European Commission

JRC TECHNICAL REPORT

AI Watch: 2020 EU AI investments

Joint Research Centre

EUR 30826 EN

EU Science Hub
https://ec.europa.eu/jrc

JRC126477

EUR 30826 EN

PDF	ISBN 978-92-76-41492-6	ISSN 1831-9424	doi:10.2760/017514

Luxembourg: Publications Office of the European Union, 2021

How to cite this report: Alessandro Dalla Benetta, Maciej Sobolewski and Daniel Nepelski, AI Watch: 2020 EU AI investments, EUR 30826 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-41492-6, doi:10.2760/017514, JRC126477.

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Foreword

Artificial Intelligence (AI) has become an area of strategic importance with potential to be a key driver of economic development. AI also has a wide range of potential social implications. As part of its Digital Single Market Strategy, the European Commission put forward in April 2018 a European strategy on AI in its Communication "Artificial Intelligence for Europe". The aims of the European AI strategy announced in the communication are:

- To boost the EU's technological and industrial capacity and AI uptake across the economy, both by the private and public sectors
- To prepare for socio-economic changes brought about by AI
- To ensure an appropriate ethical and legal framework.

In December 2018, the European Commission and the Member States published a "Coordinated Plan on Artificial Intelligence", on the development of AI in the EU. The Coordinated Plan mentions the role of AI Watch in supporting monitoring its implementation.

Subsequently, in February 2020, the Commission unveiled its vision for a digital transformation that works for everyone. The Commission presented a White Paper proposing a framework for trustworthy AI based on excellence and trust.

Furthermore, in April 2021 the European Commission proposed the AI Package, a set of actions to boost excellence in AI through the review of the Coordinated Plan on AI, and proposal for Artificial Intelligence Act, legal rules to ensure that the technology is trustworthy. The proposed Artificial Intelligence Act and the review of the Coordinated Plan on AI aim to guarantee the safety and fundamental rights of people and businesses, while strengthening investment and innovation across EU countries.

This report is published in the context of AI Watch, the European Commission knowledge service to monitor the development, uptake and impact of AI for Europe, launched in December 2018. AI Watch monitors the European Union's industrial, technological and research capacity in AI; AI-related policy initiatives in the Member States; uptake and technical developments of AI; and AI impact. AI Watch has a European focus within the global landscape. In the context of AI Watch, the Commission works in coordination with Member States. AI Watch results and analyses are published on the AI Watch Portal (https://ec.europa.eu/knowledge4policy/ai-watch_en).

From AI Watch in-depth analyses we will be able to understand better the European Union's areas of strength and areas where investment is needed. AI Watch will provide an independent assessment of the impacts and benefits of AI on growth, jobs, education, and society.

AI Watch is developed by the Joint Research Centre (JRC) of the European Commission in collaboration with the Directorate-General for Communications Networks, Content and Technology (DG CONNECT).

This report addresses a key objective of AI Watch: to provide a methodology and estimates of investments levels in AI in Europe. Following the first report describing the methodology to estimate AI investments released in 2020, it presents an update of AI investments in Europe in 2018 and 2019.

Acknowledgements

The authors would like to thank the participants of Workshop on estimating AI investments held on the October 6th 2020 including Karine Perset (OECD), Juan Fernandez de Guevara (IVIE), Andrea de Panizza (ISTAT) as well as Maikki Sipinen, Tatjana Evas and Martin Ulbrich (DG CNECT) for their comments and suggestions.

Data on AI patents and AI university programmes provided by Giuditta De Prato, Montserat López-Cobo and Miguel Vazquez-Prada Baillet from the JRC (PREDICT project) are gratefully acknowledged.

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Executive summary

AI Watch monitors AI-related development and provides analyses to support the implementation of the European AI initiatives. This AI Watch report focuses on AI investments. It updates estimates of AI investments in EU27 in 2018 and provides for the first time data for 2019.

In line with the *Coordinated Plan on Artificial Intelligence* developed by the European Commission and Member States, this report considers AI as a general-purpose technology. It assumes that comprehensive support and funding of AI development and translation of the opportunities offered by AI into new business models and processes is needed to trigger the wave of AI-driven innovation. Hence, the current framework goes beyond direct investments in the development and adoption of AI technologies and considers also investment in complementary assets and capabilities such as skills, data, product design and organisational capital among AI investments. It groups AI-related investments into four investment targets: *Skills*, *R&D*, *Data and equipment* and *Intangible assets*.

According to the current estimates in 2019, the EU invested between **EUR 7.9 billion** and **EUR 9 billion in AI**. This corresponds to 40-45% of the annual investment target of EUR 20 billion to be reached by 2030 that was set in the *Artificial Intelligence for Europe* Communication (COM(2018) 237).

The majority of EU AI investments concentrate in labour and human capital covered by the *Skills* investment target (53%). Expenditures on AI-related *Data and equipment* account for 30%. *R&D* and *Intangible assets* account for 10% and 7% of the total EU AI investments respectively.

The contribution of the European **public sector** is considerable and accounts for 41% of total AI investments in 2019. This includes outlays on AI education as well as the adoption of AI technologies by the public sector.

Regarding the **AI investments at the Member States level**, the highest absolute amounts are spent by the largest countries, i.e. France and Germany. In terms of AI investment per capita, **Nordic countries and Ireland** are the top scorers. In general, there are large variations among the countries in per capita expenditures. This is likely to reflect structural differences between their economies, different levels of AI readiness as well as prioritisation of AI in the national strategies.

Compared to 2018, **in 2019 AI investments in the EU grew by approx. EUR 2.1-2.5 billion or approx. 39%**. If the EU maintains a similar level of growth as between 2018 and 2019, by 2025 the AI investments will reach EUR 22.4 billion and **surpass the EUR 20 billion target by over 10%**. The private sector recorded a higher increase in spending than the public sector (45% vs 31% y-o-y growth). The largest increase of the private sector spending on AI was recorded in the asset category related to Data and equipment (EUR 705 million or 28% of the total difference between 2018 and 2019). Public sector spending increased predominantly in the Skills category (EUR 623 million or 25% of the total difference between 2018 and 2019).

This report builds on the work started under the AI Watch project in 2019 to estimate AI investments in Europe. Following the methodology outlined in the first report on AI investments released in 2020 (Nepelski & Sobolewski, 2020). The current methodology to estimate AI investments consists of two steps. In the first step, data on the economy-wide levels of expenditures in all relevant categories are collected. In the second step, these expenditures are weighted with AI-intensity coefficients to reflect amounts that are attributable to AI creation and adoption. While the data used in the first step come from public sources, e.g. EUROSTAT, the data used to compute AI-intensity coefficients stem from proprietary data sources, e.g. EPO PATSTAT or Study Portals.

This report is a part of a wider 'AI Watch' initiative to monitor European Union's industrial, technological and research capacity in AI; AI-related policy initiatives in the Member States; uptake and technical developments of AI; and AI impact.

1. Introduction

In order to increase investments in AI, the EC Communication on Artificial Intelligence for Europe set a target to increase investments in AI in order to reach the target of EUR 20 billion combined the public and private sector AI investment per year by 2030 (EC, 2018). Coordination of AI policy and investments at the European level is essential to seize the benefits of AI for the economy, society and the environment and help to promote European values worldwide.[1]

Even with high European and global interest and activity in AI, among many open questions around this promising technology, the one concerning estimating the level of AI investments is particularly challenging. Various sources provide various figures. This blurs the understanding of the AI-driven revolution and constraints informed decision making.

The information on AI investment in the 27 EU Member States gathered for this report allows estimating the current total AI investment volume in Europe; as well as tracking its direction as more annual figures become available. This is key in monitoring of the implementation of the Coordinated Plan on Artificial Intelligence and especially the progress toward reaching the EUR 20 billion annual investment target. The estimates are available not only on the EU level, but also in unified form on the level of EU Member States' to provide a useful estimate for Member States' policy makers on the volume and direction of their national AI investment and its components, and to help them compare their investment levels to those of other countries.

