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TO BE SMART, THE DIGITAL REVOLUTION WILL NEED TO BE INCLUSIVE

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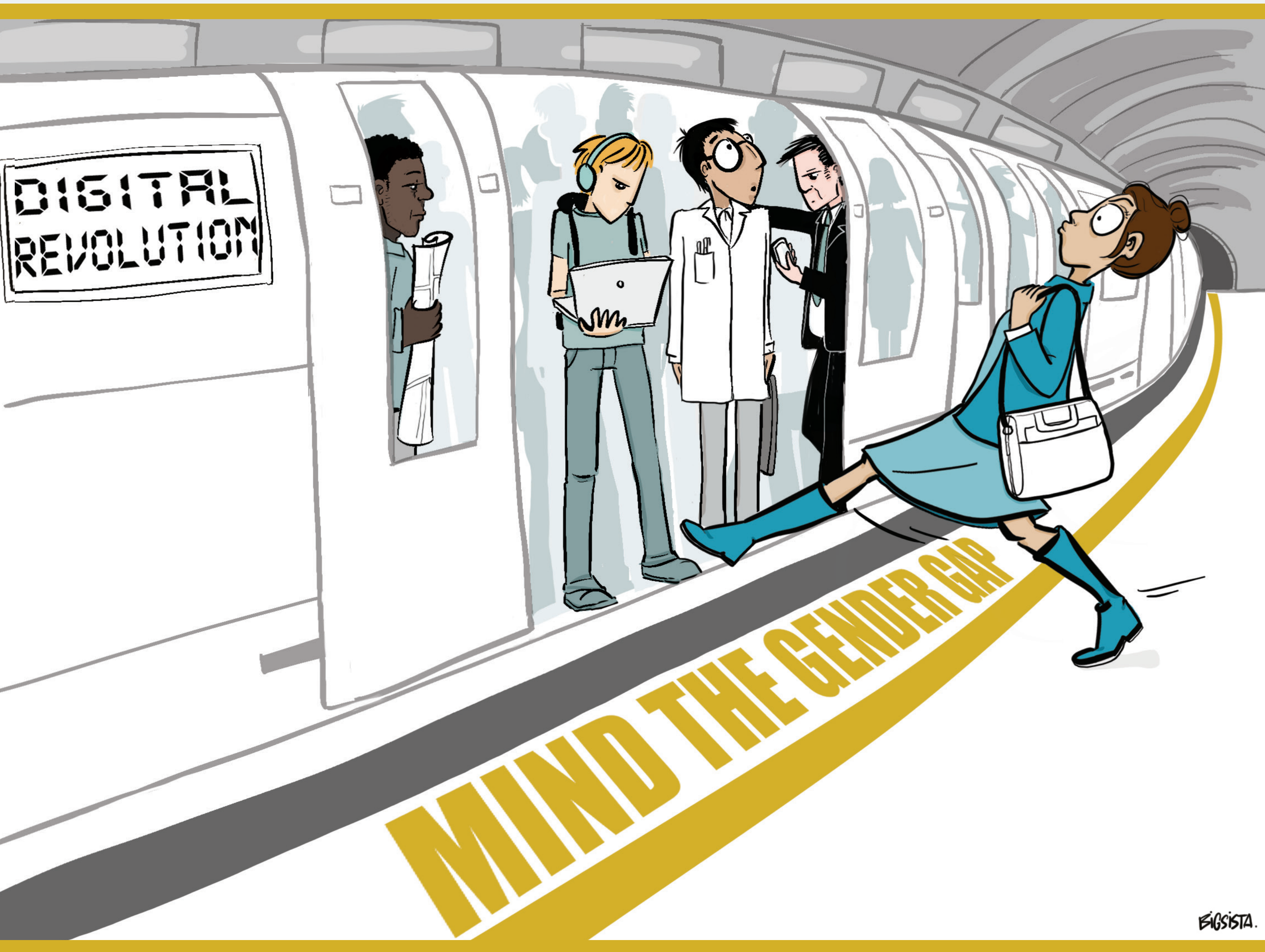

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To be smart, the digital revolution will need to be inclusive

Alessandro Bello, Tonya Blowers, Susan Schneegans and Tiffany Straza

INTRODUCTION

Women risk missing out on the jobs of the future

The world is undergoing a fundamental transformation that is changing the way we live, work and think. This has far-reaching implications for the role of women in society, in general, and in science, technology, engineering and mathematics (STEM[1]), in particular.

Climate change is heightening the frequency and intensity of environmental disasters, causing devastating economic losses and forcing us to rethink our approach to development, especially with regard to food and energy security, health care, construction and environmental management. There is evidence that the current decline in wildlife populations, such as through the conversion of forest to agriculture, urbanization, hunting and wildlife trade, has facilitated the transmission of zoonotic (animal) viruses to humans. Pandemics like Covid-19 present a major challenge for global health (Johnson *et al.*, 2020) [Box 3.1 provides an account of how Covid-19 has affected female scientists].

In parallel, what has been termed the Fourth Industrial Revolution (or Industry 4.0) is disrupting governance systems, industries and the labour market, as cyberphysical systems proliferate and become more sophisticated. Artificial intelligence (AI), robotics, nanotechnology, three-dimensional (3D) printing, genomics, biotechnology and cognitive sciences are becoming increasingly imbricated, building on and amplifying one another.

As more low-skilled jobs become automated, having a higher level of education and skills will become increasingly sought-after in the job market. A 2019 study of employment trends in England between 2011 and 2017 by the UK Office for National Statistics found that sectors dependent on highly skilled occupations were less likely to become automated (Figure 3.1). Women accounted for 70% of employees in jobs with a high risk of automation but only 43% of employees in jobs with a low risk of automation. For instance, the widespread installation of automatic checkouts in English retail outlets between 2011 and 2017 resulted in the loss of one in four cashier jobs, most of them held by women (UNESCO, 2019).

Women must not miss out on the jobs of the future. The United Nations anticipates that women will lose five jobs for every one gained through Industry 4.0, compared to the loss of three jobs by men for every one gained (UNESCO, 2018). According to a collaborative study by 29 United Nations programmes, more than 7.1 million jobs will have been displaced by 2020 and half of current jobs will have disappeared by 2050. In other words, more than 60% of children entering primary school today could end up working in jobs that do not yet exist (ITU, 2017). A fundamental transformation is under way in the workforce. This will call for institutional policies to ensure that today's teenagers understand their career options in the new world of work and can access appropriate skills training.

For women to seize upon the opportunities offered by the Fourth Industrial Revolution, there will need to be a level playing field in terms of access to enablers such as education and information. In 2016, the United Nations' Human Rights Council affirmed 'the importance of applying a comprehensive human rights-based approach in providing and expanding access to Internet'[2] and adopted a resolution stating that Internet access was a fundamental right. In developing countries, women were less likely (37%) than men (43%) in 2017 to have access to both a mobile phone and Internet, according to the Global Findex Database. In some countries, men are even twice as likely to have access to these technologies. This is the case in Bangladesh, Ethiopia, India and Pakistan, for instance. In other countries, including some of the most populous, there is no appreciable gender gap, such as in Brazil, China, Colombia, Indonesia, South Africa or Turkey.[3]

Teenagers envisaging jobs at high risk of automation

An analysis of the results of the 2018 edition of the Programme for International Student Assessment (PISA) run by the Organisation for Economic Co-operation and Development (OECD) found that many 15-year-olds anticipated pursuing jobs that were at a high risk of being automated. The ratio was particularly high among those from the most disadvantaged backgrounds. Even among high-achievers, the PISA study revealed a yawning gender gap when it came to career expectations, with more boys than girls leaning towards careers in science and engineering in 34 out of 63 countries. Less than 2% of girls had plans to become engineers or computer scientists, compared to about 16% of girls who intended to become doctors. Interestingly, fewer boys and girls expressed interest in working in computer science in 2018 than in 2000 (Mann *et al*., 2020).

A shortage of skills for Industry 4.0

Demand in the European labour market for STEM skills is expected to almost triple from 8% to 23% of the workforce between 2015 and 2025, whereas it is anticipated that employment in STEM-related sectors will rise by only about 6.5%. This compares with anticipated growth of 3% in the number of jobs across the board over the same period (EC, 2019a). Experts predict a growing divide between supply and demand for professionals with STEM skills in the European Union (EU) [Reingarde, 2017].

Box 3.1: **Covid-19 pandemic disproportionately affecting women in science and engineering**

Initial studies show that the pandemic is disproportionately affecting female researchers, even if some have been at the vanguard of responding to the crisis.

Less job security, less research time

A report released in May by the Australian Academy of Science (AAS, 2020) found that job insecurity was more of an issue for women than for men, as a higher proportion of women were employed on short-term contracts.

Myers *et al.* (2020) surveyed 4 535 faculty or principal investigators in the USA and Europe, primarily. All else being equal, female scientists reported a 5% larger decline in research time than their male peers during the Covid-19 pandemic. For scientists with at least one child five years old or younger, the decline in research time was even 17%. The authors recalled that women tended to be the primary care-givers of young children.

Initial analyses also suggest that women's publishing rate has fallen relative to men's amid the pandemic and that women are posting fewer preprints and starting fewer research projects than their male peers (Viglione, 2020).

In the media, male voices have dominated scientific commentary on the pandemic in many countries. In the UK, there was an imbalance of 2.7 men for every female expert featured on the UK's flagship television and radio news programmes on the political handling of the coronavirus outbreak across the country, according to data gathered by the Expert Women Project from the University of London.

Survey finds widespread disruption to research

In the developing world, the closure of universities and other institutions, along with the redirecting of funding in those remaining open, has brought ongoing research projects to an abrupt halt.

This was one of the findings of a survey conducted by the Organization for Women in Science for the Developing World (OWSD), a UNESCO programme unit, of its more than 5 000 members between March and June 2020.

Among OWSD members, the most commonly cited negative impact of the pandemic on work was the inability to travel to conferences or other important events (67% of respondents). This was followed by interruptions to experiments or field work (56%), teaching duties (31%) and course attendance (22%), as well as publishing delays (20%).

Members also regretted delays in, or the suspension of, ongoing funding and difficulty in finding collaborators (17% each), being unable to submit funding proposals (16%) or publications (14%), missing out on business opportunities or losing clients (13%) and being unable to take exams as scheduled (11%). Just under 5% of respondents reported directly losing their employment as a result of the pandemic.

Women actively participating in pandemic response

The survey responses also illustrated how scientists can find solutions even in the most challenging circumstances. There was the Sudanese molecular biologist leading an initiative to make ventilators using 3D printers, for instance, and the Sri Lankan biochemistry professor who had volunteered her lab for diagnostic testing, not to mention the professors at a Palestinian university who had organized a special course on Covid-19 to teach students the principles of epidemiology.

Many members reported being involved in the pandemic response. A small share (4%) were undertaking research directly on the Covid-19 virus itself, such as to develop treatments or vaccines, and 14% were studying the impact of the coronavirus on other health conditions, or its societal or economic impact. One in four scientists (26%) was raising awareness or disseminating information about the disease and a further 8% were involved in co-ordinating a policy response to Covid-19 at an institutional level.

With the pandemic having made policy-makers, governments and the general population actuely aware of the importance of science, some respondents saw an opportunity in adversity to push for greater investment in research and in public health.

Women have made the most of shorter working hours

Although 44% of survey respondents have had to cut back their working hours to assume greater household or care responsibilities during the pandemic, other respondents reported some positive outcomes. Most notably, 54% said that they had enjoyed more flexible working hours. Four in ten (42%) had been able to expand their professional skills or experience, 27% had found more time to work on their research, 26% stated that their employer had invested in new technologies for telework or telestudy, 20% had found an opportunity to broaden their public engagement and 19% had augmented their scientific publications.

Over half of respondents reported spending much more time than usual on household chores (52%) and childcare (61%) during the pandemic. On average, respondents indicated that the share of childcare falling to them had risen from 51% to 66% during the pandemic. They also reported being responsible for 69% of homeschooling.

However, the vast majority (83%) appreciated spending more time with their families, with some reporting a closer relationship with their children (41%) or with their partner (37%).

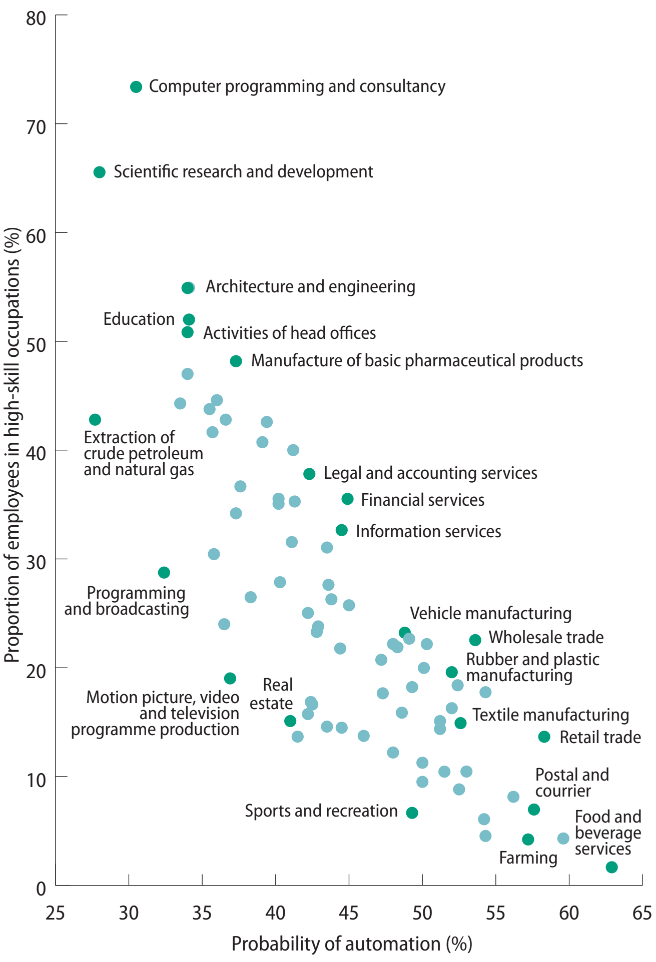
Source: adapted from Johnson, Erin (2020) *The Impact of Covid-19 on Women Scientists from Developing Countries: Results from an OWSD Member Survey*, 20 June.
See: https://www.owsd.net

A 2017 study found that closing the gender gap in STEM education would have a positive impact on economic growth in the EU, contributing to an increase in GDP per capita of 0.7–0.9% across the bloc by 2030 and of 2.2–3.0% by 2050. The study predicted a closure of the gender pay gap[4] by 2050, by which time 6.3–10.5 million jobs should have been added to the European economy, about 70% of these occupied by women (EIGE, 2017).

AI will play a key role in the Fourth Industrial Revolution. In 2019, companies lamented 'a shortage of skilled talent to clean, integrate and extract value from big data and move beyond baby steps toward AI'. This finding emerged from a 2018 survey by Price Waterhouse Coopers of nearly 1 400 chief executive officers (CEOs) in 91 countries. The report found that it was 'not only a matter of hiring or developing AI specialists and data scientists. It is equally important to cultivate a workforce ready to use AI-based systems' (PwC, 2019).

