, as also observed for AI (Figure 2), the **Anglo-Saxon countries** that are considered in this work (i.e. the UK, Australia, US and Canada) present a **good balance between the offer of bachelor and master programmes**. This is not true for areas located in continental Europe, namely the **EU27, Switzerland and Norway**. In fact, they all present an **offer almost entirely based on masters.** As discussed for AI, the origin of this finding is still unclear and may be related to a limited view offered by this report for the bachelor level, due to the lack of an appropriate education offer of bachelor degree programmes taught in English language. Additionally, this element may be the signal of a structural concentration of efforts by the EU27 in master degree programmes.

**Table 3. HPC programmes by geographic area, level and scope. 2019-20**

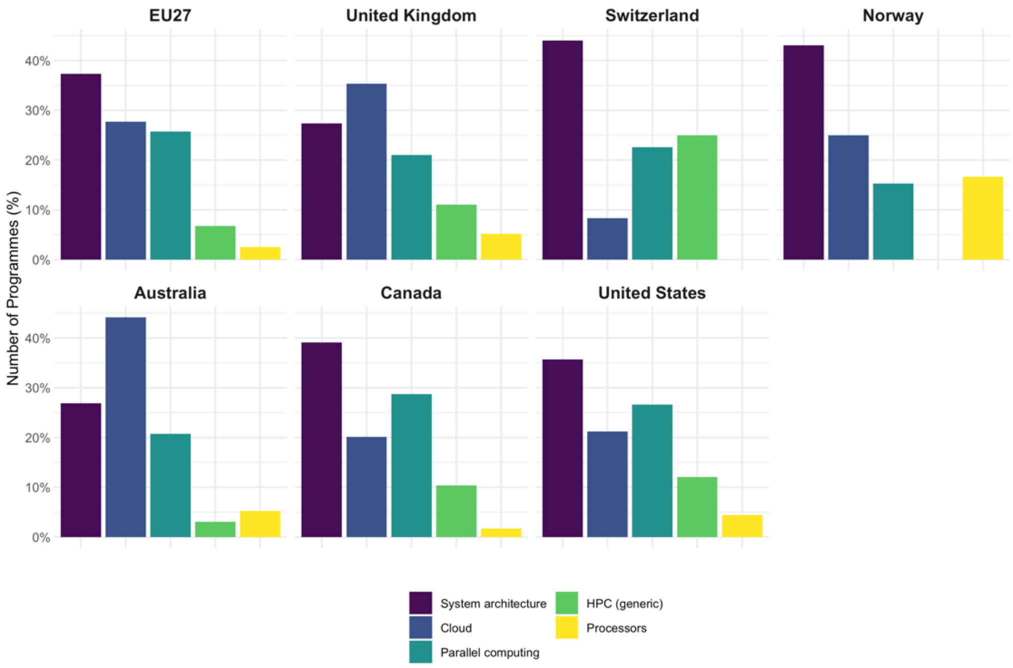
| | | Bachelor | | Master | | Short courses | | Total |
|---|---|---|---|---|---|---|---|---|
| | | Broad | Specialised | Broad | Specialised | Broad | Specialised | |
| | **EU27** | 49 | 1 | 214 | 28 | 18 | 1 | **311** |
| UK | United Kingdom | 144 | 2 | 239 | 25 | 7 | | **417** |
| NO | Norway | | | 11 | 1 | | | **12** |
| CH | Switzerland | | | 10 | | 1 | 1 | **12** |
| CA | Canada | 42 | 1 | 37 | 5 | 2 | | **87** |
| US | United States | 306 | 7 | 381 | 46 | 53 | 4 | **797** |
| AU | Australia | 49 | 1 | 55 | 2 | 24 | 1 | **132** |
| | **TOTAL** | **590** | **12** | **947** | **107** | **105** | **7** | **1,768** |

**Figure 10. HPC programmes by geographic area, level and scope (%). All geographic areas, 2019-20**




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

**Figure 11. HPC programmes by geographic area and content taught (%). All geographic areas, 2019-20**




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

The **field of education** in which HPC is mostly taught is ***ICT***, which averagely includes more than the 50% of the programmes detected (Figure A 3 in Annex 1). The other fields of education play a modest role and not substantial differences are detected among the corresponding shares.

Different patterns are detected in the composition of the **content of the HPC programmes** across geographic areas (Figure 11). The content category which usually is more prominent is the one of ***System architecture***. Also, the two content areas of ***Cloud*** and ***Parallel computing*** present good shares. The first one, *Cloud*, is relatively low only in Switzerland and, on the opposite, it is very high in the UK (around 35% of all programmes' content) and in Australia (42%). The second one, *Parallel computing*, has its largest presence in the EU27 (25%), in the US (28%) and in Canada (29%).

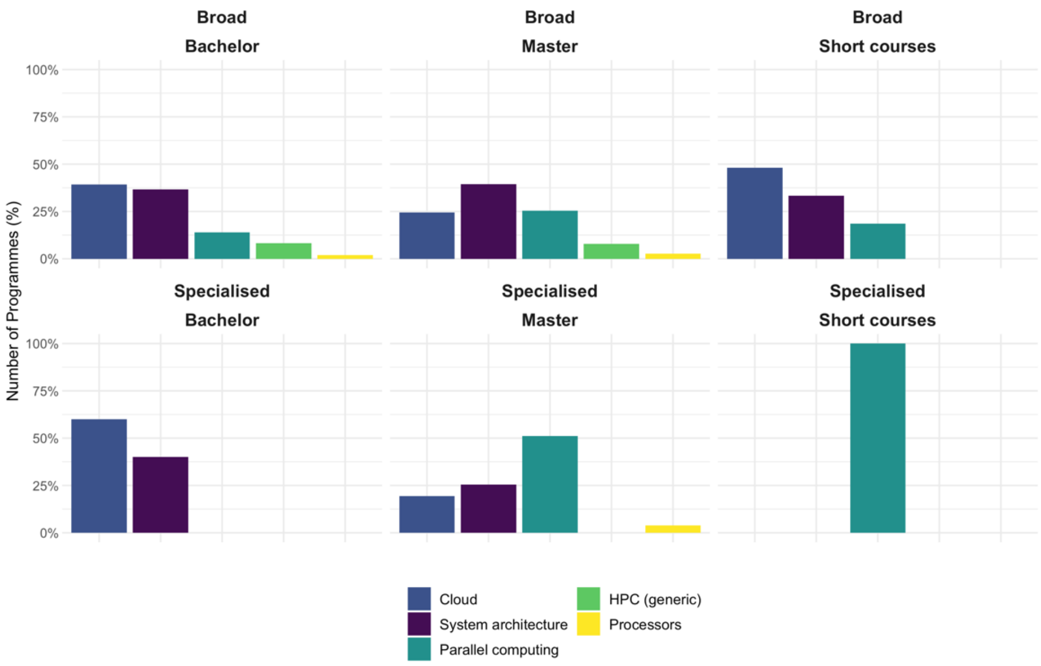
## 4.2 Focus on the EU27

Looking closely at the **EU27**, we can see a bold difference between broad and specialised programmes in terms of the fields of education in which they are taught (Figure A 3 in Annex 1). In fact, the education offer of **specialised HPC programmes** is almost entirely associable to the field ***ICT*** (always at least 65% of the offer). ***ICT*** is the prevalent field also in **broad programmes**, but here a larger variety is detected. Indeed, other two fields show a remarkable role. These are the one of ***Engineering, manufacturing and construction*** and the one of ***Business, administration and law.*** They present alternate shares (generally around the 15%) depending on the programme level.

In addition, the analysis of the EU27 HPC education offer by scope, level and content reveals an interesting point about the most specialised programmes, i.e. the **specialised master degrees**. In fact, it is possible to observe in panel 5 of Figure 12 that the largest share (almost 50%) is held by ***Parallel Computing***, while the same content area shows a much lower share in the broad master degrees and it is almost non-existent in the bachelor degrees. This finding reveals that, in the EU27, the area of ***Parallel Computing* is intensively targeted to the most specialised audience**.

The content ***Parallel Computing*** also dominates the **specialised short courses**. However, these programmes represent a **small part of the offer** (less than 10%, see Figure 10). Therefore, even if panel 6 in Figure 12 catches the attention, the point deserves little consideration.

**Figure 12. HPC programmes by scope, level and content area (%). EU27, 2019-20**




Note: The percentages are based on the number of programmes in the combination of scope and level.

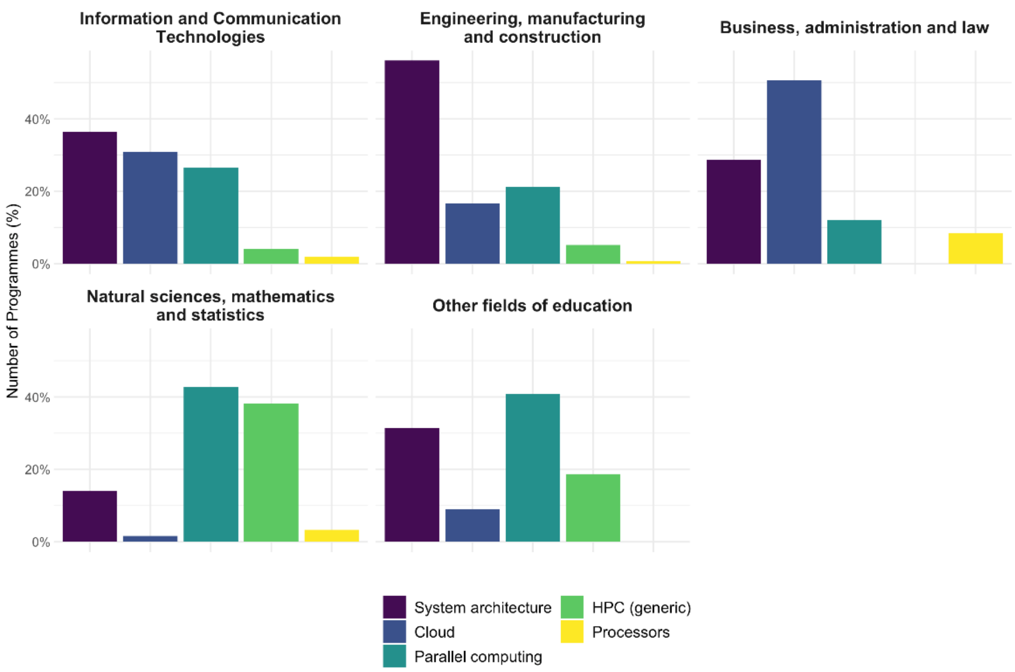
Finally, also the combination of field of education and content area (Figure 13) deserves consideration, as an interesting insight emerges. ***ICT***, which is the field of education offering the majority of programmes, **presents a balanced distribution of contents** (panel 3 of Figure 13). It is possible to observe that for the mentioned field of education, there are three areas with relevant shares: ***System architecture***, ***Cloud*** and ***Parallel Computing***. This seems to suggest that the **education offer** within the ***ICT* field is structured to cover a large variety of topics**.

On the other hand, secondary fields present some areas of specialisation in their programmes offered. ***Engineering, manufacturing and construction*** is very concentrated on the content related to ***System architecture*** (panel 4 in Figure 13). The field of ***Business, administration and law*** (panel 1 in Figure 13) is focused in ***Cloud***. And finally, the field of ***Natural sciences, mathematics and statistics*** reveals ***Parallel Computing*** and ***HPC (generic)*** as the contents with the largest shares (both around 40%). These insights suggest that in HPC certain competences have already found a good association with specific fields of education.

The distribution of programmes with HPC content by education field in the whole EU27 (orange bars Figure 14A) in comparison with the distribution of the entire education offer (full bars in Figure 14) presents a strong asymmetry. The ratio of programmes with HPC content over all programmes, which is represented in Figure 14B is mainly due to the very high concentration of HPC programmes in the field of education of *ICT*. This was expected, even more than for AI, as HPC is a very technical and specific domain. Regarding the field of *Engineering, manufacturing and construction*, it appears not to have an outstanding role in the first part of the HPC educational path (i.e. bachelor degrees), while in later and more specialised stages (i.e. HPC master degrees and short courses) its relative importance increases.

As observable in Figure 14B, out of all master's degrees in the field of *ICT*, 11% include some HPC content. The prevalence is around 5% in bachelor's and short courses. In all other fields of education, the prevalence is below 1%, with the exception of short courses in *Engineering, manufacturing and construction* (1.2%).

**Figure 13. HPC programmes by field of education and content area (%). EU27, 2019-20**

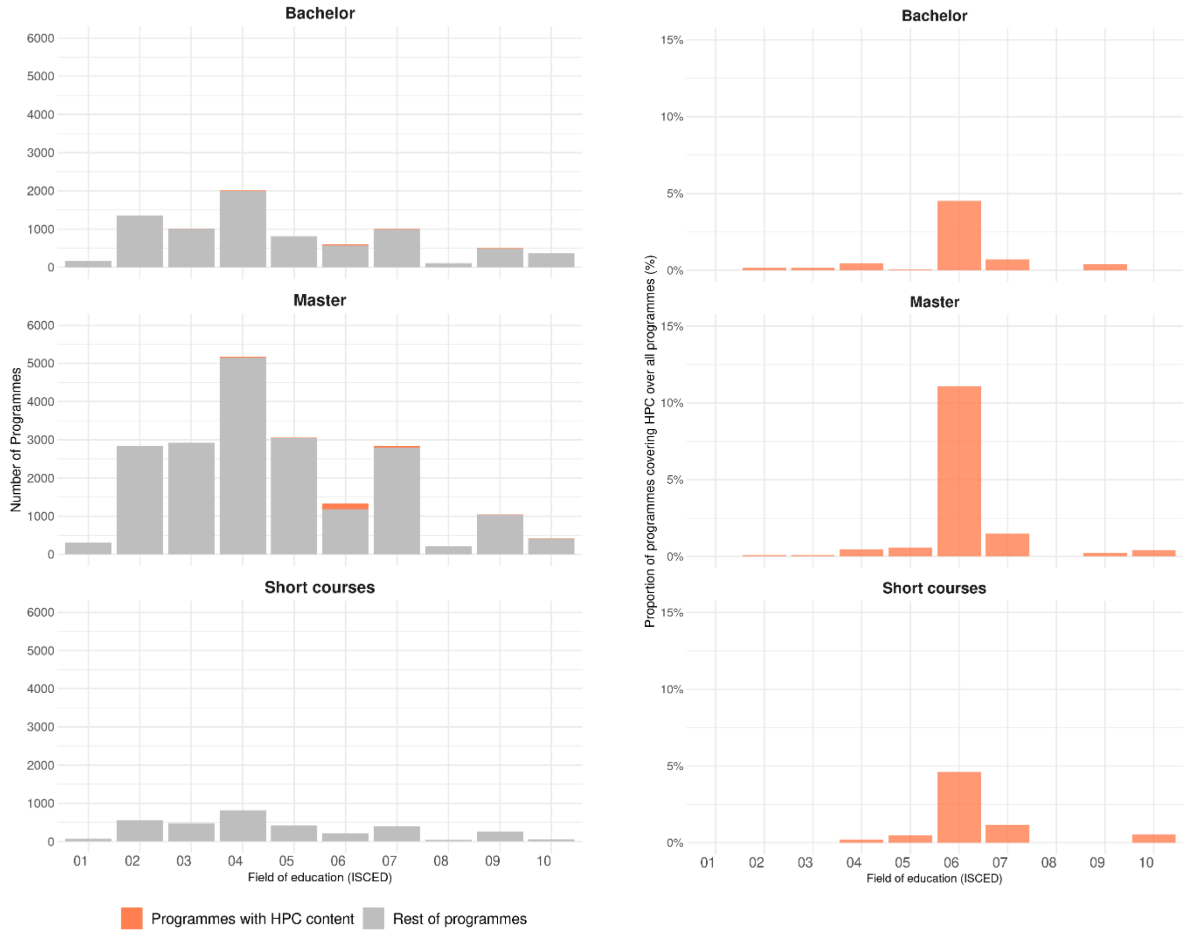



Note: The percentages are based on the number of programmes in each field of education.

**Figure 14. Distribution of all programmes according to their HPC content (A) and Proportion of HPC programmes over all programmes (B) by level and field of education. EU27, 2019-20**

**A. Distribution of all programmes according to their HPC content**

**B. Proportion of HPC programmes over all programmes**




**Field of education**

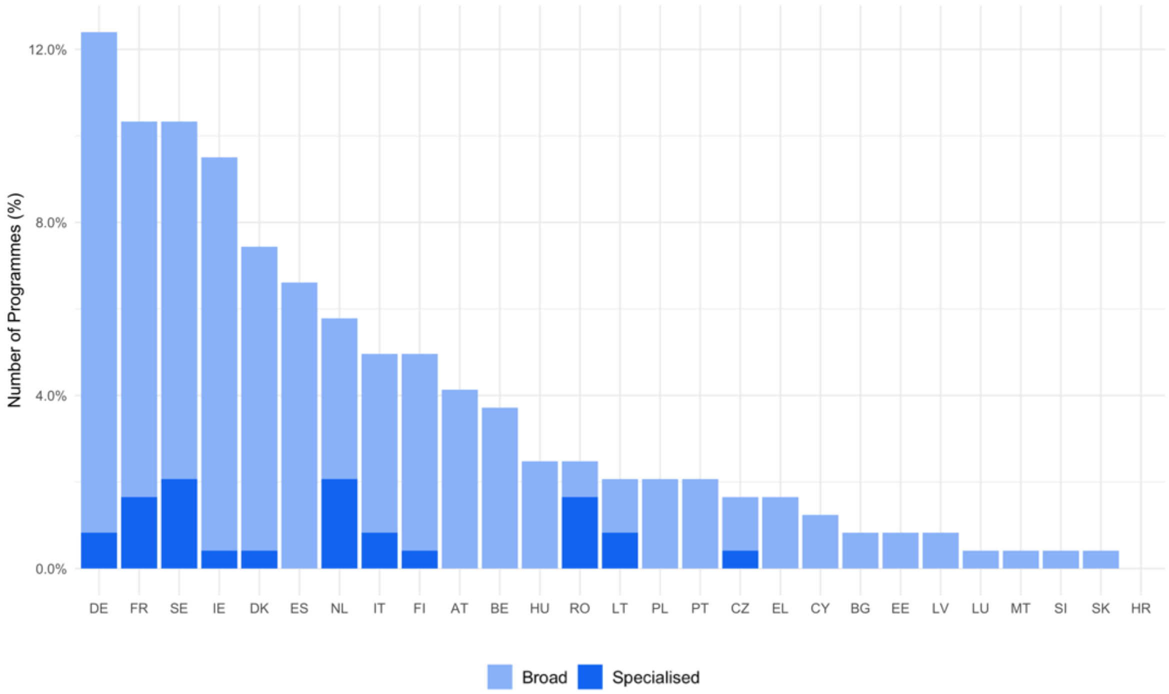
01 Education
02 Arts and humanities
03 Social sciences, journalism and information
04 Business, administration and law
05 Natural sciences, mathematics and statistics
06 Information and Communication Technologies
07 Engineering, manufacturing and construction
08 Agriculture, forestry, fisheries and veterinary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

### 4.2.1 *HPC master's programmes in the EU27 Member States*

In Figure 15 it is possible to observe that the offer of HPC master programmes is remarkable in Germany (around 12% of total master programmes offered in the EU27), and also in France, Sweden and Ireland (each around 10% of the total EU27 offer). A consistent group of countries (Denmark, Spain, Netherlands, Italy, Finland, Austria and Belgium) is in an intermediate position, with shares ranging from 8% to 4% approximately. The remaining countries follow, with percentages that in few cases are higher than 2%.