This report is based on the latest available data and presents estimates of AI investments in Europe in 2018[2] and 2019. It uses the methodology outlined in the first AI Watch report on estimating AI investments (Nepelski & Sobolewski, 2020).

The methodological approach taken in this study has a wider scope than most of the existing attempts to quantify AI investments. Most of the studies and reports take a partial view of AI investments and look only at the level of R&D expenditures of large digital firms or the flow of venture capital to AI start-ups (MGI, 2017; Science-Business, 2018).[3] In contrast, the current report considers AI as a general-purpose technology (GPT) (Brynjolfsson & McAfee, 2017; Brynjolfsson, Rock, & Syverson, 2018; Trajtenberg, 2018) and takes a top—down approach to AI investments based on national level statistics. It builds on the assumption that in addition to investments in developing AI technologies, complementary investments in intangible assets including data, skills and organisational capital are necessary for a successful deployment of AI in the economy and society. As a result, our methodology considers a wide set of expenditures on labour and tangible and intangible assets related to AI development and adoption.

In addition, the current approach recognizes the public sector as one of the main drivers of the technologically-enabled economic growth. By providing funding and support at the initial stages of technology creation and diffusion, the public sector creates the foundation for non-existing markets (Mazzucato, 2016; NIST, 2019). This is clearly the case in the context of AI. The public sector was intensively supporting the development of technology at its early stages (Delipetrev, Tsinaraki, & Kostic, 2020). Once the first technological building blocks of AI were laid down and the technology was ready for a take-up, the private sector entered into the picture and assumed further development and commercialisation of technologies. To account for this "division of labour", the current framework distinguishes between AI investments made by economic agents from market and non-market sectors. This breakdown is operationalised by the use of statistical definitions separating private from public investments to account for different roles that the two sectors have in the technologically-driven economic progress.

The approach taken in this work therefore attempts to include all relevant investment types and actors contributing to the AI-driven revolution. The estimates of AI reported in this report are thus not directly comparable with other attempts to quantify AI investments that focus on a specific aspect of AI investments.

[1] European Commission, Communication Fostering a European approach to Artificial Intelligence COM(2021) 205 final

[2] AI Watch intends to use the most recent data. In 2019, for countries that were missing the most recent data on investments, data were imputed using data available for the previous years. The current report revisits the estimations presented in 2019 and, whenever new data is available, replaces the calculations based on imputed data using data provided by the original data. For more details on the methodology and data, please see Annex I.

[3] For an overview of existing attempts to quantify AI investments please see Annex II.

2. Key elements of the methodology to estimate AI investments

This report uses the top-down approach to AI investments based on national level statistics to estimate AI investments defined in the first AI Watch report on the AI investments (Nepelski & Sobolewski, 2020). Below, the key methodological steps are recalled. Further methodological details and explanations concerning the limitations of the current approach can be found in Annex I. In addition, Annex II provides a short overview of existing attempts to estimate AI investments.

The key assumption of the AI Watch framework for estimating AI investments is that AI is a general-purpose technology (GPT). Being a GPT, the economic and innovative potential of AI lies in its capacity to modernise the entire economy rather than in the strength of the AI producing sector only. A GPT impacts production processes by increasing productivity of production factors, i.e. labour and capital.

In this light, our proposed framework identifies relevant expenditure categories related to both AI **creation** and **implementation** by all sectors of the economy in the form of augmented capital and labour inputs. On the creation side, expenditures on **education** and **skills** enhancement are considered together with expenditures on research and development (**R&D**). On the technology implementation side, selection of relevant expenditure items follows directly from the concept of the production function and the role of technological progress in augmentation of production inputs. Therefore the framework looks at investments in **tangible** and **intangible** assets, e.g. software, hardware and data, and expenditure on labour (Bresnahan, Brynjolfsson, & Hitt, 2002). Given that successful implementation of AI requires reorganisation or adaptation of an organisation around a new technology, design of new business processes and training of its staff (Brynjolfsson et al., 2018), the framework accounts for expenditures on organisational capital, brand and product design (Corrado, Hulten, & Sichel, 2005).

The set of assets and capabilities relevant for an economy-wide uptake of AI can be grouped into four target categories corresponding to the 2018 Coordinated Plan on AI:

- **Skills**: This category includes expenditures on AI-related *education programmes*, *corporate training* and *compensation of AI specialists*.
- **R&D**: This category includes expenditures on AI-related *R&D.*
- **Data and equipment**: This category contains the investments in AI-related *software, hardware, telecommunications equipment* and *data*.
- **Intangible assets**: including AI-related *product design, brand, and organisational capital*.

The public and private sectors have complementary roles in the process of AI development and diffusion. While the public sector supports the AI development at its early stages, private actors assume further development and commercialisation of AI. Balancing the investments by the two sectors is necessary for the AI uptake. In order to recognise the co-existence of both sectors in the AI creation and diffusion, the current framework distinguishes between investments made by public and by private actors.

Considering the above, the current approach considers AI investments as:

> *Expenditures on labour and skills as well as tangible and intangible capital assets incurred by public and private organisations to develop and implement AI to (re-)design business processes in order to create new or improve existing products or services.*[4]

The report relies to a large extent on publically available data such as, for example, Gross Factor Capital Formation, wages or educational statistics by Eurostat. As presented in the first AI Watch report on estimating AI investments (Nepelski & Sobolewski, 2020), this top-down approach to estimate AI investments consists of two steps. In the first step, data on the economy-wide levels of expenditures in the target categories are collected. In the second step, these expenditures are weighted with AI-intensity coefficients to reflect amounts that are attributable to AI creation and adoption.

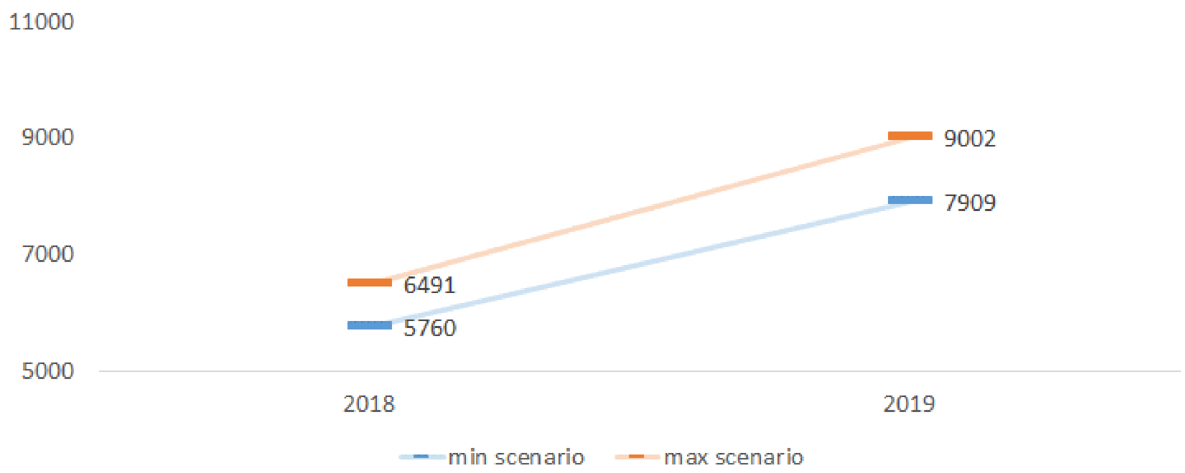
To account for changes in the structure of supply and demand for AI technologies and skills in the economy, **minimum** and **maximum AI investments scenarios** were computed. The *min* and *max* scenario takes a long- and short-term perspective on the development and diffusion of AI respectively. Figures are reported in constant prices. The base year is 2018. For further details on the data and methodology, please see Annex I.

[4] The current approach to define AI investments takes a broader view of "investments" than the one used in the context of business statistics. It includes intangible asset types that are not commonly considered as "investments" in statistics or accounting. For example, training of employees or business process improvements are accounted as "expenditures". The choice to consider such expenditures as investments in AI is justified by their critical role in the process of AI diffusion.

