European Commission

JRC TECHNICAL REPORTS

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

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2020

Joint Research Centre

EUR 30377 EN

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EU Science Hub
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JRC121683

EUR 30377 EN

PDF ISBN 978-92-76-22281-1 ISSN 1831-9424 doi:10.2760/559530

Luxembourg: Publications Office of the European Union, 2020

How to cite this report: 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, EUR 30377 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-22281-1, doi:10.2760/559530, JRC121683.

Contents

Foreword

The PREDICT project focuses on analysing the supply of Information and Communications Technologies (ICT) and of 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 evidence 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 general objective of contributing to the measuring of 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 the 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.

Acknowledgements

Authors would like to acknowledge Ms Etienne Albiser from the Organisation for Economic Co-operation and Development (OECD) for her helpful clarifications regarding some methodological aspects of the B4 indicator (Education at a Glance 2018, OECD). We also thank Silvia Merisio (DG CNECT) for her useful comments that helped improve the report.

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Abstract

In order to investigate the extent to which the education offer of advanced digital skills in Europe matches labour market needs, this study estimates the supply and demand of university places for studies covering the technological domains of Artificial Intelligence (AI), High Performance Computing (HPC), Cybersecurity (CS) and Data Science (DS), in the EU27, United Kingdom and Norway.

The difference between demand and supply of tertiary education places (Bachelor and Master or equivalent level) in the mentioned technological domains is referred in this report as unmet students' demand of places, or unmet demand. Demanded places, available places and unmet demand are estimated for the following dimensions: (a) the tertiary education level in which this demand is observed: Bachelor and Master or equivalent programmes; (b) the programme's scope, or depth with which education programmes address the technological domain: broad and specialised; and (c) the main fields of education where this tuition is offered: Business Administration and Law; Natural sciences and Mathematics; Information and Communication Technology (ICT); and Engineering, Manufacturing and Construction, with the remaining fields grouped together in a fifth category.

From these estimations, it is concluded that the number of available places in the EU27, at Bachelor level, reaches 587,000 for studies with AI content, 106,000 places offered in HPC, 307,000 places in CS and 444,000 places offered in the domain of DS. At Master level this demand is comparatively lower, except for the DS domain, were it equals the offer at bachelor level. DS outnumbers AI in demand of places at Master level, with 602,000 and 535,000 demanded places, respectively. The unmet demand for AI, HPC, CS and DS in EU27 at MSc level is approximately 150,000, 33,000, 59,000 and 167,000 places, respectively. At BSc level, the unmet demand reaches 273,000, 53,000, 159,000 and 213,000 places, respectively. Another finding is that the unmet demand for broad academic programmes is higher than for specialised programmes of all technological domains and education levels (Bachelor and Master).

Higher availability of places for AI, HPC, CS and DS domains is found for academic programmes taught in the ICT field of education, both at Bachelor and Master levels. For Bachelor studies, Germany and Finland are estimated as the countries with the highest unmet demand in AI, HPC, CS and DS, either with a broad or specialised scope. United Kingdom is the only studied country offering places for all fields of education and technological domains at Bachelor level and Master level. For Master studies, this is also found in Germany, Ireland, France and Portugal.

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

1 Introduction

The European Union (EU) has been making efforts to establish a genuine digital single market since the mid-1990s. In the framework of the 2021-2027 multiannual financial framework, the European Commission (EC) proposed in June 2018 the Digital Europe programme, aiming to support the digital transformation of the European economy (proposal, European Commission (2018b), legislative resolution, European Parliament (2019)). Digital technologies, and the internet in particular, have increasingly been transforming our world, and the need to move from national digital markets to a single one has never been more important. Accordingly, the digital single market needs to be supported in the longer term to further advance Europe's digital transformation to the benefit of citizens and businesses. Investment in advanced digital skills is crucial for the achievement of this goal. In fact, the proposed Digital Europe programme, aimed at increasing EU27's international competitiveness and reinforcing strategic digital capacities, acknowledges that artificial intelligence (AI), high performance computing (HPC), and cybersecurity (CS) are key technologies that need to be further developed and made widely accessible. The Digital Europe programme aims at "increasing Europe's talent pool, bridging the digital divide, fostering greater professionalism taking into account gender balance". 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. Also, the recent Communication "A European strategy for data" (European Commission (2020)), recognises critical shortages in big data and analytics in the EU and calls for an effort to reduce the current gap of 1 million digital specialists. The European strategy for data. foresees the establishment of a "Common European skills data space", recognising the crucial role of people's skills and the urgent need for education and training systems in advanced digital technologies. In summary, a shortage of advanced digital skills and insufficient capacities in key digital technologies are the two main challenges faced by the digital transformation in Europe. Indeed, the issue of skills evolution, Information and Communication Technologies (ICTs) and job demand is addressed by *Cedefop*[1] from different perspectives, having as part of its mandate to forecast trends in skill supply and demand for every two years since 2010. Cedefop expects a large increase in the use of ICT skills in the near future, also accompanied by a certain increase in autonomy and a reduction in routinised tasks (Cedefop, Eurofund, 2018).

A previous study within the PREDICT project provided a mapping of digital skills and its education offer in AI, HPC and CS across Europe (López-Cobo et al., 2019). The aim of the study was to frame decisions on how to improve the availability of academic education and training in the AI, HPC and CS *technological domains*, to be ready to feed the increasing industry demand and anticipate the possible lack of suitable workforce. The study analysed the industrial activity in AI, HPC and CS, but also their existing academic offer of Bachelor's degree and Master's degree programmes or equivalent levels (abbreviated as Bachelor's or BSc, and Master's or MSc in this document, respectively). According to that study, at BSc level, approximately 46% of the former EU-28 countries[2] are estimated to offer tuition for the three domains (AI, HPC and CS) simultaneously, and considering only single domains, this estimation was 78% for AI, 53% for HPC and 82% for CS. Regarding the MSc level, 96% of countries offer tuition for the three domains, with highest coverage found for AI and CS (around 96% of EU countries offer AI and CS Master's degrees), and lowest for HPC (89%). The study has been recently updated and extended (Righi & López-Cobo et al. (2020)).

To further investigate the extent to which the education offer of advanced digital skills in Europe matches labour market needs, it is worth considering the number of students enrolled in such studies. Despite the critical demand of new ICT professionals to be incorporated in all economic sectors, public or private surveys or administrative registers have not been targeting this information gap for advanced technological domains. Consequently, the current report complements the study of Righi & López-Cobo et al. (2020), by performing an estimation of supply and demand of university places in Bachelor and Master levels for the AI, HPC, CS and Data Science (DS) *technological domains*, for different *fields of education* according to ISCED-F 2013[3], in the

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

2 Data refer to 2018-19, when the United Kingdom was still an EU Member State.

3 International Standard Classification of Education – Fields of Education and Training ISCED-F (2013). Available at: http://uis.unesco.org/sites/default/files/documents/international-standard-classification-of-education-fields-of-education-and-training-2013-detailed-field-descriptions-2015-en.pdf

EU27 countries, plus the United Kingdom and Norway. The fields of education selected to be analysed in detail are Business administration and law (BAL), Natural sciences, mathematics and statistics (NScMS), Information and Communication Technologies (ICT), Engineering, manufacturing and construction (EMC), and a fifth one named as "Rest" grouping the remaining fields of education (Education, Arts and humanities; Social sciences, journalism and information; Agriculture, forestry, fisheries and veterinary; Health and welfare; and Services). The selection of those fields of education was based on their representativeness in the academic offer for AI, HPC, CS and DS domains, in such way that BAL, NScMS, ICT and EMC accumulate 87% of the courses provided by universities and other higher education institutions in such technological domains (Righi & López-Cobo et al. (2020)).

The estimation of availability and demand of places in this work is relevant for several reasons. Firstly, because it can assist administrations and analysts in assessing the relationship between labour market needs and skills supply of advanced digital skills. Secondly, it is useful to map the supply and demand of academic offer for AI, HPC, CS and DS, in order to determine if the current academic market could absorb more demand, in the short and long terms. Finally, it may be used to foresee possible development gaps due to the EU27's' unbalanced availability of academic offer for those four technological domains.

Nevertheless, this estimation is subject to certain limitations. The main limitation lays in the fact that some of the data used for the estimations were originally created with a purpose different from the one in this report, which requires the formation of reasonable assumptions. This is the case of the proportion of accepted and rejected applicants at tertiary education, which corresponds to indicator B4 from the Education at a Glance 2018 report, Organisation for Economic Co-operation and Development (OECD), for which the availability of data is limited for EU countries. Hence, it was necessary to estimate the proportions for countries missing that information. The assumptions and limitations of this study are further elaborated in Subsection 2.2.

This report is organised as follows. Section 2 presents a short description of the methodology used to estimate available places and students' demand of places in the tertiary education, while a more detailed methodology is fully presented in Annex 1. The main results of the estimation of available places and places in demand for the AI, HPC, CS and DS domains are presented in Section 3. Finally, Section 4 outlines the main conclusions of this report.

2 Methodology

This section outlines the process followed to estimate the number of available places and students' demand of places in the EU27, for the AI, HPC, CS and DS technological domains, at Bachelor's and Master's or equivalent levels, in five fields of education (BAL, NScMS, ICT, EMC, and Rest). A more detailed description of this methodology is provided in Annex 1. Subsection 2.1 describes the estimation process and the main data sources that were consulted for that purpose, and Subsection 2.2 presents the assumptions and other important considerations on the estimation process, which must be taken into account to appropriately interpret the results provided by this study.

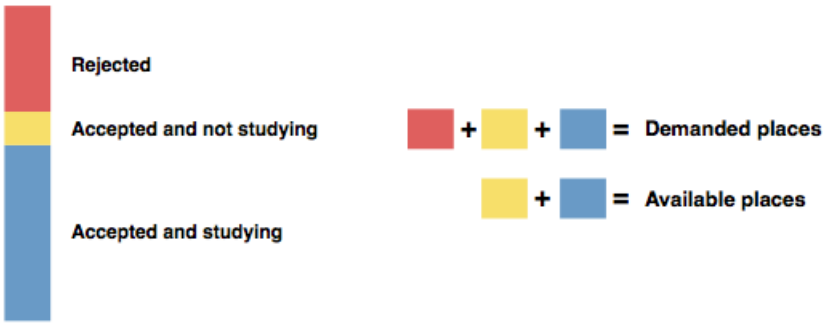
2.1 Estimation of available places and places in demand

As previously mentioned, information on available or in demand places for AI, HPC, CS and DS at Bachelor's and Master's levels are not available from public or private surveys, or administrative registers. This conclusion is obtained after thoroughly analysing relevant and abundant information related to Higher Education Institutions across Europe. (e.g. European University Association, European Association for International Education, Eurostat, UNESCO, EU27's National Statistical offices, to cite a few). This motivated the need to estimate such figures using alternative sources of information.