In the Asia–Pacific region and Africa, as many as 35% and 45% of company CEOs, respectively, expressed 'extreme concern' about the availability of necessary skills, in the survey. Globally, CEOs saw retraining and upskilling as the best answer but more than one-quarter of company CEOs in

Figure 3.1: **Probability of automation in England, 2017**



Source: UNESCO (2019), using data from the UK Office of National Statistics

the Middle East and one in five in Western Europe saw hiring outside their industry as a potential solution (PwC, 2019).

The skills shortage is driving competition, as companies and institutions vie to attract and retain talent (PwC, 2019). This can offer a window of opportunity for women trained in related fields, who may find themselves in a strong bargaining position when it comes to negotiating their working conditions with a prospective employer.

An ethical responsibility to avoid misuse of AI

Women have a stake in participating in the digital economy to ensure that Industry 4.0 does not perpetuate gender bias. AI is already defining societal priorities. If women are contributing less to big data or social media data, their needs are likely to be neglected by projects designed on the basis of these data, such as smartphone applications. To mitigate inappropriate policies and actions based on non-representative data, 'we need to put communities who will be impacted by the information systems into the process of making them,' says Catherine D'Ignazio, co-author of *Data Feminism* (Ignazio and Klein, 2020).

The disruptive potential of AI is so great because AI has evolved to the point where it can not only treat information but also interpret it, through machine learning, deep learning and natural language processing. Machine learning allows search engines to prioritize links to websites based on an internaut's browser history, for instance, potentially creating an echo chamber[5] that deprives the internaut of more varied sources of information.

Since the advent of deep learning in 2012, machines can interpret not only databases but also static and dynamic images such as photos and videos. This has led to the development of facial recognition software. Through natural language processing, a machine can now interpret the written and spoken word, paving the way to online services such as Google Translate and chatbots. It has become technically feasible to put words – literally – in the mouth of a person portrayed in a video that the person never uttered. This makes it easy to distort information. The Internet can then relay this false information to the masses, via websites and social media.

There are other forms of misuse. Virtual identities can be as fluid as we want them to be and even 'body-less', if we prefer, offering opportunities for sweeping behaviour change and a blurring of the distinction between men and women in the virtual realm. However, there is a very real danger that gendered differences will be magnified and embedded within technology. Digital images do not exist in neutral spaces free of stereotypical characteristics: avatars can walk, talk and behave in gendered ways and robots and automatons are programmed by men and women who (consciously or subconsciously) may endow their creations with gendered characteristics.

For example, a robot undertaking household chores may be given a female shape and voice, paving the way for gender dynamics to be reproduced in the relationship between robot and owner (Schiebinger, 2019). In addition, Google's speech recognition software is 70% more likely to recognize male speech than female speech, according to research conducted at the University of Washington. Another example is Siri, a servile female-gendered voice assistant used by hundreds

Box 3.2: **A gender index to quantify progress towards the Sustainable Development Goals**

In 2018, Equal Measures 2030 and partners launched a pilot gender index, in response to the urgent need for tools to support data-driven analysis and hold governments to account for gender equality in the context of the Sustainable Development Goals (SDGs).

The SDG Gender Index compiles data on a wide range of issues at the national level that are crucial to the rights of girls and women, from health and education to economic empowerment. The 2019 SDG Gender Index extends beyond the goal dedicated to gender equality (SDG5) to measure gender equality aligned with another 13 of the 17 SDGs in 129 countries. The index examines 51 issues across these SDGs.

The 2019 SDG Gender Index has found that the world is furthest behind on gender equality issues related to public finance and better gender data (SDG17), climate change (SDG13), gender equality in industry and innovation (SDG9) and gender equality overall (SDG5). The highest gender equality scores for innovation (SDG9) go to Canada (87%), followed by New Zealand, Estonia, Norway and Denmark (85%).

The index has found that countries are performing best on issues where there has been a co-ordinated and concerted policy focus and related funding over the past 10–20 years. The highest gender equality scores have been attributed to the goals for hunger and nutrition (SDG2), water and sanitation (SDG6), health (SDG3) and education (SDG4).

Source: compiled by Tonya Blowers and Susan Schneegans; see: https://data.em2030.org

of millions of internauts. She had been programmed to respond to insults with the words, 'I would blush if I could'. The algorithm behind Siri was updated in 2019 to react in a more gender-neutral way by saying 'I don't know how to respond to that' (UNESCO and Equal Skills Coalition, 2019).

The vast potential for abuse of AI illustrates the heightened ethical responsibility of individual scientists and engineers of both sexes in today's world to serve the community as vehicles of truth and human progress. The *2030 Agenda for Sustainable Development* provides a roadmap for harnessing Industry 4.0 for the public good. An index has been established to quantify the pace of progress towards gender equality in the context of the Sustainable Development Goals (SDGs) [Box 3.2]. The creative and thoughtful use of AI could be a key factor in achieving each of the 17 SDGs and their targets. In Japan, for instance, AI is being used to improve disaster readiness and recovery (see Box 24.2).

LITTLE DIVERSITY IN THE TECH SECTOR

Women a minority in Industry 4.0 fields

Women tend to be a minority in the digital labour market. In the EU, for instance, more than half of men earning degrees in information technology (IT) end up working in digital jobs, compared to one-quarter of women (UNESCO and Equal Skills Coalition, 2019).

This is all the more detrimental, in light of the severe shortage of people with the skills needed to drive Industry 4.0. The irony is that the fields most relevant to Industry 4.0 are the very ones where women remain underrepresented in most countries, namely IT, computing, physics, mathematics and engineering.

Japan is hoping that the centrepiece of its new growth strategy, Society 5.0, will enable society to adapt to a shrinking, ageing population through widespread use of AI and other digital technologies in industry, agriculture and the services sector. However, the government anticipates a shortage of 300 000 general engineers in IT in 2020 (see Chapter 24).

In the USA, women made up 57% of professionals but only 25% of computer professionals in 2015. Women are more likely than men to leave the tech field. The most common reasons given concern workplace conditions, a lack of access to key creative roles and a sense of 'feeling stalled in their career' (Ashcraft *et al.*, 2016).

In 2017, women accounted for 23% of Brazilian engineers. Over the four-year period to 2017, much of which was marked by recession, 14% of male engineers lost their jobs, compared to 11% of their female colleagues. Female engineers earn 84% of what their male colleagues take home, despite having a higher level of educational attainment: 12.0% of female engineers held a postgraduate degree in 2017, compared to 7.4% of male engineers (see Chapter 8).

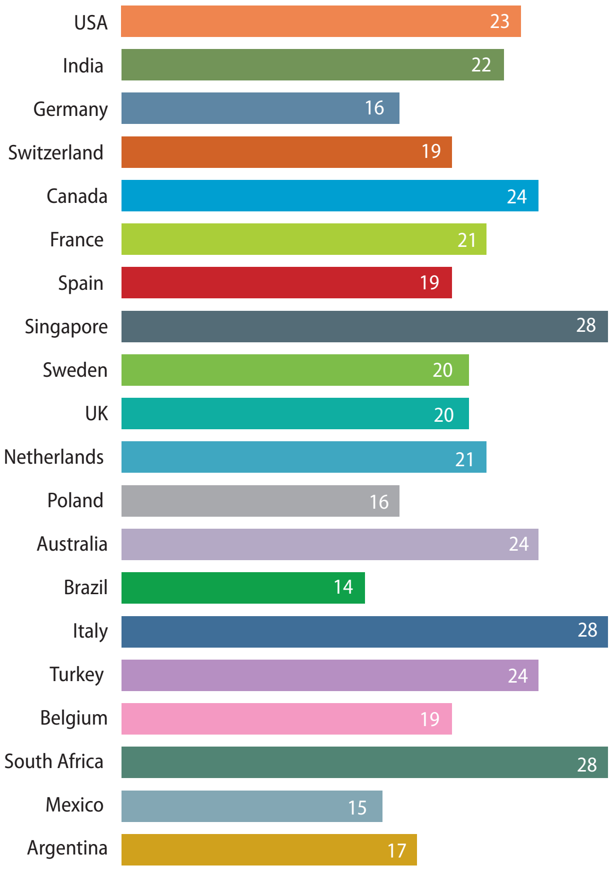
Women a minority in AI

The AI sector is expanding rapidly: from 2015 to 2017, the number of workers worldwide with AI skills increased by 190%, according to the World Ecnoomic Forum (2018a), which found that 'industries with more AI skills present among their workforce are also the fastest-changing industries'.

In the USA, AI has the highest-paid experts of any field of technology (Metz, 2017). According to the US Bureau of Labor Statistics and the Census Bureau, the pay gap in computer science is one of the smallest between male and female professionals in the USA, with women earning 94% of what men take home (AAUW, 2018).

Why, then, are women still a minority among employees of digital tech giants, even in the USA? According to data collected by the social networking site LinkedIn and published in the World Economic Forum's *Global Gender Gap Report,* only 22% of professionals working in AI around the world are female (WEF, 2018a). This gap is visible in all of the top 20 countries with the highest concentration of AI employees (Figure 3.2) and is particularly evident in Argentina, Brazil, Germany, Mexico and Poland, where fewer than 18% of women professionals have AI skills.

Figure 3.2: **Share of women in top 20 countries for share of professionals with AI skills, 2017 (%)**
In descending order for top countries



Source: WEF (2018) *The Global Gender Gap Report 2018*. World Economic Forum: Geneva.

Empowerment for the few

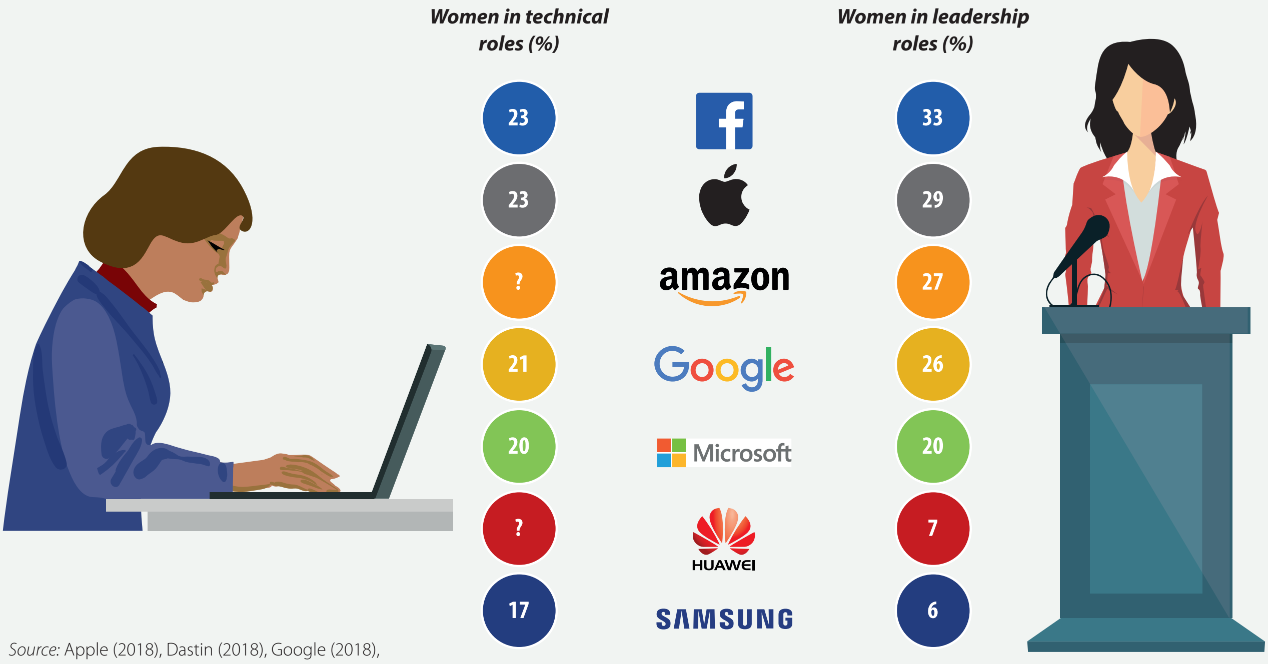
Although the top multinational technology companies are making progress, they are still not even close to closing the gender gap in technical and leadership roles (Figure 3.3). Although there has been some progress in the share of women hired by Google, less than a quarter of technical roles were filled by women in 2018 (Google, 2018).

We can see the same pattern at another US tech giant, Apple, the leading manufacturer of computers and smartphones. Despite implementing measures since 2014 to hire more women and underrepresented minorities each year, women made up only 23% of employees in technical roles and 29% in leadership positions by December 2018 (Apple, 2018).

Amazon, the world's largest e-commerce marketplace and cloud computing platform, is also attempting to correct the gender imbalance. It tracks the numbers and roles of women and underrepresented minorities among its employees. However, as of December 2018, only 27% of its managers around the world were women. When the company realized, in 2018, that its AI system was not rating candidates for software developer jobs and other technical posts in a gender-neutral way (Dastin, 2018), it committed US$ 50 million to supporting STEM programmes for underrepresented communities.

Huawei, a Chinese multinational specializing in telecommunications equipment and electronics, including smartphones and 5G technology, has launched a host of initiatives aimed at increasing diversity in the workforce (with respect to nationality, gender, age, race and religion) by, for example, emphasizing gender equality in employment and prohibiting gender bias. However, the ratio of female employees has remained low: in 2018, women made up only 7% of the

Figure 3.3: **Women in technical and leadership roles in selected top multinational technology companies, 2018–2019**



Source: Apple (2018), Dastin (2018), Google (2018), Huawei (2019), Facebook (2019) Microsoft (2019), Samsung Electronics (2019) management team (Huawei, 2019). Neither Huawei nor Amazon disclose the gender breakdown of their technical workforce.

Similarly, Samsung, the electronic and smart appliance tech giant from the Republic of Korea, reported in 2019 that only 17% of the company's employees working on product development were women and that women made up only 6% of executive directors (Samsung Electronics, 2019).

American giant Microsoft, which specializes in developing and manufacturing computer software, consumer electronics and personal computers, is making an effort to recruit women and support their career development. Although the number of women in technical roles and leadership positions has progressed in the past few years, it is still hovering around 20% (Microsoft, 2019).

Facebook fares better than its fellow tech giants for the number of women holding senior leadership positions (33%) but the percentage of women employed in technical roles remains low, at 23% (Facebook, 2019). Chief Operating Officer of the giant US social media and networking company since 2012, Sheryl Sandberg was ranked the eleventh-most powerful woman in the world in 2019 by Forbes.[6] In 2013, Sandberg published her bestselling book *Lean in: Women, Work and the Will to Lead.* She followed this with the offshoot *Lean in Circles*, a website-based movement to encourage women around the world to take up positions of influence and power.

