Understanding Amsterdam's competitive advantage

Executive summary

Amsterdam has a rich and illustrious history as a center of learning. Home to world-class universities, academic hospitals, research institutions, and global corporations, the city is a hub for knowledge and innovation in Europe.

Located in the heart of the Netherlands, Amsterdam is surrounded by other cities with strong research pedigrees including Delft, Leiden, Rotterdam, and Utrecht in what is known as the Randstad region. In recent years, Amsterdam has benefitted from Brexit and the relocation of skilled workers, corporate organizations, and institutes such as the European Medicines Agency.

With a global reputation in medicine, health and life sciences, Amsterdam has, in recent years, made substantial investments in artificial intelligence (AI) and data science, bringing together existing research institutes and establishing new initiatives such as Amsterdam Data Science[1] and the Innovation Center for Artificial Intelligence (ICAI)[2] to develop responsible AI technologies. Amsterdam was also one of the first cities to embrace sustainability in its economic and technological development plans, building on the concepts of the 'doughnut' economic model and the United Nations' Sustainable Development Goals (SDGs).

Now is the perfect moment to reflect on Amsterdam's current strengths in research and innovation, benchmarked against

"The data in this report are extremely valuable for Amsterdam. As a city we are on the right track."

Professor Mirjam van Praag, President of the Executive Board of Vrije Universiteit Amsterdam and Professor of Entrepreneurship

other Dutch and European research-intensive cities, and identify opportunities for future development.

Amsterdam is well placed to reinforce its position as a thriving, entrepreneurial, and innovative hub in Europe thanks to a combination of research excellence in medicine, health and life sciences, sustainability, and AI; a concentration of universities, research institutes, academic hospitals, and international corporations; a skilled international workforce of researchers and students; and a burgeoning start-up and scale-up entrepreneurial environment. Moreover, the municipality of Amsterdam and Amsterdam Economic Board[3] are working with the city's higher education and research institutions to unlock future potential economic development and address societal challenges through a wide-reaching impact and entrepreneurship initiative, Amsterdam Impact. The city aims to be one of Europe's "most sustainable impact economy hubs", creating both social and financial value through innovative solutions and supporting entrepreneurialism.

In the following pages, this report will explore Amsterdam's position as a research hub in comparison with other Dutch cities and a selection of leading European

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[1] Amsterdam Data Science (ADS): https://amsterdamdatascience.nl/
[2] Innovation Center for Artificial Intelligence (ICAI): https://icai.ai/
[3] Amsterdam Economic Board: https://amsterdameconomicboard.com/en/

centers of knowledge and innovation including Barcelona, Berlin, Cambridge, Copenhagen, Innsbruck, Leuven, and Stockholm.

Initially, in Chapter 1, we assess Amsterdam's research output and impact to benchmark the city's performance over the last seven years. Amsterdam is a competitive center of research in both the Netherlands and Europe. Its research output is growing, and it produces the largest number of top cited publications of any city in the country. The impact of the city's research effort is comparable with some of the highest achieving European centers of excellence like Cambridge in the UK and Copenhagen in Denmark. Medicine, health and life sciences are the dominant areas of research in Amsterdam, but computer science and AI are now emerging as new strengths.

In terms of AI, we analyze in Chapter 2 how this research area has developed over the last seven years in Amsterdam. The city's research output in AI is increasing, nearly tripling in recent years. However, AI research is booming across Europe, the US, and Asia as well. While Amsterdam's output in AI may be smaller than some of its competitors, its research is highly impactful, cited on average twice as often as the global average.

Amsterdam was one of the first cities to embrace the United Nations' Sustainable Development Goals (SDGs) and frame its research and innovation programs in terms of social and economic sustainability. In Chapter 3, we examine the city's research output in terms of these goals. Amsterdam's long-standing expertise in medicine, health and life sciences are reflected in strong performance on the 'Good Health and Well-being' goal, but the city performs above average in the impact of its 'Climate Action' research as well. As a result of its leadership in embracing sustainability, Amsterdam's research is highly impactful compared with the rest of Europe across the board, with particular strengths in equality, health and well-being, and climate action.

"Amsterdam has a tradition of wanting to do it all. We find it very hard to choose."

Nina Tellegen,
Executive Director of the Amsterdam Economic Board

One of the city's key advantages is its position at the heart of Europe, so in Chapter 4 we explore the extent of international connectivity in its research. Amsterdam's level of international collaboration is growing steadily with its researchers publishing with co-authors from other countries more than those from any other Dutch city. Moreover, the impact of the city's international collaborations is second only to the research powerhouse of Cambridge. However, although nearly 60% of Amsterdam's research output has an international co-author, three times the EU average, the top knowledge cities of Europe achieve even higher levels of connectivity, indicating potential scope for wider expansion.

Collaboration with industry is key to the transfer of knowledge from universities to the commercial sector. Amsterdam is well positioned within the Netherlands to collaborate with a diverse range of companies, spanning sectors from electronics and biotechnology to finance, from the local to the international. In Chapter 5, therefore, we look at how well Amsterdam's research effort is connected to industry. While Amsterdam produces more academic-corporate collaborative publications than any other Dutch city, it lags behind other European knowledge cities in volume. The impact of city's academic-corporate research is extremely high, however, with publications cited four times more than the global average.

Amsterdam is in a convincing position to capitalize on its research and collaborative strengths in technological innovation. In Chapter 6, we assess the city's successes in this arena in terms of filed patents. While Amsterdam performs competitively in terms of the applicability of its research, the number of patents produced is less than that of Eindhoven or other research-intensive European cities such as Cambridge and Berlin. Our analysis indicates that Amsterdam could strengthen its knowledge transfer efforts to capitalize more effectively on its obvious and undeniable research prowess.

This report focuses primarily on the Amsterdam Metropolitan area, but we also consider the performance of the wider Randstad region that includes the cites of Delft, Leiden, Rotterdam, and Utrecht. This conurbation of knowledge cities produces a huge volume of highly cited publications and academic-corporate collaborations, with a high level of international connectivity, marking out the region as a formidable contender in international research and knowledge transfer.