In the context of this report, the *available places* estimate aims to measure the maximum number of students that could have been enrolled in AI, HPC, CS or DS education programmes, at Bachelor's, Master's degrees or equivalent levels (ISCED 6 and 7, respectively, according to ISCED11[4]), considering public or private education institutions in the EU. The available places estimate considers the number of applicants accepted and studying a given program, but also, those applicants who, although accepted, are not studying. This approach represents a simplification of the enrolling systems at higher education institutions. For instance, it oversees the waiting lists for permanent admissions in which students may remain before enrolment, and does not contemplate mobility between the categories of application status. A diagram showing the distribution of applicants according to their application status is provided in Figure 1.

Regarding *places in demand*, this estimate counts not only the available places (calculated as applicants accepted to a program, either enrolled or not), but also applicants who were not successful in the admission process and were rejected. Thus, the estimate of places in demand is calculated as the number of rejected applicants plus the number of accepted applicants. The subtraction of available places from places in demand, or rejected applications, is referred in this report as students' *unmet demand* of places.

Figure 1. Distribution of applicants by application status.



Source: JRC elaboration based on OECD (2018).

4 The International Standard Classification of Education (ISCED11) is the reference international classification for organising education programmes and related qualifications by levels and fields. Available at: http://uis.unesco.org/sites/default/files/documents/international-standard-classification-of-education-isced-2011-en.pdf

Data sources

Three different sources of information were used to estimate available and places in demand:

1) Number of students actually enrolled in the five fields of education (BAL, NScMS, ICT, EMC, and the Rest of programmes) according to the ISCED-F 2013 classification, in EU27 countries, the United Kingdom, and Norway, at Bachelor's and Master's (or equivalent) education levels, for 2017 (Eurostat, 2019).

2) Proportion of applicants "accepted and studying", "accepted and not studying", and "rejected", in first-degree tertiary education in 2016 for Denmark, Estonia, France, Hungary, Portugal, Slovenia, Slovakia, Finland and Sweden. This proportion was obtained from the OECD's *Education at a glance* report (OECD, 2018) B4 indicator that examines, inter alia, the profiles of new entrants and rejection rates in tertiary education in the mentioned EU countries and other OECD countries.

3) Proportions of AI, HPC, CS and DS programmes over all programmes, in the five fields of education (BAL, NScMS, ICT, EMC, and Rest), at Bachelor's and Master's levels, for *broad* and *specialised* programmes[5], for 2019-20, in the countries covered by the study. The proportion of programmes that cover the advanced technological domains (AI, HPC, CS and DS) is provided by Righi & López-Cobo et al. (2020).

Estimation

Firstly, using data from 1) and 2), the number of available places and places in demand for the five fields of education were estimated, following the scheme presented in Figure 1. Secondly, using data from 3), we calculated these estimates restricted to the AI, HPC, CS and DS domains, by multiplying the available places and the places in demand by the proportion of AI, HPC, CS and DS programmes in all programmes taught by educational institutions.

2.2 Assumptions and considerations

As previously stated, there is no information regarding the number of available places or places in demand, neither for any of the fields of education analysed in this report nor for any geographical area. This prompted the use of supplementary information not initially suited for that purpose. However, it was the only information able to provide evidence in line with the aim of this report. Moreover, results are provided as point estimates and the calculation of a confidence interval was not feasible. Several other aspects should be noted, namely:

1) Information used to perform estimations refers to different time horizons. The Eurostat's statistics on enrolment refers to 2017; the rejection and acceptance rates from OECD's Education at a glance, to 2016; and the number of AI, HPC, CS and DS programmes and total number of programmes, to 2019-20. Since the closest dimension used to approximate the number of available places in advanced digital technologies is the proportion of AI, HPC, CS and DS programmes obtained from the JRC study on education offer, we set 2019-20 as the reference period of the results presented in this report.

2) The second step of the estimation, consisting in applying the AI, HPC, CS and DS proportions to the available places and places in demand by field of education, is based on the assumption that the domain-specific proportions observed in number of programmes (at Bachelor's and Master's education level) is transferable to the number of students. This means that if, for instance, 6% of programmes in ICT are AI-related, we assume that the same proportion of ICT students are enrolled in AI-related programmes.

3) The proportion of accepted and rejected applicants obtained from OECD originates in a survey on the number of applications and applicants to first-degree tertiary programmes (Personal Communication, 2019). These rates only cover first-degree bachelor's programmes of higher education programmes (ISCED 665, 666[6]) and first-degree master's programmes (ISCED 766[7]). Furthermore, this survey did

5 The study of López-Cobo et al. (2019) defines the scope of the programme based on its depth of involvement in the domain, distinguishing between "specialised" and "broad" programmes. Specialised programmes are those with a deep focus in the domain, technique or application field. Broad programmes are those revealed to be associated with programmes targeting to some extent the addressed domain, but almost in all cases in a more generic way, aiming at building wider profiles, or making reference to it in the framework of a programme specialised in a different discipline.

6 665: First degree (3-4 years), 666: Long first degree (more than 4 years).

7 766: Long first degree (at least 5 years).

not request separate data by level of study, namely Bachelor's and Master's programmes, or by field of study. Hence, by applying these rates we are assuming that they are equally applicable to both Bachelor's and Master's degrees individually, that they are valid for Bachelor's and Master's programmes of second or further degrees, and that they apply equally to all education fields.

4) As previously stated, information about the different status in the application process from students in higher education (i.e., accepted and studying, accepted and not studying, and rejected applications) is available from limited countries, namely Denmark, Estonia, France, Hungary, Portugal, Slovenia, Slovakia, Finland and Sweden. This prompted to calculate such proportions for the remaining EU27 countries, Norway and United Kingdom using an estimation process that is described in Annex 1. This estimation process assimilates the proportions of countries with missing information from those countries in which this information is known, after considering their similarities in the admission systems to higher education.

As a final remark, given the discussed assumptions and limitations of this methodological approach, it is noted that the produced estimates should be considered as a rough approximation of the variables of interest (available places and places in demand for AI, HPC, CS and DS domains) in all fields of education.

It is also worth mentioning that estimates produced for this report were obtained prior and during the coronavirus disease pandemic. A survey conducted from Studyportals, the main source for the estimation of the number of education programmes in AI, HPC, CS and DS, reports that a significant reduction of international students enrolments should be expected in autumn 2020 (StudyPortals, 2020). The pandemic's effect on the estimates here presented cannot be predicted.

Note on software packages

In this report, bar graphs were created using the *lattice* package in *R* (Sarkar, 2008; version 0.20-35), and maps with the *Geopandas* library in *Python* (Geopandas.org; version 0.5.1).

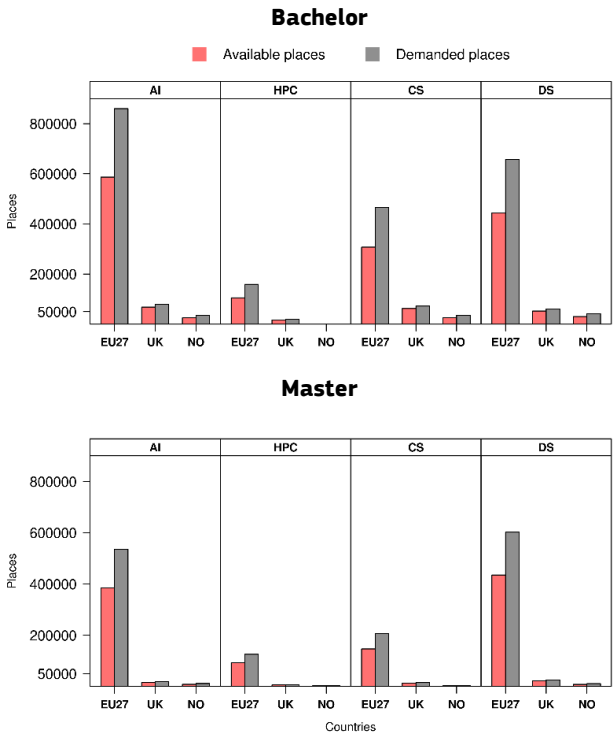
3 Available places and places in demand in the EU27, the United Kingdom and Norway

3.1 Global overview

This subsection shows the estimates of available places and places in demand for the four technological domains of interest (AI, HPC, CS and DS) at Bachelor's and Master's degrees or equivalent level. At country level, the availability and demand of places for such domains are provided in Annex 3, Table A3 1 (the value of EU27 results from the aggregation of the places of all Member States).

The demand and availability of places are presented in Figure 2 and Table 1. In the EU27, the highest students' demand of places (Figure 2, grey bars) is estimated at Bachelor level, in particular in the AI domain (860,000 places), followed by DS (657,000), CS (467,000) and HPC (159,000). At Master level this demand is comparatively lower, although it is approximately similar for the DS domain (602,000). HPC and CS show a similar quantitative relation between places in demand and available places in both levels, and DS outnumbers AI in demand of places at Master level. In the UK, the highest availability and demand of places are observed in AI and CS domains at Bachelor level, and in DS in Master level. In Norway, we find lower differences across domains in the case of Bachelors, with the exception of HPC, for which the source did not identify any bachelor degree focused on this domain, and hence, no students are estimated. Among Masters, the demanded places in AI and DS almost triples the demand of HPC and CS.

Figure 2. Available places and places in demand by education level and technological domain. EU27, United Kingdom and Norway, 2019-20.



Source: JRC elaboration.

Table 2 shows the unmet demand for the EU27, the United Kingdom and Norway. Maps showing the quartile distribution of this demand are provided in Annex 2. As explained in Subsection 2.1, unmet demand is estimated as the difference between the places in demand and available places. Estimations at Bachelor level reflect a highest number of unmet demand for AI, followed by DS, CS and HPC. However, at Master level, DS studies are more demanded than AI, maintaining the order of demand for CS and HPC. These patterns are detected uniformly for the EU27, the United Kingdom and Norway.