Although many women may have been empowered to act through the *Lean In* philosophy, Sandberg's mantra has come under fire for placing the responsibility for success on individual women, rather than on pervasive societal structures around them, such as gender-based pay inequality, the disproportionate burden of domestic responsibilities on women and the minimal maternity and family leave granted by most US workplaces – all of which remain largely unchanged. 'Critics questioned the sort of advice that seemed tailor-made for a particular brand of ambitious, corporate go-getters bestowed with certain privileges' (Gibson, 2018).

Taking the directive approach to diversifying board members

At the World Economic Forum in Davos in January 2020, Goldman Sachs' CEO David Solomon told the news station CNBC that the investment bank would not be taking companies in the USA and Europe public after 1 July 2020 unless the company had at least one 'diverse' board member, with a focus on women. Four out of eleven of Goldman Sachs' own corporate board members are women. Solomon stated that companies with greater diversity performed better in the markets. Citing Goldman Sachs' data, he added that companies with one diverse board member had seen a 44% jump in their average share price within a year of going public, compared to 13% for those with no diverse board members (Dilts Marshall, 2020).

Similarly, The Pipeline (2020) found that FTSE 350 companies in the UK with no women on their executive committee had a net profit margin of 1.5%, compared with a 6.9% profit margin for companies with up to 25% of women, a 10.6% profit margin for companies with 26–49% of women and a 12.5% profit margin for companies with 50% or more women on their executive committee.

This directive approach is gaining traction. It posits that businesses which fail to take diversity seriously are at risk of losing the confidence of their investors. In early 2020, for the third consecutive year, the Investment Association warned nearly 20% of the 350 British companies participating in the Hampton Alexander review that they were not on track to achieve the 33% target for the proportion of women in boardrooms and executive committees by 2020.

The Silicon Valley Bank undertook A *Women in Technology Leadership* survey in 2019 to measure gender parity in start-ups in technology and health care in Canada, China the UK and USA. It found that almost half (46%) had no women at all in executive positions, 40% had at least one woman on the board of directors and only 28% at least one woman among the founders. The report also showed that six in ten start-ups had programmes designed to boost the number of women in leadership positions.

In the USA, there is a new tendency to oblige publicly traded companies by law to have at least one woman on their board of directors. The State of California has already adopted a law to this effect: by 2021, boards with five members will be required to include two women and those with six directors three women. Bills along the same lines have been drafted in the states of Illinois, Massachusetts, New Jersey and Washington (Elsesser, 2020). According to research by the firm Heidrick and Struggles (2019), in the USA, women made up 22.5% of corporate boards in Fortune 500 companies in 2018. This figure should gradually improve, since the share of women appointed to corporate boards more than doubled between 2009 and 2018 from 18% to 40%.

The European Commission has a policy of promoting gender balance on the boards of publicly listed EU companies. This policy is encapsulated in its *Strategy for Equality between Women and Men* (2010–2015) and its *Strategic Engagement for Gender Equality* (2016–2019). The Commission manages a database monitoring men and women in leadership positions. Between 2010 and 2018, the share of women board members almost doubled from 11.9% to 23.3%, according to the Commission's database on women and men in decision-making. However, just 5.1 % of the largest publicly listed companies in Europe have a woman CEO.

In Africa, women make up one in four board members (McKinsey Global Institute, 2019). That is a higher ratio than either the EU (23%) or Latin America (7%).

Africa keen to embrace Industry 4.0

Currently, most AI experts are based in North America, Europe and Asia. In Africa, a growing number of governments have come to recognize the importance of training researchers and developers in AI. In 2013, a local group of industry practitioners and researchers began Data Science Africa, an annual workshop where participants can share resources and ideas. In 2017, another group formed the organization Deep Learning Indaba, which now has chapters in half of the continent's 54 countries. IBM Research opened its first African office in Nairobi in 2013 then a second in Johannesburg in 2016 (see Box 20.4). The Government of Rwanda established the East African Institute for Fundamental Research in 2018, which teaches courses in

Box 3.3: **Preparing African girls for a future in Industry 4.0**

A number of initiatives in Africa have been targeting Industry 4.0 fields to help high-achievers see a future for themselves in science and engineering.

One example is *African Girls Can Code*, a four-year programme launched in 2018 which aims to teach 2 000 teenage girls digital and business skills by 2022 through 18 coding camps. The initiative is a joint programme of the African Union Commission, UN Women Ethiopia and the International Telecommunications Union. The first two camps in 2018 and 2019 attracted a total of 570 girls from dozens of countries.

At the national level, too, governments are exploring unconventional ways to attract girls and young women to a career in science and engineering. In December 2019, the Ministry of Communications announced the three winners of its first Miss Geek Ghana competition for budding software app developers aged 13–25 years.* In addition to cash prizes, the young women will receive business training and financial support to develop their socially innovative project (see Chapter 18).

Mali held its first Miss Science competition in 2018, with UNESCO support. All 80 contestants were given computers and mobile phones by the three Ministries of National Education, Higher Education and the Promotion of Women. In an interview, 11-year-old contestant Coulibaly Seydou spoke of her passion for mathematics and how the Miss Science quiz had given her the confidence to pursue a career as a mining engineer (see Chapter 18).**

Source: compiled by authors

*See: https://msgeek.org.gh/

** See (in French): https://fr.unesco.org/news/premier-concours-miss-science-du-mali

machine learning and data science (see Box 19.9). UNESCO organized its first-ever major international forum on AI for Africa in Morocco in December 2018 and Google opened Africa's first AI lab in Ghana in 2019 (see Box 18.2).

Typically, African women are less present in this space. They accounted for only three of the 20 MSc students at the East African Institute for Fundamental Research in the 2019/2020 academic year, for instance (see Box 19.9). To redress this balance, a flurry of initiatives have sprung up, including Women in Tech Africa, based in Accra, Ghana, which hosts an annual event dedicated to women in machine learning, and the Nairobi chapter of Women in Machine Learning and Data Science. Programmes have also been launched at the national and continental levels to prepare girls for a career in promising fields (Box 3.3).

Venture capital more elusive for women

Women find it harder than men to obtain venture capital for tech-based start-ups (WEF, 2016). Companies founded by women receive only 2.3% of venture capital[7] investment, according to the 2020 *Women in Tech Report* from TrustRadius, which surveyed 700 tech companies around the world.[8] It also found that women were almost twice as likely (58%) as men (31%) to find the gender funding gap for venture capital a cause for concern.

A 2019 UNESCO survey of women tech entrepreneurs in Africa found that access to finance was the most commonly identified barrier to starting a new business (Box 3.4).

In India, close to 38% of start-ups were headed by women in 2019, according to Amitabh Kant, Chief Executive Officer of the government think tank Niti Aayog. This compares with an overall economic participation by Indian women of just 22% (Dewan, 2020). The *Strategy for a New India @ 75* (2018) proposes tax incentives for firms which meet a 30% target for the share of female employees, along with easy access to credit for vulnerable female entrepreneurs.

In 2018, Chile introduced the Human Capital for Innovation in Women's Enterprises scheme. It provides tech-based start-ups founded by women with cofinancing of up to 30 million pesos (*ca* US$ 40 000) to help them hire staff for a given project, covering 80% of the hiring cost for men and 90% for women.

Female entrepreneurs account for less than 15% of companies founded since 2017 in the EU (ESM, 2016). A 2018 *State of European Tech* report shows that the gender gap is even wider in venture-backed European start-ups where, in 2018, women made up just 6% of chief executive officers and 2% of chief technical officers.

The gender gap is also evident in the European venture capital industry, where just 13% of decision-makers are women (Atomico, 2019). Furthermore, the number of female recipients of this capital investment is negligible: in 2018, 93% of all funds raised by European venture capital-backed companies went to all-male teams.[9]

The European Commission has launched initiatives to compensate, such as the EU Prize for Women Innovators and a call for female-led EU start-ups that opened in May 2018 as part of the Women in Digital initiative. A European Commission (2018) study found that only 24 out of every 1 000 female tertiary graduates held a degree in a subject area related to information and communication technologies (ICTs) and that only six went on to work in the digital sector. Of greater concern was the drop in this proportion since 2011 at 15%. The study also found that having more women enter the digital job market could inject an additional € 16 billion into the European economy.

GLOBAL TRENDS IN HIGHER EDUCATION AND RESEARCH

Too few women studying Industry 4.0 fields

In virtually every country, a growing number of women are enrolling at university. Globally, women have achieved parity among graduates at both the bachelor's (53%) and master's (55%) levels. Although many drop out once they get to PhD level, the threshold required for a career in research, women now account for 44% of PhD graduates, up from 43% in 2013 (Huyer, 2015).

Overall, female graduates are still overrepresented in most countries in the arts and humanities, journalism and

Box 3.4: Access to finance biggest obstacle for women tech entrepreneurs in Africa

In order to understand how African women entrepreneurs are using science and technology, UNESCO commissioned a survey in 2019 of 459 women from ten African countries: Benin, the Democratic Republic of Congo, Djibouti, Ghana, Madagascar, Morocco, Mozambique, Senegal, South Africa and Tunisia.

Both rural and urban women were interviewed across different fields of industry. The majority of women had started a business in the food sector (30%) or in clothing and other textiles (14%), followed by web platforms (8%), beauty and personal care (7%) and digital marketing and services (4%).

Although engineers (less than 1%) and web designers (8%) made up a small share of the group surveyed, over 80% of respondents said that they used science or technology on a daily basis. About 25% had innovated by developing a new process or product.

Patenting was well understood but not always sought after, usually due to the cost or administrative burden. On average, 12% of entrepreneurs held a patent. Ghanaian women were the most likely to have patented their process or product, with over half reporting an invention and 19% having registered a patent.

Women from the Democratic Republic of Congo were most likely (91%) to have heard of a local innovation hub and to have been assisted by one (69%). They were followed by Ghanaians, with 57% and 25%, respectively. On average, 41% of the entrepreneurs knew of the existence of a local innovation hub but only 26% had been assisted by a start-up incubator in launching their business. It was common for the entrepreneurs to assume that they did not qualify for this form of support.

Access to finance was the most commonly identified barrier to starting a new business, faced by 67% of respondents. Only 18% reported having obtained a bank loan and less than 2% had accessed microfinance. Banks remain reluctant to finance start-ups, which they consider a risky investment, and women often lack sufficient financial guarantees; their home may be registered in their husband's name, for instance. Some respondents have also hesitated to invest in their own company over concerns about political instability in their country.

Some 17% of the women had faced challenges in obtaining premises or land for their business, the second-greatest barrier reported after lack of access to finance. Being able to rent office space was considered vital for both practical and societal reasons, because 'people are sensitive to appearances and therefore [if we] make an appointment [with a client] in a cafe, they do not take us seriously'.

Only 10% of respondents cited social or family resistance to their project, although many recalled their determination to turn a blind eye to criticism. Encouragingly, 84% said that their partner was either supportive or very supportive of their project.

Source: UNESCO (2021) *Challenges and Opportunities for Women Tech Entrepreneurs in Africa: a Survey.*

information, social sciences and health and welfare (Table 3.1).

A range of actors have come up with creative ways of attracting more girls and women to the study of science and engineering. Here are some examples:

- In 2016, Zimbabwe introduced free tuition and boarding fees for students in public schools taking advanced-level science subjects (see Chapter 20).
- In 2018, the multinational corporation Intel began inviting Costa Rican pupils in their penultimate year of secondary school to their offices to hear company engineers tell their life story and interact with them.
- The Shilpa Sayura Foundation's extracurricular *NextGen Girls in Technology* programme provided 1 051 young women and 506 secondary school teachers across Sri Lanka with skills in machine learning, cybersecurity, design and other areas over the two years to 2020, through online and *in situ* courses. The foundation was awarded the UNESCO Prize for Women's and Girls' Education in 2020.
- Afghanistan's Higher Education Development Project is striving for a fairer participation by women. Of the 336 scholarships awarded in 2018 to master's students in priority disciplines dominted by science and engineering, 35% targeted women (see Chapter 21).

The percentage of women graduating in computer science has actually decreased in the USA: according to the National Science Foundation, the percentage rose to 37% in 1984, around the same time that personal computers became popular, but has since declined to 18% (AAUW, 2018).

Israel considers computer science to be an essential subject and has allocated funds to augmenting the 32% share of women among students of mathematics, statistics and computer sciences in 2017. According to data from the Israeli Council for Higher Education, the number of women studying computer science at tertiary level has already almost doubled in eight years, from 2 658 (2009) to 5 237 (2017) [see Chapter 16].

Many of the countries displaying gender parity among graduates in ICTs and other STEM fields have majority-Muslim populations (Table 3.1). Azerbaijan, Kuwait and Malaysia have some of the highest ratios of female engineers in the world (Table 3.2). At the Mohammed bin Rashid Space Centre in the United Arab Emirates, four in ten employees are women. The lead scientist is 33-year-old Dr Sarah Al Amiri, who served as deputy manager of the project which sent the Hope Probe into Mars' orbit on 14 July 2020 from a launch site in Japan. The country's youthful space industry – the average age of staff at the centre is 27 years – is one outcome of the government's drive to 'emiratize' the country's skilled workforce, in order to reduce reliance on foreign expatriates (see Chapter 17).

In the Republic of Korea , more women are enrolling in engineering programmes than ever before; they accounted for 25% of student admissions in 2017, up from 22% in 2014. However, the *Fourth Basic Plan for Women Scientists and Engineers* notes low ratios of female graduates in high-demand sectors such as the automotive (4.0%), mechanical (7.9%), electrical (9.2%) and electronics (13.4%) industries. To address these shortages, the government is introducing measures to accompany women throughout their career, such as the provision of child care. The *Fourth Basic Plan for Women Scientists and Engineers* sets a target of raising the proportion of female scientists and engineers in their forties participating in the economy from 61% in 2017 to 70% by 2023 (see Chapter 25).

More women researchers worldwide

Globally, women make up 33.3% of researchers (in head counts), according to data from the UNESCO Institute for Statistics for 107 countries covering the years 2015–2018 (Figure 3.4). This is a much higher proportion than five years ago (28.4%) but large data gaps remain. Sex-disaggregated data on researchers are not being collected regularly by most countries in the Caribbean, Oceania, South Asia, Southeast Asia and sub-Saharan Africa, for instance, or by the populous countries of Bangladesh, Brazil, India and Nigeria. Moreover, UNESCO estimates exclude North America and China on account of the international incomparability of these data. UNESCO is among those that have been conducting surveys to document the pressures that inhibit the regular collection of sex-disaggregated data (Box 3.5).

The observed data gaps make it difficult to draw conclusions for most regions. There are sufficient data, however, to confirm the trend observed in the previous *UNESCO Science Report* (Huyer, 2015) towards gender parity in Central Asia, Southeast Europe and Latin America and the Caribbean. These regions are home to 10 of the top 20 countries for the share of women researchers, namely Venezuela (61%), Trinidad and Tobago (56%), Argentina (54%), North Macedonia and Kazakhstan (53%), Serbia (51%), Montenegro (50%), Cuba, Paraguay and Uruguay (49%).

The persistently high ratio of women researchers in many European and Asian countries is a legacy of the Soviet Union, which valued gender equality. This is true, for example, of Azerbaijan (59%), Georgia and Kazakhstan (53%), Serbia (51%) and Armenia (50%).