3. EU AI investments

In 2019, the overall level of AI investments for the 27 EU Member States is estimated to be in the range of EUR 7.9-9 billion. Compared to 2018, EU AI investments increased by EUR 2.1-2.5 billion or approx. 39%. This corresponds to 40-45% of the EUR 20 billion investment target set in the EC Communication on Artificial Intelligence for Europe (EC, 2018). If the EU maintains a similar level of growth as between 2018 and 2019, i.e. approx. EUR 2.3 billion, by 2025 the AI investments will reach EUR 22.4 billion and surpass the EUR 20 billion target by over 10%. Figure 1 presents the evolution of AI investment between 2018 and 2019 in EU.

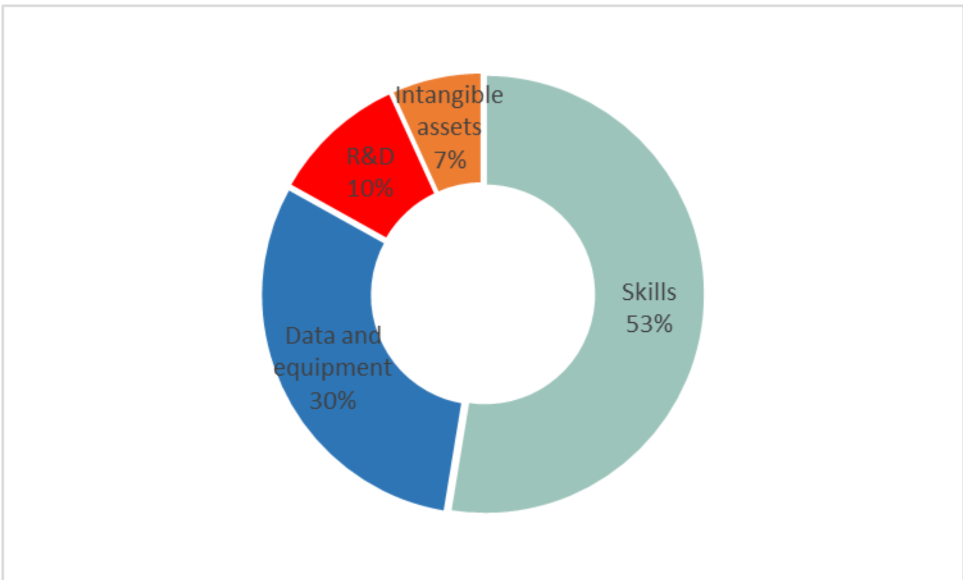
Figure 1: EU AI Investment, EUR million, 2018 and 2019



Source: JRC based on EUROSTAT, Spintan and Intan-Invest data. Note: Figure presents estimates for the maximum scenario (see Annex I) in constant prices. Base year: 2018.

The Skills investment target accounts for the majority of AI investments in Europe (53%). Expenditures on AI-related Data and equipment represent 30% of the total AI investments in the EU. R&D and Intangible assets account for 10% and 7% of the total EU AI investments respectively. Figure 2 presents the composition of expenditures by AI investment targets.

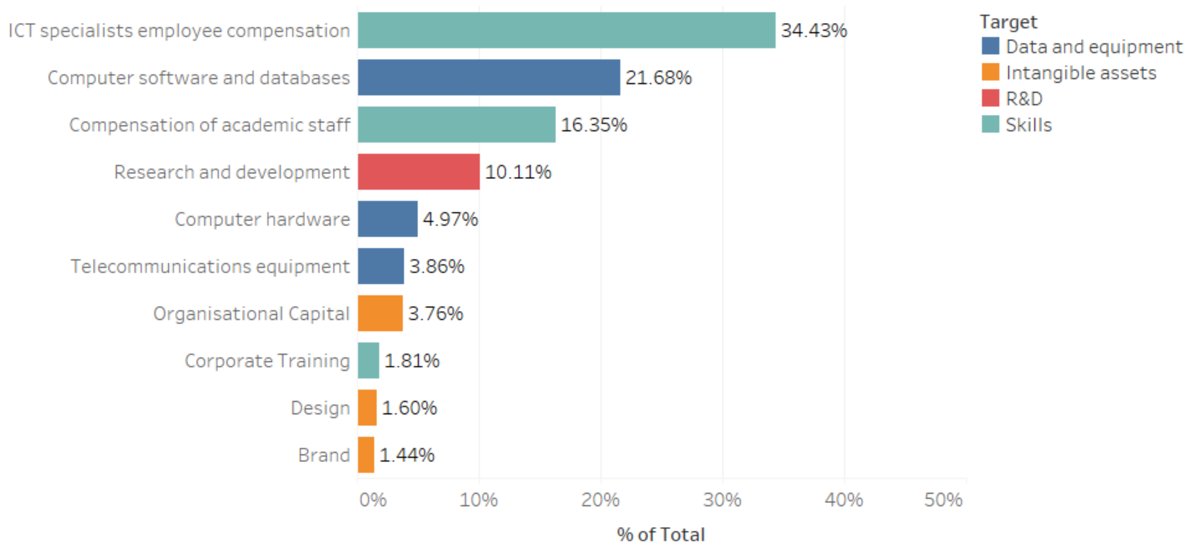
Figure 2: EU AI investment by investment target, 2019



Source: JRC based on EUROSTAT, Spintan and Intan-Invest data. Note: Figure presents estimates for the maximum scenario (see Annex I).

The largest stream of funding was targeted at AI “ICT specialists’ compensation”, followed by “Computer software and databases” and “Academic staff compensation”. Investments in intangible assets, including Brand, Computer software and databases, Design, Organisational Capital, R&D and Corporate Training, account for over 40% of the total expenses - four times more than the expenses on hard infrastructure, i.e. computer hardware and telecommunication equipment. This proportion is in line with previous findings (Brynjolfsson, et al., 2018). The detailed composition of expenditures by expenditure items is presented in Figure 3.

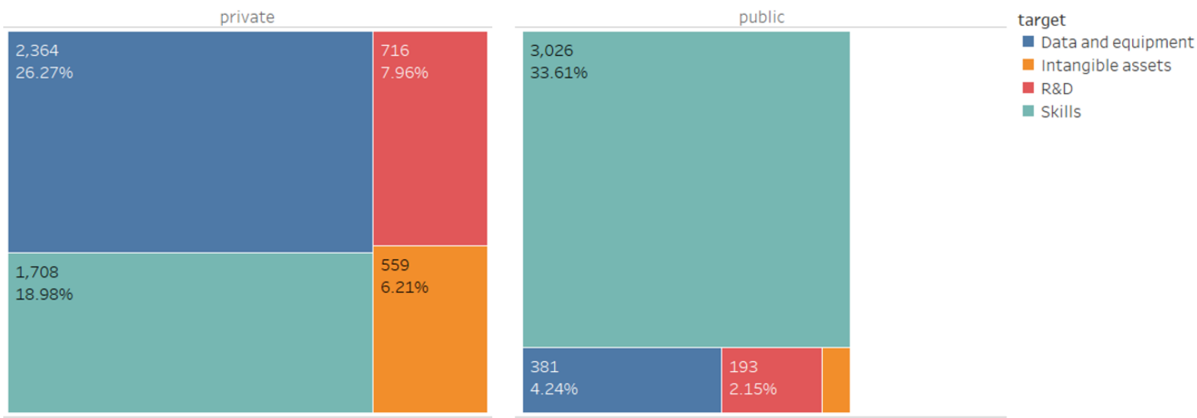
Figure 3: EU AI investments by asset items, 2019



Source: JRC based on EUROSTAT, Spintan and Intan-Invest data. Note: Figure presents estimates for the maximum scenario (see Annex I).

Figure 4 and Table 1 present the breakdown of the AI investments by the sector of activity. The public sector accounts for 41% of total AI investments. The Skills investment target has the largest share of investments made by the public sector. Overall, it accounts for 33% of the total AI investments in Europe. the private sector accounts for the lion’s share of investments in the remaining two categories, i.e. R&D and Data and equipment.