Table 1. Estimates of available places and places in demand by technological domain and education level (thousands). EU27, United Kingdom and Norway, 2019-20.

	AI		HPC		CS		DS	
	Available places	Places in demand	Available places	Places in demand	Available places	Places in demand	Available places	Places in demand
				Bachelor				
EU27	586.7	860.0	105.6	158.9	307.3	466.6	444.0	657.4
United Kingdom	68.2	78.7	17.2	19.9	62.5	72.2	52.5	60.6
Norway	25.3	34.4	-	-	25.9	35.2	30.4	41.4
				Master				
EU27	384.7	535.1	92.4	125.7	146.6	205.8	435.0	602.0
United Kingdom	16.1	18.6	5.8	6.7	13.0	15.1	22.2	25.6
Norway	8.4	11.5	2.8	3.8	3.0	4.1	8.3	11.2

Note: Figures are rounded to the nearest hundred. -: Not available due to missing information in source data.
Source: JRC elaboration.

Table 2. Estimates of unmet demand by education level and technological domain (thousands of places). EU27, United Kingdom and Norway, 2019-20.

	Bachelor				Master			
	AI	HPC	CS	DS	AI	HPC	CS	DS
EU27	273.3	53.3	159.3	213.4	150.4	33.2	59.1	167.0
United Kingdom	10.5	2.7	9.7	8.1	2.5	0.9	2.0	3.4
Norway	9.1	-	9.3	11.0	3.0	1.0	1.1	3.0

Note: Figures are rounded to the nearest hundred. -: Not available due to missing information in source data.
Source: JRC elaboration.

3.2 EU27

This section focuses on the analysis of results for the EU27 aggregate. It presents the estimates of available places, places in demand, and unmet students' demand after differentiating the scope of the studies, or depth with which education programmes address the technological domain: broad and specialised (*cf.* footnote 5), and the field of education according to the ISCED-F 2013 classification.

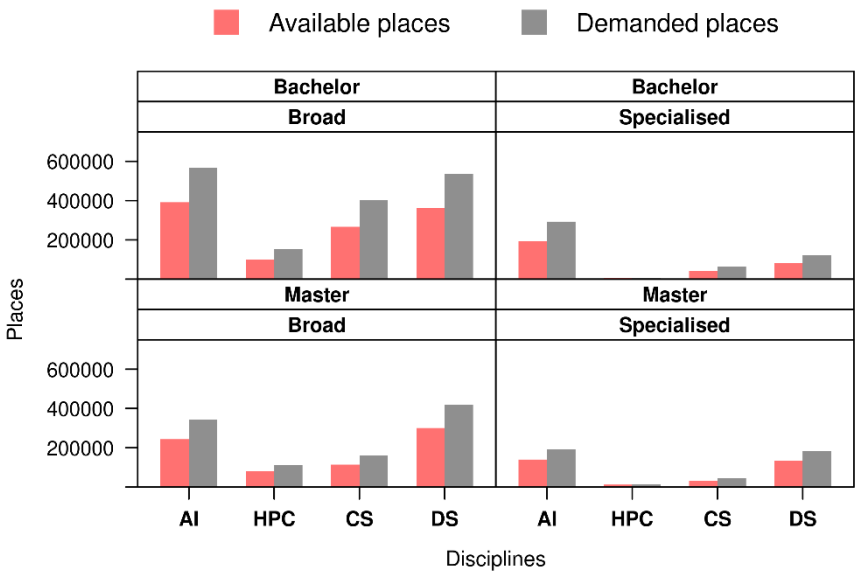
The analysis of the availability of places according to the field of education is motivated by the presence of AI, HPC, CS and DS tuition beyond the Information and Communication Technology (ICT) field, in which typically these domains were framed. Due to the increasing demand of skilled profiles and capacities in AI, HPC, CS and DS, other fields of education incorporate these technological domains to their academic offer and programmes. In this report, to reflect such current trend, three other fields of education were incorporated besides ICT, namely, Business Administration and Law (BAL), Natural sciences and Mathematics (NScMS), and Engineering, Manufacturing and Construction (EMC). The rest of fields of education which do not frequently include AI, HPC, CS or DS in their academic programmes were grouped in a fifth one (referred as "Rest" in this report)[8].Figure 3 shows the distribution of available places and places in demand by level of education (Master and Bachelor), scope (broad and specialised) and technological domain (AI, HPC, CS and DS). Absolute values of unmet demand of places for broad and specialised studies are summarised in Table 3. Estimates for studies with broad scope are higher than those of specialised ones across all technological domains, at Bachelor and Master levels of education. Most places in demand are in the DS and AI domains for broad scope studies, followed by CS and HPC domains. In specialised studies, AI is more demanded and offers more places than the DS domain.

8 As indicated at the Introduction, the four fields of education mentioned (ICT, BAL, NScMS, and EMC) accumulate 87% of the courses provided by universities and other higher education institutions in AI, HPC, CS and DS at Bachelor and Master levels (Righi & López-Cobo et al. (2020)).

The distribution of available places by field of education at Bachelor level in broad studies is quite uniformly distributed among the five fields of education (BAL, NScMS, ICT, EMC and "Rest") in the four technological domains analysed (Figure 4), with some exception as the one represented by HPC in the NScMS field. This uniformity is clearly observed in the DS technological domain. However, when analysing specialised studies, the availability of places for the ICT field is considerably higher than for the rest of fields, except in the AI technological domain, where engineering studies also present high values of available places. Availability of places for specialised studies in HPC were only detected in the ICT field of education, the latter also agglomerating most of the places for CS.

For Master studies (Figure 5), some similarities are observed with Bachelor studies. The distribution of availability of places is more similar among fields of education at studies with broad scope. Regarding specialised studies, the ICT field of education leads the tuition offer for studies in the HPC, CS and DS domains. In the case of AI, these studies are more distributed among fields of studies.

Figure 3. Estimated number of available places and places in demand, by education level, programme's scope and technological domain. EU27, 2019-20.



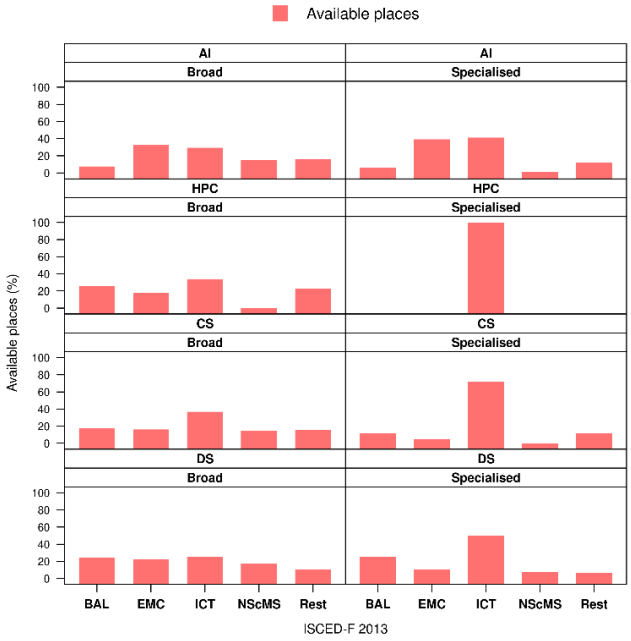
Source: JRC elaboration.

Table 3. Unmet demand by programme's scope, education level and technological domain (thousands of places). EU27, 2019-20.

	Bachelor				Master			
Scope	AI	HPC	CS	DS	AI	HPC	CS	DS
Broad	174.9	52.5	136.0	172.3	98.1	30.0	46.1	119.5
Specialised	98.3	0.8	23.3	41.1	52.3	3.3	13.0	47.5
Total	273.2	53.3	159.3	213.4	150.4	33.3	59.1	167.0

Note: Figures are rounded to the nearest hundred.
Source: JRC elaboration.

Figure 4. Distribution by field of education of available places at Bachelor level by technological domain and programme's scope (%). EU27, 2019-20.

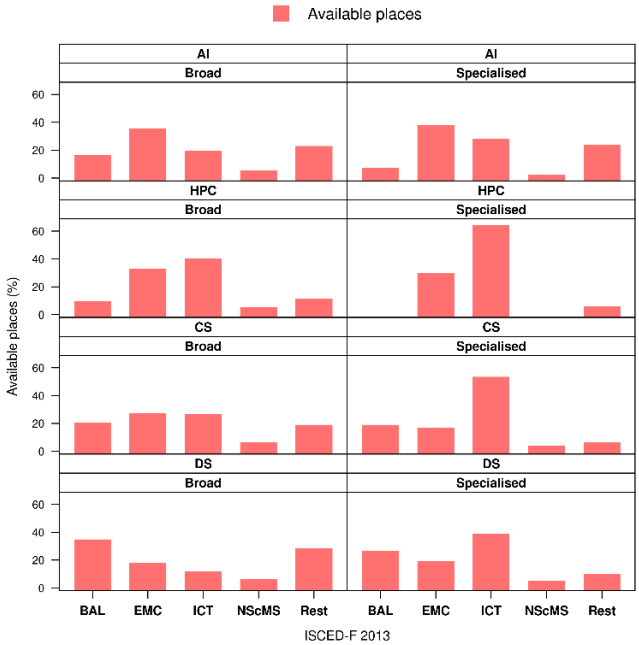


BAL: Business, administration and law, EMC: Engineering, manufacturing and construction, ICT: Information and Communication Technologies, NScMs: Natural sciences, mathematics and statistics, Rest: remaining fields.

Note: Percentages are computed over total number of places per technological domain and scope.

Source: JRC elaboration.

Figure 5. Distribution by field of education of available places at Master level by technological domain and programme's scope (%). EU27, 2019-20.