The ratio between specialised programmes and broad programmes (dark blue and light blue parts of the bars, respectively) is generally low, since only a very reduced number of specialised programmes are detected. Nevertheless, noteworthy shares are detected in Netherlands (specialised HPC master programmes represent nearly one half of broad programmes), in Romania (the number of specialised HPC programmes is larger than the corresponding number of broad programmes), and in Lithuania (specialised master programmes are nearly half of the broad ones).

**Figure 15. HPC master's programmes by Member State and scope (%). 2019-20**




Note: The percentages are based on the number of programmes in each field of education in the EU27.

# 5 Cybersecurity

Another subject strongly related to digitalisation, and for which very specific skills are required in order to properly manage its complexity, is Cybersecurity (CS). With CS we usually refer to the “activities necessary to protect network and information systems, the users of such systems, and other persons affected by cyber threats” (Cybersecurity Act (Regulation (EU) 2019/881)). Violations of privacy rights related to personal information, or lapses in the control and protection of private and businesses data, are increasingly becoming relevant issues. Examples of cyber related episodes include violation of privacy for commercial reasons, use of bots and fake identities in social networks to influence population’s opinion, use of private information to support unethical practices such as medical monitoring of population, malware and ransomware. There are several factors behind the increasing challenges posed by exchange and storage of data. The increase of computational power and the development of new algorithms are forcing the security measures to evolve and become more effective. Also, the growing inter-connectivity, and the rising capacity and use of cloud services are causing that vast amounts of valuable information is placed in servers that can be remotely accessed. Therefore, the development of new protection measures and firewalls is necessary to continue to guarantee no violations and to sustain a correct functioning of the information management system. Training a generation of highly skilled labour force in CS is, more than ever, a priority for modern societies.

The relevance of cybersecurity has led to the adoption of the European Cybersecurity Act, which revamps the European Union Agency for Network and Information Security (ENISA) and lays down an EU cybersecurity certification framework to ensure an adequate level of cybersecurity in the Union. The regulation acknowledges that “Information and communications technology (ICT) underpins the complex systems which support everyday societal activities. (…) The use of network and information systems by citizens, organisations and businesses across the Union is now pervasive” and that, most importantly, “In that context, the limited use of certification leads to individual, organisational and business users having insufficient information about the cybersecurity features of ICT products, ICT services and ICT processes, which undermines trust in digital solutions”. ENISA’s objectives include raising public awareness of cybersecurity risks, providing guidance on good practices, and promoting cybersecurity education and capacity-building. The content of this section provides relevant insights to reveal the status of the education offer related to a key technological domain such as cybersecurity.

Box 4. CS content areas and most frequent keywords

***Network & Distributed Systems Security***: computer security and distributed processing systems, fault tolerance, security protocols.

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

***Data Security and Privacy***: information security, network security, data security, firewalls, anonymization, information protection.

***Critical Infrastructure Protection***: protection of essential digital infrastructures by possible cyber attacks: control systems.

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

***Other***: cybercrimes, information assurance.

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

***Operational Incident Handling and Digital Forensics***: activities related to the use of computer/digital evidences during trials and in front of the court of law: digital forensics, digital evidence.

***Identity and Access Management (IAM)***: identity control and access management, management of public keys

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

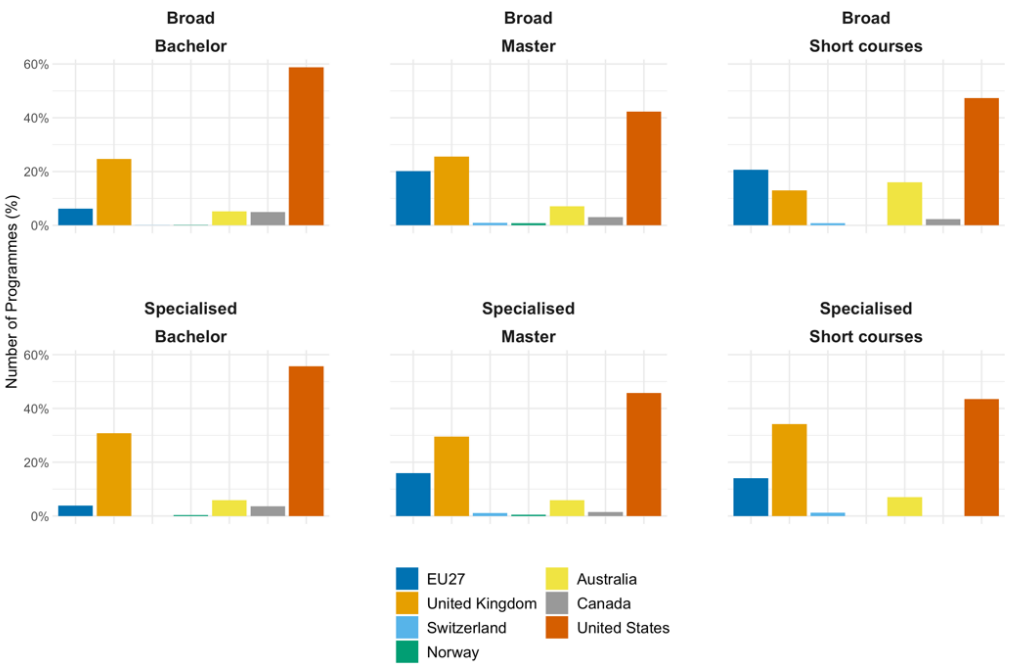
## 5.1 CS education offer in the international context

The study identified 4,217 CS programmes in all countries considered, out of which 526 (12.5%) are taught in the EU27 (Table 4). The **CS international landscape is dominated by the US** (Figure 16), which are major providers of CS-related programmes of all levels. In comparison to what observed for AI and HPC, the **EU27** replicates a similar scheme also in CS: a **modest offer of bachelor degree programmes**, and much **more substantial offer of master and short courses**. Again, this can be the evidence either a structural property of the EU27 education offer, or the consequence of few bachelor programmes provided in English language.

**Table 4. CS programmes by geographic area, level and scope, 2019-20**

| | | Bachelor | | Master | | Short courses | | Total |
|---|---|---|---|---|---|---|---|---|
| | | Broad | Specialised | Broad | Specialised | Broad | Specialised | |
| | **EU27** | 93 | 19 | 269 | 106 | 27 | 12 | 526 |
| UK | United Kingdom | 372 | 153 | 341 | 197 | 17 | 29 | 1,109 |
| NO | Norway | 2 | 2 | 10 | 3 | | | 17 |
| CH | Switzerland | 1 | | 13 | 7 | 1 | 1 | 23 |
| CA | Canada | 75 | 18 | 41 | 10 | 3 | | 147 |
| US | United States | 884 | 277 | 563 | 305 | 62 | 37 | 2,128 |
| AU | Australia | 78 | 29 | 94 | 39 | 21 | 6 | 267 |
| | **TOTAL** | 1,505 | 498 | 1,331 | 667 | 131 | 85 | 4,217 |

**Figure 16. Geographical distribution of CS programmes by scope and level (%). All geographic areas, 2019-20**

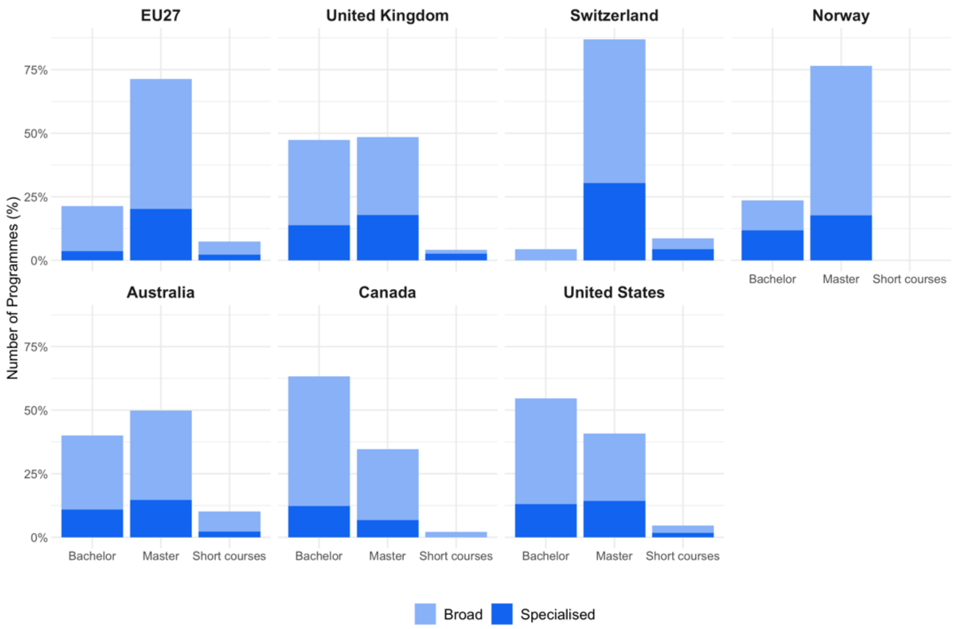



Note: The percentages are based on the number of courses in the specific combination of scope (broad vs. specialised) and level (bachelor vs. master vs. short courses)

In Figure 16, it is important to observe that the within-level comparison between broad and specialised CS programmes (i.e., broad bachelors versus specialised bachelors, broad masters versus specialised masters, and broad short courses versus specialised short courses) shows larger differences than what observed before for the other domains. More specifically, **the EU27's share of CS specialised offer is systematically 5 percentage points lower than the EU27's share in the offer of broad programmes**. This finding deserves attention, considering the increasingly frequent cybersecurity threats and attacks experienced by companies and citizens. In fact, a **lack of specialised knowledge and skills in the CS field may leave room for future attacks and attempts to destabilise the democratic principles of the Union**, which can therefore find itself weaker than expected in facing crisis of this kind. We can also observe the **modest proportion of bachelor programmes in the EU27**. This, if related with the previous observation regarding the **modest international share of masters and short courses**, **seems to confirm potential weaknesses in the educational path that the EU27 proposes in CS**. In fact, while in AI and HPC a modest EU27's share of bachelor degrees is counterbalanced by a good share of master and short courses offer in the international landscape, in CS the role of the EU27 is limited. Differently from what observed for AI and HPC, the UK appears as systematically offering a number of courses much larger than what detected for the EU27. In particular, the **specialised masters** (panel 5 in Figure 16) and **specialised short courses (**panel 6) **provided by the UK are almost double of those offered by the EU27**.

Figure 17, which presents the distribution of programmes by scope and level per geographic area, shows the **modest proportion of bachelor programmes in the EU27, as observed also for AI and HPC**.

**Figure 17. CS programmes by geographic area, level and scope (%). All geographic areas, 2019-20**



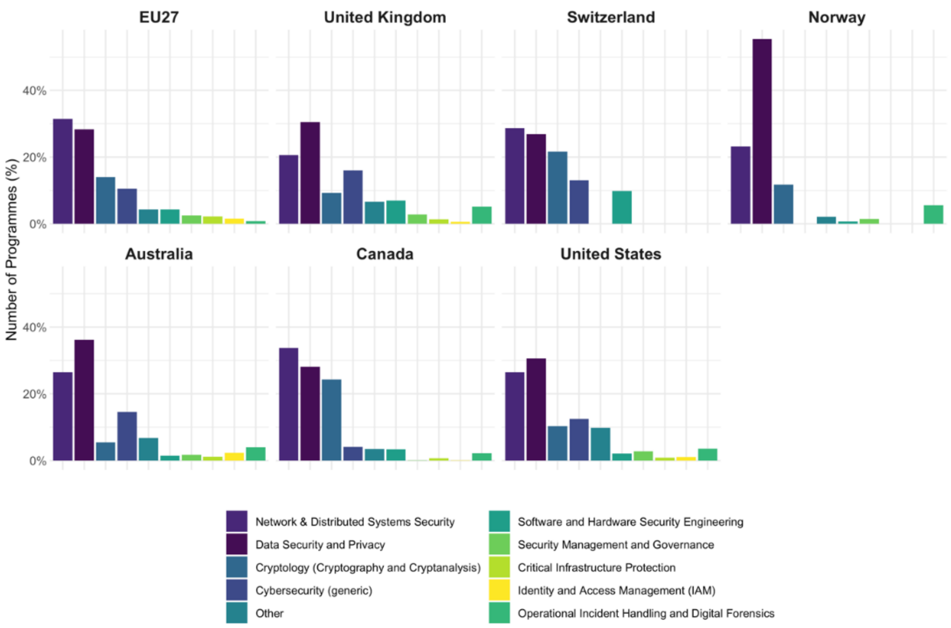

Note: The percentages are based on the number of programmes in the corresponding geographic areas.

Regarding the main **fields of education** in which CS programmes are detected (Figure A 4 in Annex 1), we find a concentration in ***ICT*** for all the geographic areas considered. The share of this field of education is constantly around **50% of programmes that are offered locally**. Second in order of importance is the field of *Business, administration and law.*

A more diversified pattern emerges regarding the **contents** that are taught. Figure 18 shows that the two major categories in CS are ***Network & Distributed Systems Security*** and ***Data Security and Privacy***. They are usually present in similar shares, apart from the case of Norway, in which the area of *Network & Distributed Systems Security* has more than twice weight than *Data Security and Privacy*. In Canada and Switzerland, a considerable share of CS programmes covers *Cryptology*. **The UK**, which internationally is second only to the US by total amount of CS programmes provided, is **concentrated in *Data Security and Privacy*** (around 30%

of all programmes' content). In addition, it presents noteworthy shares of the areas of ***Network & Distributed Systems Security*** and ***Cybersecurity (generic)***. The **content distribution of the EU27** seems to mirror the one of the US, as they are both **very concentrated in the top two categories** (*Network & Distributed Systems Security* and *Data Security and Privacy*). Considering the importance of the US in CS, this can be at least a signal of an appropriate distribution of contents in the EU27.

**Figure 18. CS programmes by geographic area and content taught (%). All geographic areas, 2019-20**



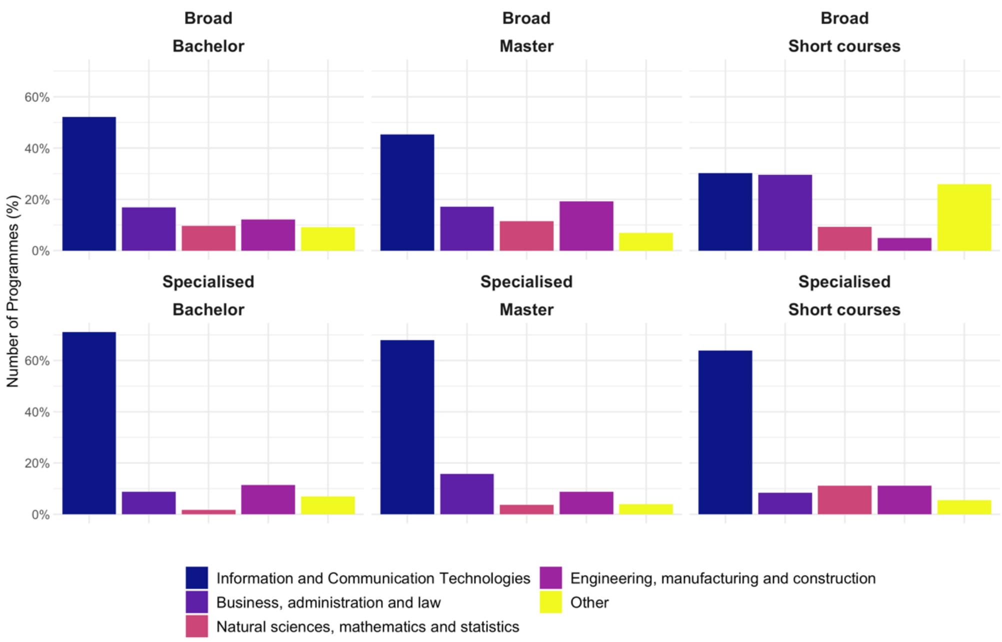

Note: The percentages are based on the number of programmes in the corresponding geographic areas.