Figure 4: EU AI investments by target and sector, EUR million and % of total, 2019



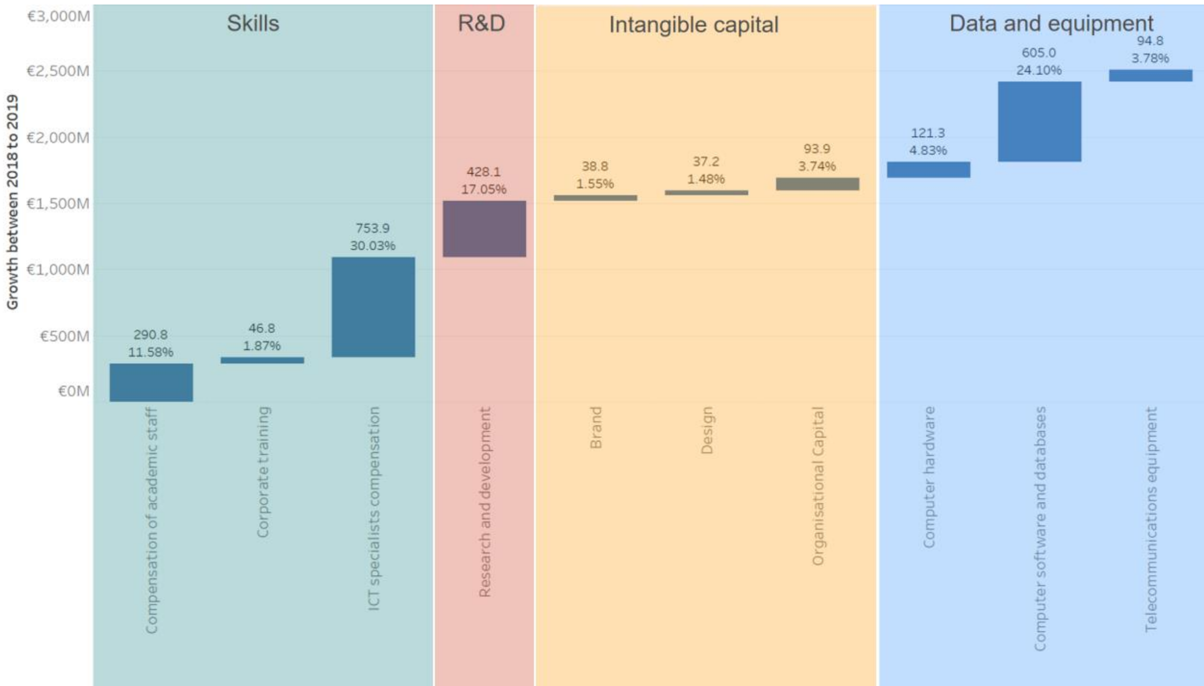
Source: JRC based on EUROSTAT, Spintan and Intan-Invest data. Note: Figure presents estimates for the maximum scenario (see Annex I) in constant prices. Base year: 2018.

4. Dynamics of EU AI investments

In 2019 the volume of AI investments increased by EUR 2.51 billion compared to 2018. A decomposition of this amount shows that this increase was driven to a larger extend by the private sector (EUR 1.66 billion or 66% share), however the contribution of the public sector also increased significantly (EUR 856 million or 34% share). Overall, the private sector recorded a higher dynamics of spending than the public sector (45% vs 31%).

Considering the maximum scenario, the EUR 2.51 billion increase in AI investment between 2018 and 2019 is decomposed to the various investment items in Figure 5. The top three items contributing to the increase in AI investments in 2019 were compensation of ICT specialists (EUR 754 million or 30% of the total increase in AI investment between 2018 and 2019), spending on Computer software and databases (EUR 605 million) and spending on R&D (EUR 428 million).

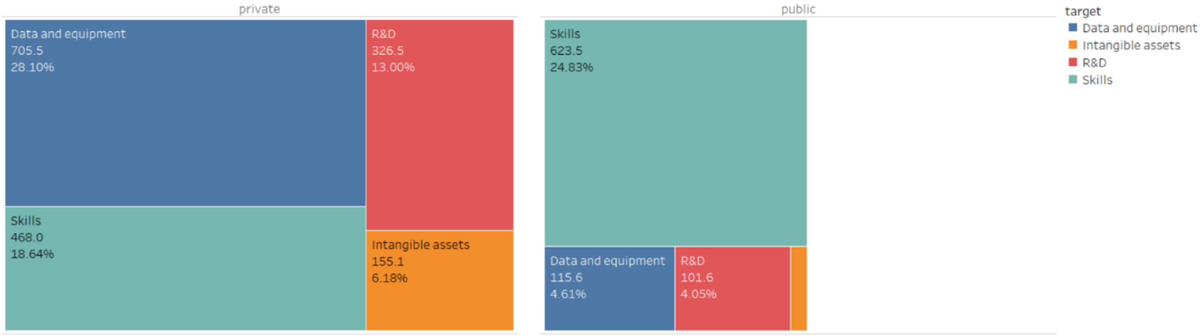
Figure 5: EU AI investment change between 2018 and 2019 by asset items, EUR million and % of total



Source: JRC based on EUROSTAT, Spintan and Intan-Invest data. Note: Figure presents estimates for the maximum scenario (see Annex I) in constant prices. Base year: 2018.

Another decomposition of the EUR 2.51 billion increase in AI investment shown in Figure 6 provides two observations. First, the private sector contributed significantly more than the public sector (EUR 1 655 vs EUR 856 million or 66% vs. 34% of the total increase in AI investment between 2018 and 2019). Second, the contribution of the private sector is much more balanced concerning the investment assets than the public sector. In the private sector, spending on Data and equipment recorded the highest increase in absolute terms (EUR 705 million) followed by spending on Skills (EUR 468 million) and R&D (EUR 326 million). On the public sector part, the increase in AI investments was predominantly driven by spending on Skills (EUR 623.5 million out of EUR 856 million) while the spending on R&D and Data and equipment asset categories increased only by EUR 101 million and EUR 115 million respectively.

Figure 6: EU AI investment change between 2018 and 2019 by sector and investment target, EUR million and % of total change



Source: JRC based on EUROSTAT, Spintan and Intan-Invest data. Note: Figure presents estimates for the maximum scenario (see Annex I) in constant prices. Base year: 2018.

Table 1 shows the structure and dynamics of AI investments. The two largest investment items in 2019 were compensation of ICT specialists and computer software and databases, amounting to nearly 56% of the total investments in that year. All investment items recorded similar to the average growth rate between 2018 and 2019 (35-45%), with a notable exception of R&D spending, which grew significantly faster in that period (89%). Looking at the sectorial breakdown, presented in the bottom part of Table 1, the prominent role of the private sector becomes apparent. Investment of the private sector were larger, making up for nearly 60% share in total AI investment spending in 2019 and grew at a significantly faster pace, compared to the public sector (45 vis-à-vis 31%) between 2018 and 2019.

In conclusions, the private sector recorded a higher dynamics of spending than the public sector (45% vs 31% y-o-y growth). As a result, its share in total AI investment increased in 2019 compared to 2018.

The largest increase of the private sector spending on AI was recorded in the asset category related to data, technology and infrastructure (EUR 705 million or 42% share). The remaining asset categories also note a significant increase of spending, which indicates a balanced composition of investments in the private sector. The public sector spending increased predominantly in the Skills asset category (EUR 623 million or 72% share) and was thus more imbalanced.

On the level of particular asset items, the increase of AI investment (EUR 2.51 billion) was driven by spending on ICT specialists (EUR 705 million), spending on computer software and databases (EUR 605 million) and spending on R&D (EUR 428 million). These three asset items make up for 71% of the total increase in AI investments between 2018 and 2019.

Looking at the dynamics, all asset items grew at a similar pace (35-45%) year-over-year. The notable exception is R&D, which recorded 89% y-o-y growth.