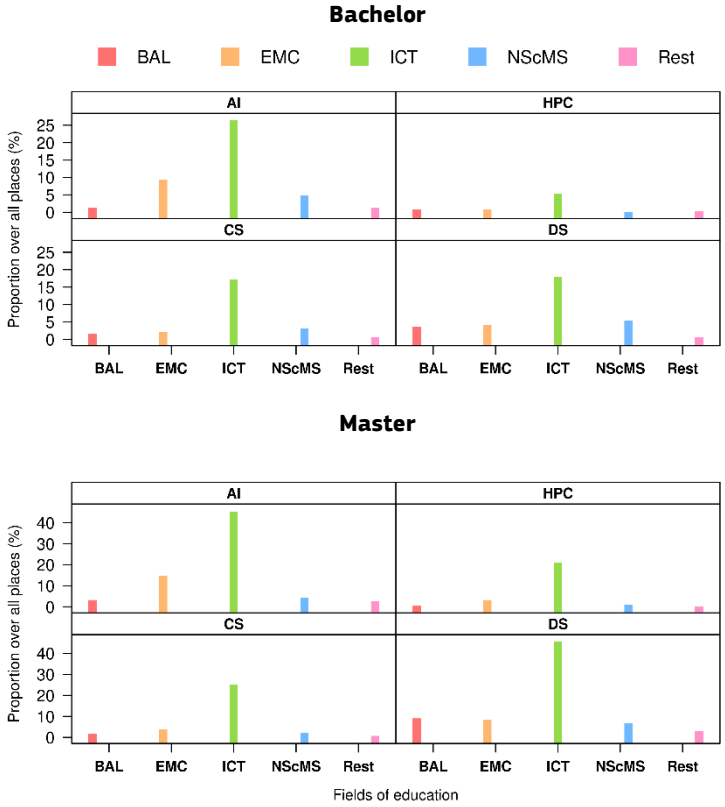
BAL: Business, administration and law, EMC: Engineering, manufacturing and construction, ICT: Information and Communication Technologies, NScMs: Natural sciences, mathematics and statistics, Rest: remaining fields.

Note: Percentages are computed over total number of places per technological domain and scope.

Source: JRC elaboration.

Figure 6 presents the proportion of available places for AI, HPC, CS and DS in each field of education over the total number of available places in each field. At bachelor level, the ICT field of education is the one offering the highest proportion of programmes covering the technological domains under study: 27% of places offered in the ICT field include contents related to AI. This proportion is 18% for available places covering DS, 17% for CS and 5% for HPC. The fields of education of EMC and NScMS follow in proportion of places, including advanced digital content in AI, HPC, CS and DS. Master's degrees are more prone to include advanced digital competences, since up to 46% of places offered in the field of ICT include DS in their curriculum, 45% of the places include AI, 25% cover CS and 21% cover HPC.

Figure 6. Proportion of available places for AI, HPC, CS and DS over total available places by education level and field of education. EU27, 2019-20.



BAL: Business, administration and law, EMC: Engineering, manufacturing and construction, ICT: Information and Communication Technologies, NScMs: Natural sciences, mathematics and statistics, Rest: remaining fields.

Source: JRC elaboration.

3.3 EU27 Member States, United Kingdom and Norway

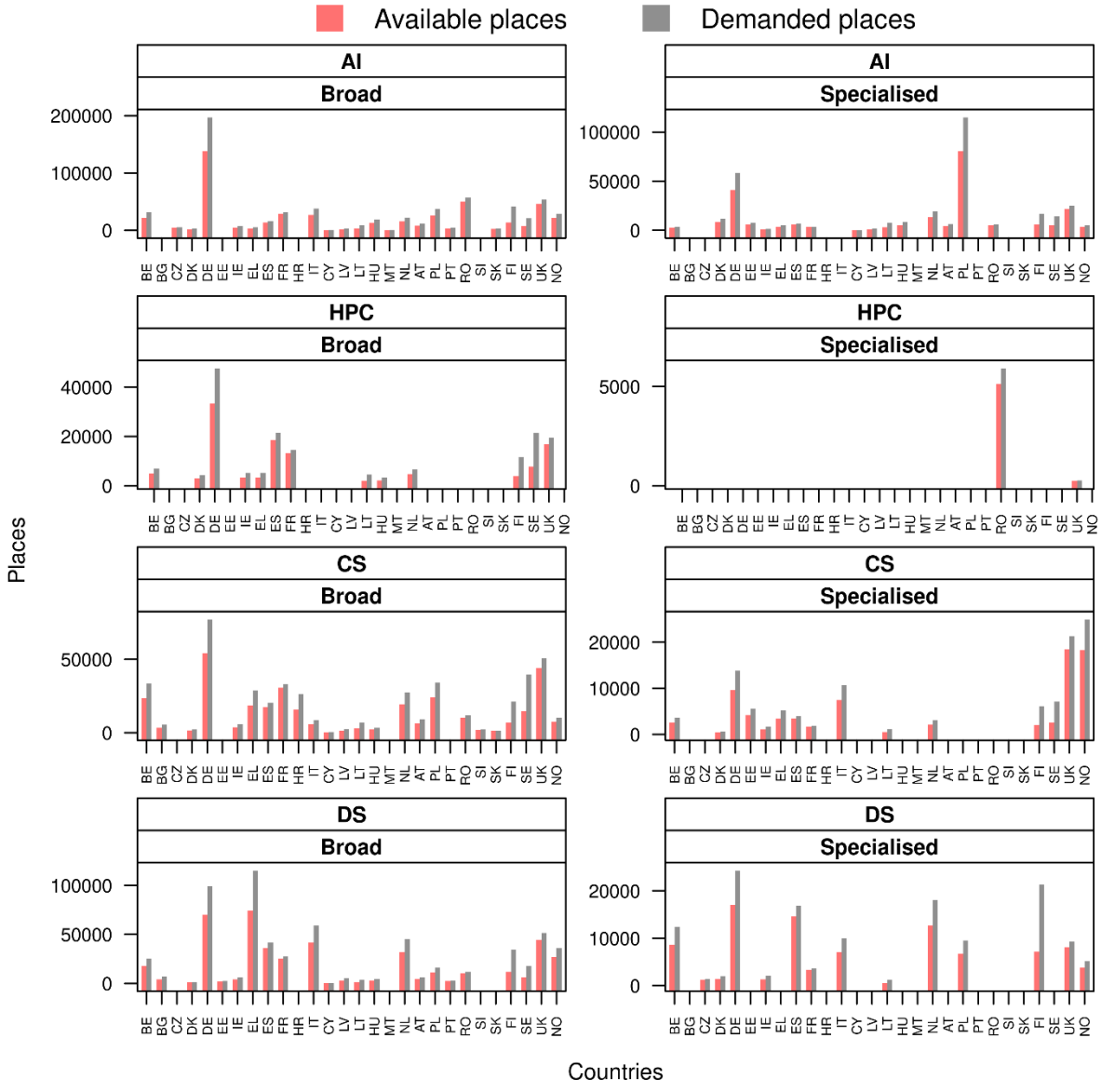
This subsection presents, at country level, estimates of available places, places in demand and unmet students' demand, considering the scope and level of studies, for the four technological domains. The results of available and demanded places are presented for Bachelor studies in Figure 7, and for Master studies in Figure 8. Unmet demand is summarised in Table 4 for Bachelor level, and Table 5 for Master level. Table A3 1 in Annex 3 provides the estimates of available and demanded places at country level, by education level.

Germany outstands as the country offering the highest number of bachelor places with broad content in the domains of AI (139,000 places), HPC (33,000) and CS (54,000) (Figure 7, left column in the figure and red bars). In DS, Greece is the country with the highest number of available places in broad programmes (74,000), closely followed by Germany (70,000). Romania ranks second in AI, followed by UK (also third in HPC and DS). France is the third country in number of available places in CS, and Spain ranks second in HPC. In Bachelor's degrees specialised in the technological domains (Figure 7, right column in the figure), the countries offering most places are Poland (81,000), Germany (41,000) and the UK (22,000) for AI; Romania (5,000 places) for

HPC; the UK, Norway (both 18,000) and Germany (10,000) for CS; and Germany, Spain and Netherlands for DS (between 17,000 and 13,000 places offered).

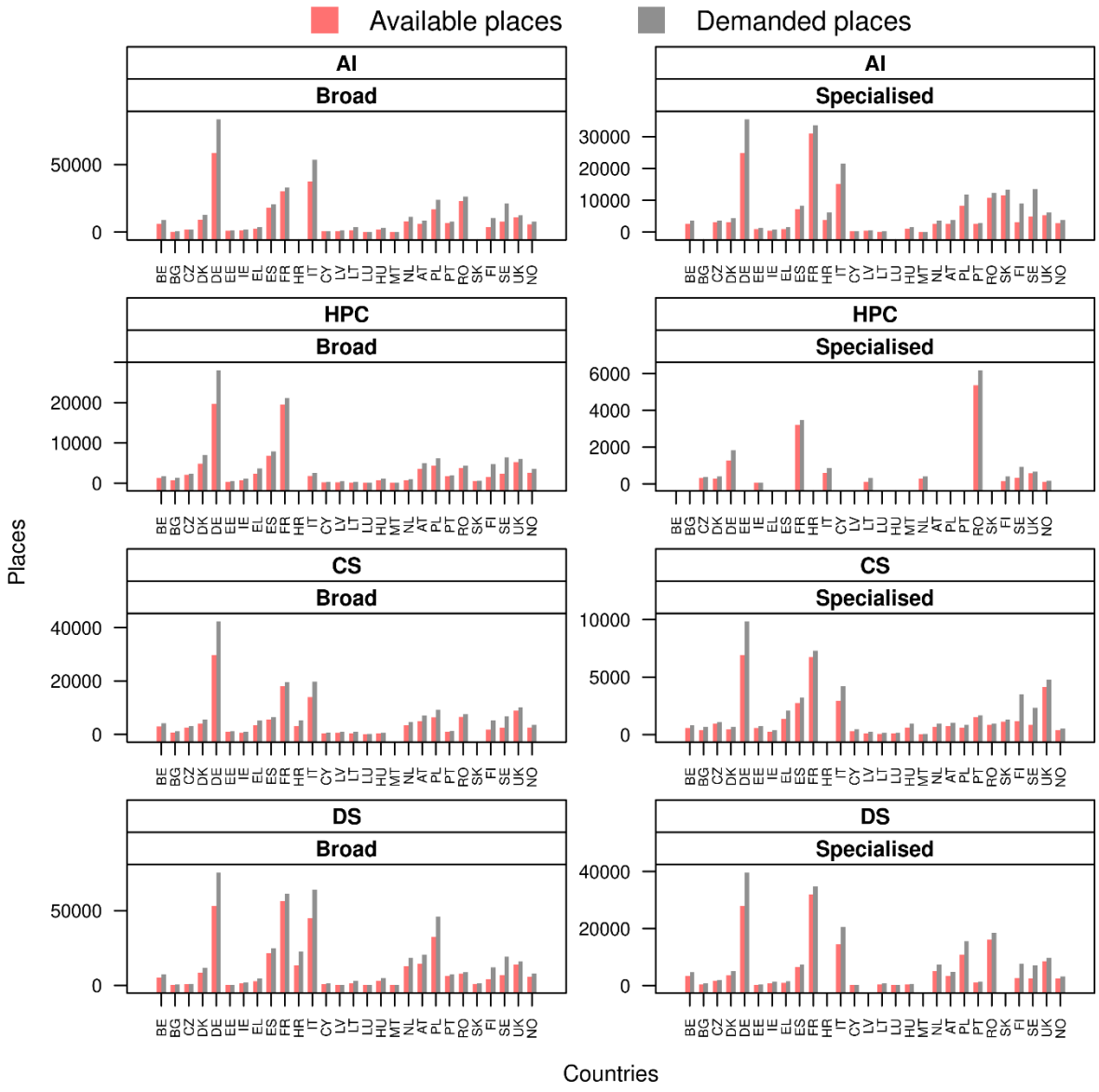
At Master's level with broad content in the technological domains (Figure 8, left column), Germany, Italy, and France hold the first positions in AI, CS and DS (exchanging the order depending on the domain), and Spain ranks third, after Germany and France, in number of available places in HPC broad masters. In what regards places in specialised masters (Figure 8, right column), France is the country offering most places in AI (31,000), followed by Germany (25,000) and Italy (15,000). Romania offers 5,400 places for specialised masters in HPC, followed by France (3,200) and Germany (1,300). In CS, Germany and France almost reach 7,000 available places for specialised masters. DS has the highest number of places offered, led by France (32,000), Germany (28,000) and Romania (16,000).