Key findings

Research output: strengths in medicine, health and life sciences

Amsterdam's research output is substantial and growing, especially in medicine, health and life sciences. The impact of the city's research is on a par with European powerhouses Cambridge and Copenhagen, and its publications are cited significantly more than the EU 28 average. The Dutch conurbation of Randstad is the largest producer of publications of the cities analyzed.

Artificial intelligence

Artificial intelligence (AI) is a small but high impact research area for Amsterdam, with a field-weighted citation impact (FWCI) of almost 3. Amsterdam's research output in AI is growing on a par with some of the best performers in Europe.

Sustainable development

Amsterdam is a global leader in research aligned with the United Nations' Sustainable Development Goals (SDGs). The city excels in the fields of 'Good Health and Well-being', 'Gender Equality', and 'Climate Action'.

International Collaboration

Amsterdam's share of publications with at least one international co-author is over 2.5 times the EU 28 average and its impact is on a par with the elite research center Cambridge.

Knowledge transfer

Amsterdam's proportion of academic-corporate publications has grown to 7% and they are highly impactful, cited above EU 28 and world averages. Most Dutch cities also perform above EU 28 and world averages, with Amsterdam leading the way.

Technological strength

Over 10,000 patents originated in Amsterdam between 2014 and 2020. While the city's patent activities are second only to Eindhoven nationally, its performance is average compared with other European research hubs.

Preface

Mirjam van Praag
President, Executive Board of Vrije Universiteit Amsterdam, Professor of Entrepreneur-ship

Kumsal Bayazit
CEO, Elsevier

In 2020, we met at a consultation between Vrije Universiteit (VU) and Elsevier, where we were representing our respective organizations, along with VU Rector Vinod Subramanian. One of the outcomes of our discussions was a consensus that an updated study of Amsterdam's research and innovation infrastructure was needed. Elsevier's last appraisal of the city was in 2015[4], so now is the perfect time to take a fresh look at its unique strengths and identify new opportunities for growth.

Amsterdam is a city of knowledge and innovation. The city is home to prestigious universities, such as VU, the country's largest academic medical center, numerous research institutes, and many corporates, large and small, home-grown and international, including Elsevier. The data-led, evidence-based insights into the state of research and innovation in Amsterdam and the surrounding Randstad region provided in this report are crucial to supporting the future development strategy of the city and its universities and research organizations, including VU.

In recent years, the city's main universities, VU, University of Amsterdam (UvA), and Amsterdam University of Applied Sciences (HvA), have joined forces with the academic medical center, Amsterdam UMC, to establish a valorization strategy for research and knowledge through Innovation Exchange Amsterdam (IXA)[5]. Amsterdam's research institutions, economic board, and municipality have rolled out an impact and entrepreneurship initiative, Amsterdam Impact, to support the development of a thriving ecosystem of knowledge transfer that will create jobs, attract and keep talent, and drive economic growth. These initiatives are based on an underlying commitment to sustainability, equality, and ethical, responsible growth. The city embraces the 'doughnut' model of fair and equitable economic growth and is striving to embed the United Nations' Sustainable Development Goals into research and development plans.

Amsterdam's research output and its impact has grown strongly since 2015. With a long-standing reputation in medicine, health and life sciences, and strong emphasis on sustainability, the city's research strategy is now heavily focused on artificial intelligence (AI) as well. But rather than deploy technology for technology's sake, Amsterdam has created the AI Technology for People[6] program to harness the methodology with the greatest benefit to the most people.

But we must pay attention to other criteria as well, to evaluate Amsterdam's research performance. Despite a relatively small population, the city boasts a highly skilled,

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[4] *Mapping Research and Innovation – Understanding Amsterdam's Competitive Advantage.* (2015). Elsevier and Urban Innovation Network. https://www.elsevier.com/__data/assets/pdf_file/0005/53483/UINAmsterdamReport.pdf
[5] Innovation Exchange Amsterdam (IXA): https://www.ixa.nl/about/
[6] AI Technology for People initiative: https://www.iamsterdam.com/en/business/key-sectors/ai/ai-technology-for-people/what-is-ai-technology-for-people

motivated workforce and is, as a city, recognized globally for its inclusivity[7]. Together with its well-connected location in mainland Europe, Amsterdam is a hub for learners, researchers, innovators, and entrepreneurs.

By interrogating Elsevier's uniquely extensive dataset of over 84 million publications, this report benchmarks Amsterdam's research performance against other cities in the Netherlands and across Europe. The picture presented here is a promising one and fills us with pride. Amsterdam is on the right track: the city and its research institutions are embracing new directions in research and developing innovative entrepreneurial hubs to transfer knowledge seamlessly from the lab to business to society. Inventive solutions will be needed to meet society's current and future challenges – in healthcare and climate change, to name but two examples. This report shows that Amsterdam has a strong foundation on which to build its research efforts, is creating a new narrative to tackle future challenges, and will be able to reap the rewards in coming years. This is an exciting time for the city.

[7] Open For Business. https://open-for-business.org/reports

Contents

Introduction

Amsterdam and the Randstad conurbation are uniquely placed to have a competitive advantage in research and knowledge transfer.

The Netherlands has a long and illustrious history in research. The Dutch capital Amsterdam, despite being a relatively small city in European terms with a population of around 1.4 million in the greater metropolitan area, is one of the "top knowledge cities in Europe"[8] and has had a reputation as a crossroads for ideas and an incubator of great thinkers since the Enlightenment in the 17th century. With Amsterdam's geographical position within the wider Randstad conurbation, which incorporates other key 'knowledge cities' of Delft, Leiden, Rotterdam, and Utrecht, and its accessible location within mainland Europe, the capital is a recognized hub for research and innovation. The research output of the Randstad region is impressive, rivalling some of the world's megacities like London or Tokyo, and makes the region an international powerhouse for intellectual endeavor and technological innovation.

The capital and wider Randstad region are home to a large number of universities, academic hospitals, and research institutions including Vrije Universiteit Amsterdam (VU), University of Amsterdam (UvA), Centrum Wiskunde & Informatica (CWI Amsterdam), National Institute for Subatomic Physics (Nikhef), Hogeschool van Amsterdam, The Netherlands Cancer Institute (NKI), the blood bank Sanquin, Instituut voor Atoom- en Moleculfysica (AMOLF), Netherlands eScience Center, and Advanced Research Center for Nanolithography (ARCNL) to name but a few. In addition, the recent merger of the university hospital affiliated with UvA and VU's Medical Center has created Amsterdam University Medical Centers (or A UMC), the largest academic medical center in the country. The region is also home to major multinational corporates, including ING Group and Philips, as well as several home-grown billion-dollar startups

(or 'unicorns') such as Adyen, Booking.com, and MessageBird, and a substantial number of innovative SMEs.