In South and Southeast Asia, a growing number of countries have achieved gender parity. This is the case for Malaysia, Myanmar and Thailand, for instance. The most recent addition is Sri Lanka, where women accounted for 46% of researchers in 2015, up from 24% in 2006.

In sub-Saharan Africa, South Africa has attained gender parity, with women accounting for 45% of researchers since 2015. Mauritius also attained gender parity in 2015 but has since shed a percentage point. Senegal stands out for having raised the share of women from 10% to 29% of the research pool between 2006 and 2015.

A growing number of Arab countries have attained gender parity. Many have made remarkable progress over a short space of time, including Algeria (from 35% in 2005 to 47% in 2017), Egypt (from 36% in 2007 to 46% in 2018) and Kuwait (from 23%

Box 3.5: A holistic approach towards gender policies through the UNESCO SAGA project

Data on the participation of women in the mathematical and natural sciences are scattered, outdated and inconsistent across regions and research fields.

UNESCO launched its STEM and ender Advancement (SAGA) project in 2015, with funding from the Swedish International Development Agency, to help policy-makers draft, implement and monitor policies promoting gender equality in science and engineering using innovative indicators.

Each participating country shared a common dilemma: the presence of women diminished as researchers progressed in their career towards more senior positions.

SAGA developed a methodology for improving evidence-based policies which included different tools, such as the SAGA Indicator Matrix containing innovative indicators and a questionnaire to understand the drivers of careers in science and engineering and barriers to these. This questionnaire was subsequently adapted by the Gender Gap project* to survey more than 40 000 scientists worldwide with a view to informing policy.

Between 2015 and 2019, the SAGA project trained over 350 policy-makers from 26 countries in measuring gender equality in science, technology and innovation using the SAGA Indicator Matrix. This resulted in reports on the status of women in science and policy gaps being submitted by Argentina, The Gambia, Haiti, Sudan, Thailand, Uruguay and the Canadian Province of Quebec. An updated online inventory of policies and related instruments was established, the SAGA Online Database.

In pilot countries, governments established inter-institutional committees on gender equality in STEM. This was an important step, as policy dialogue has proven to be a strong incentive for reform.

Some participating countries have since included gender equality in science and engineering in their broader strategies, laws and planning documents, such as Argentina's *Third Open Government National Plan* and the science bill before the Gambian parliament in 2020.

Countries have also reinforced institutional support, such as through the gender unit established in 2019 within the Gambian Ministry Of Higher Education, Research, Science And Technology or through the new UNESCO Chair in Women and Science for Development at Haiti's Institute of Science, Technology and Advanced Studies.

Source: Alessandro Bello;
see: https://en.unesco.org/saga

*Funded by the International Science Council in Paris (France), the Gender Gap project involved ten of its member unions, including the International Mathematic Union and International Union for Pure and Applied Chemistry.

Table 3.1: **Share of female tertiary graduates by field, 2018 (%)**

	Agriculture	Engineering	Health & welfare	Natural sciences	ICTs	Social sciences & journalism	Business, admin. & law	Arts & humanities
Albania	46.0	38.3	78.9	69.9	43.7	73.2	61.1	70.3
Algeria	76.8	48.5	70.5	83.1	48.9	68.4	57.7	80.2
Angola^{-3}	28.2	22.4	66.8	66.3	38.0	55.0	48.3	39.2
Armenia	24.5	22.4	72.5	60.5	38.5	58.4	49.8	75.0
Australia^{-1}	58.5	23.2	74.7	51.3	21.8	66.9	52.8	69.8
Austria^{-2}	46.9	21.5	69.3	49.6	14.3	64.3	57.0	78.0
Azerbaijan	52.0	26.6	78.3	65.3	46.0	57.1	39.6	75.6
Bahrain	–	30.6	73.2	87.1	47.1	73.2	62.2	79.4
Bangladesh	21.2	46.1	25.3	14.9	27.3	27.8	26.2	32.7
Belarus	55.3	23.2	85.2	62.0	23.0	78.9	71.1	–
Belgium^{-1}	62.1	23.4	75.6	41.4	9.9	70.3	54.1	68.4
Belize^{-3}	35.3	9.1	69.9	52.8	19.4	69.8	68.6	74.1
Benin^{-3}	60.5	54.6	63.7	54.9	55.1	61.5	61.4	56.8
Bosnia & Herzegovina	57.0	39.4	73.4	71.9	28.2	58.7	57.2	64.8
Botswana^{-1}	58.0	–	70.0	–	–	–	–	–
Brazil^{-1}	49.5	36.7	75.7	59.5	14.6	70.9	58.0	71.1
Brunei Darussalam	–	52.3	76.5	73.4	41.9	74.1	68.3	67.1
Bulgaria^{-1}	46.2	28.7	70.3	68.1	38.7	66.7	67.7	66.1
Burkina Faso	33.8	21.6	42.7	18.7	–	45.4	48.7	27.8
Burundi-1	65.1	8.0	40.4	21.1	26.6	55.1	35.9	17.6
Cabo Verde	100.0	32.7	77.4	66.7	44.0	68.9	66.8	61.0
Cambodia^{-3}	31.3	15.1	56.2	34.1	8.4	23.0	49.4	43.5
Cameroon^{-1}	29.1	25.2	60.7	36.3	–	–	54.4	53.8
Canada^{-2}	54.2	19.7	76.5	53.8	30.0	70.2	55.8	65.6
Chile^{-1}	47.2	17.7	78.0	46.5	12.7	66.7	56.3	68.3
Colombia	44.7	34.6	72.1	54.2	23.3	70.6	62.7	58.5
Comoros^{-4}	–	–	44.4	–	–	–	–	–
Congo^{-1}	21.9	15.7	37.0	22.9	26.7	41.9	48.8	37.0
Congo, Dem. Rep^{-2}	25.9	9.8	45.8	32.6	36.7	35.4	38.3	31.8
Costa Rica	42.7	35.4	76.0	51.7	20.3	69.0	61.5	69.5
Croatia^{-1}	56.3	35.7	79.8	68.6	21.0	73.7	66.9	62.0
Cuba^{-2}	39.0	41.7	59.5	52.2	33.2	73.7	70.4	44.0
Cyprus^{-1}	34.5	32.9	76.4	69.5	28.5	74.4	55.5	80.3
Czech Rep^{-1}	63.2	33.7	82.4	59.9	15.6	68.6	64.7	69.1
Denmark^{-1}	64.3	29.0	75.6	54.4	24.0	60.5	50.8	63.2
Dominican Rep^{-1}	29.0	38.4	79.7	54.1	39.4	57.0	60.7	75.8
Ecuador^{-2}	35.0	20.7	71.3	47.9	36.8	64.5	59.8	66.3
Egypt^{-2}	49.4	20.9	56.0	64.2	36.8	41.3	35.9	67.8
El Salvador	30.1	18.7	74.4	50.2	26.2	69.1	58.8	65.1
Eritrea^{-2}	51.6	28.1	37.4	28.6	–	51.5	35.8	37.4
Estonia^{-1}	57.9	32.1	88.7	63.9	28.9	74.4	68.7	70.1
Finland^{-1}	61.1	22.2	85.0	53.8	20.8	71.3	61.0	72.0
France^{-2}	43.2	26.1	74.0	49.0	16.5	65.8	59.0	67.9
Georgia^{+1}	43.4	15.7	71.0	68.1	20.6	64.6	58.5	71.1
Germany^{-1}	42.3	21.1	70.6	46.8	19.4	65.7	53.1	73.5
Ghana	26.8	16.4	60.9	26.8	19.9	40.1	44.8	43.5
Greece^{-1}	47.8	33.9	70.6	52.4	35.7	63.8	58.6	73.2
Grenada	77.2	12.7	47.6	64.9	24.1	76.5	64.2	82.3
Guatemala^{-3}	30.9	35.0	70.5	45.2	21.1	64.3	54.9	70.1
Honduras	24.7	38.5	73.5	54.9	27.1	72.9	62.4	72.3
Hungary^{-1}	48.4	29.9	73.7	52.2	16.7	68.6	65.2	75.0
India	27.5	30.8	61.6	51.4	46.3	55.1	46.8	59.4
Indonesia	48.3	24.9	78.0	74.3	34.7	50.6	57.9	67.7
Iran^{-1}	47.5	22.7	62.0	68.0	39.1	55.5	40.9	57.4
Ireland^{-2}	39.6	17.6	76.4	50.9	20.9	61.5	49.5	59.0
Italy^{-2}	50.4	31.9	62.3	58.0	16.1	71.4	52.1	74.6
Japan^{-1}	41.8	14.0	64.2	25.8	–	48.6	36.7	–
Jordan	37.6	34.8	64.4	–	–	66.2	46.9	–
Kazakhstan^{+1}	37.5	28.5	77.3	67.0	30.4	71.2	50.7	67.4
Kenya^{-2}	37.3	19.5	49.1	38.0	30.1	56.2	47.0	48.5

Share of women: <15% | 15–25% | 25.1–35% | 35.1–45% | 45.1–55% | >55%

	Agriculture	Engineering	Health & welfare	Natural sciences	ICTs	Social sciences & journalism	Business, admin. & law	Arts & humanities
Korea, DPR[-3]	19.1	16.6	57.5	53.2	36.3	53.4	20.3	65.8
Korea, Rep.[-1]	44.8	20.1	71.5	49.2	24.3	60.2	49.0	64.7
Kyrgyzstan	25.9	18.4	74.0	72.9	47.4	49.6	52.6	83.4
Lao PDR	44.7	18.0	67.1	55.0	40.8	48.0	57.3	59.9
Latvia[-1]	46.5	26.6	83.9	63.0	22.7	75.0	68.2	68.4
Lesotho	48.8	18.4	72.8	45.2	31.3	77.5	61.8	67.0
Lithuania[-1]	53.4	25.5	83.0	57.8	16.8	74.0	68.5	71.9
Luxembourg[-2]	22.9	19.8	70.4	45.2	19.6	67.7	50.2	63.4
Madagascar	41.2	18.5	67.9	37.3	33.6	46.0	53.8	52.3
Malaysia	47.7	27.1	72.4	70.7	46.0	69.2	67.4	64.9
Malta[-1]	50.0	28.2	71.9	53.0	16.0	62.8	55.7	62.7
Mauritania[-1]	–	11.7	57.7	29.6	41.3	37.6	48.6	20.4
Mauritius[-1]	29.1	25.3	64.6	66.1	31.6	73.5	59.2	73.2
Mexico[-1]	36.8	28.5	68.2	51.1	28.4	70.4	55.1	65.7
Moldova, Rep.	22.8	29.7	68.8	54.8	22.9	76.3	60.7	76.5
Mongolia	51.9	30.8	82.5	51.9	37.7	69.1	64.8	68.1
Morocco[-1]	44.2	42.2	72.3	48.7	41.3	55.8	48.7	47.9
Mozambique	35.4	28.6	75.2	45.3	21.0	57.0	55.1	41.6
Myanmar	53.9	42.3	57.2	66.4	67.4	51.0	70.8	68.8
Namibia[-1]	53.1	33.9	79.5	60.1	38.2	71.4	66.0	73.9
Netherlands[-1]	55.4	23.1	75.9	43.8	14.5	68.2	47.3	63.6
New Zealand[-1]	64.6	28.6	79.9	55.7	23.1	68.3	54.1	66.2
Niger	18.7	7.5	31.4	20.7	22.8	45.9	27.1	46.1
North Macedonia[-1]	39.5	47.8	74.1	69.5	35.1	61.4	55.4	62.1
Norway[-1]	55.6	23.9	82.8	51.5	15.2	63.1	56.9	62.4
Oman	81.5	43.2	84.2	75.5	75.6	71.8	60.6	84.2
Palestine	35.6	32.9	65.6	78.1	45.6	61.5	50.4	76.5
Panama[-2]	42.9	40.0	76.7	59.9	43.9	68.8	68.3	68.5
Peru[-1]	40.6	47.5	78.8	46.0	49.6	51.5	58.0	61.8
Philippines[-1]	53.4	24.5	71.9	62.0	48.1	70.0	67.5	68.0
Poland[-1]	56.8	42.1	72.2	70.8	21.2	72.1	68.3	75.3
Portugal[-1]	58.1	32.3	77.9	62.1	17.4	69.9	60.2	60.9
Qatar	–	37.2	88.1	75.8	53.4	77.5	65.8	73.7
Romania[-2]	40.7	35.3	71.8	66.9	33.2	75.3	67.0	60.7
Rwanda	37.5	26.6	58.3	41.3	39.1	47.8	55.4	43.4
Saudi Arabia	–	2.7	60.4	67.5	46.0	54.6	45.5	69.1
Serbia	48.9	38.5	74.9	71.2	28.6	65.4	60.0	67.9
Singapore[-1]	65.0	27.8	71.0	61.7	32.2	65.8	58.3	66.8
Slovakia[-1]	59.3	28.2	77.0	63.7	12.2	70.8	66.0	68.8
Slovenia[-1]	58.6	26.7	77.7	61.4	14.1	70.4	65.7	74.4
South Africa[-1]	52.2	32.2	74.9	56.4	38.4	68.3	57.3	73.2
Spain[-1]	43.5	26.6	72.6	49.9	13.0	64.0	55.9	64.7
Sri Lanka	58.3	28.4	62.5	56.9	37.6	–	56.5	–
Sudan[-3]	55.1	46.3	49.9	47.7	–	48.0	–	49.8
Sweden[-1]	66.0	32.8	80.8	52.0	30.2	66.4	64.4	73.0
Switzerland[-1]	36.5	16.0	73.8	41.9	9.9	68.5	44.6	59.6
Syria[-2]	50.2	43.9	54.9	60.5	57.3	65.9	47.4	73.5
Thailand[-2]	52.0	16.8	76.3	70.7	47.9	62.2	69.2	66.7
Tunisia	73.9	44.2	75.3	77.2	55.6	77.3	71.3	74.4
Turkey[-4]	43.6	27.1	67.0	58.0	34.5	53.1	47.0	59.2
United Arab Emirates[-1]	81.0	33.3	81.1	85.9	55.4	77.4	43.2	83.7
Ukraine	32.9	25.2	77.7	58.3	17.5	73.0	59.2	60.8
UK[-2]	65.0	23.5	75.4	53.0	19.4	62.4	53.7	68.0
Uruguay[-1]	39.7	45.9	77.5	70.7	17.7	74.3	62.7	64.3
USA[-2]	52.0	20.4	81.4	52.5	23.6	65.3	50.5	62.1
Uzbekistan	26.7	17.7	41.6	52.3	17.8	55.0	23.1	60.7
Viet Nam[-2]	53.0	37.1	58.7	50.6	26.4	57.2	59.5	60.0
Zimbabwe[-3]	50.9	20.5	30.8	30.6	46.1	45.7	51.8	44.7