Figure 7. Available places and places in demand at Bachelor level in the EU27 Member States, the United Kingdom and Norway, by technological domain and scope, 2019-20.



Source: JRC elaboration.

Figure 8. Available places and places in demand at Master level in the EU27 Member States, the United Kingdom and Norway, by technological domain and scope, 2019-20.



Source: JRC elaboration.

The magnitude of the unmet demand in countries varies depending on the technological domain (AI, HPC, CS and DS), scope (broad and specialised) and level of studies (Bachelor and Master).

Unmet demand for Bachelor studies is presented in Table 4 and the top three countries schematically next.

- Unmet demand for bachelor programmes with a broad scope. For AI: Germany, Finland and Sweden; for HPC: Germany, Sweden and Finland; for CS: Sweden, Germany and Finland; and for DS: Greece, Germany and Finland.
- Unmet demand for bachelor programmes with a specialised scope. For AI: Poland, Germany, and Finland; for HPC: Romania is the only country offering specialised bachelors; for CS: Norway, Sweden, Finland and Germany; and for DS: Finland, Germany and Netherlands.

Table 4. Unmet demand at Bachelor level, by country, scope and technological domain (in thousands of places). EU27, Norway and United Kingdom, 2019-20.

		Broad				Master			
	Country	**AI**	**HPC**	**CS**	**DS**	**AI**	**HPC**	**CS**	**DS**
BE	Belgium	9.3	2.1	10.0	7.6	1.1	-	1.1	3.7
BG	Bulgaria	-	-	2.3	2.9	-	-	-	-
CZ	Czechia	0.7	-	-	-	-	-	-	0.2
DK	Denmark	0.9	1.3	0.7	0.5	3.5	-	0.2	0.6
DE	Germany	58.8	14.2	23.0	29.6	17.4	-	4.1	7.2
EE	Estonia	-	-	-	0.7	1.9	-	1.4	-
IE	Ireland	2.5	1.9	2.1	2.4	0.5	-	0.6	0.7
EL	Greece	1.9	1.9	10.3	41.1	1.9	-	1.9	-
ES	Spain	2.2	2.9	2.7	5.6	0.9	-	0.5	2.3
FR	France	2.5	1.1	2.6	2.2	0.3	-	0.1	0.3
HR	Croatia	-	-	10.6	-	-	-	-	-
IT	Italy	11.4	-	2.6	17.6	-	-	3.2	3.0
CY	Cyprus	0.4	-	0.2	0.1	0.1	-	-	-
LV	Latvia	1.4	-	1.0	2.1	0.6	-	-	-
LT	Lithuania	5.3	2.7	4.0	2.0	4.5	-	0.7	0.7
LU	Luxembourg	-	-	-	-	-	-	-	-
HU	Hungary	6.4	1.1	1.1	1.6	2.8	-	-	-
MT	Malta	0.3	-	-	-	-	-	-	-
NL	Netherlands	6.6	2.0	8.2	13.4	5.7	-	0.9	5.4
AT	Austria	3.4	-	2.7	1.9	1.9	-	-	-
PL	Poland	11.1	-	10.2	4.8	34.3	-	-	2.8
PT	Portugal	0.5	-	-	0.3	-	-	-	-
RO	Romania	7.7	-	1.6	1.6	0.8	0.8	-	-
SI	Slovenia	-	-	0.6	-	-	-	-	-
SK	Slovakia	0.4	-	0.2	-	-	-	-	-
FI	Finland	27.8	7.8	14.1	23.0	11.2	-	4.1	14.2
SE	Sweden	13.5	13.5	25.2	11.4	9.0	-	4.5	-
UK	United Kingdom	7.2	2.6	6.8	6.9	3.4	0.0	2.9	1.2
NO	Norway	7.7	-	2.7	9.6	1.4	-	6.6	1.4

Source: JRC elaboration

As in the Bachelor level, the ranking of countries according to the unmet demand in Master studies is presented by the scope of the studies and technological domain (Table 5):

- Unmet demand for Master studies with a broad scope. For AI: Germany, Italy and Sweden; for HPC: Germany, Sweden and Finland; for CS: Germany, Italy and Finland; for DS: Greece, Germany and Poland.
- Unmet demand for Master studies with an specialised scope. For AI: Germany, Sweden and Italy; for HPC: Romania, Sweden and the United Kingdom; for CS: Germany, Finland and Sweden; for DS: Germany, Italy and Finland.

Table 5. Unmet demand at Master level, by country, scope and technological domain (in thousands of places), EU27, Norway and United Kingdom, 2019-20.

		Broad				Specialised			
	Country	AI	HPC	CS	DS	AI	HPC	CS	DS
BE	Belgium	2.6	0.5	1.3	2.2	1.1	-	0.2	1.4
BG	Bulgaria	0.3	0.5	0.5	0.3	-	-	0.3	0.3
CZ	Czechia	0.3	0.3	0.4	0.1	0.5	0.0	0.1	0.3
DK	Denmark	3.9	2.1	1.7	3.6	1.3	0.1	0.2	1.5
DE	Germany	25.0	8.4	12.6	22.5	10.6	0.5	2.9	11.8
EE	Estonia	0.3	0.1	0.3	0.1	0.3	-	0.2	0.1
IE	Ireland	0.7	0.4	0.3	0.8	0.3	0.0	0.1	0.5
EL	Greece	1.4	1.3	1.8	1.6	0.5	-	0.8	0.5
ES	Spain	2.8	1.1	0.9	3.3	1.1	-	0.4	1.0
FR	France	2.6	1.7	1.6	4.8	2.7	0.3	0.6	2.7
HR	Croatia	-	-	2.1	9.1	2.5	-	-	-
IT	Italy	16.0	0.8	5.9	19.1	6.4	0.3	1.3	6.1
CY	Cyprus	0.4	0.1	0.3	0.5	0.1	-	0.2	0.1
LV	Latvia	0.6	0.2	0.4	0.1	0.3	-	0.1	-
LT	Lithuania	2.2	0.2	0.5	1.9	0.2	0.2	0.1	0.5
LU	Luxembourg	0.1	0.0	0.0	0.1	-	-	0.0	0.0
HU	Hungary	1.1	0.4	0.2	1.7	0.5	-	0.3	0.2
MT	Malta	0.1	0.0	-	0.1	0.0	-	0.0	-
NL	Netherlands	3.4	0.3	1.4	5.5	1.1	0.1	0.3	2.2
AT	Austria	2.6	1.5	2.1	6.2	1.1	-	0.3	1.4
PL	Poland	7.2	1.8	2.7	13.7	3.5	-	0.3	4.6
PT	Portugal	0.8	0.2	0.1	0.8	0.3	-	0.2	0.1
RO	Romania	3.5	0.6	1.0	1.2	1.7	0.8	0.1	2.5
SI	Slovenia	-	-	-	-	-	-	-	-
SK	Slovakia	-	0.1	-	0.2	1.8	-	0.2	-
FI	Finland	7.1	3.2	3.5	8.0	6.0	0.3	2.3	5.1
SE	Sweden	13.5	4.1	4.3	12.1	8.6	0.6	1.5	4.4
UK	United Kingdom	1.7	0.8	1.4	2.1	0.8	0.1	0.6	1.3
NO	Norway	2.1	1	0.9	2.1	1	0	0.1	0.9