Amsterdam is a recognized world leader of "indisputable strength"[1] in medicine, health and life sciences research. Elsevier's previous analysis of Amsterdam's research strengths identified a growing comparative advantage in computer science, so this report will interrogate that finding more deeply, assessing the potential of Dutch research to capitalize on the new possibilities offered by artificial intelligence (AI).

Recently, for example, a group of academic, medical, and other organizations in Amsterdam launched the EUR 1 billion 'AI Technology for People' investment to develop

> *"This report is an excellent foundation on which to build our efforts and we will reap the rewards in the coming years."*
>
> Professor Mirjam van Praag,
> President of the Executive Board of Vrije Universiteit Amsterdam and Professor of Entrepreneurship

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[8] *Mapping Research and Innovation – Understanding Amsterdam's Competitive Advantage.* (2015). Elsevier and Urban Innovation Network.

https://www.elsevier.com/__data/assets/pdf_file/0005/53483/UINAmsterdamReport.pdf

responsible AI technologies over the next decade[9]. The initiative will establish research programs and collaborations with public and private global partners to attract top researchers and train students in state-of-the-art AI[10]. In addition, the city's universities, the municipality, and Amsterdam Economic Board aim to unlock further potential in AI to strengthen economic development and earning capacity, as well as develop solutions for societal challenges. These aims will be realized via the 'Impact and Entrepreneurship' initiative, which aims to:

- Create a thriving research hub for AI and data, health and life sciences, and sustainability;

- Develop networks and ways of working to support entrepreneurial and impact-oriented research that addresses societal challenges;

- Provide attractive conditions for start-ups and scale-ups;

- Establish public-private initiatives focused on societal challenges; and

- Create a new generation of researchers and students with entrepreneurial skills.

In the five years since Elsevier's the last assessment of Amsterdam's research performance, there have been significant global changes. Apart from the knock-on effects and impacts of the global pandemic, Amsterdam has

"In recent years, Amsterdam has made a deliberate choice to focus on a limited number of areas. The results of [this] will become visible in the near future."

Professor Arjen Brussaard,
Vice Dean Valorization of Research at Amsterdam UMC and Scientific Director of Amsterdam Neuroscience

benefitted from Brexit, with an influx of skilled workers, corporate organizations, and large institutes such as the European Medicines Agency.

Between 2014 and 2022, the Dutch government increased research and development funding from EUR 4.7 billion in 2014 to EUR 7.3 billion in 2022. Most of the funds are earmarked for universities and fundamental research, with a smaller proportion aimed at applied research in industry and technology. In the last two years, the Dutch government has increased the levels of funding for research and innovation by 20%, representing an additional investment of EUR 1.2 billion. Most of the additional investment comes from the National Growth Fund, which is a government initiative focusing on research and development in areas with the highest potential for structural and durable economic growth. In April 2022, a second round of funds was granted to research projects in the fields of AI in the healthcare sector, key technologies such as photonics, start-ups in the pharmaceutical industry, hydrogen, green chemistry, and digitization in the logistics sector. Universities in Amsterdam and others spread across the rest of the country are involved in 21 of the 28 research projects. In the coming years, the Dutch government has earmarked a total of EUR 20 billion for 'knowledge development' and 'research, development and innovation' through the National Growth Fund[11].

In general, universities and research organizations/ institutes, play a key role in defining cities. Institutions have longevity and long-term development plans, they are

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[9] https://amsterdameconomicboard.com/en/news/ amsterdam-knowledge-institutions-invest-1- billion-in-ai/ https://www.iamsterdam.com/en/business/key- sectors/ai/ai-technology-for-people/what-is-ai- technology-for-people

[10] https://www.cwi.nl/news/2019/amsterdam- knowledge-institutions-invest-1-billion-euros- in-ai

[11] https://www.nationaalgroeifonds.nl/english/the- national-growth- fund#:~:text=With%20the%20National%20Gr owth%20Fund,knowledge%20development

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significant local employers of highly skilled and high-wage workers, as well as training the next generation of 'knowledge' workers for cutting-edge technological sectors. Universities and research institutions supply industry with skilled workers as well as acting as the source of new start-ups and scale-ups. Higher education and the training of future highly technical workers is one of the twelve pillars by which the World Economic Forum measures national competitiveness[12].

Amsterdam and its universities and research institutions have long valued their skilled workforce and have a reputation for inclusion. In Open For Business' latest appraisal of global cities' inclusivity and competitivity[13], the Dutch capital received the highest 'AAA' rating alongside a handful of other cities including Berlin, London, Copenhagen, and Stockholm as 'fully open for business'. This coalition of global companies interrogate hundreds of academic studies, business reports, data sets, and expert perspectives to assess the links between LGBT+ inclusion and economic growth for over 140 cities around the world.

Moreover, the city as an entity comprising its universities, the municipality and Amsterdam Economic Board is taking an active role in defining its future development in terms of the well-recognized 'doughnut model' of sustainable development, which incorporates a social foundation to ensure that society's basic needs are met with as much equality as possible without overly impacting the planet's ecology. These aims build heavily on the United Nation's 17 globally agreed Sustainable Development Goals (SDGs)[14], which aim to address the challenges faced by the world and

> *"Apart from physical data, numbers, and graphs, we must pay attention to other criteria to complete the picture of research at Amsterdam's institutions."*
>
> Professor Mirjam van Praag, President of the Executive Board of Vrije Universiteit and Professor of Entrepreneurship

"achieve a better and more sustainable future for all"[15] by 2030. The targets, which were agreed upon by all member states, relate to climate, health, sustainable infrastructure, clean energy and water, responsible consumption and production, as well as justice, equality and ending poverty and hunger, to name but a few [for full details see Appendix A]. As we near the 2030 deadline for the UN's SDGs, this report will analyze Amsterdam's research profile and performance in light of these goals.