## 5.2 Focus on the EU27

Figure 19 shows that the education offer of the **EU27** in CS is mainly **concentrated in the field of *ICT*, regardless of the level and scope of the programmes**. The only exception is represented by broad short courses, although it is important to remind that they do not represent a large proportion of programmes (Figure 17). The case of broad short courses is the only one in which the field of *Business, administration and law* concentrates almost as many programmes as *ICT*. This is an interesting finding, as it testifies **the relevance of CS in professional areas related to business and law** (short courses are the typology of programme that best fits the timely training needs of professionals and, in general, workers looking for expanding their skills catalogue). When considering specialised programmes (panels 4-5-6 in Figure 19), the field of *ICT* is constantly hosting around 65% of programmes, independently from the level (bachelor, master or short courses).

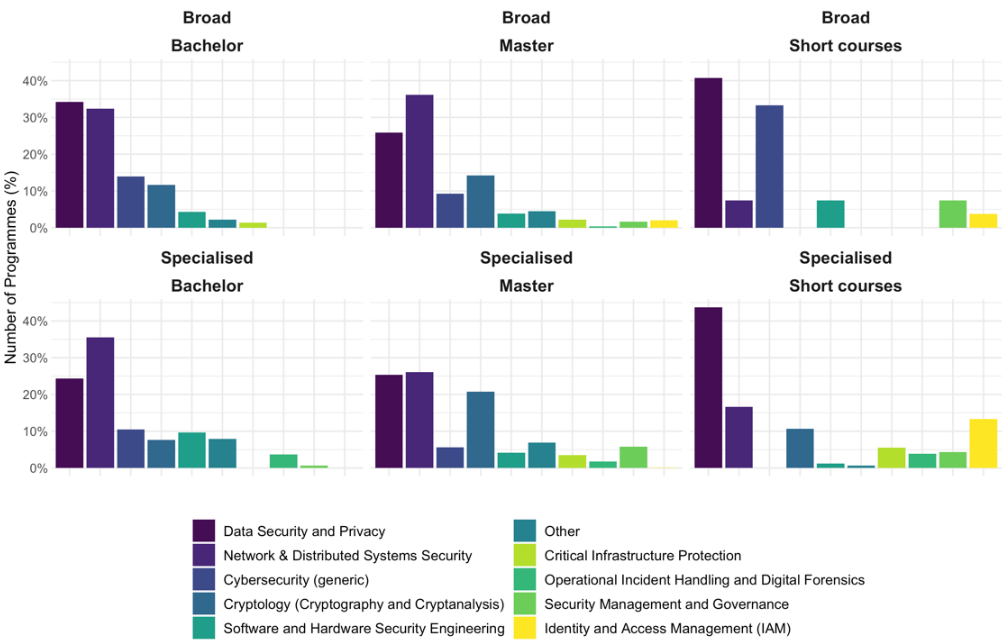
As observable in panel 1 of Figure 20, in the **EU27 broad bachelor CS programmes**, the contents related to ***Data Security and Privacy*** and to ***Network & Distributed Systems Security*** **are equally proposed** (both with shares larger than 30%), and the gap with other content areas is substantial. An **increase in the specialisation**, either in the sense of the scope or in the sense of the level (panels 2 & 4 of Figure 20, respectively), is associated with a larger proposal of contents related to ***Network & Distributed Systems Security*** (approximately 10 percentage points larger than *Data Security and Privacy* in both cases). When considering the **most advanced type of programmes** (specialised master degrees, panel 5 of Figure 20) the two main content areas are again taught in equal proportion, but with shares smaller than in case of broad bachelor programmes (around 25%). In addition, a third area becomes of major relevance: ***Cryptology (Cryptography and Cryptanalysis)***. The **short courses** show a high concentration of content areas, with ***Data Security and Privacy*** as the main area covered, while a high share of broad short courses covers *generic cybersecurity* content. The match of the information about the fields of education and the type of content proposed does not present a specific pattern (Figure A 5 in Annex 1). Nonetheless, the field of education offering the largest quantity of programmes (***ICT***) is content-wise equally concentrated in the two most relevant areas, namely those of ***Data Security and Privacy*** and ***Network & Distributed Systems Security***.

**Figure 19. CS programmes by scope, level and field of education (%). EU27, 2019-20**




Note: The percentages are based on the number of programmes in the combination of scope and level.

**Figure 20. CS programmes by scope, level and content area (%). EU27, 2019-20**



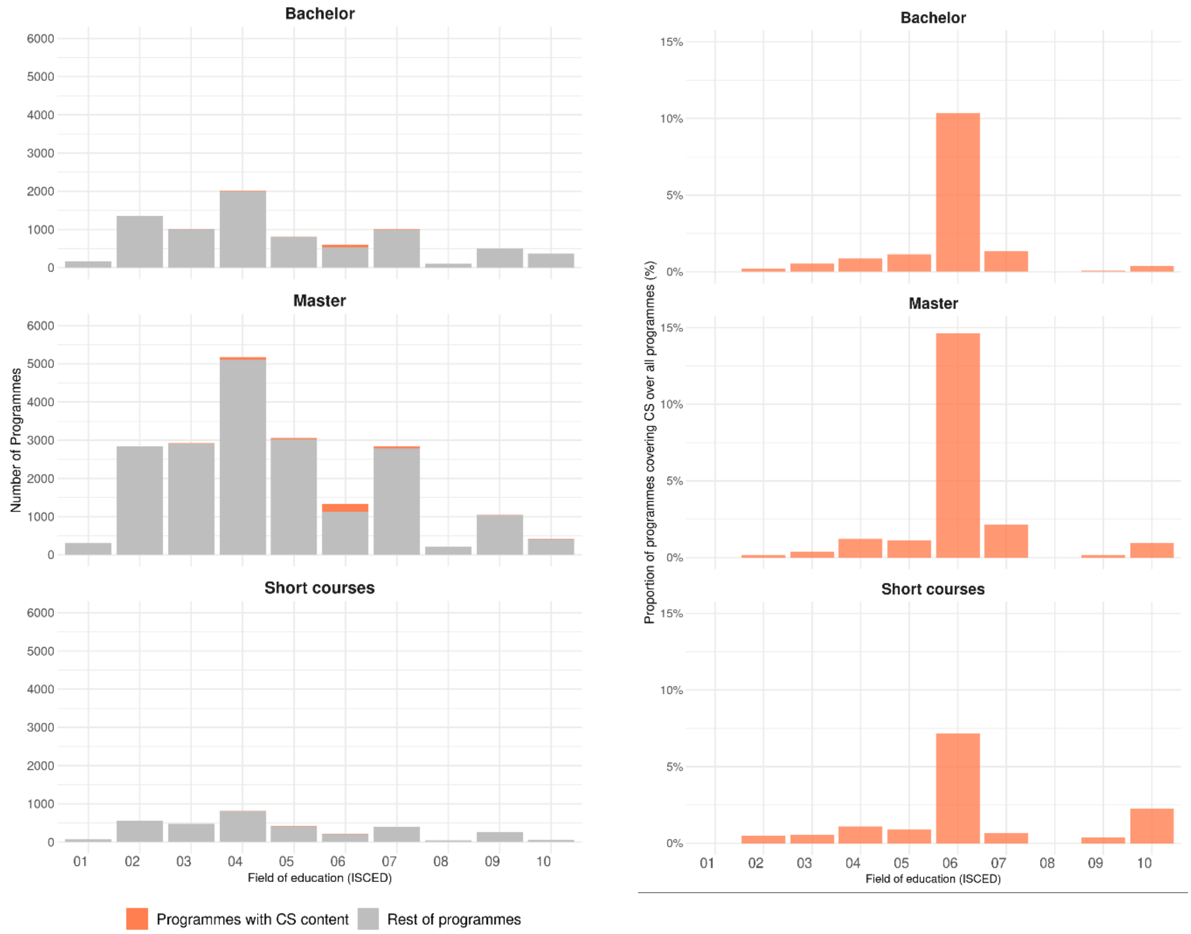

Note: The percentages are based on the number of programmes in the combination of scope and level.

The comparison between the distribution of fields of education in the entire education offer and in the offer of CS programmes is clearly uneven Figure 21. The imbalance is generated by a much stronger concentration of CS in the field of education of Information and communication technologies. As observable in Figure 21B, the prevalence of CS among all programmes in the field of ICT reaches 10% in bachelor's degrees, almost 15% in master's degrees and 7% in short courses. In all other fields of education, the prevalence is below 2%, with the exception of masters in Engineering, manufacturing and construction and short courses in the field of Services, both close to 2.5%.

**Figure 21. Distribution of all programmes according to their CS content (A) and Proportion of CS programmes over all programmes (B) by level and field of education. EU27, 2019-20**

**A. Distribution of all programmes according to their CS content**

**B. Proportion of CS programmes over all programmes**




**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

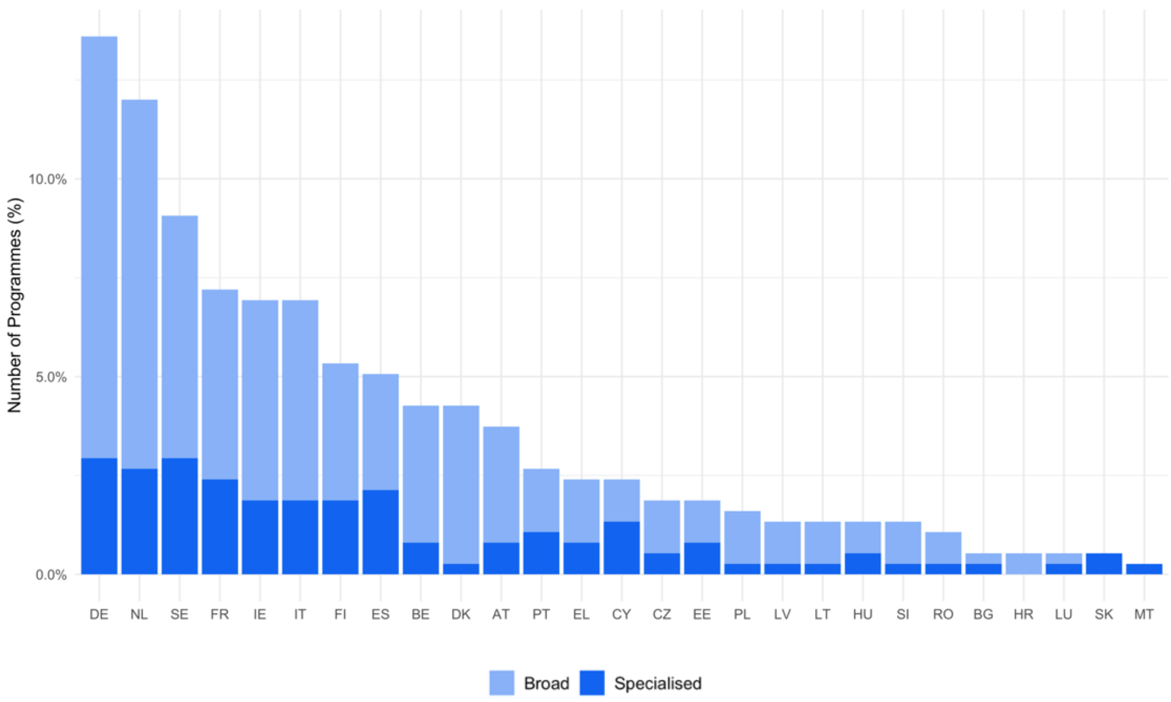
#### 5.2.1 ***CS master's programmes in the EU27 Member States***

Regarding the offer of CS master's programmes at country level, we can observe in Figure 22 that in overall terms (specialised and broad courses) Germany leads, followed by Netherlands (with 14% and 12% of total offer of CS master programmes in the EU27, respectively). Then, we can observe Sweden (9%), France, Ireland and Italy (7%), Finland and Spain (5%). What is very interesting is that these eight countries offer a very similar amount of specialised CS master programmes, around 2.5% of all EU27 offer (dark blue part of the bars). Consequently, the countries at the end of the list hold higher ratios of specialised programmes over broad ones.

Some reflections follow the previous finding. First, given the strategic importance of the CS domain, this may suggest that all these eight countries accounting for two-thirds of the CS master's level offer need a critical mass of specialised workforce. Second, since the number of specialised master degree programmes is very similar for all these countries, the inter-country differences mostly depend on the offer of broad courses. Third, in relative terms the situation favours the countries presenting a smaller offer of broad courses. For instance, while for Spain the specialised courses represent almost one half of the national offer, for Germany they represent nearly one fifth of it.

Other countries play a smaller role in the EU27 CS landscape, as none of them is associated with a share larger than 5%. Nevertheless, it is relevant to observe that the offer of specialised CS master degree courses is considerably large in relative terms (at national level) in Cyprus and Estonia. In this sense, also Luxemburg, Slovakia and Malta have to be mentioned, although the number of master programmes that they offer master is very modest.

**Figure 22. CS master's programmes by Member State and scope (%). 2019-20**




Note: The percentages are based on the number of programmes in each field of education in the EU27.

# 6 Data Science

The increasing capabilities of new algorithms and computers to process larger and larger quantity of data has led to the formation of a new field strictly related to statistics and computer science: Data Science. Indeed, DS deals with the study of a large set of approaches and methodologies allowing the user to treat and disentangle the vast quantity of available data, and to transform it into knowledge. DS is therefore rooted on the knowledge of the functioning of algorithms, both in terms of their mathematical and statistical theoretical foundations, and in terms of their specific implementations (which can vary depending on different coding languages and hardware architectures). Nowadays, the amount and variety of digital information collected and processed make their interpretation so complex that the analysis needs to be channelled through the synthesis of the available data. A mix of skills is therefore required to handle the increasing information complexity, detect relevant results, and elaborate and communicate key insights. If this is not the case, the abundance of data will lead to a paradox: too much information produces no knowledge. Indeed, if not properly considered and addressed, the multi-dimensionality, amount and variety of data would leave room for arbitrary analyses, conclusions based on partial visions, and misleading results. In addition, the lack of appropriate DS skills would hinder the identification of incomplete, wrong, unethical and eventually malicious uses of information. For all these reasons, DS skills are increasingly crucial for public and private economic activities.

The importance of data as an asset has been stressed by the European Commission with several communications and regulations addressing the digital economy development. In the Communication "Towards a common European data space" (European Commission (2018b)), it is possible to read that "data-driven innovation is a key driver of growth and jobs that can significantly boost European competitiveness in the global market" and that "data is also recognised as an increasingly critical asset for the development of new technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT)". More recently, the Communication "A European strategy for data" (European Commission (2020b)), acknowledges the role of data to empower societies to make better decisions, and highlights the need for the right governance structures to facilitate data flows, to increase availability of quality data pools for use and re-use, while protecting personal data and consumer protection. In addition, the communication foresees the establishment of nine common European data spaces, among which the "Common European skills data space", recognising the crucial role of people's skills and the urgent need for education and training systems "to quickly adapt to new and emerging skills needs. This requires high-quality data on qualifications, learning opportunities, jobs and the skill sets of people". It is therefore clear that not only data have to be considered as a crucial factor, but that also competences related to the use of these data are necessary for the economic and social development of the Union. In the present section, we explore the education offer related to DS, mapping the presence and the structure of these skills, and providing useful insights that reveal potential elements of strength and weakness in view of supporting policy decisions in this area.

Box 5. DS content areas and most frequent keywords

***Data analytics (generic)***: it refers to the main techniques to collect, process and analyse data.

***Machine learning & Statistical modelling***: supervised and unsupervised learning, including also neural networks, pattern recognition, predictive analytics, etc.

***Business intelligence***: management of specific processes related to the business activities and decision support

***Natural language processing***: information retrieval, natural language processing, automatic translation

***Big data***: knowledge of methodologies and software to handle and analyse vast quantity of data

***Data mining***: theoretical and practical knowledge of algorithms and techniques to extract information

***Data science architectures***: knowledge about the architecture and the functioning of new types of computing systems (software and hardware). For instance, parallelization, scalability, distributed computing, etc.

***Other***: this category includes other specialised content, such as data visualisation, genetic and evolutionary algorithms, metaheuristic optimisation.

## 6.1 DS education offer in the international context

The study revealed a total number of 5,938 DS programmes in all the countries considered, 1,172 (or 19%) of them correspond to the EU27 (Table 5). The worldwide distribution of courses in DS, as the other ones presented, shows the **primary role of the US**. **The EU27 and the UK are also major actors**, but with lower shares, as observable in Figure 23. It is worthwhile highlighting the low **gap between the EU27 and other major countries (UK and US) in the master degree programmes**. This has positive implications for the EU27, since the master degree programmes can be considered as the most important part of the educational path, especially in view of future employment opportunities.

As also detected in the other domains considered, **in the EU27 the offer of bachelor programmes** (broad or specialised, indistinctively) **is considerably lower than the one of the UK** (Table 5), although with a similar distribution between broad and specialised programmes (Figure A 6 in Annex 1). The geographic pattern coincides with the one previously observed for all other domains: on the one hand, the EU27, Norway and Switzerland are very concentrated in master degree programmes; on the other hand, the Anglo-Saxon countries (the UK, the US, Canada, Australia) show more similar proportions between bachelor and master courses that are offered. The determinants of this finding may be rooted either in some structural feature of the EU27 high-technological education offer (very concentrated on master degrees), but most probably in the reduced picture provided by this report in what concerns bachelor studies due to the lack of an adequate provision of bachelor programmes in English language.