Source: JRC elaboration

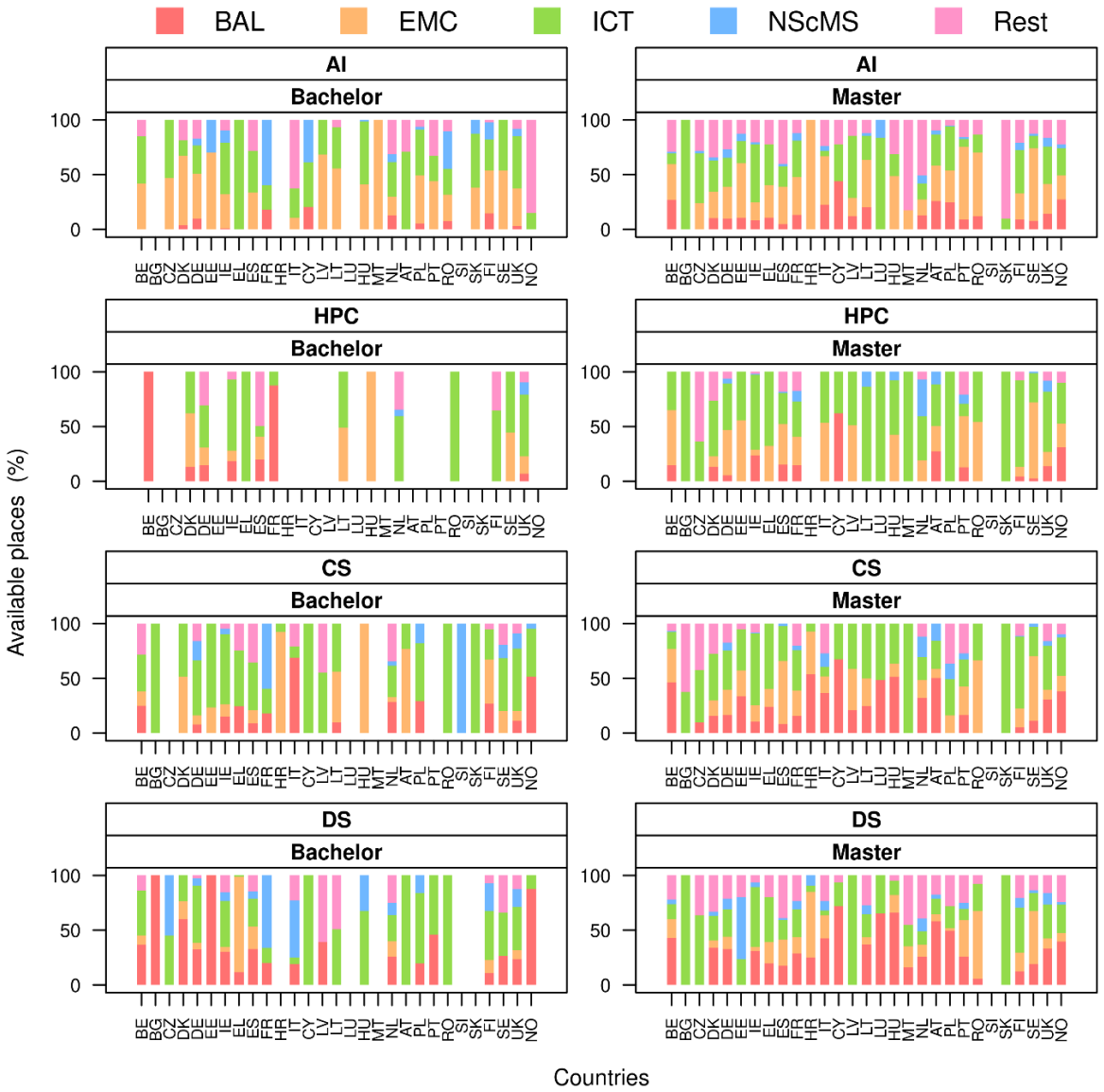
Finally, the analysis is completed considering the distribution of available places by field of education for each technological domain and level of studies (Figure 9). These results are summarised in Table 6. The countries that present availability of places for all fields of education and technological domains are United Kingdom at Bachelor level, and Germany, Ireland, France, Portugal and the United Kingdom at Master level. Countries with availability places for tuition in AI, HPC, CD and DS in at least four out of five fields of education are at Bachelor level, Germany and Ireland, and at Master level, Denmark, Spain, Netherlands, Austria, Finland, Sweden, and Norway. The fields of education offering highest proportions of places at Bachelor level are EMC and ICT in AI, ICT and EMC in HPC, ICT and EMC in CS, and ICT and BAL in DS. At Master level: EMC and ICT in AI, ICT and EMC in HPC, ICT and BAL in CS, and BAL and ICT in DS.

Table 6. Average percentage of available places by technological domain, level of studies and field of education, EU27, Norway and United Kingdom, 2019-20.

Field of education	Bachelor				Master			
	AI	HPC	CS	DS	AI	HPC	CS	DS
Total	100%	100%	100%	100%	100%	100%	100%	100%
BAL: Business, administration and law	7%	22%	16%	26%	14%	14%	23%	29%
EMC: Engineering, manufacturing and construction	33%	23%	23%	13%	32%	26%	21%	17%
ICT: Information and Communication Technologies	29%	33%	32%	29%	27%	41%	33%	27%
NScMS: Natural sciences, mathematics and statistics	14%	5%	16%	17%	4%	7%	5%	8%
Rest of fields	18%	17%	14%	15%	23%	13%	18%	19%

Source: JRC elaboration.

Figure 9. Percent distribution of available places at Bachelor and Master levels, by fields of education according to ISCED-F 2013 and technological domains, EU27, Norway and United Kingdom, 2019-20.



BAL: Business, administration and law, EMC: Engineering, manufacturing and construction, ICT: Information and Communication Technologies, NScMs: Natural sciences, mathematics and statistics, Rest: remaining fields.

Source: JRC elaboration.

4 Conclusions

This study aims to estimate the number of available places, places in demand and unmet students' demand of places in tertiary education for four technological domains (Artificial Intelligence (AI), High performance Computing (HPC), Cybersecurity (CS) and Data Science (DS)) in the EU27, the United Kingdom and Norway. This demand was estimated in the main fields of education (according to the ISCED-F 2013 classification) where this tuition is offered, namely, in Business, administration and law; Natural sciences, mathematics and statistics; Information and Communication Technologies; and Engineering, manufacturing and construction. A fifth group was also considered uniting the rest of fields of education. Additionally, the study also considers the scope of the academic programmes, or depth with which the technological domains are covered in the programmes (broad and specialised), for tuition in AI, HPC, CS and DS.

The unmet demand was calculated as the difference between the number of places in demand and the available places in tertiary education. To that end, an estimation process considering different sources of information was *ad hoc* devised for this study.

The main conclusions of this study are summarised as follow:

— At Master level, the estimated number of unmet demand of places for AI, HPC, CS and DS in the EU27 is around 150,000, 33,000, 59,000 and 160,000, respectively. At Bachelor level, the number of students who could not access the studies are 273,000, 53,000, 159,000 and 213,000, also respectively.

— The unmet demand for broad academic programmes is higher for all technological domains and levels of study (Bachelor and Master) than for specialised programmes.

— Higher availability of places for AI, HPC, CS and DS is estimated in academic programmes offered in the ICT field of education, both at Bachelor and Master studies. The fields of education of Business, administration and law, and of Engineering, manufacturing and construction also offer a significant number of places in the studied technological domains.

— France and Germany are the countries with highest number of places in specialised masters. France outstands as the country offering the highest number of places in specialised masters in the domain of AI, followed by Germany and Italy. Romania leads the specialised offer in HPC; Germany and France are equally important in CS, and France again offers the most places in specialised masters in DS, closely followed by Germany.

— For bachelor studies, Germany and Finland are estimated as the countries with higher unmet demand in AI, HPC, CS and DS studies, either with a broad or specialised scope. Regarding Master studies it is less evident which countries lead in the unmet demand, with the exception of Germany.

— United Kingdom offers places for all fields of education and technological domains at Bachelor and Master studies. For Master studies, this is also the case of Germany, Ireland, France and Portugal.

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List of abbreviations

AI	Artificial Intelligence
BAL	Business, Administration and Law
BSc	Bachelor of Science
CS	Cybersecurity
DS	Data Science
EMC	Engineering, Manufacturing and Construction
EU	European Union
HPC	High Performance Computing
ICT	Information and Communication Technology
MSc	Master of Science
NScMs	Natural Sciences, Mathematics and Statistics
OECD	Organisation for Economic Co-operation and Development
Rest	Rest of fields of education
UNESCO	United Nations Educational, Scientific and Cultural Organization

List of country codes and country names

Country code	Country name	Country code	Country name
EU27 Member States			
BE	Belgium	LU	Luxembourg
BG	Bulgaria	HU	Hungary
CZ	Czechia	MT	Malta
DK	Denmark	NL	Netherlands
DE	Germany	AT	Austria
EE	Estonia	PL	Poland
IE	Ireland	PT	Portugal
EL	Greece	RO	Romania
ES	Spain	SI	Slovenia
FR	France	SK	Slovakia
HR	Croatia	FI	Finland
IT	Italy	SE	Sweden
CY	Cyprus	***Non-EU27 countries***	
LV	Latvia	UK	United Kingdom
LT	Lithuania	NO	Norway

List of boxes

List of figures

Figure A2 1. Estimations of unmet demand (quartiles) for AI (A), HPC (B), CS (C) and DS(D), Bachelor or equivalent level, EU27, United Kingdom and Norway, 2019-20. 28

Figure A2 2. Estimations of unmet demand (quartiles) for AI (A), HPC (B), CS (C) and DS(D), at Master or equivalent level, EU27, United Kingdom and Norway, 2019-20. 29

List of tables

Annexes

Annex 1. Methodology

This section describes the stepwise approach to estimate available places and places in demand at Bachelor (BSc's) and Master (MSc's) or equivalent levels (ISCED levels 6 and 7, respectively) in the EU27 Member States, the United Kingdom, and Norway, for AI, HPC, CS and DS.

(I) Estimation of available places and places in demand for the fields of education.

The first step estimates the number of places in demand and available places, at BSc and MSc levels, in the studied fields of education according to ISCEDF-2013 (BAL, NScMS, ICT, EMC, and Rest). Two main sources of information were used for this purpose. Firstly, the Eurostat's data for 2017 from the table "Students enrolled in tertiary education by education level, programme orientation, sex and field of education (educ_uoe_enrt03)" [Table educ_uoe_enrt03] (Eurostat, 2019). From this table, the number of students enrolled in BAL, NScMS, ICT, EMC, and Rest, at BSc and MSc levels was obtained (Table A1.1). Secondly, from the OECD's "Applicants to first-degree tertiary education by application status" [Indicator B4] for 2016 (OECD, 2018), we obtain the distribution of applicants by result of their application (Table A1.2). In Eurostat, Bachelor's and Master's or equivalent levels of education are referred according to the ISCED11 classification.

Table A1 1. Students enrolled by education level (Bachelor and Master) at the five fields of education.