Since 2014, moreover, the UvA, VU, Amsterdam University of Applied Sciences (HvA), and Amsterdam UMC have joined forces on knowledge transfer to capitalize more effectively on the academic and practice-based research and knowledge emerging from these institutions. Innovation Exchange Amsterdam (IXA)[16] aims to encourage and facilitate ground-breaking innovations and applications to transform lives and industries, creating societal and economic impact.

For cities to maximize the impact of their knowledge expertise and intellectual capital, as well as attract and drive investment, development strategies must be aligned with research strengths. In addition, the challenges faced by the globe in terms of climate change and sustainability are demanding the development of new research strengths and capabilities. Amsterdam is already a global leader in research, with great strengths in medicine, health and life sciences, behavioral sciences, physics, climate change, and computer science, and the city is now working to integrate these recognized strengths with the new opportunities and advances offered by AI and the drive for sustainable development. To maximize these efforts, a full understanding of the research and innovation landscape is vital.

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[12] From[1]: Schwab, K., & Sala-i-Martin, X. The Global Competitiveness Report 2013-2014. (2013). Geneva. (p. 569). Retrieved from http://www3.weforum.org/docs/WEF_GlobalCompetitivenessReport_2013-14.pdf

[13] Inclusive cities, Dynamic economies, Better lives: Open for Business City Ratings 2022.

(2022). Open For Business. https://open-for-business.org/reports

[14] United Nations' Sustainable Development Goals: https://sdgs.un.org/

[15] https://www.un.org/sustainabledevelopment/sustainable-development-goals/

[16] Innovation Exchange Amsterdam (IXA): https://www.ixa.nl/about/

Aims and scope

This report analyzes the research strengths of Amsterdam and the wider Randstad conurbation, benchmarking performance against other leading technological cities in Europe with a research-focus including Barcelona, Berlin, Copenhagen, Stockholm, Cambridge, Leuven, and Innsbruck using a range of quantitative indicators. The selected cities are comparable peers to Amsterdam in terms of their research enterprise and strength in life sciences. Innsbruck, moreover, is part of Aurora University Alliance[17], along with VU.

How do we identify and assess Amsterdam's research performance? One way is to analyze the city's research output, in terms of the number of peer-reviewed papers published, and the influence of these publications, in terms of the number of citations they receive. In academic research, peer-reviewed publications are one of the primary means by which new ideas and data are communicated to the research community and beyond. Scholarly peer review ensures that new results/data are scrutinized by experts in the same field and deemed suitable for publication. Every publication also refers to the previous works on which its ideas and findings are constructed. These citations are, therefore, an effective measure of the importance or influence of a piece of research.

While publications and citations are only one measure of research output and performance, this analysis uses Elsevier's Scopus database of over 84 million peer-reviewed documents from some 7000 publishers to provide source data of depth and breadth[18]. Bibliometric techniques offer a means of interrogating this dataset quantitatively to gather a snapshot of research performance, in terms of academic publications and the impact of those publications in terms of citations.

The increasingly widespread use of bibliometric indicators for the evaluation of research, universities, departments, and individual researchers has come under scrutiny in recent years. In this report, we adhere to best practice and principles such as those set out in the Leiden Manifesto[19] in the design and calculation of indicators, which at the level of aggregation for entire cities can be reasonably expected to reflect their knowledge creation and influence in a meaningful and objective way. When calculated using comprehensive and curated data such as Scopus, these indicators are relied upon for many of the world's most prominent research assessment exercises[20].

In this analysis, we use multiple indicators to build up a comprehensive picture of the level and quality of research performed by institutions in Amsterdam and the wider Randstad region, in which disciplines, the impact of that research, how collaborative these efforts are internationally as well as with corporates, and how well knowledge is transferred to industry when compared with the national average, the average across the European Union (EU 28), the world average, and a selection of seven comparator research-focused European cities.

This aim of this report is to help universities, research organizations, funding bodies, industry, and governments make data-based decisions on current strengths and where research focus, direction, support, and development could be best deployed in the future to realize potential growth.

In the following sections, therefore, this report will ask:

- What are Amsterdam's current, unique strengths in research?

- In which fields of research does the city's research institutions and universities excel?

- What are the city's strengths in AI?

- How do the city's research strengths mesh with the UN's SDG goals?

- How do the region's research entities interact with the global research community and industry?

- How does Amsterdam compare with its peers in Europe in knowledge transfer?

[17] Aurora University Alliance: https://aurora-universities.eu/about/

[18] https://www.elsevier.com/solutions/scopus

[19] Hicks, D., et al., Bibliometrics: The Leiden Manifesto for research metrics. Nature (2015) 520, 429-431. https://www.nature.com/articles/520429a

[20] Baas, J., et al., Scopus as a curated, high-quality bibliometric data source for academic research in quantitative science studies. Quantitative Science Studies (2020) 1 (1): 377–386. https://doi.org/10.1162/qss_a_00019

Amsterdam's research output: strengths in medicine, health and life sciences

Amsterdam's research output: strengths in medicine, health and life sciences

Understanding Amsterdam's research landscape supports evidence-based decisions for future investment, innovation, and growth.

Amsterdam boasts two internationally renowned universities (University of Amsterdam or UvA and Vrije Universiteit Amsterdam or VU), the largest university medical center in the Netherlands (Amsterdam UMC), a prestigious university of applied sciences (Hogeschool van Amsterdam), and numerous specialized research institutions with a large workforce of skilled staff. The wider Randstad region encompasses other world-leading universities and institutions, as well as large-scale corporate research and innovation centers. To set the scene and form the basis of subsequent discussions, we initially aim to explore the scale of Amsterdam's research in comparison with the Randstad region, the Netherlands, and Europe more broadly, both in terms of seven comparator cities and, where possible, the average across EU 28 countries. This analysis aims to provide a detailed picture of the city's research strengths and its performance from basic research to the transfer of knowledge into the private sector.

"This report makes it clear that Amsterdam scores extremely well on research output and impact."