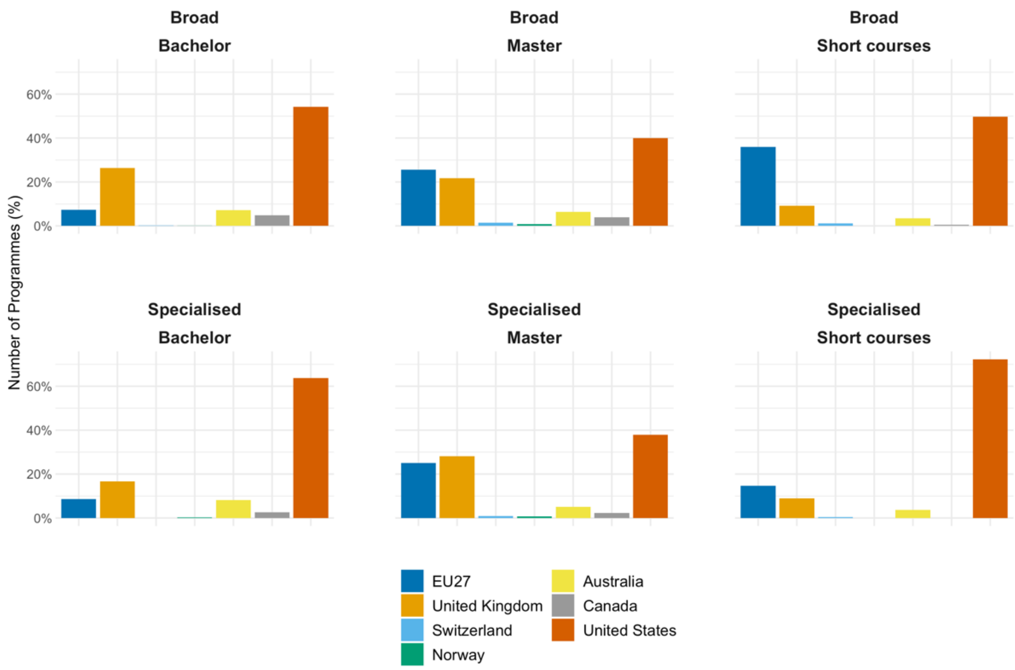
**Table 5. DS programmes by geographic area, level and scope, 2019-20**

| | | Bachelor | | Master | | Short courses | | Total |
|---|---|---|---|---|---|---|---|---|
| | | Broad | Specialised | Broad | Specialised | Broad | Specialised | |
| | **EU27** | 106 | 34 | 605 | 325 | 63 | 39 | 1,172 |
| UK | United Kingdom | 377 | 66 | 515 | 365 | 16 | 24 | 1,363 |
| NO | Norway | 1 | 1 | 20 | 10 | | | 32 |
| CH | Switzerland | 2 | | 36 | 12 | 2 | 1 | 53 |
| CA | Canada | 69 | 10 | 94 | 29 | 1 | | 203 |
| US | United States | 776 | 252 | 946 | 492 | 87 | 193 | 2,746 |
| AU | Australia | 102 | 32 | 153 | 66 | 6 | 10 | 369 |
| | **TOTAL** | 1,433 | 395 | 2,369 | 1,299 | 175 | 267 | 5,938 |

In Figure 24, it is possible to observe that the distribution of fields of education in which the DS programmes are offered is relatively uniform throughout all the considered areas. The **most important role is played by *ICT* studies**, as it was expected. It is also interesting to observe that in the **second position of the most frequent fields of education** we detect ***Business, Administration and Law***. This finding suggests a **good connection between DS and the competences that are useful in the context of private working initiatives**. Other fields of education in the context of DS play a marginal role. Nevertheless, the field of ***Natural sciences, mathematics and statistics*** has a more **prominent presence** in **the US and Canada**. Given the importance of these geographic areas, the relation between the domain of DS and this field of education needs to be taken into account.

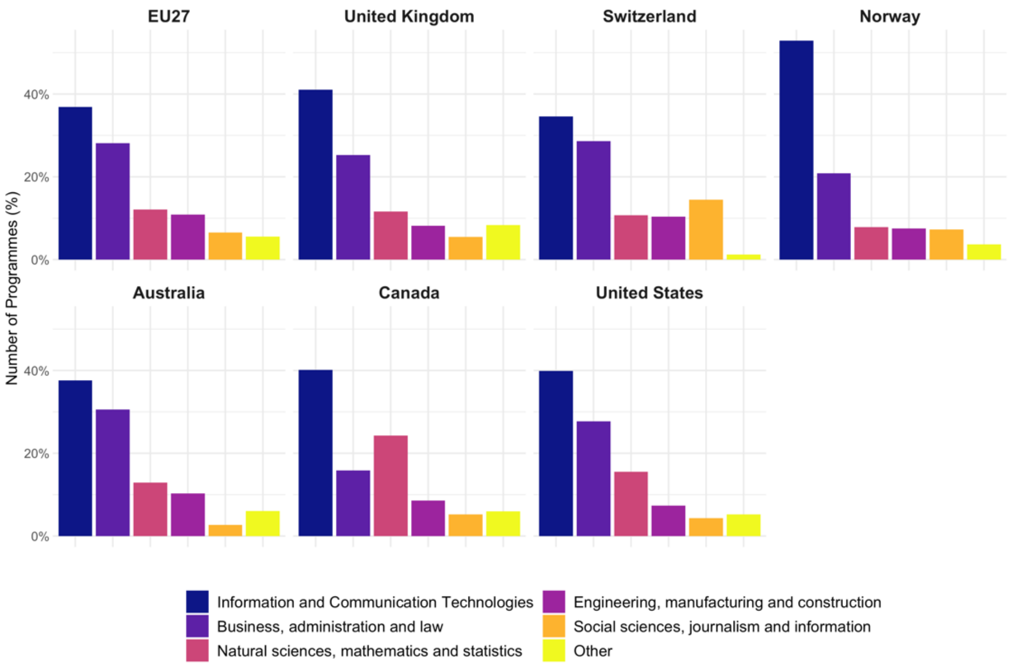
About the contents that are taught in the field of DS, in Figure 25 very different patterns emerge depending on the geographic area considered. In the EU27, the most prevalent ones are ***Big data*** and ***Machine learning & Statistical modelling*** (around 25% each), and with a secondary role we find ***Business Intelligence*** and ***Data analytics (generic)*** (around 15% each). Similarly, **the UK** also presents as mostly important the content areas of *Big data* and *Machine learning & Statistical Learning*. However, in the UK, **the generic category of *Data analytics* has a relevant position (18%).** The previous consideration is also true for Canada and the US, which (along with the UK) show a very intense proposal (larger than 20%) in a kind of content that is suitable to business services and commercial activities. It is possible to observe that Canada and the US present also a relevant percentage of *Machine learning & Statistical Modelling* (around 20%). Canada is the only area in which ***Data mining*** and ***Data science architectures*** are both present in almost 15% of the programmes' content.

**Figure 23. Geographical distribution of DS programmes by scope and level (%). All geographic areas, 2019-20**



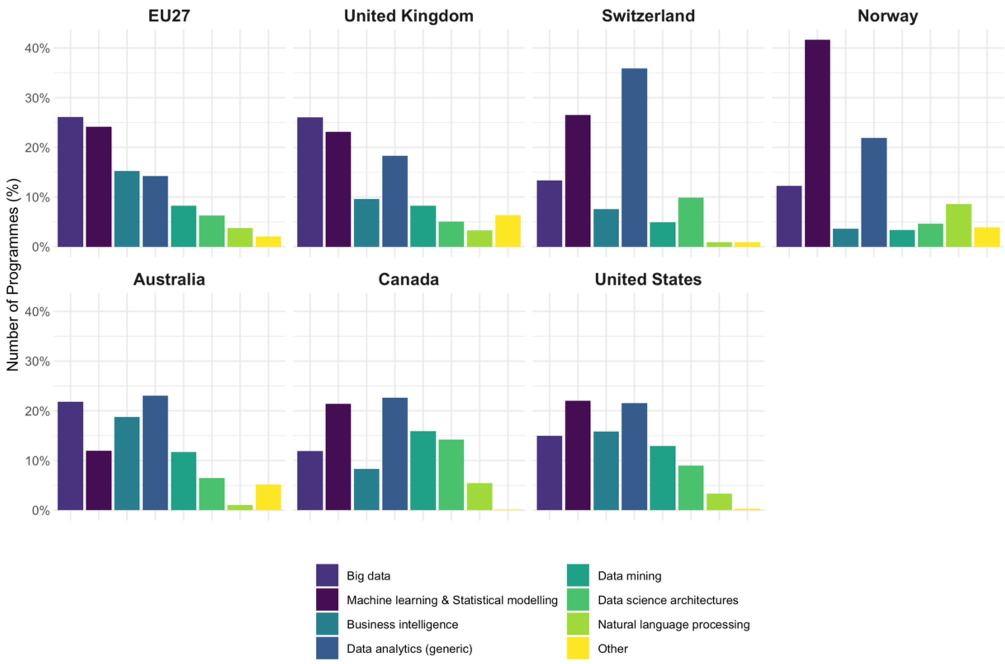

Note: The percentages are based on the number of courses in the specific combination of scope (broad vs. specialised) and level (bachelor vs. master vs. short courses)

**Figure 24. DS programmes by geographic area and field of education (%). All geographic areas, 2019-20**




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

**Figure 25. DS programmes by geographic area and content taught (%). All geographic areas, 2019-20**




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

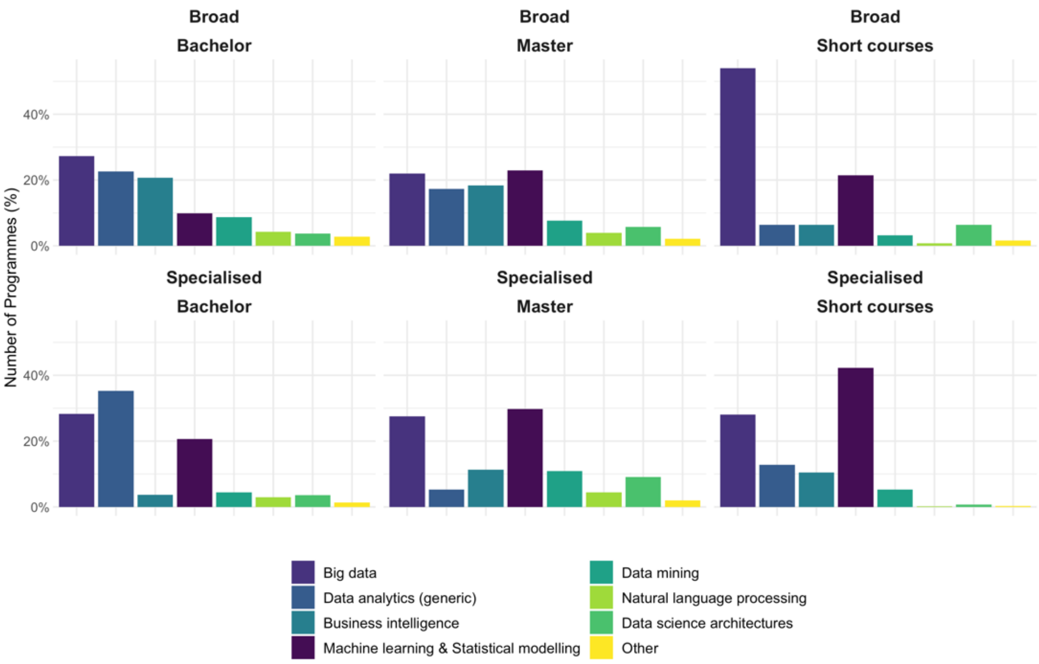
## 6.2 Focus on EU27

In the EU27, the distinction between broad and specialised programmes reveals a clear differentiation in terms of the most frequent fields of education where DS is taught (Figure A 7 in Annex 1). While in broad programmes the distribution is more uniform, with ***Business, administration and law*** capturing the highest number of programmes, more than 50% of specialised programmes (regardless of the level) are offered in the field of ***ICT***.

The programme scope (broad or specialised) also yields a different distribution of content areas, in particular when comparing bachelor and master degrees. **Broad bachelor and master degrees** (panels 1 & 2 of Figure 26), show three areas that are evenly taught (nearly 20% each): ***Big Data***, ***Data analytics (generic)*** and ***Business intelligence***. In addition, but only for the master programmes, the role of ***Machine learning & Statistical modelling*** reaches 20% (panel 2). The specialised programmes in the EU27 appear to be more specifically focused in two areas of contents (panel 4 & 5): ***Big Data*** and ***Machine learning & Statistical modelling***. The content related to ***Machine learning & Statistical modelling*** has a marginal role in broad programmes but they are **largely taught in the specialised programmes**. The constant element is the substantial presence of the content related to ***Big data***, which is therefore **confirmed to lie at the core of the field of DS**. The contents related to ***Business intelligence*** **are more present in broad programmes than in specialised ones**, as they are probably associated to less specific and technical notions, but more on applications. It is also important to mention the large percentage of specialised bachelor programmes addressing the content related to ***Data analytics (generic)***, which seems therefore to be a pertinent content for the initial part of a focused educational path.

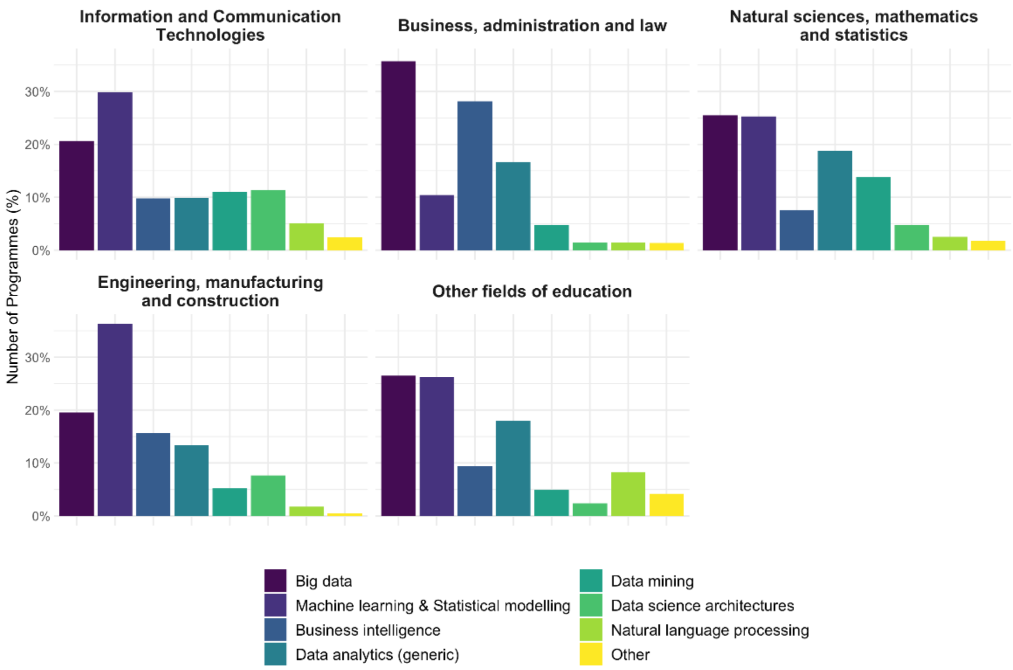
Regarding the short programmes (panels 3 & 6 of Figure 26), they appear to be very focused on ***Big data*** and ***Machine learning & Statistical modelling***, and this is an additional element confirming the importance of these two content areas in the framework of DS.

**Figure 26. DS programmes by scope, level and content area (%). EU27, 2019-20**




Note: The percentages are based on the number of programmes in the combination of scope and level.

**Figure 27. DS programmes by field of education and content area (%). EU27, 2019-20**



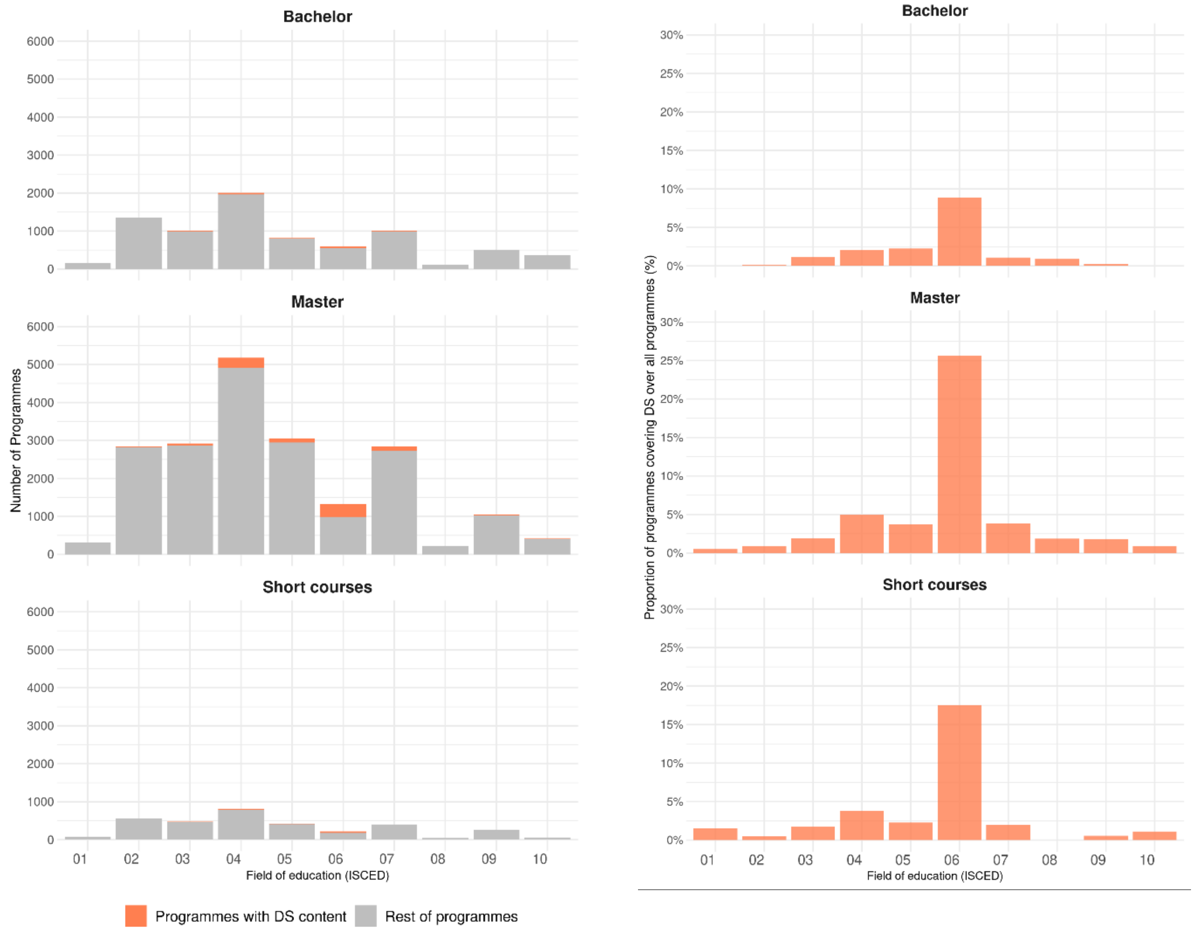

Note: The percentages are based on the number of programmes in each field of education.