Table 1: 2019 AI investment structure and dynamics by target and sector

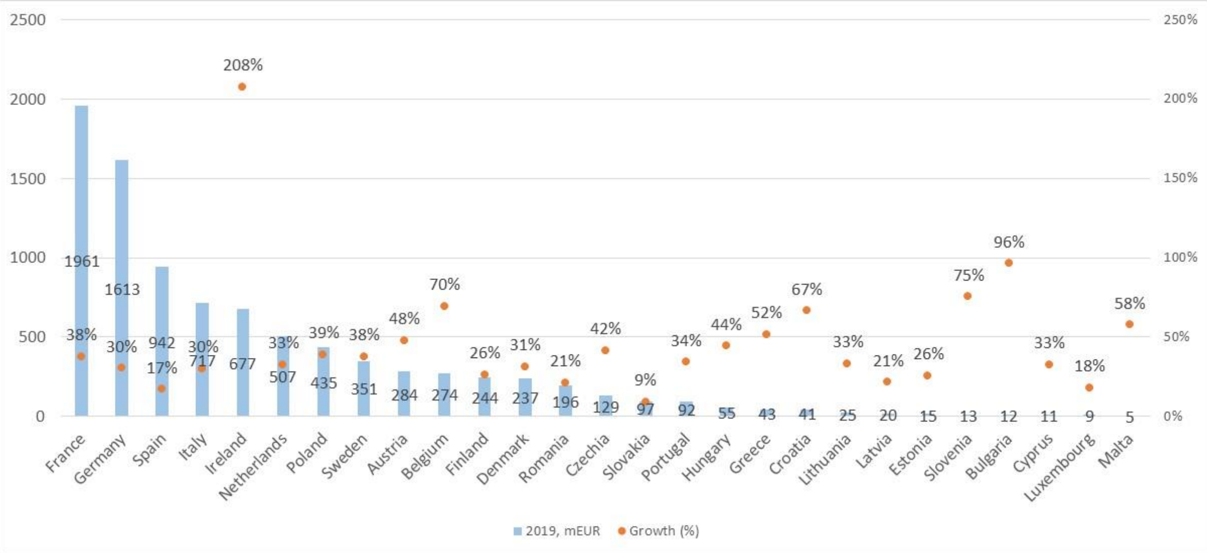
Investment target	Investment item	Investment structure	Growth 2018 – 2019 (%)
Skills	ICT specialists' compensation	34%	132%
	Academic teachers' compensation	16%	125%
	Corporate training	2%	140%
Intangible assets	Brand	1%	143%
	Organisational Capital	4%	138%
	Design	2%	135%
R&D	Research & development	10%	189%
Data and equipment	Computer hardware	5%	137%
	Computer software and databases	22%	145%
	Telecommunications equipment	4%	138%
Sector			
	Private	59%	145%
	Public	41%	131%
Total Investments			**139%**

Source: JRC based on EUROSTAT, Spintan and Intan-Invest data. Note: Table presents estimates for the maximum scenario (see Annex I).

5. AI investments by country

Figure 7 presents the amount and growth rate between 2018 and 2019 of AI investments by country according to the max scenario. Similarly to 2018, as can be expected, the highest absolute amounts are spent in the largest countries. France and Germany account for nearly 40% of the total AI investments in the EU.

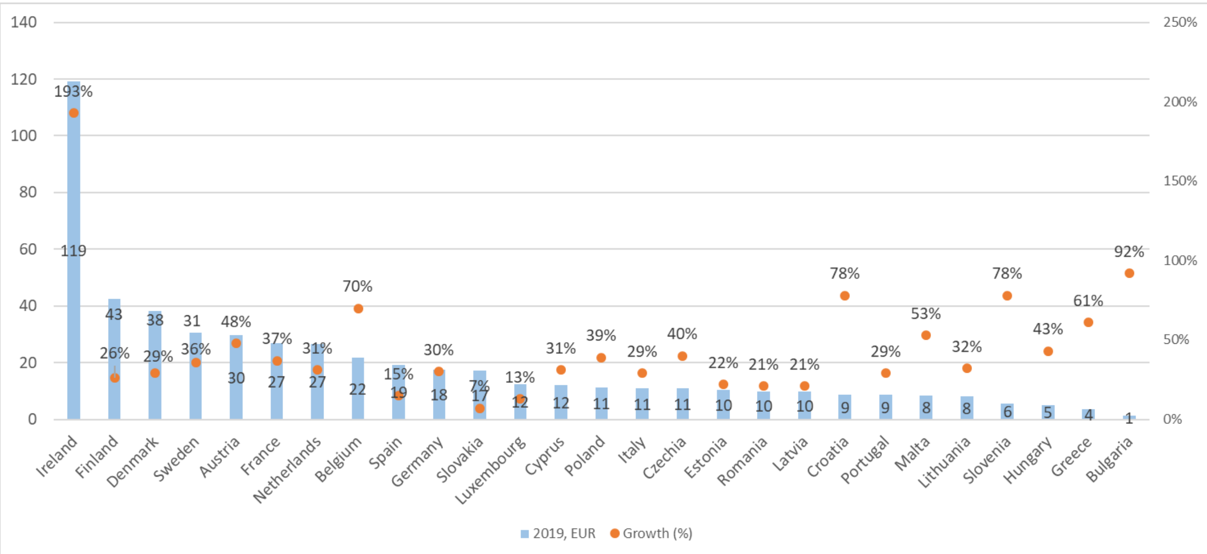
Figure 7: 2019 AI investments by country (EUR million) and growth (%) between 2018 and 2019



Source: JRC based on EUROSTAT, Spintan and Intan-Invest data. Note: Figure presents estimates for the maximum scenario (see Annex I) in constant prices. Base year: 2018.

When the per capita investments or the share of AI investments in a country's GDP are examined (see Figure 8), Nordic countries and Ireland are the top scorers, spending more than EUR 40 per capita on AI.[5] In general there is a large variation among the Member States in per capita expenditures, with developing economies spending considerably less than developed ones.

Figure 8: AI investments per capita by country (EUR) in 2019 and growth (%) between 2018 and 2019



Source: JRC based on EUROSTAT, Spintan and Intan-Invest data. Note: Figure presents estimates for the maximum scenario (see Annex I) in constant prices. Base year: 2018.

[5] The large increase of AI investments in Ireland is discussed in Annex II analysing the limitations of data used in estimating AI investments.

6. Concluding remarks

Drawing on the latest available data, this report presents the estimates of AI investments in Europe in 2018 and 2019 using the methodology outlined in the first AI Watch report on estimating AI investments (Nepelski & Sobolewski, 2020).

According to the estimates, in 2019, EU AI investments reached approx. EUR 7.9-9 billion. This corresponds to 40-45% of the EUR 20 billion investment target and, compared to 2018, represents an increase by EUR 2.1-2.5 billion. If the EU maintains a similar level of growth as between 2018 and 2019, by 2025 the AI investments will reach EUR 22.4 billion and surpass the EUR 20 billion target by over 10%.

The increase of AI investments in 2019 was driven to a larger extent by the private sector. The private sector recorded also a higher growth of spending than the public sector, which indicates that the share of private investments in total AI investments increased in 2019 compared to 2018.

The largest increase took place in private investments in Data and equipment, which increased by EUR 705 million and represented 28% of the total increase of EU AI investments between 2018 and 2019. Other asset categories also recorded a strong increase, indicating a more balanced composition of expenditures. The public sector spending increased predominantly in the Skills category (EUR 623 million).

On the level of particular asset items, the increase of AI investment (EUR 2.5 billion) was driven by spending on ICT specialists (EUR 705 million), spending on Computer software and databases (EUR 605 million) and R&D (EUR 428 million).

In geographical terms, countries with the fastest-growing AI investments are Ireland[6], Bulgaria, Slovenia and Belgium.

The current study is the only existing attempt to estimate economy-wide AI investments and monitor them consistently over time. At the end of 2021, the AI Watch plans to publish an updated report on AI investments. It will include revised figures for 2018 and 2019 as well as new estimates for 2020.

[6] The large increase of AI investments in Ireland is discussed in Annex II analysing the limitations of data used in estimating AI investments.