Nina Tellegen,
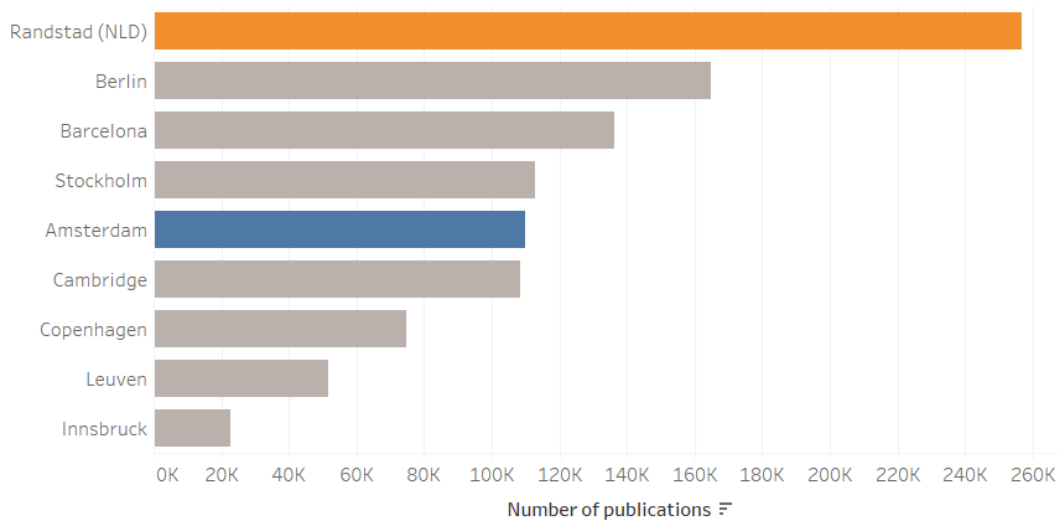Executive Director of the Amsterdam Economic Board

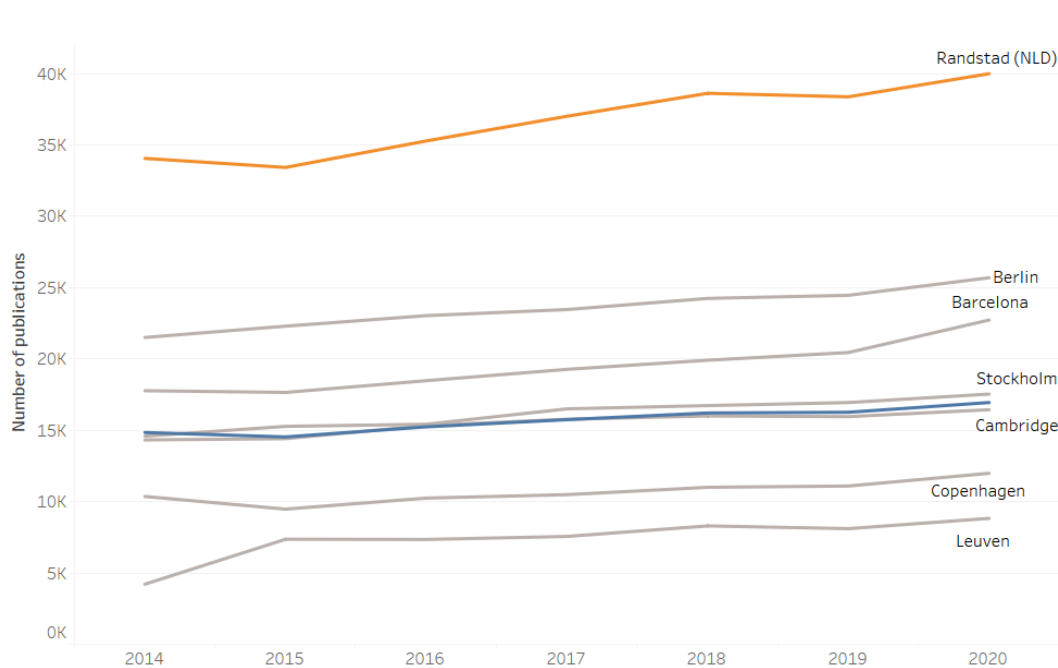Figure 1.1 *Number of publications by city and for the Randstad region, 2014-2020.*

Figure 1.2 *Number of publications per year by city and for the Randstad region, 2014-2020.*

Over the seven-year period of this report, Amsterdam produced a total of approximately 110,000 publications (Fig. 1.1), representing an output of just over 11 publications per 1000 residents per year[21], an increase over the figure calculated for the previous period of 2004-2013[22]. It is also worth noting that Amsterdam's research output per capita is more than double that of the wider Randstad region[23]. Amsterdam's annual output of scholarly publications increased from around 15,000 in 2014 to 17,000 in

[21] This calculation assumes a total number of publications from Amsterdam of 110,000 over the period of the report and a population of 1.4 million in 2020.

[22] *Mapping Research and Innovation: Understanding Amsterdam's Competitive Advantage.* (2015). Elsevier and Urban Innovation Network. https://www.elsevier.com/__data/assets/pdf_file/0005/53483/UINAmsterdamReport.pdf

[23] The calculation for the Randstad region, assuming a population of 8 million and a total number of publications of 255,000, yields a figure of 5 publications per 1000 residents per year over the period of the report.

2020 (Fig. 1.2), reflecting the city's strong academic performance and confirming its reputation as a 'knowledge city'.