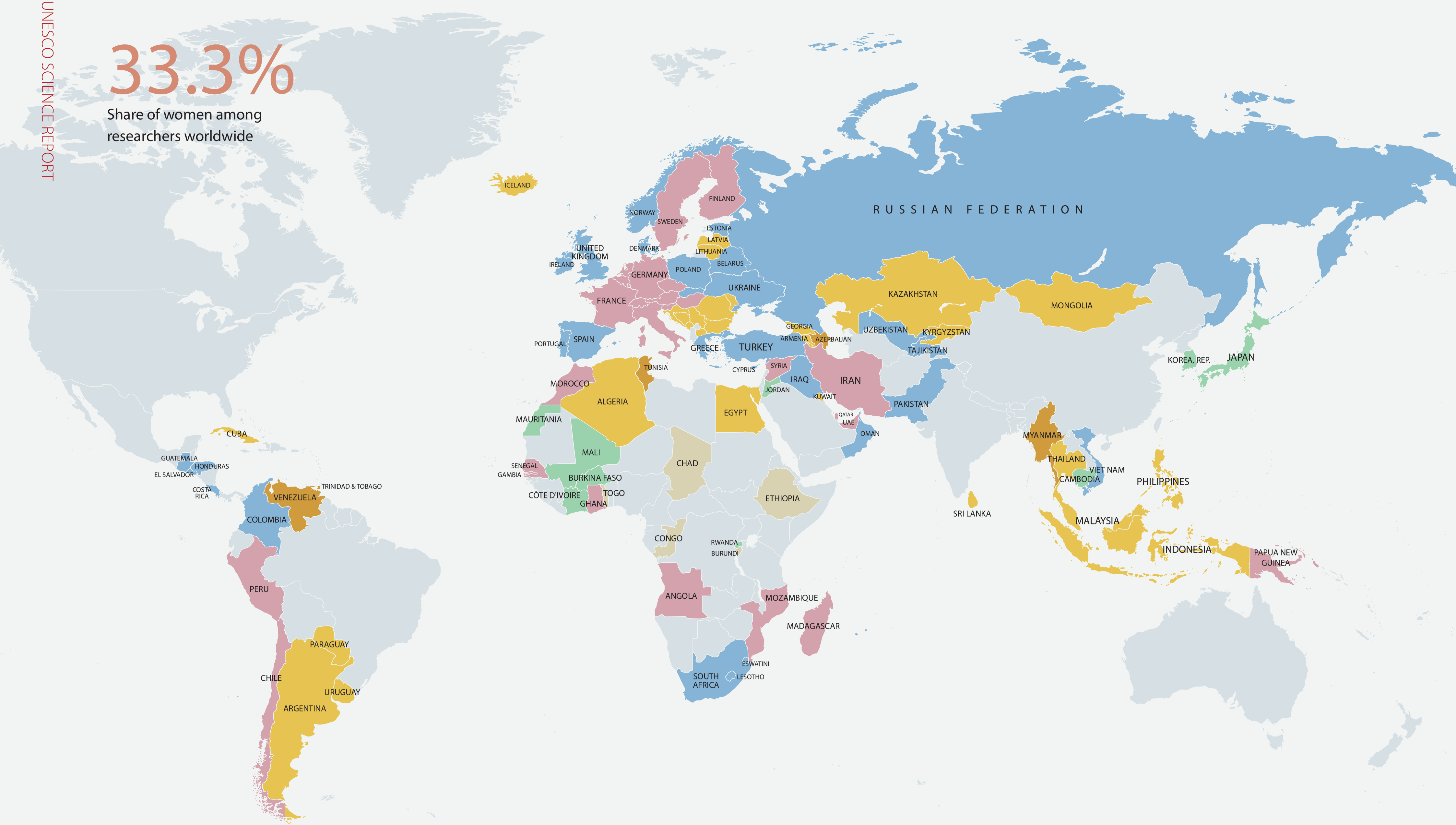
-n: data refer to *n* years before reference year

Source: UNESCO Institute for Statistics

Figure 3.4: **Women as a share of total researchers (HC), 2018 or closest year (%)**

33.3%

Share of women among researchers worldwide



Regional shares of female researchers, 2018 (%)

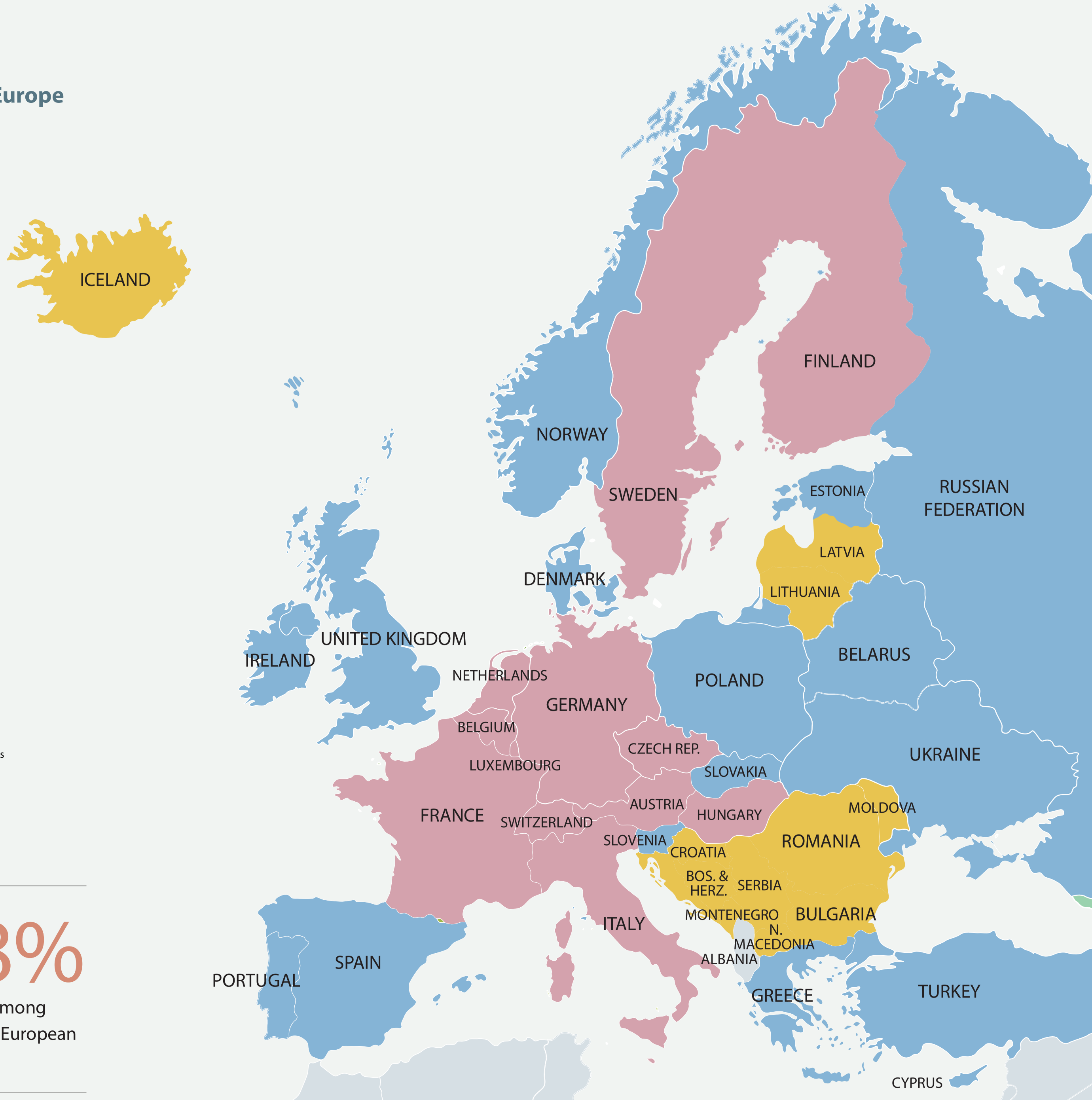
Southeast Europe	51.2
Latin America and the Caribbean	49.8
West Asia	48.3
Central Asia	44.9
Arab States	42.6
Eastern Europe	41.8
European Free Trade Association	36.6
European Union	33.8
Sub-Saharan Africa	33.5
Southeast Asia	26.3

Note: Data are for the most recent year since 2015. There are no available data for some of the most populous countries: Bangladesh, Brazil, China, India, Nigeria and USA; this limitation compromises the reliability of the global total and most regional totals. There is no regional total for South Asia or Oceania because data are available for only one or two countries. Eastern Europe excludes countries that are members of the European Union.

Source: UNESCO Institute for Statistics

Spotlight on Europe

- 0–14.9%
- 15–24.9%
- 25–34.9%
- 35–44.9%
- 45–55%
- 55.1% or more
- Données non disponibles



33.8%

Share of women among researchers in the European Union in 2008 to 53% in 2018). Tunisia now has a slight imbalance in favour of women in its research ecosystem (56%). Also of note is the rapid progress made by Oman between 2015 (28%) and 2018 (36%). Among those countries reporting data in the Arab world, only Jordan (20%) and Mauitania (24%) fall below the global average.

Many OECD countries have a low density of female researchers

There is no guaranteed correlation between a country's wealth and its success in achieving gender parity. Among countries having reached this status, only a handful are OECD members, including Iceland, Latvia and Lithuania (Figure 3.4). Other OECD countries still have a strikingly low proportion of women researchers, including the Republic of Korea (20%) and Japan (17%), which also have the largest gender pay gaps among OECD countries (see Chapters 24 and 25). In France and Germany, just over one in four researchers (28%) is a woman, less than the global aveage (33%).

Even OECD countries leading in gender equality rankings (WEF, 2018b) have a share of women researchers that hovers around the global average; such as Finland (33%), Norway (38%) and Sweden (33%). By contrast, in a least developed

Table 3.2: **Female researchers as a share of total researchers (HC) by field, 2018 (%)**

	Total	Natural sciences	Engineering & technology	Health & welfare	Agricultural sciences	Social sciences & humanities
Algeria -1	47.1	71.7	42.7	60.3	51.8	50.9
Angola -2	28.7	32.4	19.4	50.9	25.0	22.9
Armenia	50.4	46.5	42.1	65.2	59.4	58.5
Azerbaijan	58.6	61.4	52.0	50.0	42.8	64.2
Belarus	39.3	48.9	28.7	68.0	57.4	60.0
Bosnia & Herzegovina	47.1	48.7	37.0	62.7	47.6	52.4
Brunei Darussalam	45.2	40.7	28.7	66.2	33.3	48.1
Burkina Faso -1	17.0	17.4	16.9	18.4	12.1	15.8
Burundi	14.3	14.5	8.1	21.7	12.8	15.2
Cambodia -3	23.7	23.0	14.8	31.6	20.8	27.4
Chad -2	3.4	8.7	0.7	5.5	5.9	5.9
Colombia -1	37.4	34.3	25.6	48.6	31.4	41.4
Congo, Dem. Rep. -3	8.7	8.2	13.4	15.0	7.6	6.2
Costa Rica -1	44.3	41.2	24.0	55.3	36.7	56.1
Côte d'Ivoire -2	17.0	15.4	9.6	23.4	14.6	14.7
Egypt	45.6	40.6	28.9	48.9	35.3	54.6
El Salvador -1	38.6	46.0	21.6	63.2	16.7	41.4
Eswatini -3	41.4	11.1	29.2	63.2	29.3	50.5
Ethiopia -1	11.5	14.1	11.5	13.4	12.0	8.8
Gambia	27.2	37.5	–	28.8	18.2	50.0
Georgia	53.0	46.6	38.2	63.0	50.2	59.1
Ghana -3	26.1	9.3	6.8	11.2	24.7	40.8
Guatemala -1	43.9	44.1	30.6	72.0	22.1	46.7
Honduras -1	36.4	43.9	21.5	45.8	30.8	47.4
Iran -1	31.2	43.0	18.6	46.9	27.6	31.9
Iraq	38.1	45.4	31.6	45.5	26.0	37.5
Japan -3	16.6	13.6	5.6	31.9	22.4	32.7
Jordan -1	19.5	17.8	16.8	37.1	21.5	22.9
Kazakhstan	52.8	53.4	44.0	65.3	48.9	60.2
Korea, Rep. -3	20.4	28.3	10.6	45.9	27.3	43.1
Kuwait	53.2	58.5	47.3	57.6	26.9	53.1
Kyrgyzstan -1	46.5	44.9	33.3	49.1	44.4	54.5
Latvia -1	52.2	47.6	37.4	67.3	58.7	70.1
Lesotho -3	36.4	39.7	10.3	33.3	60.9	40.0

Share of women: <15% | 15–25% | 25.1–35% | 35.1–45% | 45.1–55% | >55%

country like Myanmar, women consistently make up more than 80% researchers and dominate senior positions in academia (Figure 3.4).

Women still a minority among researchers in industry

Female researchers have now reached parity in the government and academic sectors in four out of ten countries reporting data. In 2018, Ireland took the step of linking research funding from the Higher Education Authority to an institution's ability to reduce gender inequality.

Men tend to be overrepresented in the business sector, where salaries are higher (Figure 3.5). This is true even for those countries that have reached gender parity across all sectors. Indeed, only eight countries have reached parity in the business sector out of the 73 for which recent data are available: Algeria, Azerbaijan, Kazakhstan, Kyrgyzstan, Mozambique, North Macedonia, Sri Lanka and Trinidad and Tobago. Of these countries, women are overrepresented in three: Azerbaijan, North Macedonia and Trinidad and Tobago.

The percentage of women in the business sector is particularly low in OECD countries, with a few exceptions, such as Iceland, Latvia, Lithuania and Spain, where women account for about 30–40% of researchers in industry. Elsewhere, fewer than one in four researchers is a woman in

	Total	Natural sciences	Engineering & technology	Health & welfare	Agricultural sciences	Social sciences & humanities
Lithuania -1	49.5	48.0	33.3	64.0	57.1	63.8
Madagascar	33.0	32.7	24.9	34.6	37.5	38.7
Malaysia -3	48.2	47.8	47.2	50.3	50.5	50.2
Mali -1	15.1	22.2	4.5	34.6	9.8	12.1
Mauritania	24.5	24.3	25.0	8.6	12.5	25.4
Mauritius	43.7	36.8	23.4	63.3	49.7	57.6
Moldova, Rep.	48.6	50.0	23.1	55.6	49.7	57.3
Mongolia	48.9	55.1	33.2	57.3	53.6	43.2
Montenegro	49.9+2	49.8	35.6	56.3	50.0	46.9
Morocco -2	33.8	–	–	40.4	26.7	29.9
Mozambique -3	28.9	27.0	24.4	53.5	25.6	25.3
Myanmar -1	75.6	72.7	78.5	72.0	75.0	70.8
North Macedonia	53.4	57.0	42.9	73.4	46.9	53.0
Oman	36.4	23.3	15.5	54.7	5.7	34.4
Pakistan -1	38.8	44.2	22.0	49.3	21.6	42.3
Papua New Guinea -2	33.2	37.4	34.2	34.8	19.5	46.9
Paraguay -1	49.3	50.8	25.5	72.8	40.1	51.2
Peru	28.6	24.4	18.9	35.2	30.1	26.7
Philippines -3	51.2	54.0	42.9	64.0	53.4	56.2
Qatar	34.1	30.7	16.7	44.6	23.8	40.1
Russian Fed. -3	39.2	41.8	34.8	59.6	56.4	59.9
Rwanda -2	22.6	18.1	16.5	21.5	17.9	27.1
Senegal -3	29.3	23.1	19.9	36.7	29.6	30.9
Serbia	51.4	58.1	40.4	58.6	51.5	53.1
Sri Lanka -3	46.6	47.7	39.3	43.2	48.2	49.4
Syria -3	34.9	30.2	32.3	26.5	34.8	46.0
Tajikistan	37.5	36.2	24.1	61.4	27.4	31.9
Togo	11.2	9.5	10.2	10.7	8.5	13.0
Trinidad & Tobago -1	55.9	52.2	31.5	59.9	52.9	69.0
Ukraine	44.7	43.0	34.1	65.2	53.0	64.2
Uruguay	49.3	49.6	35.1	53.5	48.1	52.6
Uzbekistan	40.8	35.2	31.2	54.3	27.0	47.5
Venezuela -2	61.4	56.1	50.6	72.3	59.0	66.0

-n: data refer to *n* years before reference year
Note: Countries with data older than 2015 for female researchers by field are excluded, including much of the EU.
Source: UNESCO Institute for Statistics

the business world. In some cases, the percentage is even lower, such as in Germany (15%), Japan (10%) and Saudi Arabia (2%).