Annex I: Methodology to estimate AI investments

This report uses the methodology to estimate AI investments defined in the first AI Watch report on the AI investments (Nepelski & Sobolewski, 2020). Drawing on the latest available data, it revisits the 2018 estimates and adds AI investment estimates for 2019. Below, the key methodological steps are recalled.

As presented in the first AI Watch report on estimating AI investments, AI investments estimation is carried out with a top-down approach and consists of two steps. In the first step, data on the economy-wide levels of expenditures in all relevant categories are collected. In the second step, these expenditures are weighted with AI-intensity coefficients to reflect amounts that are attributable to AI creation and adoption.

I. Step one: Economy-wide levels of investments

In the first step, the country-level data is compiled on economy-wide expenditures in the European Union corresponding to the three investment targets: *Skills*, *R&D* and *Data and equipment* and *Intangible assets.* The three targets include ten different investment items. The final dataset consists of 532 data points per year corresponding to country-item-sector combinations. Table 2 presents the three investment targets, items and data sources used.

Table 2: Investment targets, items and data sources

Investment targets	Investment item	Data source
Skills	ICT specialists' compensation	Eurostat: ICT statistics (isoc_sks_itspe) / National Accounts (nama_10_a64_e) / Wages (earn_ses_hourly; lc_lci_lev; lfsa_esegn2) / Educational statistics (educ_uoe_grad02)
	Academic teachers' compensation	Eurostat: Educational statistics (educ_uoe_fini01, educ_uoe_perp02)
	Corporate training	Intan-invest (private sector)
Intangible assets	Organisational capital	Intan-invest (private sector) Spintan (public sector)
	Brand	
	Design	
R&D	Research & development	Eurostat: National Accounts GFCF (nama_10_an6; nama_10_nfa_fl)
Data and equipment	Computer hardware	
	Computer software and databases	
	Telecommunications equipment	

Source: JRC.

II. Step two: AI intensity coefficients

In the second step, for each type of aggregated expenditures collected in the first step, a corresponding share of AI was estimated. To obtain the AI share of investments, all economy-wide expenditure items from step one were weighted by the respective AI intensity coefficients, which can take values between 0% and 100%.

Table 3 provides the correspondence between expenditure items and AI intensity coefficients and their definitions. Each aggregate expenditure item has been treated with exactly one coefficient as indicated in the last column of Table 3.

Table 4 provides definitions of the AI intensity coefficients together with the data source and description of methodologies that were used to compute them. In addition, the time coverage of the data used is provided. Basic descriptive statistics of the coefficients are given in Table 5.

According to Table 5, the first two intensity coefficients, *the share of AI patents in total number of patents worldwide* and *the share of AI patents in total number of ICT patents worldwide*, have the same value for all the countries, i.e. 0.1% and 0.8% respectively. The remaining three, i.e. *the share of AI ICT specialists in country's total number of ICT specialists*, *the share of AI patents in country's total number of patents* and *the share of AI university programmes in country's total programmes*, take individual values for each country. According to Table 5, *the share of AI ICT specialists in country's total number of ICT specialists* ranges between 0% and 3.8% and has an average of 1%. *The share of AI patents in country's total number of patents* takes values between 0% and 1.1% and *the share of AI university programmes in country's total programmes* between 0% and 6.5%. It must be mentioned that, in most of the cases, value zero is a result of unavailable data for an individual country.

To partially account for changes in the structure of supply and demand for AI technologies and skills in the economy, minimum and maximum AI investments scenarios were computed. In the *min* scenario, to take a long-term perspective of the AI impact on the economy, patent-based coefficients based on the 18-year period between 2000 and 2017 were used (see Table 4). The *max* scenario relies on patent coefficients computed for the 8-year period between 2010 and 2017 that is assumed to reflect the most recent developments in the field of AI and its diffusion in the economy. As patent coefficients under the *max* scenario are larger, the implied AI estimates are larger as well.

Table 3: Investment items and corresponding AI intensity coefficients

Investment targets	Investment item	AI intensity coefficient applied
Skills	ICT specialists' compensation	% AI ICT specialists in country's total number of ICT specialists
	Academic teachers' compensation	% of AI university programmes in country's total programmes
	Corporate training	% of AI patents in total number of patents worldwide
Intangible assets	Organisational capital	
	Brand	
	Design	
R&D	Research & development	% of AI patents in country's total number of patents
Data and equipment	Computer hardware	% of AI patents in total number of ICT patents worldwide
	Computer software and databases	
	Telecommunications equipment	

Source: JRC.

Table 4: AI intensity coefficients, time coverage and data sources

AI intensity coefficient applied	Coefficient definition	Time coverage and data source	Compilation method
% of AI patents in total number of ICT patents worldwide	Number of AI patent applications over total ICT patent applications submitted worldwide.	Min. scenario: 2000-2017; Max. scenario: 2010-2017; PATSTAT by European Patent Office	Text matching on dictionary with AI terms with patent titles and descriptions (De Prato et al. 2019)
% of AI patents in total number of patents worldwide	Number of AI patent over total number of patent applications submitted worldwide.		
% of AI patents in country's total number of patents	Number of AI patent applications over total number of patent applications submitted in a given country.		
% AI ICT specialists in country's total number of ICT specialists	Number of AI ICT specialists, approximated by the number of AI ICT graduates in the years 2015-17, over total number of ICT specialists in a given country.	2020; Study Portals and (Lopez-Cobo et al., 2019) 2016-2017; Eurostat educational statistics	Text matching on dictionary with AI terms with university programme descriptions (De Prato et al. 2019)
% of AI university programmes in country's total programmes	Number of specialized AI programs over all university programs available in a given country.	2020; Study Portals and (Lopez-Cobo et al., 2019)	

Source: JRC.

Table 5: Descriptive statistics of AI intensity coefficients in the max scenario

statistics	% of AI patents in total number of patents worldwide	% of AI patents in total number of ICT patents worldwide	% AI ICT specialists in country's total number of ICT specialists	% of AI patents in country's total number of patents	% of AI university programmes in country's total programmes
min	0.1%	0.8%	0%	0%	0%
max	0.1%	0.8%	3.8%	1.1%	6.5%
average	0.1%	0.8%	1%	0.2%	2.5%

Source: JRC.

Annex II: Data limitations

Before the final figures of all investment items were computed for year 2019 and re-computed for year 2018, a number of data limitations were addressed. These limitations concerned both data sources used to compile the raw data on investments as well as data sources used to derive the AI intensity coefficients. Below, the main limitations and proposed solutions are described. The section concludes with an overview of the main implications of data-related limitations for the deviation between 2018 estimates computed with the most recent data and the 2018 estimates reported in the first AI Watch report on AI investments (Nepelski & Sobolewski, 2020).

I. Data on economy-wide investments

The challenges of estimating most recent AI investments start at the very beginning of the process with the collection of the most recent data on economy-wide investments and expenditures for all EU Member States. For example, the Eurostat Gross Fixed Capital Formation (GFCF) database does not include data for all EU Member States, e.g. Croatia is missing. In other data sources, numerous different gaps in the data for various countries exist. The most common problem is missing figures for one or two most recent years. A more serious issue relates to the unavailability of data for selected elementary assets, e.g. software, hardware or data. For confidentiality reasons, some statistical offices publish only data on aggregated categories. Finally, updates of data sources used in the current exercise include also corrections of past data. This results in changes of the AI investments estimates when updated raw data are used. Below are the main data issues, challenges and remedies that were applied.