While Amsterdam's total number of publications over the period of analysis is comparable with Stockholm and Cambridge, all these cities are outstripped by Barcelona and Berlin (Fig. 1.1). The cities compared here, including Amsterdam, show roughly similar growth rates in the number of publications from 2014 to 2020 (Fig. 1.2). The Randstad region, unsurprisingly given its size and high density of universities and research institutions in Amsterdam, Delft, Leiden, Rotterdam, and Utrecht, produced an impressive 256,000 publications over the same period, 50% more than the largest of the comparator cities, Berlin.
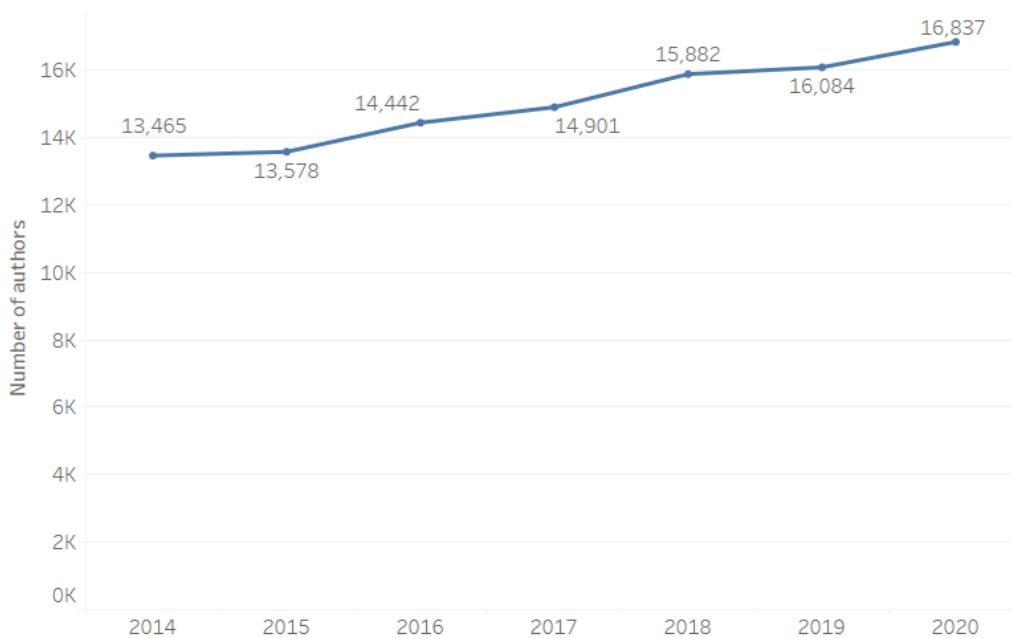

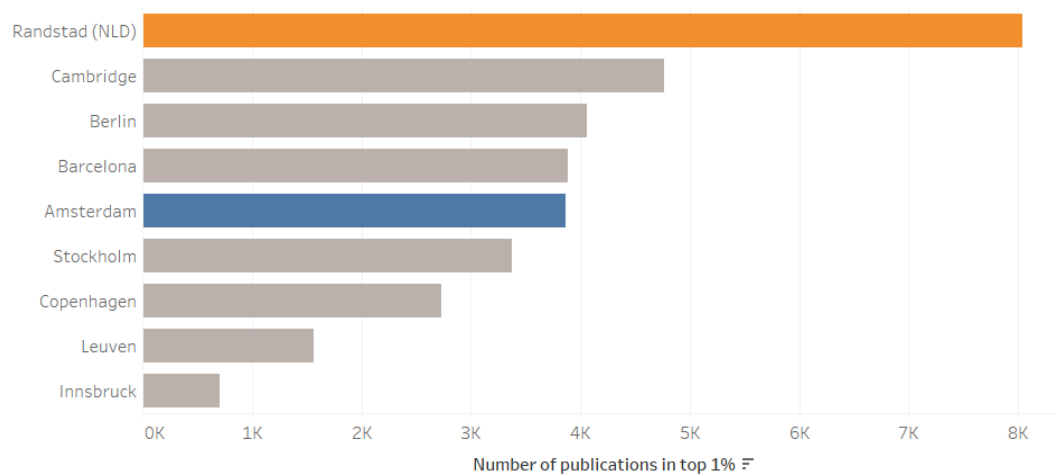Figure 1.3 *Number of authors from Amsterdam per year, 2014-2020.*

Figure 1.4 *Number of publications with top 1% of citations by city and the Randstad region, 2014-2020.*

The upward trend in research output from Amsterdam and the Randstad region is likely the result, at least in part, of rising numbers of authors of academic publications, which reached nearly 17,000 by 2020 (Fig. 1.3). While the analysis cannot determine the number of active researchers, the steady increase over the period indicates the city's ability to retain productive staff.

Not only are Amsterdam and the wider Randstad region prolific generators of publications, but the impact of this research also ranks very highly. Here we measure impact by counting the number of citations a publication receives and recording how many publications are in the top 1% of the number of citations. Amsterdam produces a comparable number of top cited publications to Barcelona, Berlin, and Cambridge and more than the Scandinavian research centers of Stockholm and Copenhagen (Fig. 1.4). Our analysis indicates that while Amsterdam may not generate the largest volume of publications, the impact of its research output is as high or higher than many of its competitors. In other words, Amsterdam's research efforts favor quality over quantity. The wider Randstad region, moreover, with its size and concentration of research-heavy cities, tots up twice as many top cited publications as Amsterdam, Barcelona, or Berlin.
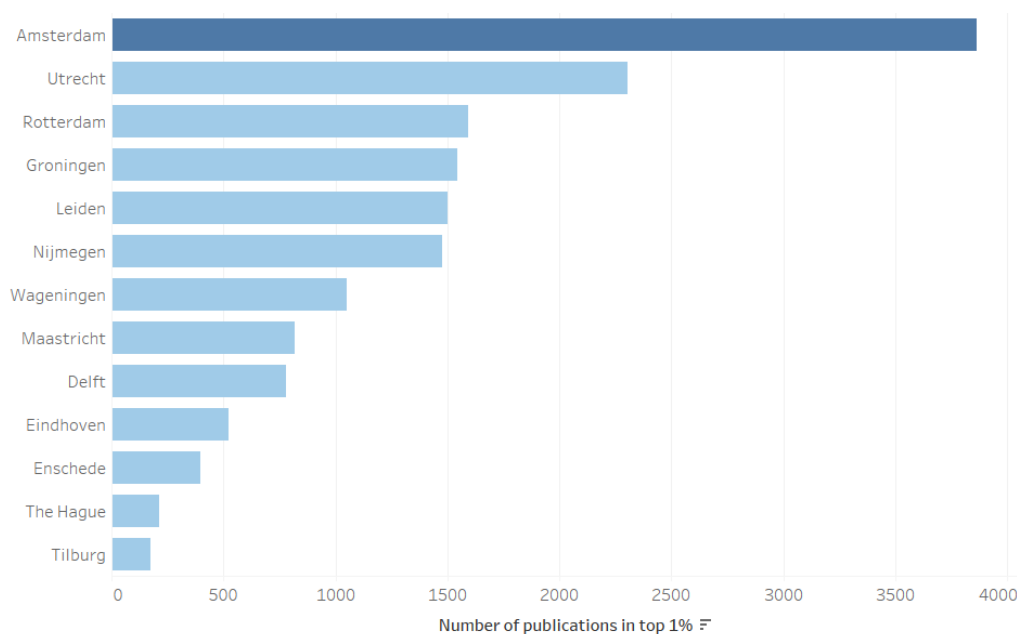