Figure 27, showing the combination of field of education and areas of contents, confirms a sort of complementarity between the two fields of education covering the largest shares of programmes, namely ***ICT*** (panel 3) and ***Business, administration and law*** (panel 1). While the former is mainly occupied by programmes focused on ***Machine learning & Statistical modelling***, the latter is more focused on ***Big data*** and also ***Business intelligence***. This result corroborates that within the field of DS, there is a part of courses aimed at covering specific and technical aspects that are an essential part of DS. In addition, the field of *Business, administration and law* incorporates the competences related to business services and commercial use. Therefore, the offer of DS in the EU27 appears to be well structured and **able to tackle both the need of specific competences in technical fields**, **and also the need of broader DS competences in fields-related to business enterprises**. This is a **promising sign of integration between the existing education offer and the demand of specific skills**.

**Figure 28. Distribution of all programmes according to their DS content (A) and Proportion of DS programmes over all programmes (B) by level and field of education. EU27, 2019-20**

**A. Distribution of all programmes according to their DS content**

**B. Proportion of DS programmes over all programmes**




**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

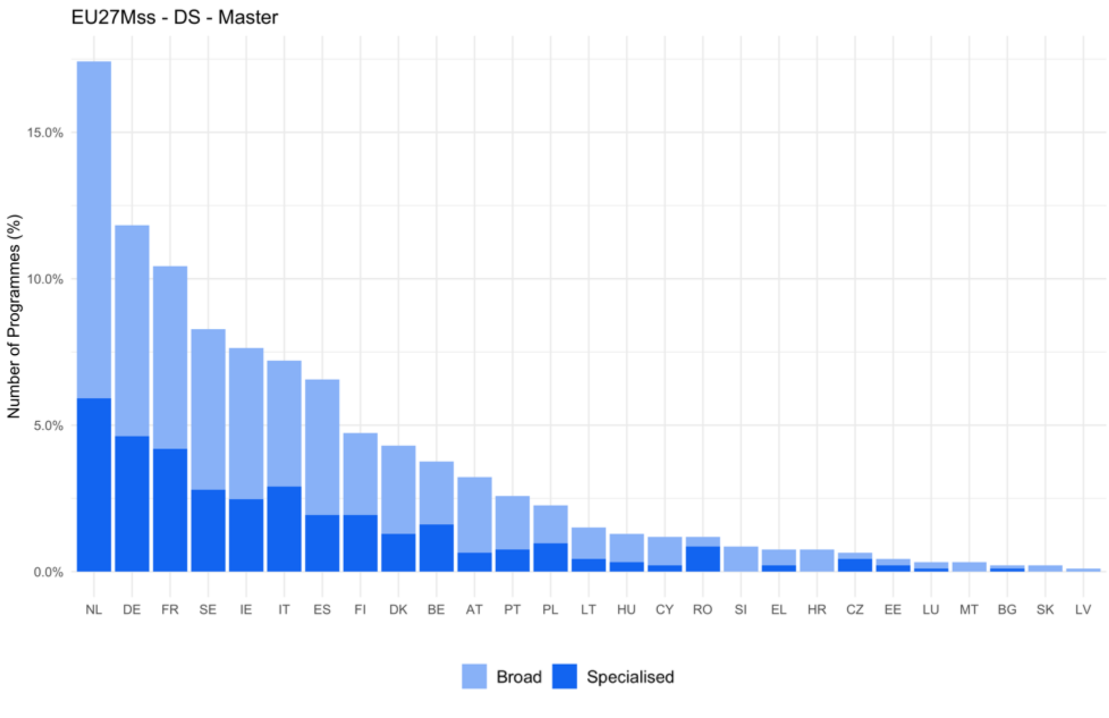
The relation between the distribution by fields of education of the DS offer (orange bars in Figure 28A) and the overall education offer (full bars in Figure 28A) is represented in Figure 28B and it is the most uniform among those observed in this report. Clearly, also for DS holds true what noticed in the other domains: the role of the field of education of *ICT* is very strong. What in DS appears as different is the fact that the share of DS programmes in all the other fields of education (Figure 28B) are higher than what observed for AI (Figure 7B), HPC (Figure 14B) or CS (Figure 21B). This means that DS is more spread across the different fields of education than the other technological domains (while still more concentrated in ICT). This property of DS may be important in view of a progressive diffusion of the other advanced technological domains considered in this report. DS, which has overlaps with AI, HPC and CS, may be seen as a facilitator to introduce AI, HPC and CS in other fields of education that these technological domains barely address, and where DS is already present in a more prominent way. The proportion of programmes offering DS content in the education field of *ICT* reaches 9% for bachelors, 26% of masters and 18% of short courses. In the field of *Business, administration and law*, these proportions are 2%, 5% and 4% respectively. Also noteworthy is the prevalence in *Natural sciences, mathematics and statistics*, with 2%, 4% and 2% respectively. In *Engineering, manufacturing and construction*, 1% of bachelors cover DS content, 4% of masters and 2% of short courses.

#### 6.2.1 ***DS master's programmes in the EU27 Member States***

The most remarkable position in the offer of DS master degree programmes is certainly held by Netherlands (Figure 29), accounting for 17% of the entire EU27 offer. Germany and France also have a noteworthy position, (12% and 11%, respectively, of the EU27 offer of DS master's programmes). Then, with shares between 8% and 7%, it is possible to observe Sweden, Ireland, Italy and Spain. The remaining countries do not present shares larger than 5%.

The relation between specialised and broad DS master programmes (dark blue parts of the bars and light blue parts of the bars, respectively) remains relatively stable across countries. The few cases in which the proportion of specialised courses is above 40% of the national offer are Romania (70%), Czech Republic (60%), Estonia, Bulgaria, Finland (50%), Belgium, Poland, Italy, France, and Germany (40%).

**Figure 29. DS master's programmes by Member State and scope (%). 2019-20**




Note: The percentages are based on the number of programmes in each field of education in the EU27.

# 7 Overlap and comparison of education offer in AI, HPC, CS and DS

In this last section we provide an overview of how the technological domains addressed by this study are intertwined. One of the features of the methodology proposed in this work is that education programmes may be assigned to multiple technological domains. For instance, a master degree can include a mixture of AI and DS content. For this reason, programmes may be attributed to multiple domains. These overlaps are discussed in the first subsection. Then, another interesting point to be considered is the distribution of the fields of education in each domain, which has been already discussed for each domain separately throughout the report. Here, we compare the previously observed distributions and we dig into more detailed levels of the fields of education classification.

Box 6. Methodological notes for the section: fractional count of programmes

In order to allow any programme to belong to multiple fields of education, we use the fractional counting of the programmes with equal weights. For instance, if a programme belongs to the fields of education "*Arts and humanities*" and "*Health and welfare*", then we consider each field with a weight equal to 0.5. This weighted number of programmes is reflected in the column named "*N. of Prog.*" In Table 7, Table 8 and Table 9.

Similarly, programmes can be detected in multiple technological domains. For instance, a program may belong to both AI and DS. In this study, each programme is fully considered in all the technological domains to which it is attributed. While the fractional counting of programmes is implemented within each technological domain, it is not implemented between technological domains. This is the reason why the sum of the total number of programmes by technological domain in all the countries studied (i.e. 5,297 (AI) + 1,768 (HPC) + 4,217 (CS) + 5,938 (DS), see Table 6) does not equal the total number of programmes detected (i.e. 11,927).

## 7.1 Technological domains' overlap

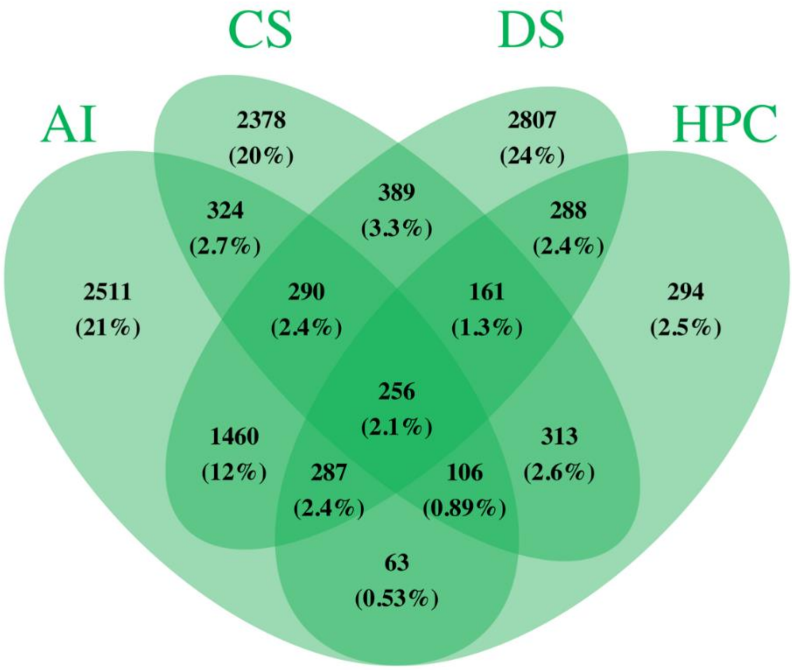
The presence of overlaps among technological domains, determined by programmes belonging to more than one technological domain, is represented in Figure 30, in which programmes detected in all geographic areas are considered. It is possible to observe that only four combinations correspond to a share higher than 10% of the total number of programmes. These are: (i) 2,807 programmes (equal to 24%) exclusively belonging to DS, (ii) 2,511 programmes (equal to 21%) exclusively belonging to AI, (iii) 2,378 programmes (equal to 20%) exclusively belonging to CS, and (iv) 1,460 programmes (equal to 12%) belonging to both AI and DS. These four cases account therefore for more than 75% of all the programmes detected. The remaining combinations observed in Figure 30 have a maximum share of 3.3%, which confirms their relatively small role in the whole picture.

The fact that large shares are associated to programmes belonging exclusively to one technological domain seems to confirm that these technological domains (i.e. DS, CS and AI) have a large and specifically dedicated education offer. This seems to be a positive finding, as too many overlaps would have suggested a blurred education offer structure.

The only considerable emerging intersection deserves also some consideration. The connection between AI and DS highlights the fact that the educational profiles emerging from these two technological domains have a good common background, which should facilitate also interchangeability between them. This finding is to some extent expected as AI and DS are both related to extraction of information from data. While in AI the focus is more on the development of algorithms and procedures allowing computers to self-learn and automatise processes, in DS the focus is on the application of appropriate methodologies and algorithms to (i) process and model data, and (ii) to investigate specific research questions. This overlap should therefore be considered in view of possible cross-fertilisations, as AI might benefit from the knowledge related to DS and vice-versa.

In Table 6, it is possible to observe that HPC is revealed to be the most overlapping technological field, since only 16% of its programmes have been detected exclusively in the same field. This could be a consequence of the fact that it is the domain addressing the technological and physical evolution of computers. While AI, CS, and DS are domains that represent new emerging functions, HPC is more about the development of the way computers are built and operate. For this reason, certainly HPC deserves a special consideration.

**Figure 30. Overlap of technological domains. All geographic areas, 2019-20**




Note: The percentages are based on the total number of courses detected.

**Table 6. Percentage of overlap of technological domains. All geographic areas, 2019-20**

| | % Programmes Not Shared with other domains | % Programmes Shared with other domains | Number of programmes |
|---|---|---|---|
| AI | 47% | 53% | 5,297 |
| HPC | 16% | 84% | 1,768 |
| CS | 56% | 44% | 4,217 |
| DS | 47% | 53% | 5,938 |
| **All 4 domains** | | | **11,927** |

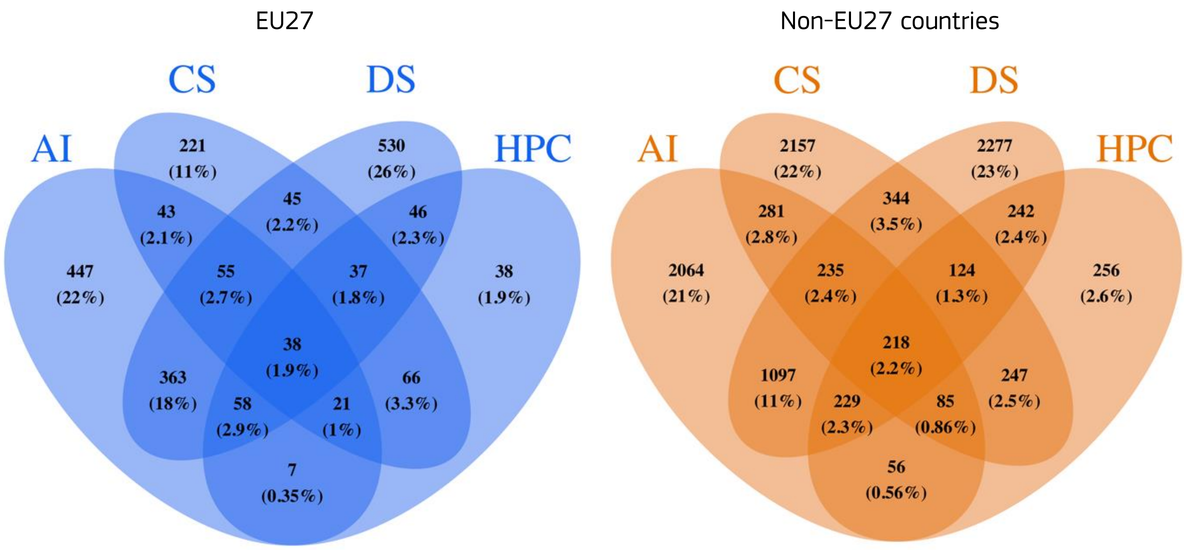
Note: The percentages are based on the total number of courses detected in each domain.

In Figure 31, the technological fields' overlaps are presented separately for the EU27 (left, blue Venn diagram) and for the rest of the geographic areas studied -United Kingdom, Switzerland, Norway, Australia, Canada, and United States- (right, orange Venn diagram). In both diagrams, the same combinations discussed for Figure 30 still have a major role: (i) programmes exclusively belonging to DS (26% in the EU27, 23% out of the EU27), (ii) programmes exclusively belonging to CS (11% in the EU27 and 22% out of the EU27), (iii) programmes exclusively belonging to AI (22% in the EU27 and 21% out of the EU27), and (iv) programmes belonging to both AI and DS (18% in the EU27 and 11% out of the EU27). It is relevant to observe that the main difference is found for combinations (ii) and (iv), i.e. programmes exclusively belonging to CS and programmes belonging to both AI and DS, respectively. The former has a larger share out of the EU27, while the latter has a larger share in the EU27.

The EU27 appears therefore as showing a gap (with regard to the other countries considered) of more than 10 percentage points in the offer of "pure" CS. This is a finding that deserves consideration, as the ongoing digitalisation process of economy and society continuously opens new possibilities, but also new and more challenging threats, which may affect both the private and the public sphere. Clearly, CS should have a role in preventing them, and the results shown here highlight a less intense focus on CS in the EU27 in comparison with the international context.

A much larger percentage is detected for the EU27 for programmes belonging to both AI and DS (18% in the EU27 and 11% out of the EU27). This larger degree of "interdisciplinarity" in a so crucial combination may be seen in opposite ways. On the one hand, it may be associated to a lack of "hard" specialisation. On the other, this situation may lead to a cross-fertilisation from which both technological fields may take advantage, ensuring a more flexible and wider set of digital skills for students, which will eventually be reflected in the labour market and in industrial and R&D capabilities.

**Figure 31. Overlap of technological domains. EU27 and non-EU27 countries, 2019-20**




Note: The percentages are based on the total number of courses detected in the corresponding geographic area (EU27 (left), non-EU27 (right)).

## 7.2 Distribution of fields of education by technological domain

In Table 7 and Table 8 it is possible to compare the weight of each field of education in the different technological domains[16], for programmes offered in the EU27 and in non-EU countries, respectively. They present from a comparative perspective the analysis performed in Sections 3 to 6. It is possible to observe that the fields of education highlighted as offering the largest number of programmes, i.e., *ICT*, *Engineering, manufacturing and construction*, and *Business, administration and law*, present different weights depending on the technological domain.

The field of education of *ICT* is the most prominent in all the technological domains considered. However, the shares that it presents vary considerably: the largest ones, which are detected in HPC (59% in the EU27 and 59% in other countries) and CS (52% in the EU27 and 54% in other countries), are approximatively 10 percentage points above the corresponding shares in AI (41% in the EU27 and 43% in other countries) and DS (37% in the EU27 and 40% in other countries).

The field of education of *Engineering, manufacturing and construction* has an important share in AI (27% in the EU27 and 29% in other countries), while in other technological domains presents considerably lower shares (in the EU27: 18% in HPC, 15% in CS and 11% in DS; in other countries: 16% in HPC, 8% in CS and 8% in DS).

We note that *Business, administration and law* is much more relevant in DS than in the others technological fields: 28% in the EU27 and 27% in the rest of the considered countries, although this field still holds a considerable share in CS (17% in the EU27 and 20% in the other countries).