Few female engineers in the workforce

When it comes to engineering, the trends analysed earlier with regard to higher education are even more pronounced in the research community: in many countries, women are overrepresented in medical and health sciences, humanities, social sciences and the arts (Table 3.2). Only a handful of countries (Azerbaijan, Kuwait, Malaysia, Myanmar and Venezuela) have achieved gender parity among researchers in engineering and technology (Table 3.2).

The vast majority of countries reporting the lowest proportions of women researchers in engineering and technology are African, with the notable exception of Japan, where the proportion (6% in 2015) is much lower than for any other OECD country. Senegal is actively seeking to turn the situation around. National research funding is targeting the advancement of women through the Project for Supporting Female University Researchers in Senegal (see Chapter 17). By 2015, 20% of Senegalese researchers in engineering and technology were women.

African female engineers less mobile than men

Mobility tends to be beneficial for a researcher's output and career. In a recent survey of 7 513 African scientists, the largest gender difference in mobility was found in the field of engineering and applied technologies: here, 85% of women but only 63% of men had obtained their PhD in Africa and only 23% of female respondents had studied or worked abroad in the past three years (Prozesky and Beaudry, 2019).

Mobile African women were more likely to collaborate internationally: 47% of mobile and 35% of non-mobile female researchers collaborated regularly with researchers at institutions outside Africa. Mobile women were also more likely than their non-mobile female peers to have been primary recipients of research funding, at 54% versus 45% (Prozesky and Beaudry, 2019).

Fellowships for women in the South

To facilitate scientific mobility, the Organization for Women in Science for the Developing World has partnered with the Swedish International Development Cooperation Agency since 1998 to award South to South PhD Fellowships to enable women from least developed countries to study in another developing country. By 2020, over 300 women from 30 countries participating in the programme had graduated.

The organization also helps female scientists to maintain high-level research in their home countries. Since 2018, it has offered 61 Early Career Fellowships in partnership with the Canadian International Development Research Centre. Fellows may use the grant to set up a laboratory, buy equipment and consumables, invite visiting scholars, attend conferences, publish in open-access journals, buy software, develop a patent and pay for child or elder parent care. Training in leadership skills and in linking with industry is built into the programme.

Women remain a minority among inventors

Despite 2019 having marked a record high for the percentage of patent applications that include at least one woman, women still make up just 19% of inventors (Figure 3.6). Progress may have been slow but at least it has been steady; women accounted for 14% of inventors in 2013.

The global average for international (Patent Cooperation Treaty, PCT) patent applications submitted by at least one female inventor increased from 28% to 35% between 2010 and 2019, according to data from the World Intellectual Property Organization (WIPO) [Figure 3.7]. The only region not affected by this change was Africa. This ratio compares with 20% of filed patents counting at least one female inventor in 2000.

Figure 3.5: **Share of women among researchers in the business enterprise sector, 2018 or closest year (%)**

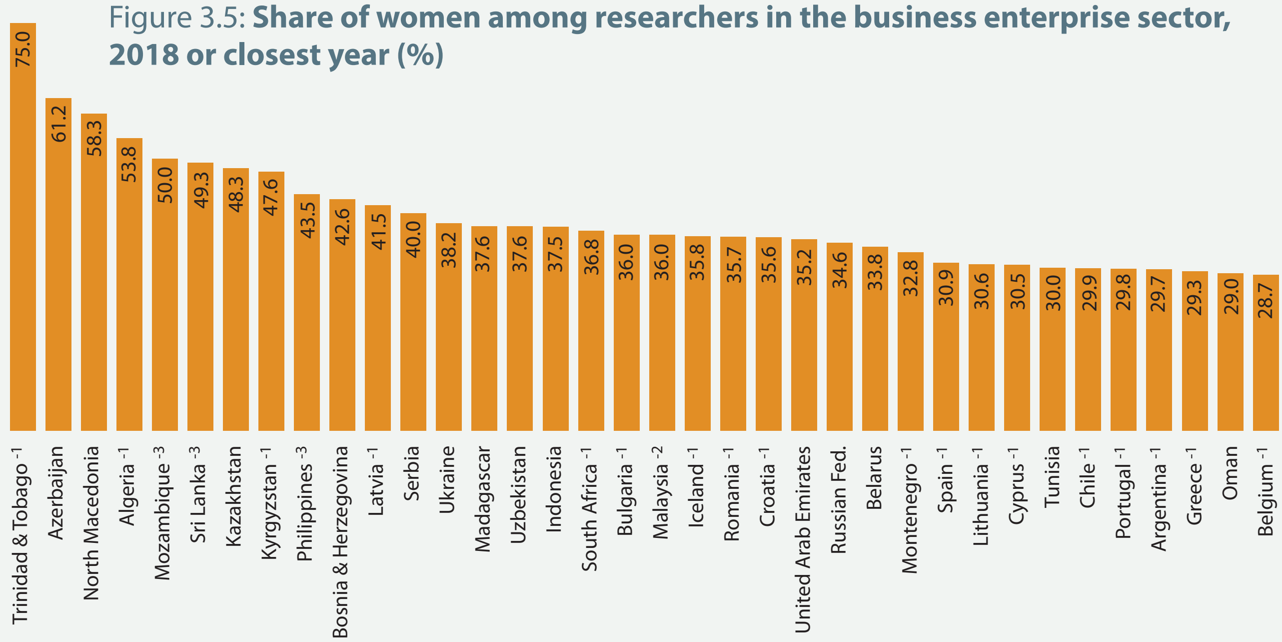
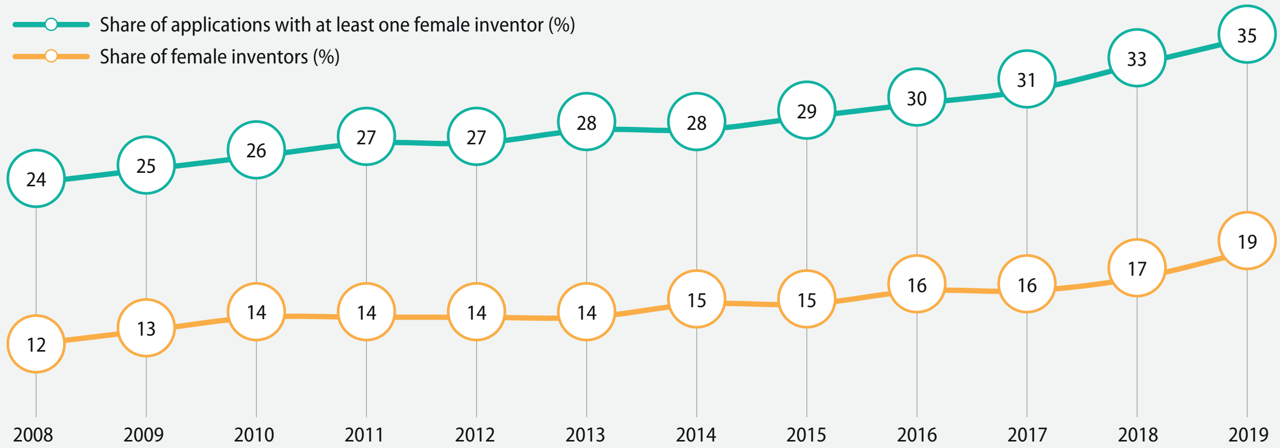


Figure 3.6: **Share of Patent Cooperation Treaty applications with female innovators, 2008–2019**



Source: : World Intellectual Property Organization, May 2020, see: https://www.wipo.int/pct/

The share of female inventors among patent applicants varies from one country to another: in 2019, the highest proportions of women were found in Iran (70%), Antigua and Barbuda (64%), China (55%), the Republic of Korea (51%) and Sri Lanka (47%), whereas the countries with the lowest proportions were Serbia (7%), Oman and Romania (both 8%).

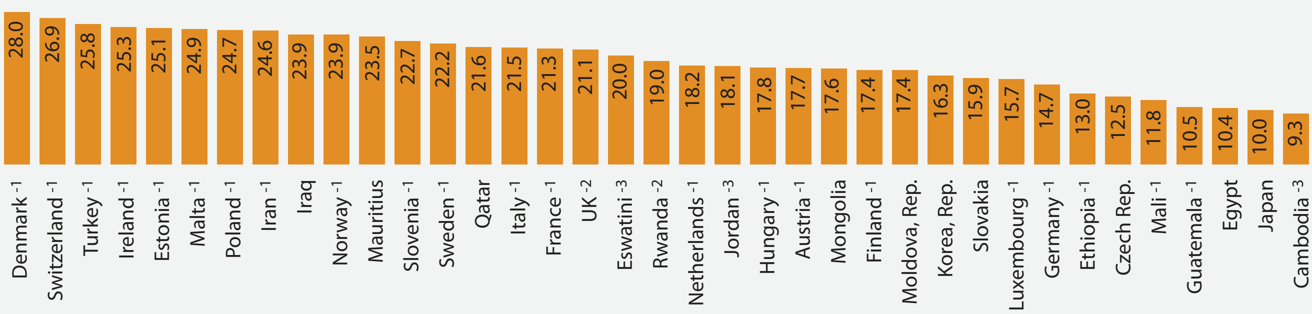
Although women account for only 17% of researchers in Japan, 23% of PCT patent applications from Japan included at least one female inventor in 2019, the same proportion as Sweden, where one-third of researchers are women.

There is also a large variation by year. For instance, of all the patents filed in Uruguay, 70% included at least one female inventor in 2018 but only 45% in 2019, according to WIPO data.

These trends reflect the picture we have already observed in higher education and at the research level: fields related to life sciences have a higher uptake among female inventors. More than half of PCT applications included at least one female inventor in 2019 in the fields of biotechnology, organic fine chemistry, pharmaceuticals, the analysis of biological materials and food chemistry (Figure 3.7).

Although the number of PCT applications by women has grown in every field in the past decade, their share remains below 20% in fields related to engineering, such as civil engineering (18%), machine tools (18%), mechanical elements (16%) and engines, pumps and turbines (16%).

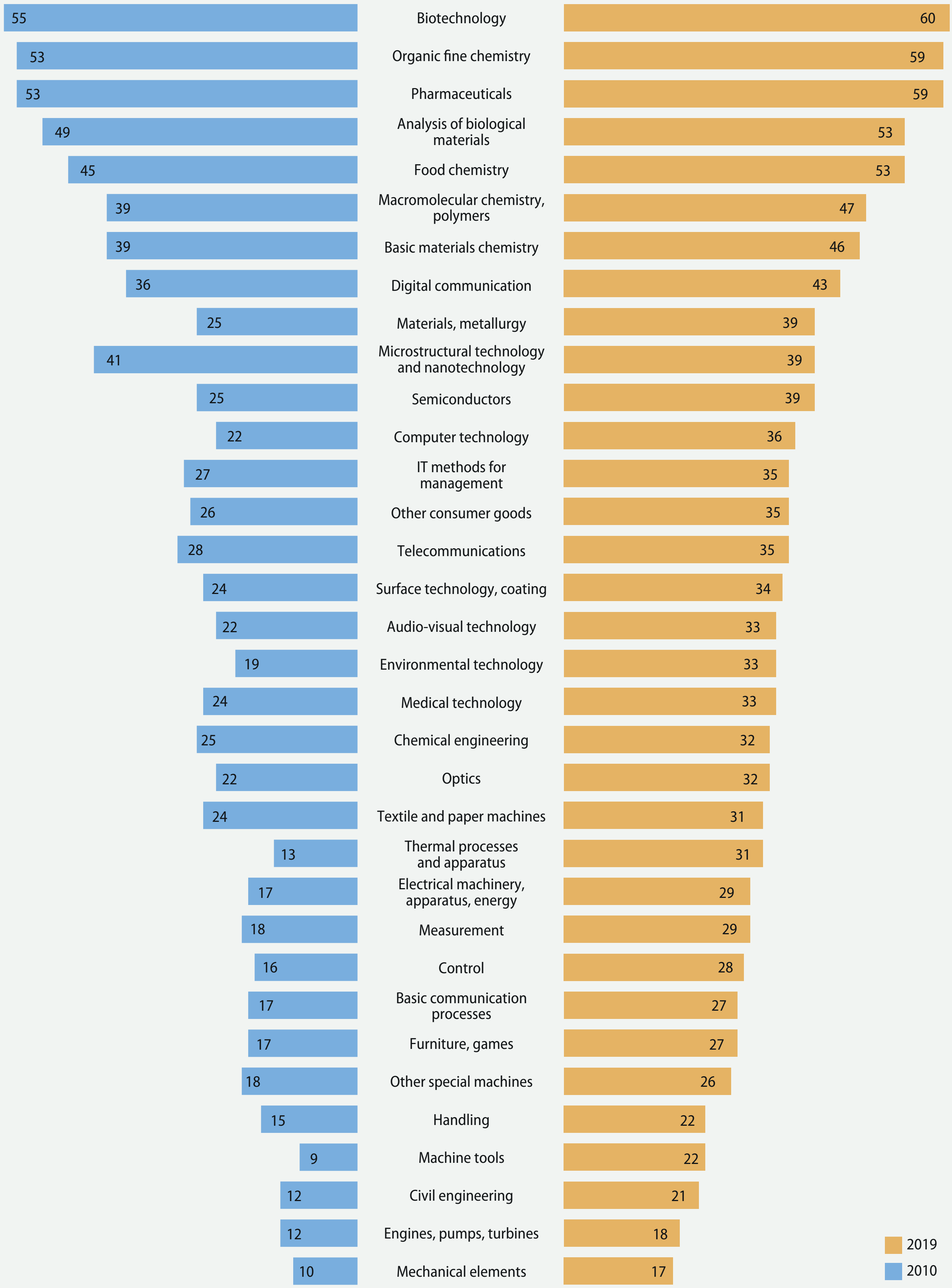
According to WIPO, female inventors are proportionally more internationally mobile than men, although men are closing this gap. Men are also more likely than women to participate in registering patents with a larger group of inventors (WIPO, 2016).