Figure 1.5 *Number of publications in top 1% of citations by Dutch city, 2014-2020.*

Looking at the same indicator for other cities across the Netherlands, the outstanding strength of Amsterdam's research enterprise is revealed (Fig. 1.5). The city produced almost twice as many top cited publications between 2014 and 2020 as the next best city, Utrecht, and is way ahead of all other cities in the Netherlands with a significant research output.
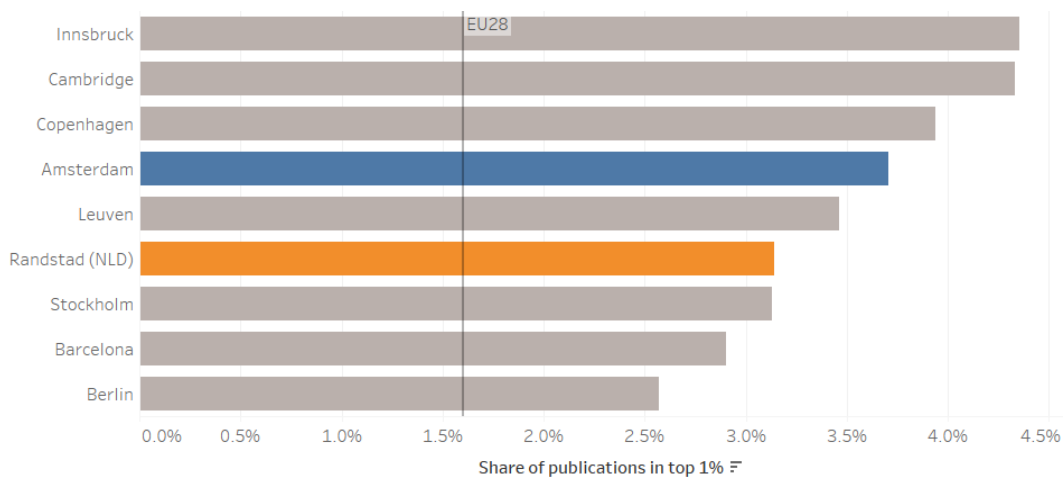
Figure 1.6 *Share of publications with top 1% of citations by city and the Randstad region, with the EU 28 average, 2014-2020.*

Moreover, if we look at the top 1% of cited publications as a share of the total number published (Fig. 1.6), Amsterdam's comparative strength in research clearly emerges. The city's share of most highly cited publications is more than twice the EU 28 average and ranks just behind the research powerhouses of Cambridge and Copenhagen, as well as Innsbruck. Interestingly, Amsterdam ranks well above the wider Randstad region by this measure, which produces a much larger volume of publications and is itself well above the EU 28 average. The data are further evidence that while Amsterdam may produce a smaller volume of research than the Randstad region, its impact is greater with a larger proportion of its output highly cited.
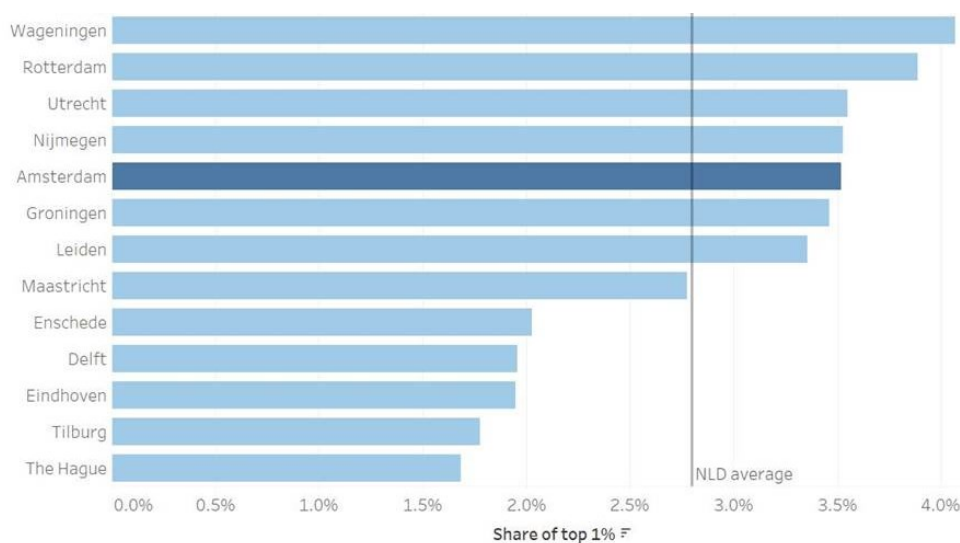

Figure 1.7 *Share of publications in top 1% of citations by Dutch city, with the national average for The Netherlands, 2014-2020.*

At the national level, Amsterdam performs well above the average in terms of its share of top cited publications on a par with Utrecht, Nijmegen, Groningen, and Leiden, while Rotterdam and Wageningen

are slightly ahead with impressive shares of top cited publications of around 4% (Fig. 1.7). The analysis underscores the highly successful and influential research enterprise of the universities located in these cities. The much younger Maastricht University is close to the national average by this measure, while the technical universities of Enschede, Delft, and Eindhoven trail below the national average.
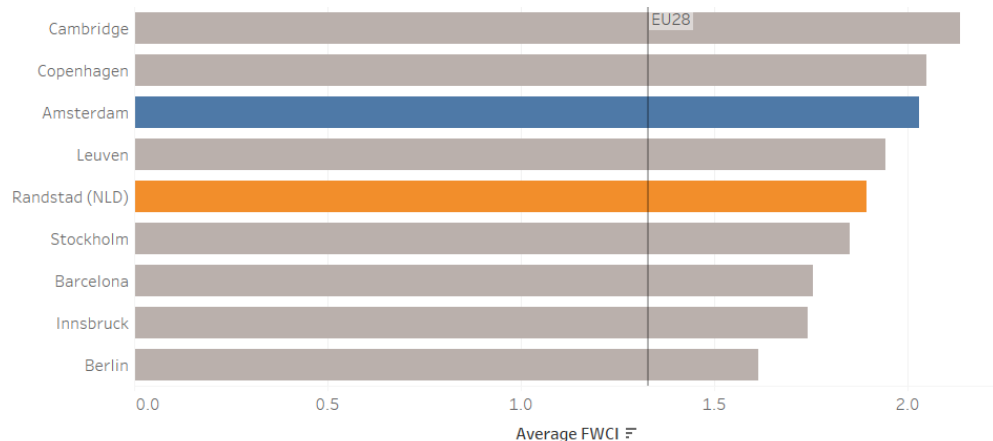