	BAL		NScMS		ICT		EMC		Rest	
Country (code)	Bachelor's	Master's	Bachelor's	Master's	Bachelor's	Master's	Bachelor's	Master's	Bachelor's	Master's
Belgium (BE)	76802	23600	9317	5250	13292	1185	35194	12953	249568	59079
Bulgaria (BG)	36833	26042	6068	1827	8774	1637	29371	11074	84526	37047
Czechia (CZ)	40295	24490	11164	4436	14472	5200	31772	14871	108365	73255
Denmark (DK)	36283	18293	9687	5722	6406	4661	18943	7448	124650	35027
Germany (DE)	438170	222727	155769	112032	158654	45040	439879	153717	667335	499742
Estonia (EE)	7098	3486	1521	760	2958	991	4547	2874	14139	6785
Ireland (IE)	31537	7210	17290	1346	12730	2511	17736	1993	87598	17163
Greece (EL)	130355	17402	57181	11255	20572	2592	148895	6212	277021	34860
Spain (ES)	283801	48916	83193	9061	44869	6702	154760	55419	645007	214439
France (FR)	253567	257702	158919	51238	25800	32796	52379	159562	551091	421592
Croatia (HR)	22727	21350	4332	2267	5414	1009	22991	7294	43649	30771
Italy (IT)	184978	195026	101157	34773	25251	3435	180547	102475	610204	360462
Cyprus(CY)	9619	6849	1046	134	939	496	2185	978	7843	9295
Latvia (LV)	13200	4491	1452	479	3265	1058	9051	1975	21354	9709
Lithuania (LT)	26270	8020	3284	965	4553	541	20695	3226	40737	14835
Luxembourg	761	1329	151	120	172	88	314	135	1798	787
Hungary (HU)	37453	20369	7159	1716	16333	850	35783	8829	90617	47234
Malta (MT)	2175	1309	572	130	686	149	1061	264	3865	2383
Netherlands	165713	27640	25759	13729	23368	2815	51654	12387	393131	120371
Austria (AT)	25316	44600	23800	8289	11679	4921	32774	13679	102395	64071
Poland (PL)	202736	142870	44033	16454	65438	12100	212017	51700	503017	256441
Portugal (PT)	54012	14528	12412	5412	4345	1818	29074	39895	100724	54118
Romania (RO)	96199	29079	16809	6380	27513	6591	81819	27873	125570	94599
Slovenia (SI)	7603	-	2828	-	2053	-	6978	-	24662	-
Slovakia (SK)	15798	12316	4937	2651	4901	1725	11515	6881	48146	36970
Finland (FI)	39515	11093	10092	3733	20100	5564	41749	9618	99600	35594
Sweden (SE)	31840	19072	13870	3959	11521	2446	22780	40509	160676	74723
United	287637	108611	288018	36965	79449	12619	146270	38519	795910	238137
Norway (NO)	40636	12740	8950	4129	9046	2605	12261	11677	129605	35806

-: not available.

Source: Eurostat (2018)

Table A1 2. Distribution of applicants by result of their applications (%).

Country	AS: Accepted and studying	ANS: Accepted and not studying	R: Rejected
DK	51.5	18.4	30.1
EE	68.7	5.8	25.5
FR	88.7	3.4	7.9
FI	31.2	2.2	66.5
HU	58.9	7.2	33.9
LT	36.6	4.7	58.7
PT	79.8	9.2	11.0
SK	76.3	10.3	13.4
SI	61.3	13.2	25.5
SE	30.9	5.6	63.5
NO	44.8	28.7	26.5

Source: adapted from OECD (2018)

Using information from both Tables A1.1 and A1.2, the estimation of places in demand and available places for each of the five fields of education (FoE) and countries was carried out according to the next expressions:

- Equation 1: Number of in demand places in FoE = number of FoE students / (AS /100).
- Equation 2: Number of available places in FoE = Number of in demand places in FoE * (AS + ANS)/100.

Where AS is the proportion of students whose applications were accepted and they are studying, ANS is the proportion of students whose applications were accepted and they are not studying, and R is the proportion of rejected students.

For missing EU countries in Table A1.2, (e.g., without information on the distribution of applications status), their distributions were estimated according to the similarity to their admission systems in higher education to other countries (Table A1.3). The mean values of countries' coefficients belonging to the same group was used to calculate the estimated proportion of students accepted and studying (Table A1.4).

Table A1 3. Countries grouped in four types of admission systems. EU27 and UK.

Type 1: AT, BE, DE, **DK**, **HU**, IT, LU, NL, PL, **SI**	Type 2: BG,CY,**EE**,**FI**,HR,**LT**,LV,**PT**
Type 3: EL, **FR**, IE, MT, **SE**	Type 4: CZ, ES, RO, **SK**, UK

Note: Countries for which information about the rejection and acceptance rates exists are highlighted in bold.
Source: adapted from Education and Training Monitor, 2017.

These four groups of admission systems were constructed considering the autonomy of higher education institutions in selecting students according to different criteria. A complete description of this clustering can be found in Orr et al. (2017).

Table A1 4. Estimation of the accepted and studying (AS) and rejection (R) rates for countries (in %) with missing information.

Country code	Countries used to assimilate AS, ANS and R	Averaged AS	Averaged ANS	Averaged R
BE	DK, HU, SI	57.2	12.9	29.8
BG	EE, FI, LT, PT	54.1	5.5	40.5
CZ	SK	76.3	13.4	10.3
DE	DK, HU, SI	57.2	12.9	29.8
IE	FR, SE	59.8	4.5	35.7
EL	FR, SE	59.8	4.5	35.7
ES	SK	76.3	13.4	10.3
HR	EE, FI, LT, PT	54.1	5.5	40.5
IT	DK, HU, SI	57.2	12.9	29.8
CY	EE, FI, LT, PT	54.1	5.5	40.5
LV	EE, FI, LT, PT	54.1	5.5	40.5
LU	DK, HU, SI	57.2	12.9	29.8
MT	FR, SE	59.8	4.5	35.7
NL	DK, HU, SI	57.2	12.9	29.8
AT	DK, HU, SI	57.2	12.9	29.8
PL	DK, HU, SI	57.2	12.9	29.8
RO	SK	76.3	13.4	10.3
UK	SK	76.3	13.4	10.3

Source: JRC elaboration.

As an example, Box A1.1 shows how the estimation process is performed for France and Belgium, at BSc level.

Box A1 1. Estimation of available places and places in demand for ICT, in France and Belgium, at BSc level.

France. To estimate the number of places in demand in tertiary education in ICT, the Equations 1 and 2 are used as follows:

Number of ICT places in demand =25800 / (88.7/100) =29086.

Number of ICT available places =29086 * (88.7+3.4)/100 =26788.

Belgium. In this case, AS and ANS rates are missing for this country. Therefore, for the estimation of places in demand, the AS value from DK, HU and SI will be used. Then, the estimation is performed calculating the average value of AS from DK, HU and SI: Average (51.5, 58.9, 61.3) = 58.9. The same applies for the estimation of the ANS rate: R = 12.9.

Number of ICT places in demand =13292 / (57.2/100) =23237.

Number of ICT available places =23237 * (57.2+12.9)/100 = 16289.

In the report, the figures have been rounded to the nearest hundred. However, all calculations and graphical representations were made with unrounded values.

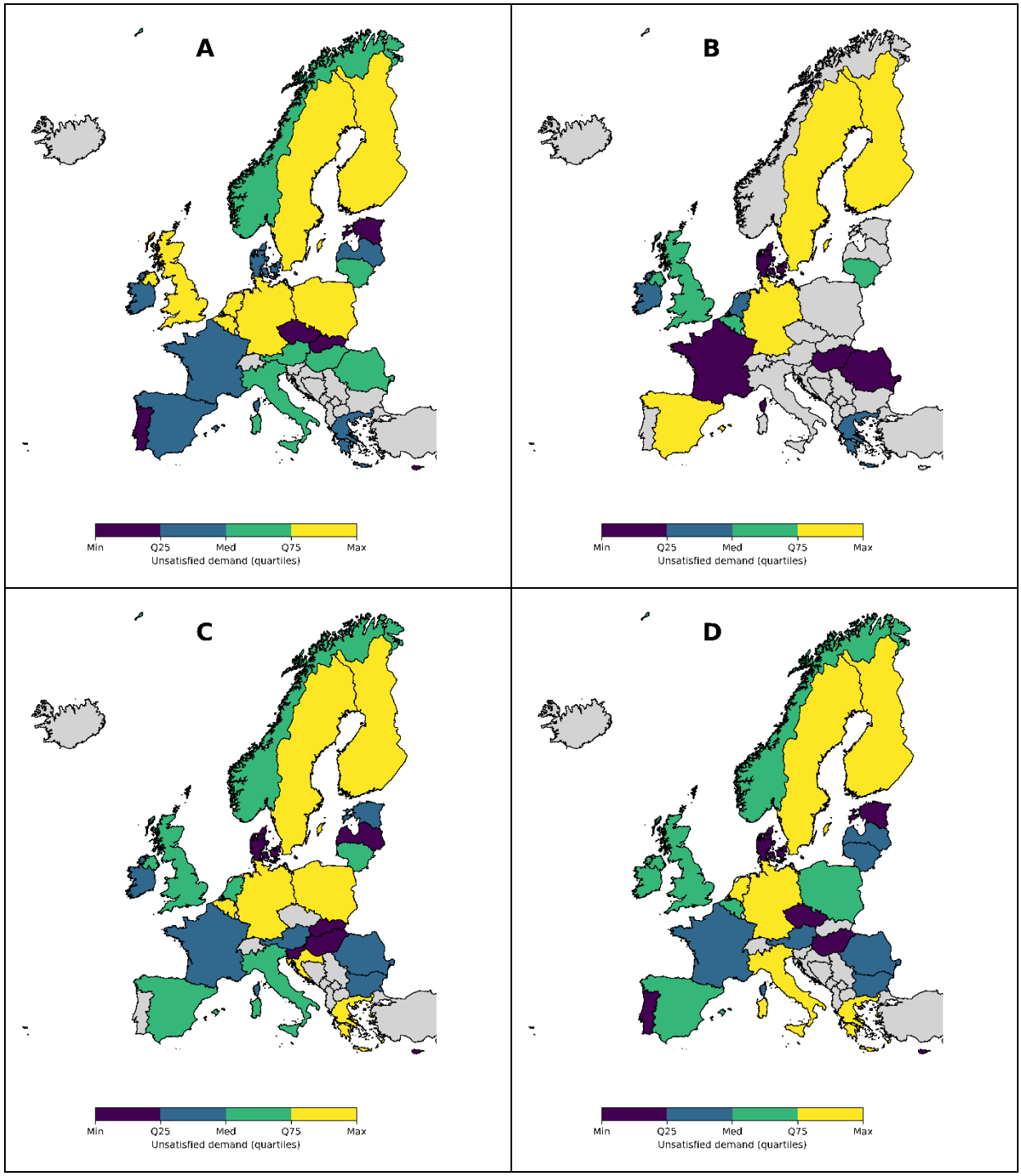
(II) Estimation of available places and places in demand for the domains of AI, HPC, CS and DS.