16 From a methodological point of view, it is important to remind that each programme may be included in multiple technological domains and, within each technological domain, in several fields of education. Each programme allocates a fraction or weight to each field of education to which it is associated. See Box 6.

In addition, the comparison between Table 7 and Table 8 shows a very high alignment between the distributions in the EU27 and in the other countries considered, which appear as very symmetric. The difference between the corresponding percentages always falls within a range of 5 points, with the only exception of *Engineering, manufacturing and construction* in CS: 15% of the programmes taught in CS lie under this field of education in the EU27 (Table 7), and 7 percentage points lower (8%) in the rest of studied countries (Table 8).

Table 9 provides a closer look at the fields of education in the EU27, by penetrating into a more detailed level of the classification, the "narrow field of education"[17] (see Box 1 for details of the ISCED-F 2013). First of all, it is important to observe that in the broad field of education of *Business, administration and law* only a small share of programmes is accounted under the narrow field of *Law* (narrow code 42). The largest share that this narrow field presents is 3% in the technological domain of CS. Clearly, as expected given private business implications, the narrow field of education dominating is the one of *Business and administration* (narrow code 41).

The field of education of *ICT* is not structured in narrower fields of education, so no further comments are possible about it.

The field of education of *Engineering, manufacturing and construction* is dominated by the narrow field of *Engineering and engineering trades* (narrow code 71) with almost no programmes detected under the remaining narrow fields, i.e. *Manufacturing and processing* (narrow code 72) and *Architecture and construction* (narrow code 73).

17 The first column of the table ("Broad field code") can be used to bridge the narrow fields of education (listed in the table), and the broad fields of education considered and discussed so far in the report.

**Table 7. Programmes by broad field of education and technological domain. EU27, 2019-20**

| | | 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. | % |
| 01 | Education | 5 | *0%* | 0 | *0%* | 0 | *0%* | 3 | *0%* |
| 02 | Arts and humanities | 62 | *6%* | 5 | *2%* | 11 | *2%* | 31 | *3%* |
| 03 | Social sciences, journalism and information | 48 | *5%* | 4 | *1%* | 20 | *4%* | 77 | *7%* |
| 04 | Business, administration and law | 104 | *10%* | 36 | *12%* | 89 | *17%* | 329 | *28%* |
| 05 | Natural sciences, mathematics and statistics | 91 | *9%* | 20 | *6%* | 48 | *9%* | 142 | *12%* |
| 06 | Information and Communication Technologies | 419 | *41%* | 184 | *59%* | 272 | *52%* | 432 | *37%* |
| 07 | Engineering, manufacturing and construction | 283 | *27%* | 55 | *18%* | 77 | *15%* | 127 | *11%* |
| 08 | Agriculture, forestry, fisheries and veterinary | 2 | *0%* | 0 | *0%* | 0 | *0%* | 5 | *0%* |
| 09 | Health and welfare | 16 | *2%* | 5 | *2%* | 3 | *1%* | 22 | *2%* |
| 10 | Services | 1 | *0%* | 2 | *1%* | 7 | *1%* | 4 | *0%* |
| | **Total** | **1,032** | ***100%*** | **311** | ***100%*** | **526** | ***100%*** | **1,172** | ***100%*** |
| | **Total number of programmes detected: 2,015** | | | | | | | | |

**Table 8. Programmes by broad field of education and technological domain. Non-EU27 countries, 2019-20**

| | | 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. | % |
| 01 | Education | 34 | *1%* | 2 | *0%* | 13 | *0%* | 25 | *1%* |
| 02 | Arts and humanities | 249 | *6%* | 24 | *2%* | 58 | *2%* | 138 | *3%* |
| 03 | Social sciences, journalism and information | 122 | *3%* | 15 | *1%* | 176 | *5%* | 223 | *5%* |
| 04 | Business, administration and law | 337 | *8%* | 148 | *10%* | 721 | *20%* | 1,272 | *27%* |
| 05 | Natural sciences, mathematics and statistics | 384 | *9%* | 145 | *10%* | 335 | *9%* | 691 | *14%* |
| 06 | Information and Communication Technologies | 1,818 | *43%* | 862 | *59%* | 1,999 | *54%* | 1,911 | *40%* |
| 07 | Engineering, manufacturing and construction | 1,232 | *29%* | 228 | *16%* | 300 | *8%* | 376 | *8%* |
| 08 | Agriculture, forestry, fisheries and veterinary | 7 | *0%* | 1 | *0%* | 0 | *0%* | 20 | *0%* |
| 09 | Health and welfare | 70 | *2%* | 12 | *1%* | 13 | *0%* | 86 | *2%* |
| 10 | Services | 12 | *0%* | 21 | *1%* | 78 | *2%* | 24 | *1%* |
| | **Total** | **4,265** | ***100%*** | **1,457** | ***100%*** | **3,691** | ***100%*** | **4,766** | ***100%*** |
| | **Total number of programmes detected: 9,912** | | | | | | | | |

Note: Data in this table refers to the aggregate of the following countries: United Kingdom, Norway, Switzerland, Canada, United States, and Australia.

**Table 9. Programmes by narrow field of education and technological domain. EU27, 2019-20**

| | | | 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. | % |
| 01 | 11 | Education | 5 | *0%* | 0 | *0%* | 0 | *0%* | 3 | *0%* |
| 02 | 21 | Arts | 37 | *4%* | 5 | *2%* | 10 | *2%* | 18 | *1%* |
| 02 | 22 | Humanities (except languages) | 2 | *0%* | 0 | *0%* | 0 | *0%* | 2 | *0%* |
| 03 | 23 | Languages | 23 | *2%* | 0 | *0%* | 0 | *0%* | 12 | *1%* |
| 03 | 31 | Social and behavioural sciences | 34 | *3%* | 0 | *0%* | 12 | *2%* | 61 | *5%* |
| 03 | 32 | Journalism and information | 14 | *1%* | 4 | *1%* | 8 | *2%* | 16 | *1%* |
| 04 | 41 | Business and administration | 100 | *10%* | 35 | *11%* | 76 | *14%* | 325 | *28%* |
| 04 | 42 | Law | 4 | *0%* | 1 | *0%* | 14 | *3%* | 5 | *0%* |
| 05 | 50 | Natural sciences, mathematics and statistics n.f.d. | 3 | *0%* | 1 | *0%* | 1 | *0%* | 5 | *0%* |
| 05 | 51 | Biological and related sciences | 26 | *3%* | 3 | *1%* | 7 | *1%* | 40 | *3%* |
| 05 | 52 | Environment | 1 | *0%* | 0 | *0%* | 2 | *0%* | 5 | *0%* |
| 05 | 53 | Physical sciences | 25 | *2%* | 8 | *2%* | 5 | *1%* | 36 | *3%* |
| 05 | 54 | Mathematics and statistics | 37 | *4%* | 9 | *3%* | 33 | *6%* | 56 | *5%* |
| 06 | 61 | Information and Communication Technologies | 419 | *41%* | 184 | *59%* | 272 | *52%* | 432 | *37%* |
| 07 | 71 | Engineering and engineering trades | 274 | *27%* | 52 | *17%* | 74 | *14%* | 119 | *10%* |
| 07 | 72 | Manufacturing and processing | 6 | *1%* | 2 | *0%* | 2 | *0%* | 3 | *0%* |
| 07 | 73 | Architecture and construction | 3 | *0%* | 2 | *1%* | 1 | *0%* | 5 | *0%* |
| 08 | 81 | Agriculture | 2 | *0%* | 0 | *0%* | 0 | *0%* | 4 | *0%* |
| 08 | 82 | Forestry | 0 | *0%* | 0 | *0%* | 0 | *0%* | 1 | *0%* |
| 09 | 91 | Health | 12 | *1%* | 3 | *1%* | 2 | *0%* | 12 | *1%* |
| 09 | 98 | Interdisciplinary programmes involving broad field 09 | 4 | *0%* | 1 | *0%* | 1 | *0%* | 10 | *1%* |
| 10 | 101 | Personal services | 1 | *0%* | 1 | *0%* | 2 | *0%* | 2 | *0%* |
| 10 | 103 | Security services | 0 | *0%* | 0 | *0%* | 4 | *1%* | 0 | *0%* |
| 10 | 104 | Transport services | 0 | *0%* | 1 | *0%* | 1 | *0%* | 2 | *0%* |
| | | **Total** | **1,032** | ***100%*** | **311** | ***100%*** | **526** | ***100%*** | **1,172** | ***100%*** |
| | | **Total number of programmes detected: 2,015** | | | | | | | | |

# 8 Conclusions

The main objective of this study is to provide a map of the academic offer in AI, HPC, CS, and DS in the EU27 and its Member States, plus six additional countries: the United Kingdom, Norway, and Switzerland in Europe, Canada and United States in America, and Australia. Such an objective is reached by collecting and analysing data on the academic offer related to these technological domains, for three different education levels - bachelor, master and short professional courses- in 2019-2020. This report updates and extends the first report of this kind, published by the JRC in 2019. The main improvements in comparison with the 2019 report focus on: (i) broadening the geographical coverage, by adding five non-EU27 countries not included in the first edition; (ii) inclusion of data science as a technological domain of interest; (iii) inclusion of short professional courses to capture a specific kind of offer targeted to professionals and graduate students; and (iv) the addition of the field of education in which the programme is taught as a variable for the analysis.

The study identifies US as the leading country in education offer related to the considered technological domains, followed by the UK and the EU27. The EU27 holds a better position at masters' level (where it equals the UK) and in short professional courses' offer (doubling the number of programmes of the UK) than at the bachelor level, where it has a modest role. This finding is inevitably linked to the fact that the data source used covers only programmes taught in English language. Even though this might appear as a constraint of this study, not allowing the proper analysis of the entire offer (in any language) of bachelor programmes, it uncovers a characteristic of continental Europe's education and implies a limitation of the EU27's offer. As English is definitely the most used language in the business context, to have language fragmentation in the provision of education offer may be retained as an obstacle for future economic developments. Additionally, English-taught programmes ease the access to international faculties and worldwide experts.

While almost two thirds of programmes can be exclusively associated to a single domain (AI, HPC, CS or DS), we detect a considerable overlap between AI and DS (12% of all detected programmes, and 17% of the EU27's offer). This overlap, rooted in the common involvement of AI and DS in the extraction of information from complex data, seems to be a good indication of a well-shaped structure of the education offer of advanced digital skills. In addition, the overlap between AI and DS may open the floor for further cross-fertilisations. In fact, the two technological domains can take advantage one from another, with the twofold consequence of (i) ensuring a more flexible and wider set of digital skills for students, and consequently a larger niche of employment possibilities for graduate students, and of (ii) facilitating connection and exchanges between economic sectors where these domains are employed.

The presence of the EU27 in the international landscape of advanced digital skills education is not even. While in AI, HPC and DS the weight of the EU27 reaches 17% to 19% of the overall education offer covered by the study, in CS the EU27 provides only 12% of the overall offer. This finding deserves attention, as it suggests a potential mismatch between the education offer and the needs of an industry and a society challenged more and more frequently by cyber threats. The reduced supply of education in CS by the EU27 is more acute in the case of specialised programmes, where the EU27 shows a much smaller weight than the one it has in CS broad programmes. This does not happen in the other considered domains, where the EU27's position in specialised programmes is stronger or equivalent to the one in broad programmes. This is of upmost importance, considering how much the misuse of digital resources and fraudulent practices are affecting both the private and the public spheres. In this sense, a lack of specialised knowledge and skills in the CS domain weakens the capability of the EU27 to face future cyber attacks that, in the worst scenario, may attempt to destabilise the democratic principles of the Union.

In what refers to AI, the offer of specialised master programmes in the EU27 surpasses that of the UK, reaching almost 30% of all education offer at this level (of the countries covered by this study). Given the role of these programmes in providing the latest stage of skills training for the workforce (bachelor's degrees are only the initial part of the academic training, and short courses generally address specific and technical aspects or provide a general introduction to a topic), this finding highlights the good position of the EU27 in the education offer related to this domain. The analysis of the programmes' content areas identifies *Robotics & Automation*, *Machine learning*, *AI applications*, and *AI ethics* as the main areas covered by AI programmes. A more prominent role of *Machine learning* is observed in master programmes and short courses, suggesting it to be one of the key competences in the professional development and implementation of AI. AI programmes are mostly offered in *ICT* studies and in *Engineering, manufacturing and construction* studies, with distinct patterns content-wise: while the former present a balanced multiplicity of contents (with the four main areas covered with similar shares, around 20% each), the latter are clearly concentrated on *Robotics & Automation* (with over 50% of the content). This shows a wider diversification of AI programmes taught in the field of education of *ICT*.

In the EU27's offer in HPC, *Parallel computing* is intensively addressed by the programmes targeted to the most specialised audience: masters' students. As observed for AI, the education offer developed in the field of *ICT* is structured to cover a large variety of topics, with the three main content areas holding relevant shares: *System architecture*, *Cloud* and *Parallel Computing*.

In DS, as in AI, we can highlight the very low gap observed between the EU27 and the other leading countries (namely the US and the UK) in the offer of master degree programmes. This is very relevant, as master degrees represent the ultimate step in the formal education leading to incorporation in the labour market. DS programmes are more likely to be found in the fields of education of *ICT* and *Business, Administration and Law.* The latter is particularly relevant because it suggests a good connection between DS and the competences that are demanded in corporate enterprises and in the management of public and private institutions.

Additionally, it might be interesting to consider the inclusion of DS programmes in the field of *Natural sciences, mathematics and statistics* in the EU27, taking into account that US, leader also in the DS domain, offers a relevant number of programmes in this field of education. As well as it is observed in AI, the offer of DS in the EU27 appears to be well structured and able to tackle both the need of specific competences in technical fields, and the need of broader and less specialised DS competences in business-related applications. We reach this conclusion by observing a sort of complementarity between the contents taught in the fields of education of *ICT* –mostly *Machine learning & Statistical modelling* – and the contents taught in *Business, administration and law* – more focused on *Big data* and *Business intelligence* -. This is a promising sign of integration between the existing education offer and the demand of advanced skills.

As a final remark, we observe that in the EU27 the DS domain is quite widespread among the fields of education, which can be considered as an opportunity for the progressive expansion of the other advanced technological domains considered in this report. DS, which has overlaps with AI, HPC and CS, may therefore be seen as a facilitator to further introduce AI, HPC and CS in the fields of education barely addressed by these technological domains.

## References

Council Regulation (EU) 2018/1488 of 28 September 2018 establishing the European High Performance Computing Joint Undertaking.

Craglia M. (Ed.), Annoni A., Benczur P., Bertoldi P., Delipetrev P., De Prato G., Feijoo C., Fernandez Macias E., Gomez E., Iglesias M., Junklewitz H, López Cobo M., Martens B., Nascimento S., Nativi S., Polvora A., Sanchez I., Tolan S., Tuomi I., Vesnic Alujevic L., *Artificial Intelligence - A European Perspective*, EUR 29425 EN, Publications Office, Luxembourg, 2018, ISBN 978-92-79-97217-1, doi:10.2760/11251, JRC113826.

De Prato G., López Cobo M., Samoili S., Righi R., Vázquez-Prada Baillet M., Cardona M., *The AI Techno-Economic Segment Analysis. Selected Indicators*, EUR 29952 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76- 12584-6, doi:10.2760/576586, JRC118071.

European Commission (2012), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "High-Performance Computing: Europe's place in a Global Race" COM(2012) 45 final, 15.2.2012.

European Commission (2016a), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "European Cloud Initiative - Building a competitive data and knowledge economy in Europe" COM(2016) 178 final, 19.4.2016.

European Commission (2016b), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "Digitising European Industry - Reaping the full benefits of a Digital Single Market" COM(2016) 180 final, 19.4.2016.

European Commission (2017), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the Mid-Term Review on the implementation of the Digital Single Market Strategy: "A Connected Digital Single Market for All" COM(2017) 228 final, 10.5.2017.

European Commission (2018a), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the Digital Education Action Plan, SWD(2018) 12, Brussels, 17.1.2018

European Commission (2018b), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - "Towards a common European data space" COM(2018) 232 final, 25.4.2018.

European Commission (2018c), Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions "Artifical Intelligence for Europe" COM(2018) 237 final, 25.4.2018.

European Commission (2018d), Proposal for a Regulation of the European Parliament and of the Council establishing the Digital Europe programme for the period 2021-2027, COM(2018) 434 final, 6.6.2018.

European Commission (2018e), Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions "Coordinated Plan on Artificial Intelligence" COM(2018) 795 final, 7.12.2018.

European Commission (2020a), "White paper on AI - A European approach to excellence and trust" COM(2020) 65 final, 19.2.2020.

European Commission (2020b), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions "A European strategy for data" COM(2020) 66 final, 19.2.2020.

Gómez Losada, Á., López-Cobo, M., Samoili, S., Alaveras, G., Vázquez-Prada Baillet, M., Cardona, M., Righi, R., Ziemba, L., and De Prato, G., Estimation of supply and demand of tertiary education places in advanced digital profiles in the EU. Focus on Artificial intelligence, High performance computing, Cybersecurity and Data science (*in press*).

López Cobo M., De Prato G., Alaveras G., Righi R., Samoili S. , Hradec J., Ziemba L.W., Pogorzelska K., Cardona M., *Academic offer and demand for advanced profiles in the EU. Artificial Intelligence, High Performance*

*Computing and Cybersecurity*, EUR 29629 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-79-98983-4, doi:10.2760/016541, JRC113966.

Nai-Fovino, I.; Neisse, R.;Lazari, A.; Ruzzante, G.; Polemi, N.; Figwer, M. *European Cybersecurity Centres of Expertise Map - Definitions and Taxonomy*. EU27R 29332 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-92956-4, doi:10.2760/622400, JRC111441.

Regulation (EU) 2019/881 of the European Parliament and of the Council of 17 April 2019 on ENISA (the European Union Agency for Cybersecurity) and on information and communications technology cybersecurity certification and repealing Regulation (EU) No 526/2013 (Cybersecurity Act).