-n: data refer to n years before reference year

Source: UNESCO Institute for Statistics

Figure 3.7: **Share of Patent Cooperation Treaty applications with at least one woman inventor by technology, 2010 and 2019 (%)**



Source: World Intellectual Property Organization, May 2020,
see: https://www.wipo.int/pct/

VERTICAL SEGREGATION IN ACADEMIA

An impenetrable glass ceiling?

As we saw earlier, women have now largely achieved gender parity at university, although they remain a minority in Industry 4.0 fields. It is as women embark upon a scientific career that the gender gap widens. Their presence becomes increasingly rarefied as they reach the higher echelons of research governance structures, such as academies of science (Box 3.6) or science councils.

Although women account for four out of ten academics worldwide, they often face an impenetrable glass ceiling.

Box 3.6: **Women still a minority in academies of science**

Members of science academies are elected on the basis of agreed academic indicators of scientific excellence. The number of women among members of a national academy of sciences can serve as a litmus test of the perception and status of women scientists in a given country.

In October 2015, the Interacademy Partnership published the first comprehensive survey of science academies belonging to its global network, in order to ascertain the extent of inclusion and participation of women scientists. Across 69 national science academies for which data were available, (Figure 3.8) women made up 10% or less of members in almost half (30) of countries. In most European countries (8), only one out of 10 members was a woman. Women were better represented in the governing bodies (20%) of academies than in overall membership (12%).

Among the top 10 academies for the share of female members, six are from Latin America and the Caribbean: Cuba (27%), the Caribbean (26%,) Mexico and Nicaragua (23%), Peru (20%) and Uruguay (19%).

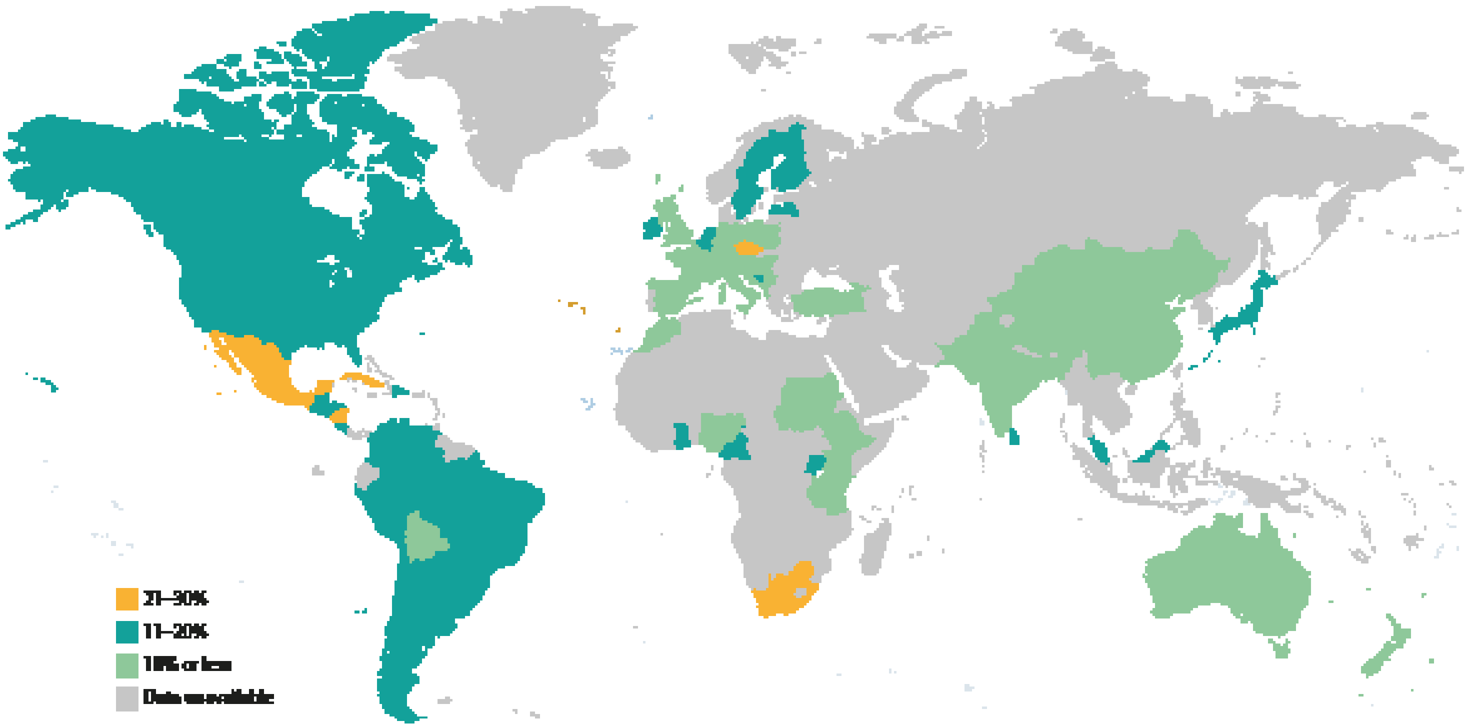
That women should remain severely underrepresented in national science academies is a major challenge, since these academies often form the backbone of efforts to strengthen countries' national innovation systems.

The survey also found that women academicians were better represented in the social sciences, humanities and arts (16%), biological sciences (15%) and medical and health sciences (14%). The lowest percentages of women academicians were to be found in mathematical (6%) and engineering sciences (5%).

In the year following the report, the Royal Netherlands Academy of Arts and Sciences took the radical step of accepting only female nominations for membership to reduce the Academy's perpetual gender imbalance: at the time, men accounted for 87% of its 556 members.

Source: compiled by Tonya Blowers, particularly from ASSAf and IAP (2015) *Women for Science: Inclusion and Participation in Academies of Science.* Academy of Science of South Africa: Pretoria

Figure 3.8: **Share of female members of national science academies, 2013 (%)**

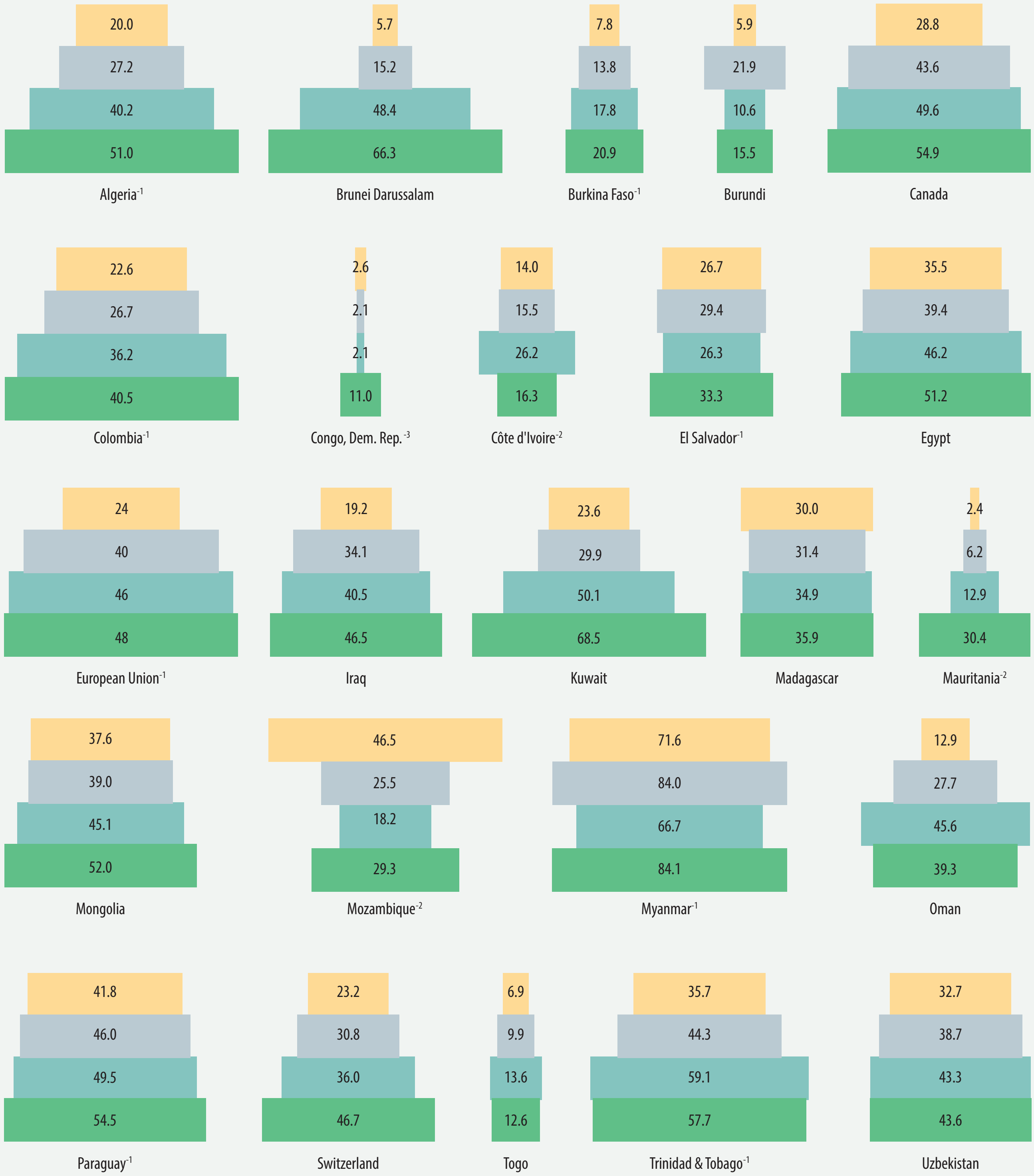


Note: For each country aside from Switzerland, the data reflect one academy of science; for Switzerland, the data reflect the combined membership of the Swiss Academy of Medical Sciences (17% women) and the Swiss Academy of Engineering Sciences (10% women).

Source: ASSAf (2015) *Women for Science: Inclusion and Participation in Academies of Science: a Survey of the Members of IAP*: the Global Network of Science Academies. Academy of Science of South Africa: Pretoria

Figure 3.9: **The career pyramid: 24 case studies**

Share of female researchers by seniority grade (HC), 2018 (%)



-n: data refer to n years before reference year

Note: Seniority levels are classified as follows:

Category A: the single highest grade/post at which research is normally conducted. Examples: Director of Research or Full Professor.
Category B: researchers working in positions that do not qualify as Category A but are more senior than newly qualified doctoral graduates. Examples: Senior Researcher, Principal Investigator or Associate Professor.
Category C: the first grade/post into which a newly qualified doctoral graduate would normally be recruited. Examples: Researcher, Investigator, Assistant Professor or Post-doctoral Fellow.
Category D: either doctoral students who are engaged as researchers or researchers working in posts that do not normally require a doctorate. Examples: PhD student or Junior Researcher. Master's students counted as researchers would also fall into this category.

Source: UNESCO Institute for Statistics; for Switzerland: Federal Bureau of Statistics; for European Union: EC (2019b)

The representation of women decreases with the level of seniority. This vertical segregation can be encountered in almost every country and not only in science. Although data by seniority are available for only a score of countries and comparisons of women by seniority grade are unreliable owing to variations across countries, the data available clearly point to this trend, with a few notable exceptions such as Mozambique and Myanmar (Figure 3.9).

Considered a world leader in innovation, Switzerland is still mired in gender inequality. By 2016, the country's 12 universities had established equality action plans with the explicit goal of increasing the percentage of women on different rungs of the academic ladder (Figure 3.9). Most Swiss universities have introduced gender-specific requests in advertising positions, minimum quotas and at least one equality delegate on appointment committees. Most have also introduced preference rules favouring the less-represented gender in the hiring process, as long as both candidates are equally competent. Despite these efforts, the target set in the Federal Equal Opportunity Programme of having women make up 25% of full professors by 2017 has been missed. The trend for new appointments offers cause for optimism, however, since women represented 33% of new hires in 2016, according to swissuniversities, a lobby group for 14 Swiss universities.[10]

Gillian Norton, chair of the trust that runs St George's University Hospital in London, one of the largest in Europe, observed in 2020 that 'if you are a woman even now, I would say you have to work harder, be more on the ball and be more persistent to get to senior levels than men have had to be in the past'. In 2020, women represented 77% of the National Health Service's 1.4 million employees and 46% of those in executive roles but only 29% of medical directors – albeit an improvement on 25% in 2017 (NHS Confederation, 2020).

Tougher standards for women

Career prospects for female researchers remain daunting. Women are held to tougher standards for funding applications, peer review, tenure review and job applications (Brower and James, 2020; Witteman *et al*., 2019; Kaatz *et al.,* 2016; Hengel, 2017).

The calibre of women is often underestimated, even though they show greater and faster rates of improvement throughout their career, in terms of writing standards and contributions to research (Brower and James, 2020; Hengel, 2017). They are typically given smaller research grants. In Argentina, for instance, female researchers who led scientific projects in 2015 tended to request and receive 25% less in funding than their male counterparts (UNESCO, 2018).

It has been demonstrated that women are as productive as men in terms of research output but tend to have shorter careers, with greater rates of departure at each stage of their career (Huang *et al*., 2020). The difficulty in balancing work and family has been documented as one reason why women cut short their research career.

The gender pay gap in academia may be another reason (Box 3.7). In October 2020, Princeton University in the USA agreed to award backpay totalling US$ 925 000 to 106 women occupying the position of full professor, in a settlement with the Department of Labor over alleged gender pay discrimination. The university considered that its pay model by academic discipline accurately reflected the labour market but agreed to conduct annual equity reviews of salaries for all full professors over the years to 2025 (Tomlinson, 2020).

Article 24 of the *UNESCO Recommendation on Science and Scientific Researchers* (2017) urges member states to ensure that scientific researchers enjoy equitable conditions of work, recruitment and promotion, appraisal, training and pay without discrimination on the basis of their sex.

Box 3.7: **This unique scheme can track the gender pay gap among researchers**

New Zealand is the only country that scores the research performance of every academic using a common metric.

The government's Performance-based Research Fund tracks an academic's publication record alongside factors that include peer esteem, student supervision, public dissemination and non-publication contributions to research. The scores are calibrated to account for potential variations among academic fields.

In parallel, New Zealand uses a clear pay scale across all universities. Although both an academic's pay and score are confidential, the standardized metrics make it possible to analyse the impact of a researcher's career and their quality of life within the science system.

Brower and James (2020) were, thus, able to analyse data from 2003 to 2012 for all researchers in New Zealand. They found that each female academic was paid, on average, NZ$ 400 000 less than her male colleague over the course of her career. About half of this gap could be explained by differences in age, research prowess and field of expertise.