While estimating missing values, a number of constraints must be met, starting from the fact that the total level of investments must be respected. This means that one cannot extrapolate based on time trends of individual investment items. Instead, extrapolation based on a top-down approach, i.e. sub-categories of investment items must follow the changes in their categories. In addition, because of the distinction between sectors of investments, the distribution between the public and private sectors must be taken into account. In order to address the issue of missing data, the following procedures were applied:

- Lack of data for particular countries. This problem was encountered in the Eurostat's table on GFCF as well as in the Spintan and Intan-Invest databases. In the first case the structure of assets for Croatia was assumed to be an arithmetic average of structures for Greece and Slovenia. In the latter cases the structures of intangible assets missing in the Spintan and Intan-Invest databases were established based on the results of factor and cluster analysis of gross fixed capital formation assets.
- Lack of data for some disaggregated assets. This problem concerned only the Eurostat's GFCF data where some categories of expenditures are not reported separately but only as a part of a broader category of assets. For the purpose of data compilation the implied expenditures on these elementary assets were separated based on their weighted shares in structurally similar countries.
- Lack of data for most recent years. This type of issues are very common and also the most straightforward to fix. For example at the time of compilation (September 2020) the data on GFCF for 2019 was not available for all countries. The missing data points were extrapolated based on the structure of expenditures from the last available year.

II. Data on AI intensity coefficients

In order to estimate AI investments, data on economy-wide investments collected from official data providers like Eurostat are weighted with a set of relevant AI intensity coefficients (see Table 4). Currently, there are two data sources that we used to compute the AI intensity coefficients. The first one is PATSTAT by the European Patent Office (EPO) and is used to determine AI intensity coefficients to proxy, for example, AI-related R&D expenditures or investments in AI-related software and hardware. The second one is Study Portals and is used to determine the AI education offers of universities, which at the later stage is used to estimate the level of expenditures in AI education or the compensation of AI ICT specialists. The main limitations concerning the use of these two data sources and their consequences for the final AI estimates are described below.

Regarding the PATSTAT by the EPO, the first AI Watch report on estimating AI investments relied on the 2018 PATSTAT edition. The current one, which reports new figures for 2019 and revised figures for 2018 uses the

2020 PATSTAT edition. In both cases, the relevant raw data used to calculate the AI intensity coefficients include the following set of indicators for each country and for the period from 2000 until 2017 in the first report and 2018 in the current one:

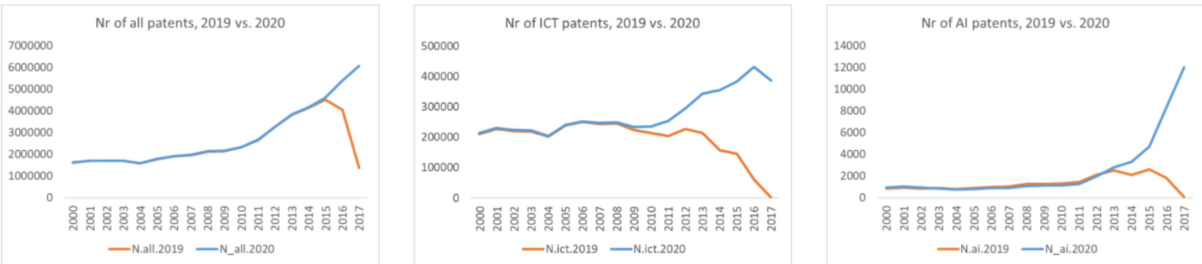
- Total number of patents,
- Total number of ICT patents and
- Total number of AI patents.

ICT patents were identified using the IPC classification codes corresponding to the definition of ICT technology provided by the PREDICT project. The methodology to identify AI patents is described in López-Cobo et al. (2019).

Figure 9 reports the raw patent data underlying the AI intensity coefficients retrieved from PATSTAT 2018 and 2020 editions. Figure 10 shows the subsequently computed AI intensity coefficients using the raw data listed above. Without major exceptions, there are significant discrepancies in the number of the total, ICT and AI patents retrieved from the two editions of PATSTAT. Regarding the total number of patents, the most obvious explanation for the discrepancy in the most recent years is the continuous updating of the raw data by the EPO. Each PATSTAT edition does not only include an addition of one more year, but also updates of the years already covered by previous editions. This explains, for example, a higher number of patents in 2016 reported by PATSTAT 2020 edition compared to the 2018 one. This issue becomes amplified for smaller sub-sets of the data, e.g. the total number of ICT or AI patents.

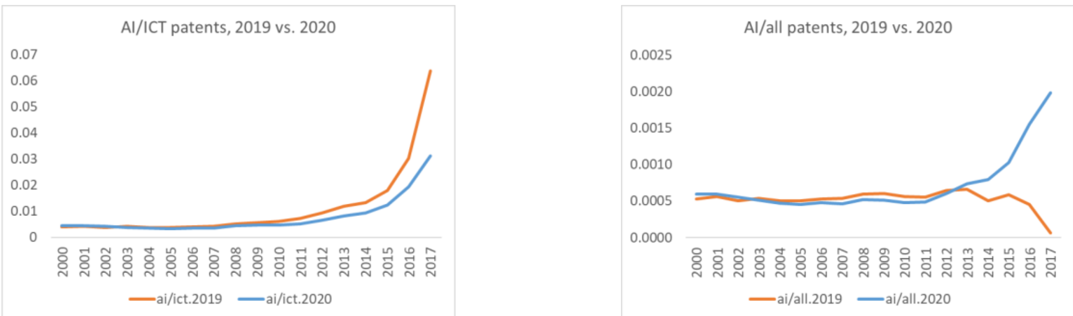
Differences between the raw data reported by various PATSTAT edition produce also varying results for the AI intensity coefficients applied to estimate AI investments (Figure 10). For example, the lower ratio of AI to ICT patents based on PATSTAT 2018 edition than the one based on PATSTAT 2020 edition is a result of a significantly higher number of ICT patents retrieved out of the PATSTAT 2020 edition than our of the PATSTAT 2018. The reason for the higher ratio of AI to all patents based on PATSTAT 2020 edition than the ratio based on PATSTAT 2018 edition is a result of a higher number of AI patents in the last three years retrieved out of the PATSTAT 2020 edition than out of the PATSTAT 2018 edition.

Figure 9: Raw patent data underlying the AI intensity coefficients, PATSTAT 2018 and 2020 edition



Source: JRC calculations based on PATSTAT 2018 and 2020 editions.

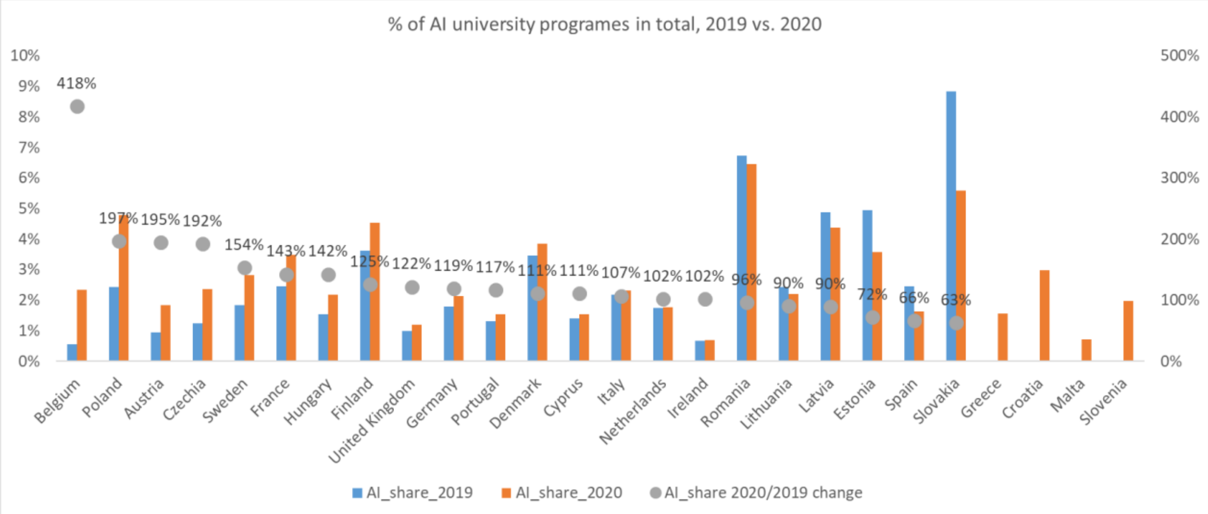
Figure 10: AI intensity coefficients based on PATSTAT 2018 and 2020 edition



Source: JRC calculations based on PATSTAT 2018 and 2020 editions.