Once the number of available places and places in demand for the five fields of education was estimated at Bachelor's and Master's education levels, the proportion of AI, HPC, CS and DS places by country and scope of the programme (broad or specialised) was calculated, considering the proportion of programmes in each field of education including AI, HPC, CS and DS contents, according to the information from Righi & López-Cobo et al. (2020).

Annex 2. Supplementary figures. Quartile distribution for unmet demand

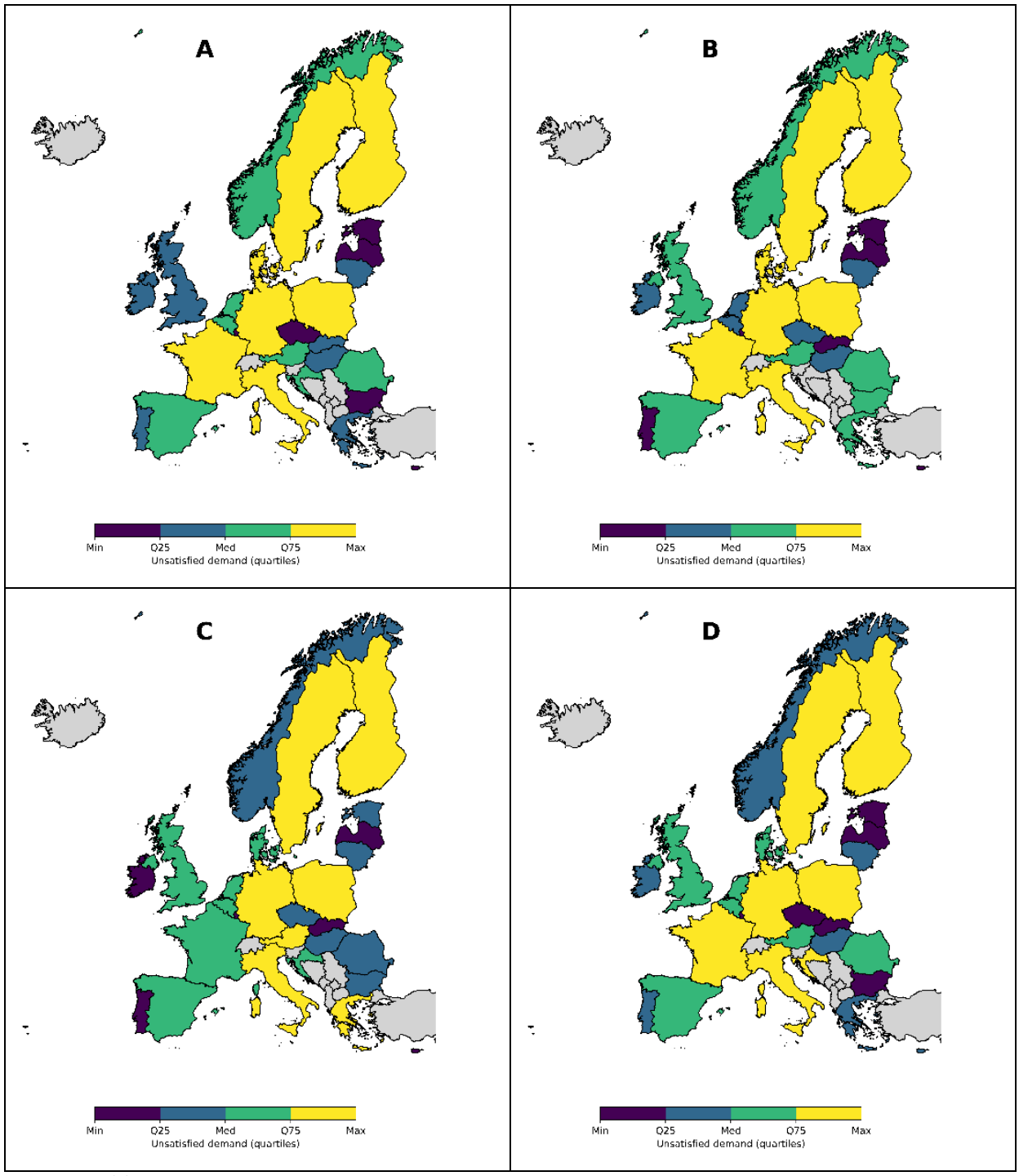
Maps showing the quantile distribution of unmet demand, estimated as the difference between places in demand and available places. Min: minimum value; Q25: 25th percentile, Med: median, Q75: 75th percentile, Max: maximum value.

Figure A2 1. Estimations of unmet demand (quartiles) for AI (A), HPC (B), CS (C) and DS(D), Bachelor or equivalent level, EU27, United Kingdom and Norway, 2019-20.



Source: JRC elaboration.

Figure A2 2. Estimations of unmet demand (quartiles) for AI (A), HPC (B), CS (C) and DS(D), at Master or equivalent level, EU27, United Kingdom and Norway, 2019-20.



Source: JRC elaboration.

Annex 3. Estimates of available places and places in demand

Table A3 1 Estimates of available (AP) and in demand (DP) places for AI, HPC, CS and DS, by education level (in thousands). EU27 Member States, United Kingdom and Norway, 2019-20.

	Bachelor								Master							
	AI		HPC		CS		DS		AI		HPC		CS		DS	
Country	AP	DP	AP	DP	AP	DP	AP	DP	AP	DP	AP	DP	AP	DP	AP	DP
BE	24.4	34.8	4.9	7.0	26.1	37.2	26.6	37.9	8.8	12.5	1.2	1.8	3.5	5.0	8.4	12.0
BG	-	-	-	-	3.3	5.6	4.3	7.1	0.4	0.7	0.8	1.3	1.1	1.8	0.8	1.3
CZ	4.6	5.3	-	-	-	-	1.2	1.4	4.8	5.6	2.4	2.7	3.6	4.2	2.6	3.0
DK	10.2	14.7	3.0	4.3	2.0	2.9	2.6	3.7	12.1	17.3	5.2	7.4	4.4	6.3	11.9	17.0
DE	179.6	255.8	33.4	47.6	63.9	91.0	86.8	123.7	83.7	119.3	21.0	29.9	36.7	52.2	80.9	115.3
EE	5.6	7.5	-	-	4.2	5.6	2.0	2.6	1.8	2.4	0.4	0.5	1.4	1.9	0.6	0.8
IE	5.4	8.4	3.4	5.2	4.9	7.6	5.6	8.7	1.7	2.7	0.8	1.3	0.9	1.4	2.2	3.5
EL	6.7	10.4	3.4	5.2	21.8	33.9	74.0	115.1	3.5	5.4	2.3	3.6	4.7	7.3	3.9	6.0
ES	19.6	22.6	18.7	21.6	21.1	24.3	50.6	58.5	25.1	29.0	6.9	7.9	8.3	9.6	28.0	32.4
FR	32.2	34.9	13.3	14.4	32.2	34.9	28.8	31.3	61.4	66.6	22.7	24.6	24.8	27.0	88.3	95.9
HR	-	-	-	-	15.7	26.3	-	-	3.7	6.2	-	-	3.2	5.3	13.5	22.6
IT	26.8	38.1	-	-	13.6	19.3	48.4	69.0	52.7	75.1	2.4	3.4	16.9	24.0	59.4	84.6
CY	0.6	1.1	-	-	0.3	0.5	0.1	0.2	0.7	1.2	0.2	0.4	0.7	1.1	1.0	1.6
LV	3.0	5.0	-	-	1.4	2.4	3.2	5.3	1.2	2.0	0.3	0.4	0.7	1.2	0.1	0.2
LT	6.9	16.7	1.9	4.6	3.3	8.1	1.9	4.6	1.6	4.0	0.3	0.7	0.4	1.1	1.7	4.1
LU	-	-	-	-	-	-	-	-	0.1	0.2	0.1	0.2	0.2	0.3	0.3	0.4
HU	18.0	27.2	2.2	3.3	2.2	3.3	3.1	4.6	3.1	4.7	0.8	1.2	1.0	1.5	3.6	5.5
MT	0.5	0.7	-	-	-	-	-	-	0.1	0.2	0.0	0.1	0.0	0.1	0.1	0.2
NL	29.0	41.3	4.8	6.8	21.5	30.6	44.3	63.2	10.5	14.9	1.0	1.4	4.0	5.7	18.0	25.7
AT	12.4	17.6	-	-	6.3	9.0	4.4	6.2	8.7	12.3	3.5	5.0	5.7	8.1	17.8	25.4
PL	107.1	152.6	-	-	24.0	34.2	18.0	25.7	25.2	35.8	4.3	6.2	7.0	9.9	43.1	61.4
PT	4.0	4.5	-	-	-	-	2.5	2.9	9.3	10.4	1.7	1.9	2.6	3.0	7.7	8.6
RO	55.0	63.5	5.1	5.9	10.2	11.8	10.2	11.8	33.6	38.8	9.1	10.5	7.4	8.6	23.7	27.4
SI	-	-	-	-	1.7	2.3	-	-	-	-	-	-	-	-	-	-
SK	2.6	3.0	-	-	1.3	1.5	-	-	11.6	13.4	0.6	0.6	1.1	1.3	1.1	1.3
FI	19.6	58.6	3.9	11.7	9.1	27.3	18.7	55.9	6.6	19.7	1.7	5.1	3.0	8.8	6.6	19.7
SE	13.0	35.5	7.8	21.3	17.1	46.8	6.5	17.9	12.7	34.7	2.7	7.4	3.4	9.2	9.5	26.1
UK	68.2	78.7	17.2	19.9	62.5	72.2	52.5	60.6	16.1	18.6	5.8	6.7	13.0	15.1	22.2	25.6
NO	25.3	34.4	-	-	25.9	35.2	30.4	41.4	8.4	11.5	2.8	3.8	3.0	4.1	8.3	11.2

-: Not available due to missing information in source data.

Source: JRC elaboration.

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KJ-NA-30377-EN-N

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doi:10.2760/559530

ISBN 978-92-76-22281-1