However, men still progressed farther in their career and earned greater pay than women who obtained the same score, with the pay gap varying among fields. In engineering, for example, 58% of the pay gap was unexplained by research performance.

Brower and James (2020) tested several common explanations for the gender pay gap at university. They found that effort alone did not suffice for a woman to catch up. Among researchers at an early stage of their career, women improved their research scores by 13 points more than men, on average between 2003 and 2012, but still stood a lesser chance of being promoted.

The authors found that 'a man's odds of being ranked professor or associate professor were more than double a woman's with a similar recent research score, age, field and university'.

They concluded that no field of science would achieve gender parity by 2070 under current hiring practices.

Source: Brower and James (2020)

In the Republic of Korea, research expenditure per senior researcher amounted to KRW 200 million (*ca* US$ 190 000) for women and KRW 410 million for men in 2017 (see Chapter 25). The Ministry of Science and Information and Communication Technologies uses a point system to assess research grant applications. Under the *Fourth Basic Plan for Fostering Women in STEM* for 2019–2023, bonus points are being allocated to projects which respect at least one of the following criteria: the supervising manager is a woman; women account for more than 20% of participating researchers; or women account for more than 20% of participating researchers in the supervising organization. The ministry also allocates 20% of its total research expenditure to female senior researchers in 'veteran researcher assistance projects', providing KRW 50–300 million over one to five years. This practice is to be adopted by non-profit organizations and other government ministries by 2023.

Less visibility for female academics

Vertical segregation, with a low percentage of women in higher and senior academic positions, is partly a result of reduced visibility, owing to the lower number of papers

Box 3.8: The world needs science and science needs women

For the past 20 years, the L'Oréal–UNESCO Programme for Women in Science has been raising the profile of exceptional women researchers through a system of annual prizes and research fellowships, in order to change attitudes towards female researchers and provide young girls with positive role models. The programme's slogan is 'the world needs science; science needs women'.

In 2019, the programme extended its own international prizes and fellowships to include mathematics and computer science, in recognition of the lack of visibility of female role models in fields which are at the heart of the Fourth Industrial Revolution. Two mathematicians figure among the five regional laureates of the 2019 edition of the prize, Claire Voisin (France) and Ingrid Daubechies (USA). Each of these five laureates took home € 100 000.

Among the 15 rising talents distinguished by L'Oréal and UNESCO in 2020, one is a mathematician (Olena Vaneeva from Ukraine), two are physicists (Huanqian Loh from Singapore and Paula Giraldo Gallo from Colombia) and one is a material engineer (Vida Engmann from Denmark).

Four Nobel Prize winners, Emmanuelle Charpentier (Chemistry, 2020), Jennifer A. Doudna (Chemistry, 2020), Ada Yonath (Chemistry, 2009) and Elizabeth Blackburn (Physiology and Medicine, 2009) were nominated *after* being distinguished by the L'Oréal–UNESCO Awards for Women in Science.

Source: UNESCO

Dr Nazek El-Atab in her laboratory in Saudi Arabia. Dr El-Atab's research focuses on the fabrication of 3D nanotube-based nano-electronics for implantation in the brain. Brain implants could enable the deaf to hear, the blind to see and the paralyzed to control robotic arms and legs. Her work is tackling the major problem of maintaining sufficient data memory in tiny electronic devices. Dr El-Atab is a Postdoctoral Research Fellow at the King Abdullah University of Science and Technology. In 2017, she won the L'Oréal-UNESCO For Women in Science International Rising Talent award. © l'Oréal Middle East published by women (de Kleijn *et al*., 2020). This difference is related to women's shorter careers, despite similar publication output per career year (Huang *et al*., 2020). Although publication in high-profile journals is a key factor in career advancement, female authors have been persistently underrepresented.

An analysis of nearly 3 million computer science papers published between 1970 and 2018 concluded that gender parity would not be reached in this field until at least 2100, even under a scenario in which women authored 90% of all publications in the coming years. The authors noted that, in comparison, gender parity in the biomedical literature was attainable within three decades. Co-authorship by men and women in computer science had actually decreased since 1970. Although both men and women were more likely to collaborate with authors of their own gender, the degree of same-gender preference was declining among female authors even as it rose among male authors (Wang *et al.* 2019).

Women are less likely than men to be first or last authors and women-authored publications receive fewer citations. Since having a low citation rate negatively affects a journal's impact factor, this can discourage publishers from accepting women-authored papers for publication (Wang *et al*., 2019; de Klein *et al*., 2020; Shen *et al*., 2018). In clinical basic science journals, female authors are less likely to be listed as first author (Aakhus *et al*., 2018).

Gender bias can also be found in the peer-review process. A study analysing over 23 000 research manuscripts submitted to six journals in ecology and evolution from 2010 to 2015 found that, on average, women received slightly worse scores and were more likely to be rejected during peer review (Fox and Paine, 2019).

Being invited to give keynote and plenary presentations provides recognition of scientific excellence and visibility; however, female scientists are invited and assigned oral presentations less often than men (Ford *et al*., 2018; Farr *et al*., 2017). Men are invited to speak on scientific panels at twice the rate of women. An analysis of attendance rates at the world's top machine-learning conferences in 2019 found that just 18% of participants overall were women, with the 19% average for academia inching ahead of the 16% average for industry (Kiser and Mantha, 2019).

The Request a Woman Scientist database is one response to this trend. Part of the 500 Women Scientists organization, this database connects a multidisciplinary network of vetted women in science with anyone who needs to consult, invite, collaborate with or identify a female specialist (McCartney, 2019).

Prestigious prizes are another way to showcase excellence and, thereby, challenge negative stereotypes about women in science. One example is the L'Oréal–UNESCO Programme for Women in Science (Box 3.8). The Awards for Early Career Women Scientists are another; since 2013, the Organization for Women in Science for the Developing World has teamed up with the Elsevier Foundation to present these annual awards to five women from developing countries who have overcome considerable obstacles to achieve research excellence.

CONCLUSION

Women still a minority in Industry 4.0 fields

There are signs that women are inching closer to parity in science, at least in terms of numbers. In higher education, they have achieved parity (45–55%) at the bachelor's and master's levels of study and are on the cusp at PhD level (44%). Women accounted for 33% of researchers in 2018, up from 28% in 2013. In many countries, they have achieved parity in life sciences, or even dominate the field.

However, women remain a minority in digital information technology, computing, physics, mathematics and engineering, the very fields that are driving the Fourth Industrial Revolution and, thus, many of the jobs of tomorrow. This trend is all the more problematic in that there is a skills shortage in many of these very fields, such as in artificial intelligence. This trend suggests that progress towards righting the gender imbalance could be compromised, unless strenuous efforts are made at the government, academic and corporate levels not only to attract girls and women to these fields but, above all, to retain them.

Women are leaving tech fields in greater numbers than men. They cite workplace conditions, lack of access to creative roles and a stalled career as the primary reasons for their decision. This correlates with their underrepresentation in company leadership and technical roles, even if corporate attitudes are evolving as studies link investor confidence and greater profit margins to having a diverse workforce. Be they large corporations or start-ups, the picture is similar. A 2019 study by the Silicon Valley Bank of start-ups in technology and health care in Canada, China, the UK and USA found that almost half (46%) had no women at all in executive positions.

Even when women lead start-ups in tech fields, they struggle to access venture capital and other forms of financial support. Just 2.3% of venture capital is being channelled towards start-ups led by women, according to a 2020 global survey of 700 firms by Trustradius.

In academia, women tend to receive less grant funding, even though they are as productive as men. On an annual basis, they publish as much as men but are less likely to publish in high-profile journals or to be first or last authors. Women-authored publications receive fewer citations. Women are passed over for promotion. One New Zealand study found that 'a man's odds of being ranked professor or associate professor [were] more than double a woman's with similar recent research score, age, field and university' (Brower and James, 2020).

A need to transform gender relations

In light of the foregoing, it is hardly surprising that many female graduates are opting not to pursue a career in research – women now account for 44% of PhDs but only 33% of researchers – or choosing to leave the research profession altogether.

There are support programmes targeting women in underrepresented fields such as computing, physics, mathematics and engineering. However, scholarships, fellowships and other incentive measures can only be as effective as the quality and number of applicants. If a high number of girls are not attracted early on in their educational *parcours* to such fields, there will not be the critical mass of quality female applicants to apply for fellowships in advanced research or to receive awards for excellence.

To this extent, such programmes remain gender-accommodating, rewarding those with the tenacity to make it through the system against the odds, rather than changing the system itself. Although this approach can make a difference to individual careers, it cannot reduce gender inequality or address the gender systems that contribute to inequality. To be truly transformative, gender policies and programmes need to transform gender relations.

This will entail eliminating gender stereotypes in education, through initiatives such as *African Girls Can Code*, but also in the workforce. It will entail building awareness among senior managers of the need to level the playing field at work to ensure that men and women enjoy equal opportunity and equal pay. It is not enough to attract a woman to a scientific or technical field of study. We must also ensure that her career is not strewn with obstacles that men do not have to face. As we have seen, women are leaving the tech field in the USA primarily because they feel undervalued.

Whenever awareness-building campaigns prove insufficient, more coercive measures may be needed to change the status quo. The quota system introduced by the State of California in the USA obliges publicly traded companies by law to have boards of directors composed of at least 40% women by 2021.

The good news is that having a diverse workforce is becoming a determinant of investor confidence and higher profit margins. The desire to project an image of social responsibility is inciting companies – and large public bodies like the National Health Service in the UK – to initiate change themselves.

Industry 4.0: an opportunity for those with the right skills

Advances in artificial intelligence and other digital technologies hold the promise of making the male and female characteristics that have been a pretext for gender inequality for so long less relevant in a virtual world. However, there is also a danger that, without due oversight from both men and women, these technologies could further entrench gender stereotypes, cancelling out any advantages.

Industry 4.0 will lead to widespread automation of jobs. Automation could eliminate hazardous manual occupations and repetitive tasks, while creating new professional opportunities for those who can acquire the right skills. It will be important for women to seize this opportunity, as the alternative could be dire. As we have seen, women in England accounted for 70% of employees in jobs with a high risk of automation in 2017 (UNESCO, 2018).

The current shortage of skills in fields such as artificial intelligence, computer science and engineering offers women an opportunity to fill this gap, both as employees and as employers. It will be important to put mechanisms in place to ensure that female entrepreneurs in tech fields have much greater access, in future, to venture capital and other sources of finance.

One advantage of digital businesses is that they tend to be less capital-intensive and less labour-intensive than traditional industries. They also tend to require less office space. In countries where women face impediments in accessing capital, or in leasing and owning property, being able to dispense with the need for expensive real estate could make all the difference to female entrepreneurs.

Digital technologies, which facilitate telework and networking, while providing broader access to information, have been invaluable in ensuring social distancing and information-sharing during the Covid-19 pandemic.

Some of the radical changes to the work–family balance induced by the pandemic may be here to stay. It will be important for these changes to be converted into policies which ensure that women do not spend a disproportionate amount of time as unpaid carers, homemakers and educators but, rather, have the time and the energy to make their mark on the science and innovation of tomorrow, to tackle the defining challenges of our time: climate change, biodiversity loss, pandemics of disease, environmental degradation, unsustainable urban development and so on.

You cannot manage what you cannot measure

One last issue that must be addressed is the lack of comprehensive data on gender trends. This is a chronic problem. Sex-disaggregated data on researchers are not being collected regularly by most countries in the Caribbean, Oceania, South Asia, Southeast Asia and sub-Saharan Africa. UNESCO estimates of women researchers worldwide also exclude North America and China, owing to the international incomparability of these data. These data gaps limit the conclusions that can be drawn at national, regional and global levels.

UNESCO is one of several actors that have been conducting global and national surveys to document the pressures that inhibit the regular collection of sex-disaggregated data. Through its STEM and Gender Advancement (SAGA) project, UNESCO has designed a toolbox for a holistic approach to gender policies, including through an Indicator Matrix blending existing and innovative indicators.

Attitudes are changing. We can see from the examples in the preceding pages and throughout the present report that initiatives to foster gender equality have proliferated in recent years. These have been initiated by a wide range of actors, including governments, legislators, regional bodies, universities, research centres, civil society and private companies. It would be worthwhile for these actors to co-ordinate their initiatives, to ensure greater impact and coherence.

Numerous countries have launched gender-specific equality policies in science and engineering in recent years, signalling that the topic is rising to the top of their domestic agenda. Many of these initiatives remain sporadic, fragmented and limited in time and space but they are widespread. This dynamic gives cause for optimism.

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ENDNOTES

1 STEM refers in the present chapter to the fields of study under the International Standard Classification of Education, namely natural sciences and mathematics, information and communication technologies and, thirdly, engineering, manufacturing and construction.
2 See: https://www.article19.org/data/files/Internet_Statement_Adopted.pdf
3 See: https://globalfindex.worldbank.org/
4 A year after the adoption of the EU's gender pay gap action plan in 2017, France, Ireland and Portugal introduced labour laws which impose financial penalties on employers who do not take pro-active measures to reduce the gender pay gap. In Iceland since January 2018, companies and government agencies with more than 25 employees are required to obtain government certification from an independent entity that their pay policies are gender-equal, or face fines. This measure aims to close Iceland's gender pay gap by 2022 (EC, 2019b).
5 An echo chamber (also known as a filter bubble), is an unwanted feature of an algorithm which does things that were not explicitly intended by its programmer. For instance, the algorithm that builds a person's Facebook feed filters information to show the person the things they like most. In this way, it is easy to convince a person that an idea is false, such as that vaccines cause autism. The person can then live in a virtual bubble (or echo chamber) in which almost everyone in their feed is convinced that vaccines cause autism (UNESCO, 2019).
6 See: Forbes (2019) The World's 100 Most Powerful Women.
7 According to the Venture Capital Female Founders Dashboard, US companies created solely by women received 2.7% of the total venture capital invested in start-ups in 2019 but this value slid back to 2.0% in 2020.
8 See: https://www.trustradius.com/buyer-blog/women-in-tech-report
9 See: dealroom.co
10 See: https://www.swissinfo.ch/eng/gender-inequality_universities-fail-to-fulfil-female-quotas/42551926

AT A GLANCE

- *Globally, women have achieved parity (45–55%) at the bachelor's and master's levels of study and are on the cusp at PhD level (44%) but the gender gap tends to widen as they pursue their career.*
- *Women represented 33.3% of all researchers in 2018, up from 28.4% in 2013, with the caveat that data are only available for 107 countries.*
- *There is a risk that the Fourth Industrial Revolution could perpetuate the gender imbalance, since women remain a minority in digital information technology, computing, physics, mathematics and engineering.*
- *In academia, female researchers tend to have shorter, less well-paid careers. Their work is underrepresented in high-profile journals. An analysis of nearly 3 million computer science papers published between 1970 and 2018 concluded that gender parity would not be reached in this field until the year 2100.*
- *Women also remain underrepresented in company leadership and technical roles. Corporate attitudes are evolving, however, as studies link investor confidence and greater profit margins to having a diverse workforce.*

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