Righi R., Samoili S., López Cobo M., Vázquez-Prada Baillet M., Cardona M., De Prato G., *The AI techno-economic complex System: Worldwide landscape, thematic subdomains and technological collaborations*, Telecommunications Policy, Volume 44, Issue 6, 2020.

Samoili, S., López Cobo, M., Gómez, E., De Prato, G., Martínez-Plumed, F., and Delipetrev, B., *AI Watch. Defining Artificial Intelligence. Towards an operational definition and taxonomy of artificial intelligence*, EUR 30117 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-17045-7, doi:10.2760/382730, JRC118163.

Samoili S., Righi R., Cardona M., López Cobo M., Vázquez-Prada Baillet M., and De Prato G., *TES analysis of AI Worldwide Ecosystem in 2009-2018*, EUR 30109 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-16661-0, doi:10.2760/85212, JRC120106.

UNESCO Institute for Statistics, 2015, *International Standard Classification of Education. Fields of education and training 2013 (ISCED-F 2013). Detailed field descriptions*, Montreal, Canada, ISBN 978-92-9189-179-5, DOI http://dx.doi.org/10.15220/978-92-9189-179-5-en.

## 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 |
| NScMs | Natural sciences, mathematics and statistics |
| OECD | Organisation for Economic Co-operation and Development |
| PREDICT | Prospective Insights on R&D in ICT |
| R&D | Research and development |
| TES | Techno-economic segments |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |

## List of country codes and names

| ***EU Member States*** | | | | | | ***Non-EU27 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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# Annexes

## Annex 1 Detailed results

**Table A 1. AI programmes by country, level and scope. All countries, 2019-20**

| | | Bachelor | | Master | | Short courses | | Total |
|---|---|---|---|---|---|---|---|---|
| | | Broad | Specialised | Broad | Specialised | Broad | Specialised | |
| BE | Belgium | 5 | 1 | 22 | 12 | 1 | 2 | 43 |
| BG | Bulgaria | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| CZ | Czechia | 2 | 0 | 4 | 6 | 0 | 0 | 12 |
| DK | Denmark | 2 | 7 | 38 | 13 | 4 | 4 | 68 |
| DE | Germany | 15 | 4 | 75 | 31 | 10 | 11 | 146 |
| EE | Estonia | 0 | 2 | 4 | 4 | 0 | 2 | 12 |
| IE | Ireland | 33 | 7 | 44 | 12 | 0 | 0 | 96 |
| EL | Greece | 1 | 1 | 4 | 2 | 1 | 0 | 9 |
| ES | Spain | 3 | 1 | 29 | 14 | 1 | 1 | 49 |
| FR | France | 4 | 2 | 34 | 33 | 4 | 1 | 78 |
| HR | Croatia | 0 | 0 | 0 | 1 | 2 | 0 | 3 |
| IT | Italy | 4 | 0 | 44 | 17 | 0 | 1 | 66 |
| CY | Cyprus | 3 | 1 | 6 | 3 | 0 | 0 | 13 |
| LV | Latvia | 2 | 2 | 5 | 3 | 0 | 0 | 12 |
| LT | Lithuania | 5 | 5 | 14 | 1 | 0 | 1 | 26 |
| LU | Luxembourg | 0 | 0 | 2 | 0 | 0 | 0 | 2 |
| HU | Hungary | 5 | 2 | 8 | 6 | 0 | 0 | 21 |
| MT | Malta | 1 | 0 | 2 | 1 | 0 | 0 | 4 |
| NL | Netherlands | 10 | 8 | 65 | 24 | 9 | 5 | 121 |
| AT | Austria | 2 | 1 | 15 | 6 | 0 | 0 | 24 |
| PL | Poland | 3 | 9 | 13 | 8 | 1 | 0 | 34 |
| PT | Portugal | 3 | 0 | 14 | 6 | 0 | 0 | 23 |
| RO | Romania | 3 | 1 | 9 | 4 | 0 | 0 | 17 |
| SI | Slovenia | 0 | 0 | 3 | 2 | 0 | 0 | 5 |
| SK | Slovakia | 2 | 0 | 0 | 3 | 0 | 0 | 5 |
| FI | Finland | 6 | 3 | 24 | 19 | 0 | 1 | 53 |
| SE | Sweden | 2 | 1 | 56 | 28 | 2 | 0 | 89 |
| | **EU27** | **116** | **58** | **535** | **259** | **35** | **29** | **1,032** |
| UK | United Kingdom | 402 | 185 | 430 | 227 | 16 | 15 | 1,275 |
| NO | Norway | 1 | 1 | 22 | 11 | 0 | 0 | 35 |
| CH | Switzerland | 1 | 0 | 19 | 8 | 0 | 0 | 28 |
| CA | Canada | 88 | 51 | 78 | 38 | 4 | 0 | 259 |
| US | United States | 878 | 305 | 685 | 293 | 66 | 118 | 2,345 |
| AU | Australia | 134 | 49 | 96 | 24 | 11 | 9 | 323 |
| | **TOTAL** | **1,620** | **649** | **1,865** | **860** | **132** | **171** | **5,297** |

**Table A 2. HPC programmes by country, level and scope. All countries, 2019-20**

| | | Bachelor | | Master | | Short courses | | Total |
|---|---|---|---|---|---|---|---|---|
| | | Broad | Specialised | Broad | Specialised | Broad | Specialised | |
| BE | Belgium | 1 | 0 | 9 | 0 | 1 | 0 | 11 |
| BG | Bulgaria | 0 | 0 | 2 | 0 | 0 | 0 | 2 |
| CZ | Czechia | 0 | 0 | 3 | 1 | 0 | 0 | 4 |
| DK | Denmark | 4 | 0 | 17 | 1 | 1 | 0 | 23 |
| DE | Germany | 4 | 0 | 28 | 2 | 3 | 0 | 37 |
| EE | Estonia | 0 | 0 | 2 | 0 | 0 | 0 | 2 |
| IE | Ireland | 21 | 0 | 22 | 1 | 0 | 0 | 44 |
| EL | Greece | 1 | 0 | 4 | 0 | 0 | 0 | 5 |
| ES | Spain | 4 | 0 | 16 | 0 | 0 | 1 | 21 |
| FR | France | 3 | 0 | 21 | 4 | 2 | 0 | 30 |
| HR | Croatia | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| IT | Italy | 0 | 0 | 10 | 2 | 0 | 0 | 12 |
| CY | Cyprus | 0 | 0 | 3 | 0 | 0 | 0 | 3 |
| LV | Latvia | 0 | 0 | 2 | 0 | 0 | 0 | 2 |
| LT | Lithuania | 3 | 0 | 3 | 2 | 0 | 0 | 8 |
| LU | Luxembourg | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| HU | Hungary | 1 | 0 | 6 | 0 | 0 | 0 | 7 |
| MT | Malta | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| NL | Netherlands | 3 | 0 | 9 | 5 | 10 | 0 | 27 |
| AT | Austria | 0 | 0 | 10 | 0 | 0 | 0 | 10 |
| PL | Poland | 0 | 0 | 5 | 0 | 0 | 0 | 5 |
| PT | Portugal | 0 | 0 | 5 | 0 | 0 | 0 | 5 |
| RO | Romania | 0 | 1 | 2 | 4 | 0 | 0 | 7 |
| SI | Slovenia | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| SK | Slovakia | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| FI | Finland | 2 | 0 | 11 | 1 | 0 | 0 | 14 |
| SE | Sweden | 2 | 0 | 20 | 5 | 1 | 0 | 28 |
| | **EU27** | **49** | **1** | **214** | **28** | **18** | **1** | **311** |
| UK | United Kingdom | 144 | 2 | 239 | 25 | 7 | 0 | 417 |
| NO | Norway | 0 | 0 | 11 | 1 | 0 | 0 | 12 |
| CH | Switzerland | 0 | 0 | 10 | 0 | 1 | 1 | 12 |
| CA | Canada | 42 | 1 | 37 | 5 | 2 | 0 | 87 |
| US | United States | 306 | 7 | 381 | 46 | 53 | 4 | 797 |
| AU | Australia | 49 | 1 | 55 | 2 | 24 | 1 | 132 |
| | **TOTAL** | **590** | **12** | **947** | **107** | **105** | **7** | **1,768** |

**Table A 3. CS programmes by country, level and scope. All countries, 2019-20**

| | | Bachelor | | Master | | Short courses | | Total |
|---|---|---|---|---|---|---|---|---|
| | | Broad | Specialised | Broad | Specialised | Broad | Specialised | |
| BE | Belgium | 5 | 1 | 13 | 3 | 5 | 0 | 27 |
| BG | Bulgaria | 1 | 0 | 1 | 1 | 0 | 0 | 3 |
| CZ | Czechia | 0 | 0 | 5 | 2 | 0 | 0 | 7 |
| DK | Denmark | 2 | 1 | 15 | 1 | 1 | 0 | 20 |
| DE | Germany | 7 | 1 | 40 | 11 | 1 | 1 | 61 |
| EE | Estonia | 0 | 1 | 4 | 3 | 2 | 0 | 10 |
| IE | Ireland | 25 | 7 | 19 | 7 | 0 | 0 | 58 |
| EL | Greece | 4 | 1 | 6 | 3 | 1 | 0 | 15 |
| ES | Spain | 4 | 1 | 11 | 8 | 0 | 0 | 24 |
| FR | France | 5 | 1 | 18 | 9 | 1 | 0 | 34 |
| HR | Croatia | 1 | 0 | 2 | 0 | 2 | 0 | 5 |
| IT | Italy | 1 | 1 | 19 | 7 | 0 | 0 | 28 |
| CY | Cyprus | 3 | 0 | 4 | 5 | 1 | 0 | 13 |
| LV | Latvia | 2 | 0 | 4 | 1 | 0 | 0 | 7 |
| LT | Lithuania | 4 | 1 | 4 | 1 | 0 | 0 | 10 |
| LU | Luxembourg | 0 | 0 | 1 | 1 | 0 | 0 | 2 |
| HU | Hungary | 1 | 0 | 3 | 2 | 1 | 0 | 7 |
| MT | Malta | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| NL | Netherlands | 11 | 1 | 35 | 10 | 11 | 11 | 79 |
| AT | Austria | 1 | 0 | 11 | 3 | 1 | 0 | 16 |
| PL | Poland | 4 | 0 | 5 | 1 | 0 | 0 | 10 |
| PT | Portugal | 0 | 0 | 6 | 4 | 0 | 0 | 10 |
| RO | Romania | 2 | 0 | 3 | 1 | 0 | 0 | 6 |
| SI | Slovenia | 1 | 0 | 4 | 1 | 0 | 0 | 6 |
| SK | Slovakia | 1 | 0 | 0 | 2 | 0 | 0 | 3 |
| FI | Finland | 4 | 1 | 13 | 7 | 0 | 0 | 25 |
| SE | Sweden | 4 | 1 | 23 | 11 | 0 | 0 | 39 |
| | **EU27** | **93** | **19** | **269** | **106** | **27** | **12** | **526** |
| UK | United Kingdom | 372 | 153 | 341 | 197 | 17 | 29 | 1,109 |
| NO | Norway | 2 | 2 | 10 | 3 | 0 | 0 | 17 |
| CH | Switzerland | 1 | 0 | 13 | 7 | 1 | 1 | 23 |
| CA | Canada | 75 | 18 | 41 | 10 | 3 | 0 | 147 |
| US | United States | 884 | 277 | 563 | 305 | 62 | 37 | 2,128 |
| AU | Australia | 78 | 29 | 94 | 39 | 21 | 6 | 267 |
| | **TOTAL** | **1,505** | **498** | **1,331** | **667** | **131** | **85** | **4,217** |

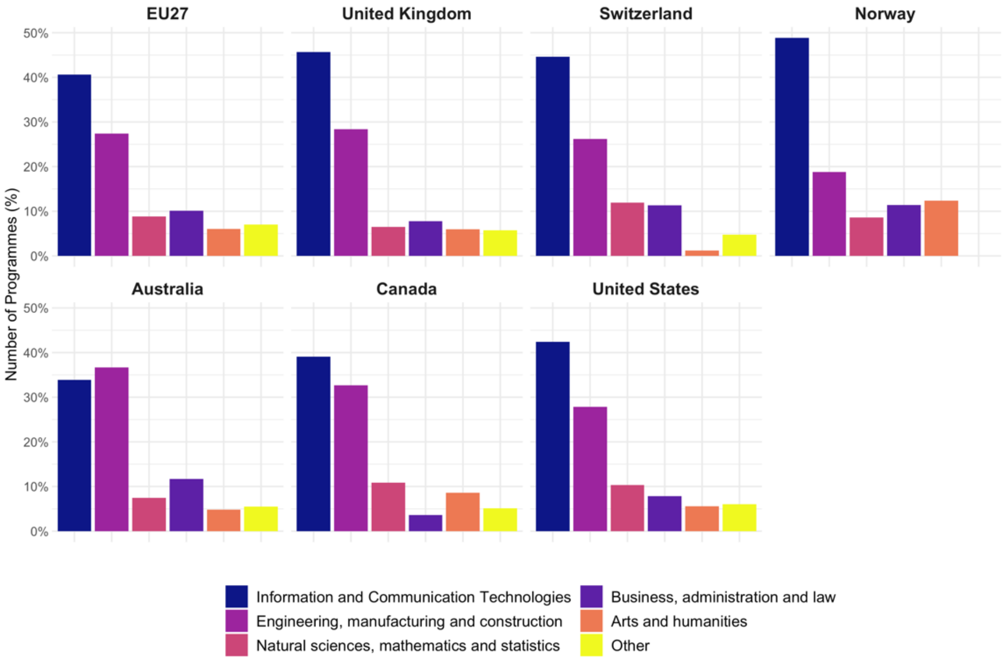
**Table A 4. DS programmes by country, level and scope. All countries, 2019-20**

| | | Bachelor | | Master | | Short courses | | Total |
|---|---|---|---|---|---|---|---|---|
| | | Broad | Specialised | Broad | Specialised | Broad | Specialised | |
| BE | Belgium | 5 | 2 | 20 | 15 | 1 | 3 | 46 |
| BG | Bulgaria | 1 | 0 | 1 | 1 | 0 | 0 | 3 |
| CZ | Czechia | 0 | 1 | 2 | 4 | 0 | 0 | 7 |
| DK | Denmark | 1 | 2 | 28 | 12 | 5 | 5 | 53 |
| DE | Germany | 10 | 2 | 67 | 43 | 8 | 5 | 135 |
| EE | Estonia | 1 | 0 | 2 | 2 | 0 | 1 | 6 |
| IE | Ireland | 28 | 8 | 48 | 23 | 0 | 0 | 107 |
| EL | Greece | 3 | 0 | 5 | 2 | 0 | 2 | 12 |
| ES | Spain | 10 | 3 | 43 | 18 | 3 | 3 | 80 |
| FR | France | 2 | 2 | 58 | 39 | 25 | 3 | 129 |
| HR | Croatia | 0 | 0 | 7 | 0 | 1 | 0 | 8 |
| IT | Italy | 4 | 1 | 40 | 27 | 0 | 1 | 73 |
| CY | Cyprus | 1 | 0 | 9 | 2 | 0 | 0 | 12 |
| LV | Latvia | 2 | 0 | 1 | 0 | 0 | 0 | 3 |
| LT | Lithuania | 2 | 1 | 10 | 4 | 1 | 1 | 19 |
| LU | Luxembourg | 0 | 0 | 2 | 1 | 0 | 0 | 3 |
| HU | Hungary | 2 | 0 | 9 | 3 | 0 | 0 | 14 |
| MT | Malta | 0 | 0 | 3 | 0 | 0 | 0 | 3 |
| NL | Netherlands | 20 | 8 | 107 | 55 | 17 | 13 | 220 |
| AT | Austria | 1 | 0 | 24 | 6 | 0 | 1 | 32 |
| PL | Poland | 2 | 1 | 12 | 9 | 0 | 0 | 24 |
| PT | Portugal | 2 | 0 | 17 | 7 | 0 | 0 | 26 |
| RO | Romania | 2 | 0 | 3 | 8 | 0 | 0 | 13 |
| SI | Slovenia | 0 | 0 | 8 | 0 | 1 | 0 | 9 |
| SK | Slovakia | 0 | 0 | 2 | 0 | 0 | 0 | 2 |
| FI | Finland | 5 | 3 | 26 | 18 | 0 | 0 | 52 |
| SE | Sweden | 2 | 0 | 51 | 26 | 1 | 1 | 81 |
| | **EU27** | **106** | **34** | **605** | **325** | **63** | **39** | **1,172** |
| UK | United Kingdom | 377 | 66 | 515 | 365 | 16 | 24 | 1,363 |
| NO | Norway | 1 | 1 | 20 | 10 | 0 | 0 | 32 |
| CH | Switzerland | 2 | 0 | 36 | 12 | 2 | 1 | 53 |
| CA | Canada | 69 | 10 | 94 | 29 | 1 | 0 | 203 |
| US | United States | 776 | 252 | 946 | 492 | 87 | 193 | 2,746 |
| AU | Australia | 102 | 32 | 153 | 66 | 6 | 10 | 369 |
| | **TOTAL** | **1,433** | **395** | **2,369** | **1,299** | **175** | **267** | **5,938** |