The data on AI education offers of universities are retrieved from the Study Portals, an inventory of university programmes in Europe, using the methodology defined in Lopez-Cobo, De Prato, et al. (2019). Figure 11 compares the shares of AI university programmes retrieved from the Study Portals in 2019 and 2020. With the exception of 6 out of 22 countries for which data was available for both years, the share of AI university programmes in the total number of university programmes increased. In some cases, e.g. Belgium or Poland, the increase was four- and two-fold respectively. In Ireland, the AI educational offer increased by only 2%. In six countries, the share of AI university programmes decreased. For example, in Romania there was a drop of 6% and in Slovakia a decrease of 37%. One reason for such deviations from one year to another is the relatively small number of AI programmes in total. Hence, like it was the case in Belgium, adding only few AI-related university to the total educational offer increases manifold the ration of AI and total university programmes. It must be added that often this does not mean necessarily creating a new programme. Instead, considering the high interest in AI, re-branding or changing the descriptions existing programmes can lead to an inflation of the identified AI programmes. In general, however, as complete knowledge of the methodology behind the Study Portals data is not available is difficult to determine the reasons for such strong variations between two years.

Figure 11: % of AI university programmes in the total number of university programmes in 2019 and 2020



Source: JRC calculations based on Source: Study Portals 2019 and 2020 editions.

III. Consequences of data limitations for final estimates of AI investments

The limitations of raw data described in the preceding sections have consequences for the final estimates of AI investments. These consequences are, for example, visible when estimates computed in the past are re-computed using updated raw data. Table 6 illustrates this effect for the 2018 AI investments estimates computed in 2019 and re-computed in 2020. As discussed above, the 2018 estimates re-computed in 2020 are based on updated raw data on economy-wide investments from Eurostat and on updated raw data from PATSTAT by the EPO used to determine the AI intensity coefficients.

As shown in Table 6, the overall 2018 AI investments estimates re-computed in 2020 for the maximum scenario are 9% lower than the estimates computed in 2019. The main reasons for the decrease were lower estimated AI-related investments in software, hardware, data and telecommunication equipment as well as lower estimated expenditures on AI R&D, education and ICT specialists' compensation. These decreases are explained by the lower share of AI in ICT patents, differences in the original Eurostat data as well as a methodological change in the computation of the compensation of AI ICT specialists. Concerning the latter, in order to compute the wage premium for professionals using the Labour Force Survey data, in 2019 hourly wage for specialists was divided by the median instead of the mean hourly wage for all employees. In order not to overestimate the wage premium, the mean hourly wage was applied in the 2020 edition. Correcting this methodological detail resulted in over 15% lower 2018 ICT compensation computed in the 2020 edition as compared to the 2019 edition.

As illustrated by investments in intangibles, e.g. Corporate Training, Brand and Design, updates in the original data sources can produce also upward shifts. The 2018 investments in these categories of investments in the 2019 edition are over 70% higher than in the 2020 edition. Considering that these types of investments represent only approx. 5% of the AI investments, this change does not have a major impact on the total estimates.

Large variations of values from one year to another are also visible at the level of individual countries. The case of Ireland illustrates it very well. Eurostat does not report computer software and databases and R&D expenditures for Ireland in 2019. Because they belong to a higher category of intellectual property products, the change in value of investments in intellectual property products is taken to estimate the level of investments in the sub-categories. The shares of sub-categories in total are taken from the last available year. In 2019, Eurostat reports 250% increase in investments in intellectual property products in Ireland. This increase is then further transmitted to the sub-categories of investments used in the current exercise, i.e. computer software and databases and R&D. Similarly, Eurostat reports an over tenfold increase of investments in telecommunications equipment between 2018 and 2019 in Bulgaria.

In conclusion, the above examples illustrate that the process of estimating AI investments is very sensitive to methodological choices and any changes in underlying data.

Table 6: Reasons for discrepancies in 2018 EU AI investments estimates between 2019 and 2020 editions

Investment type	2019 edition, m EUR	2020 edition, m EUR	Ratio of 2000 and 2019	AI intensity coefficient	Reason for change
Computer hardware	358.3	326.0	91%	AI patent in ICT patent global	Decreased, due to a larger increase in ICT patent than AI patent
Computer software and databases	1441.0	1346.3	93%		
Telecommunications equipment	354.4	252.3	71%		
Brand	53.1	90.4	170%	AI patent in total patent global	Increased, due to larger increase in AI patent than total patent
Design	64.8	107.1	165%		
Organisational Capital	147.3	244.6	166%		
Corporate Training	70.1	116.3	166%		
Research and development	666.0	481.8	72%	AI patent in total patent country level	Decreased number of AI patents in in the entire EU
Academic staff compensation	1342.9	1180.9	88%	AI university programmes	Indicator changed due to changes in methodology and update in Eurostat (ICT specialists)
ICT specialists employee compensation	2722.0	2345.2	86%		
Total, m EUR	**7219.8**	**6491.0**	**90%**		

Source: JRC based on EUROSTAT, Spintan and Intan-Invest data.

Annex III: Other attempts to quantify AI investments

As indicated above, the methodological approach taken in this study differs in terms of scope compared to existing attempts to quantify AI investments. It includes investments and expenditures in education, tangible and intangible capital assets incurred by public and private organisations to develop and implement AI. In contrast, most of the existing studies quantifying investments rely on Venture Capital and private investments in AI-related start-ups. Surprisingly, even though they seem to follow a similar approach, their findings differ substantially. Table 7 provides a short overview of the main studies of AI investments and highlights their methodologies, data sources and findings.

Table 7: Overview of AI investments analyses

SOURCE	DATE	SCOPE	DATA SOURCES	SELECTED FINDINGS
McKinsey & Company	Jun-17	Unclear, but includes VC and private equity	Unclear	$18–27 billion in "internal corporate investment," $2–3 billion in M&A activity, and $6–9 billion in venture capital, private equity, and "other external funding," in 2016
China Institute for Science and Technology Policy	2018	Annual "global AI investment" from 2013 to 2017	Data scraped from various public and private sources	"In 2017, global AI investment reached US$39.5 billion, including 1,208 investment transactions, with China alone posting US$27.71 billion of investment and 369 investment transactions."
CB Insights	2018	"Equity deals" in AI from 2013 to 2017	CB Insights	$15.2 billion in investment, and 1 349 discrete investment transactions, globally in 2017
OECD	Dec-18	Equity investments in AI start-ups	Crunchbase	More than $16 billion in investment, and over 1 400 discrete investment transactions, globally in 2017
CB Insights	Jul-19	Funding for AI startups from 2014 to Q2 2019	CB Insights	$7.4 billion in investment, and 488 discrete investment transactions, globally in Q2 2019
Center for Data Innovation	Aug-19	AI VC and private equity funding between 2017 and 2018	CB Insights	$33.2 billion in investment in China, the U.S. and the EU "between 2017 and 2018"
AI Index (Stanford University)	Dec-19	Investment (including M&A and IPO) into AI companies with over $400 000 in capital raised in the past 10 years	Quid, CapitalIQ and Crunchbase	$40.4 billion investment in more than 3 000 companies in 2018
Pitchbook/National VC Association	Jan-20	VC investment into AI-related companies	Pitchbook	$18.5 billion in VC funding into 1 356 AI-related U.S. companies in 2019
Tech Nation	Mar-20	Investment into AI-related companies	Crunchbase	$11.2 billion GBP in investment into U.S. companies in 2019, across 663 transactions
Center for Security and Emerging Technology	Sep-2020	Private market investments in AI	Crunchbase and Refinitiv	In 2019, privately held AI companies attracted nearly $40 billion
EIB	2021	Equity investments in AI and blockchain technologies	Crunchbase	Global equity investments in AI and blockchain technologies amounted to €80–85 billion between 2010 and 2019 (annual growth rate of 38%).

Source: Based on (CSET, 2020)

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KJ-NA-30826-EN-N

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doi:10.2760/017514

ISBN 978-92-76-41492-6