**Table A 5. Programmes by narrow field of education and technological domain. All geographic areas, 2019-20**

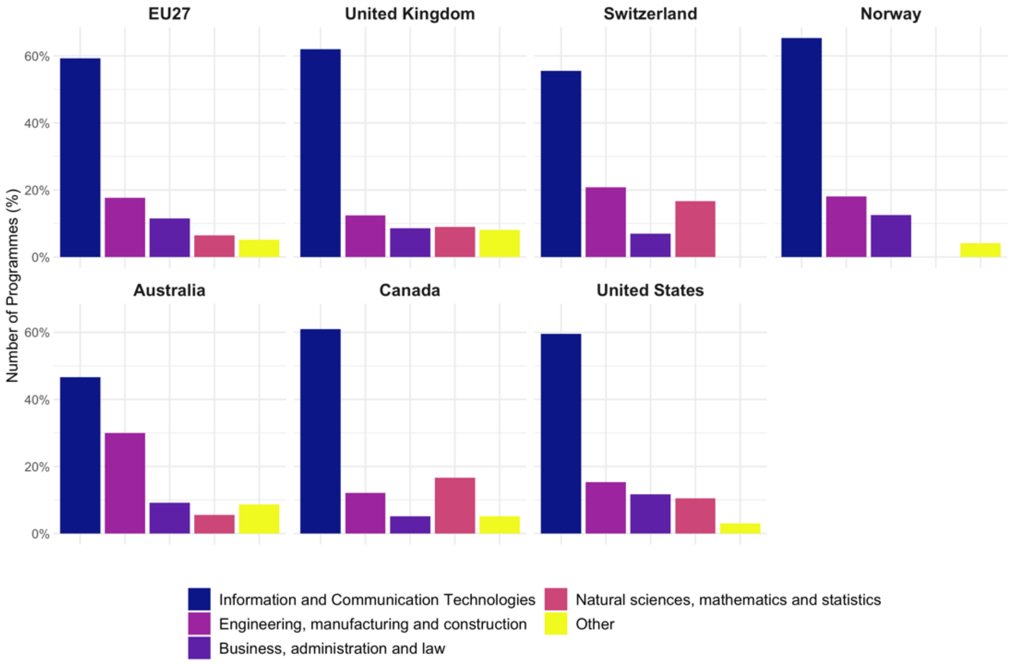
| | | | AI | | HPC | | CS | | DS | |
|---|---|---|---|---|---|---|---|---|---|---|
| Broad field of educ. code | Narrow field of educ. Code | Narrow field of education | N. of Prog. | % | N. of Prog. | % | N. of Prog. | % | N. of Prog. | % |
| 01 | 11 | Education | 39 | *1%* | 2 | *0%* | 13 | *0%* | 28 | *0%* |
| 02 | 21 | Arts | 171 | *3%* | 26 | *1%* | 50 | *1%* | 94 | *2%* |
| 02 | 22 | Humanities (except languages) | 14 | *0%* | 2 | *0%* | 8 | *0%* | 12 | *0%* |
| 03 | 23 | Languages | 126 | *2%* | 1 | *0%* | 11 | *0%* | 63 | *1%* |
| 03 | 31 | Social and behavioural sciences | 125 | *2%* | 8 | *0%* | 152 | *4%* | 228 | *4%* |
| 03 | 32 | Journalism and information | 45 | *1%* | 12 | *1%* | 44 | *1%* | 72 | *1%* |
| 04 | 41 | Business and administration | 426 | *8%* | 180 | *10%* | 707 | *17%* | 1,583 | *27%* |
| 04 | 42 | Law | 15 | *0%* | 4 | *0%* | 103 | *2%* | 19 | *0%* |
| 05 | 50 | Natural sciences, mathematics and statistics n.f.d. | 5 | *0%* | 2 | *0%* | 2 | *0%* | 15 | *0%* |
| 05 | 51 | Biological and related sciences | 130 | *2%* | 24 | *1%* | 76 | *2%* | 165 | *3%* |
| 05 | 52 | Environment | 14 | *0%* | 4 | *0%* | 5 | *0%* | 26 | *0%* |
| 05 | 53 | Physical sciences | 125 | *2%* | 76 | *4%* | 25 | *1%* | 149 | *3%* |
| 05 | 54 | Mathematics and statistics | 201 | *4%* | 58 | *3%* | 274 | *7%* | 479 | *8%* |
| 06 | 61 | Information and Communication Technologies | 2,238 | *42%* | 1,046 | *59%* | 2,271 | *54%* | 2,343 | *39%* |
| 07 | 71 | Engineering and engineering trades | 1,450 | *27%* | 249 | *14%* | 355 | *8%* | 461 | *8%* |
| 07 | 72 | Manufacturing and processing | 33 | *1%* | 9 | *1%* | 4 | *0%* | 12 | *0%* |
| 07 | 73 | Architecture and construction | 32 | *1%* | 25 | *1%* | 18 | *0%* | 30 | *1%* |
| 08 | 81 | Agriculture | 8 | *0%* | 0 | *0%* | 0 | *0%* | 24 | *0%* |
| 08 | 82 | Forestry | 1 | *0%* | 0 | *0%* | 0 | *0%* | 1 | *0%* |
| 08 | 83 | Fisheries | 0 | *0%* | 1 | *0%* | 0 | *0%* | 0 | *0%* |
| 08 | 84 | Veterinary | 1 | *0%* | 0 | *0%* | 0 | *0%* | 0 | *0%* |
| 09 | 91 | Health | 65 | *1%* | 12 | *1%* | 8 | *0%* | 57 | *1%* |
| 09 | 92 | Welfare | 2 | *0%* | 0 | *0%* | 0 | *0%* | 3 | *0%* |
| 09 | 98 | Interdisciplinary programmes involving broad field 09 | 20 | *0%* | 4 | *0%* | 8 | *0%* | 49 | *1%* |
| 10 | 101 | Personal services | 8 | *0%* | 21 | *1%* | 11 | *0%* | 19 | *0%* |
| 10 | 103 | Security services | 5 | *0%* | 1 | *0%* | 71 | *2%* | 6 | *0%* |
| 10 | 104 | Transport services | 1 | *0%* | 1 | *0%* | 2 | *0%* | 3 | *0%* |
| | | **Total** | **5297** | ***100%*** | **1768** | ***100%*** | **4216.5** | ***100%*** | **5,938** | ***100%*** |
| | | **Total number of programmes detected: 11,927** | | | | | | | | |

**Figure A 1. AI programmes by geographic area and field of education (%). 2019-20**



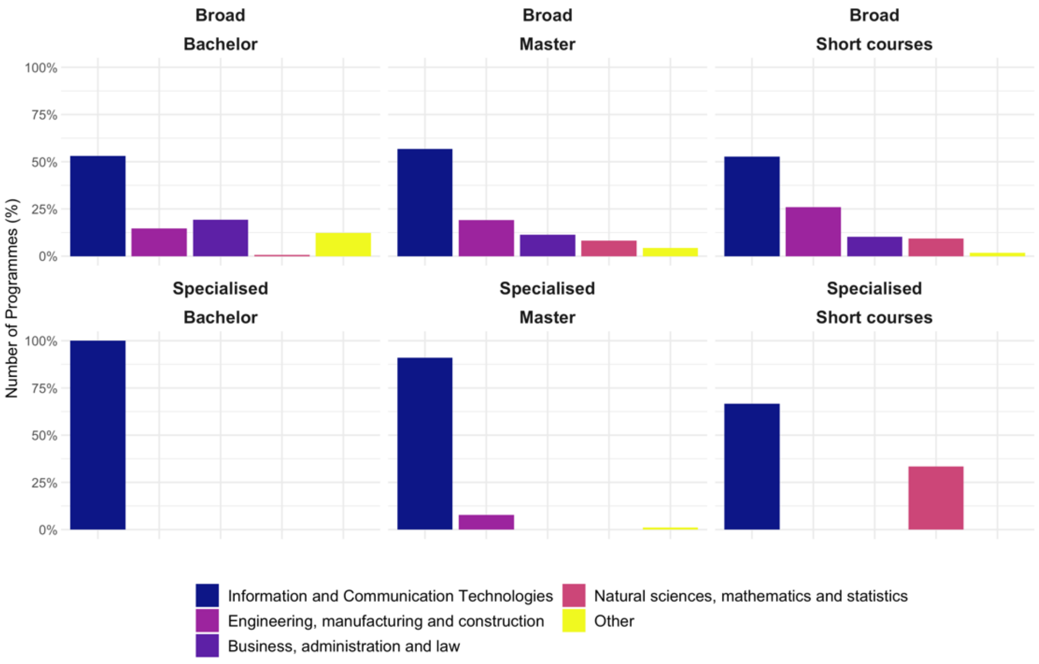

Note: The percentages are based on the number of programmes in the corresponding geographic areas

**Figure A 2. HPC programmes by geographic area and field of education (%). 2019-20**



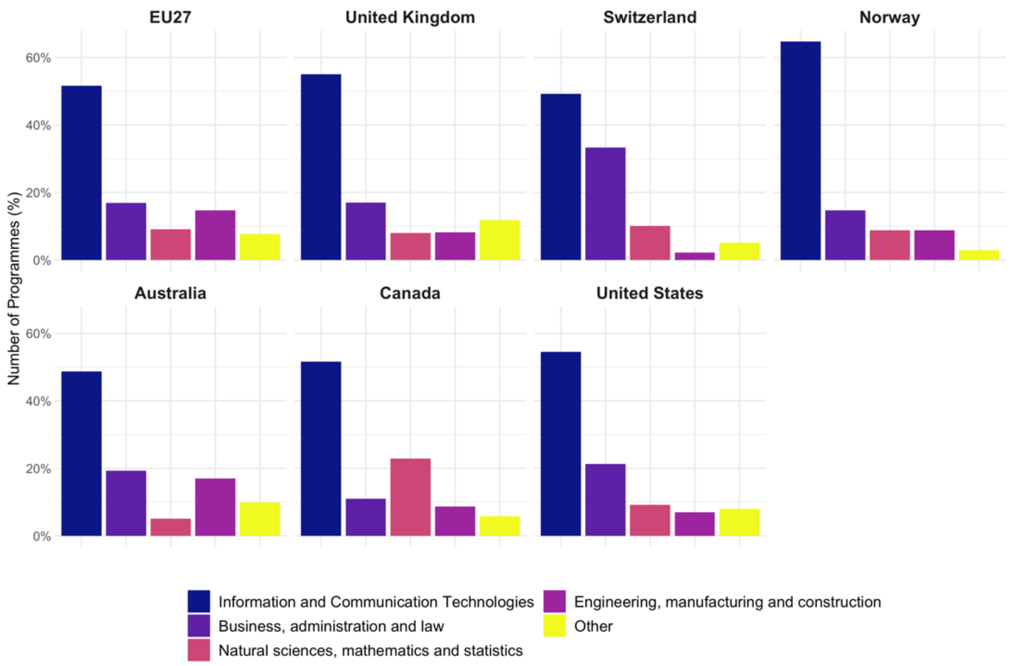

Note: The percentages are based on the number of programmes in the corresponding geographic areas

**Figure A 3. HPC programmes by scope, level and field of education (%). EU27, 2019-20**



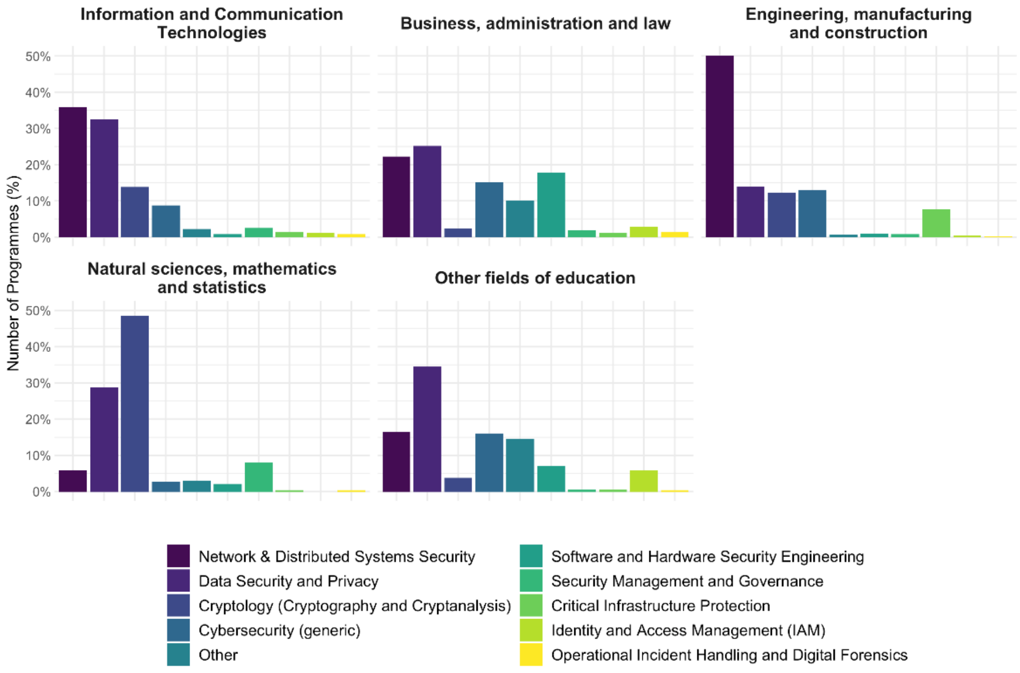

Note: The percentages are based on the number of programmes in the combination of scope and level.

**Figure A 4. CS programmes by geographic area and field of education (%). 2019-20**



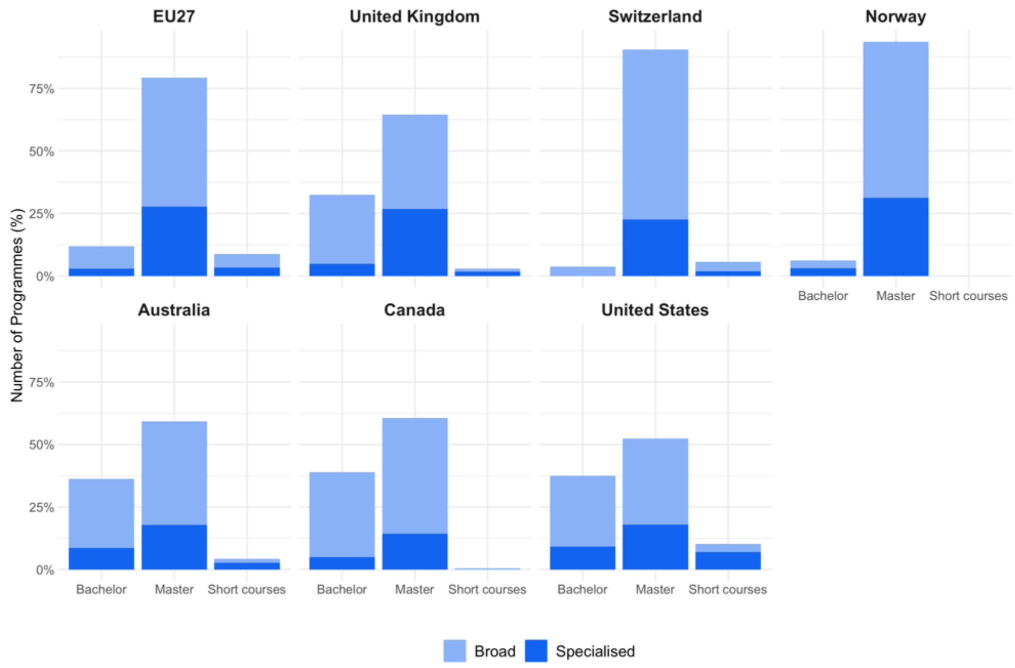

Note: The percentages are based on the number of programmes in the corresponding geographic areas

**Figure A 5. CS programmes by field of education and content area (%). EU27, 2019-20**



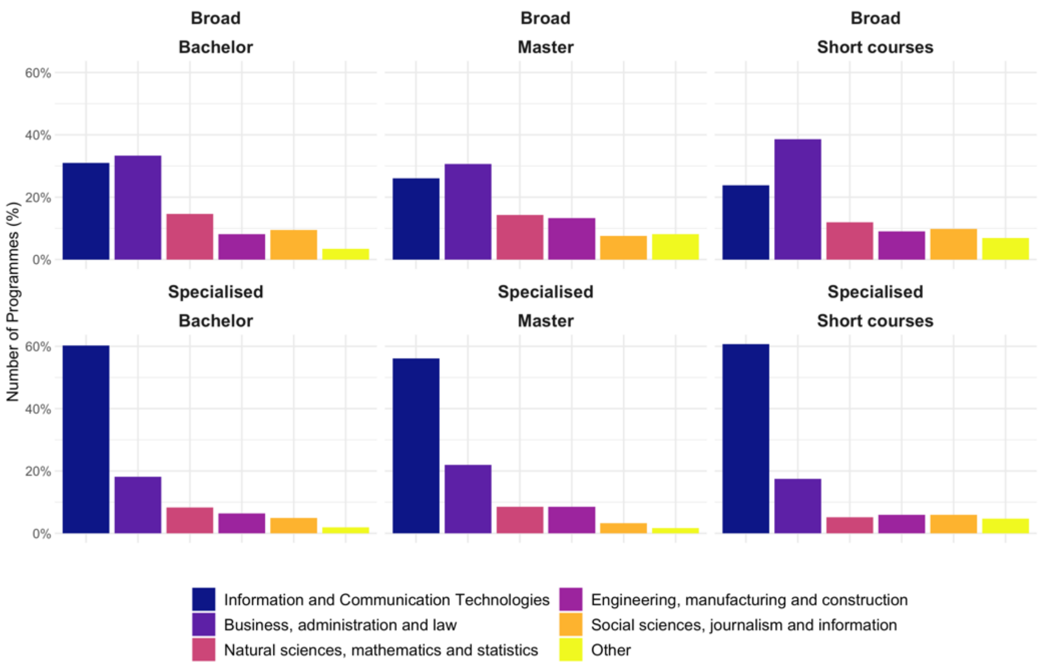

Note: The percentages are based on the number of programmes in each field of education.

**Figure A 6. DS programmes by geographic area, level and scope (%). All geographic areas, 2019-20**




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

**Figure A 7. DS programmes by scope, level and field of education (%). EU27, 2019-20**




Note: The percentages are based on the number of programmes in the combination of scope and level.

## 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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