Figure 1.8 Field-weighted citation impact (FWCI) by city and for the Randstad region, with the EU 28 average, 2014-2020.

When publication citations are normalized to account for differences in subject areas, publication type, and year of publication by using field-weighted citation impact (FWCI), Amsterdam performs significantly better than the EU 28 average and twice as well as the world average, outperforming the wider Randstad region and on a par with the research hubs of Cambridge and Copenhagen (Fig. 1.8). Normalizing citations offers a more accurate indicator of research performance by taking into consideration the fact that some fields such as medicine and biochemistry produce more publications with more co-authors on average, often receiving more citations than other disciplines such as mathematics or education. If non-weighted values were used, a medical institution would appear to be better performing than one specializing in social sciences, for example.
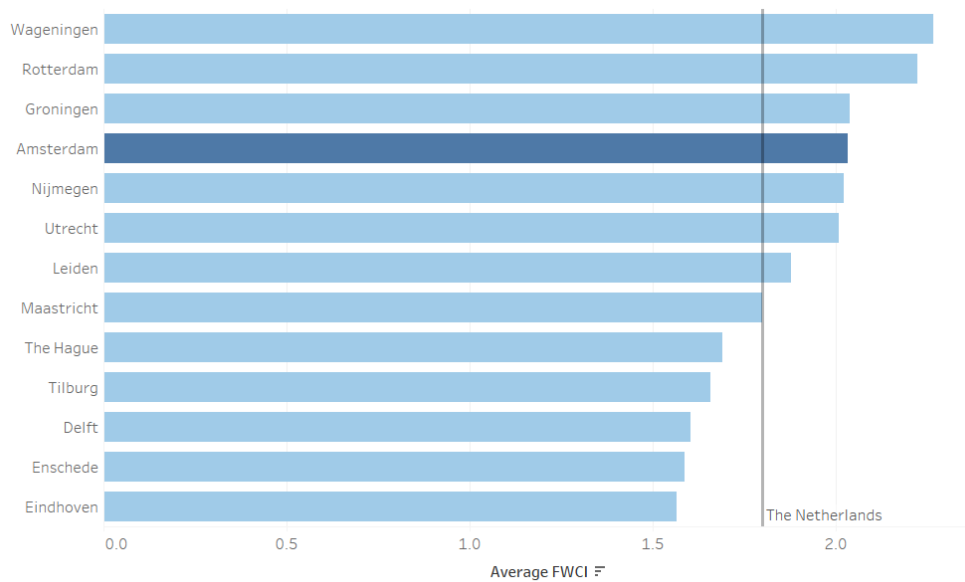
Figure 1.9 *Field-weighted citation impact (FWCI) by Dutch city with the national average for The Netherlands, 2014-2020.*

As a country, the Netherlands performed better over the period analyzed on average than EU 28 countries (FWCI of 1.8 versus 1.3, respectively). Within the Netherlands, Amsterdam exceeds the national average in terms of normalized citations, along with other Randstad cities Rotterdam and Leiden, and a handful of other cities (Fig. 1.9). Wageningen and Rotterdam achieve an impressive FWCI of 2.2 for the period, indicating the high impact of these cities' research output. Once again, the non-specialized universities of Amsterdam, Groningen, Nijmegen, and Utrecht perform similarly, while the technical universities of Eindhoven, Enschede, and Delft perform slightly less well, below the national average. Overall, Amsterdam and the surrounding cities in the Randstad region are among the best performing knowledge cities in Europe, producing a significant volume of research and a high proportion of the most cited publications compared with national, European, and world averages.
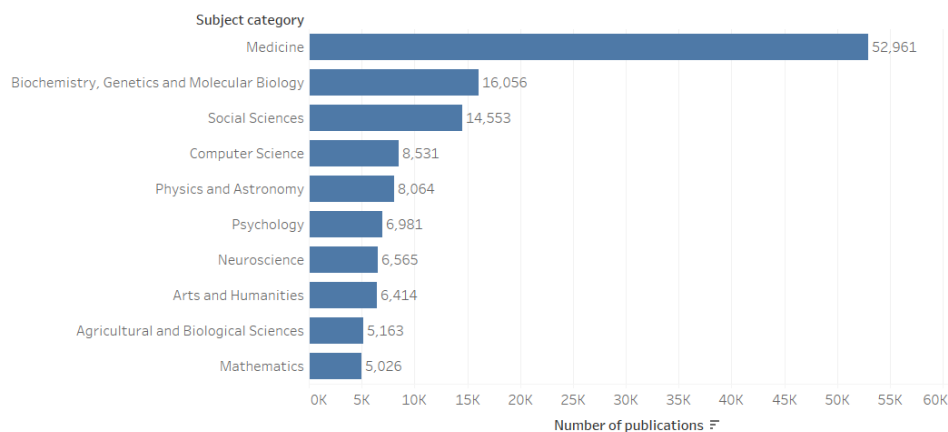

Figure 1.10 *Number of publications from Amsterdam in the top 10 subject categories (using All Science Journal Classifications or ASJC27), 2014-2020.*

Since our analysis reveals that Amsterdam is clearly a leading research city both nationally and within Europe across all research disciplines considered as a whole, it is useful to drill down to determine in which specific specialized fields the city excels. Publications in medicine dominate Amsterdam's output, dwarfing even the fields of biochemistry, genetics, and molecular biology for which the city is renowned (Fig. 1.10). For this analysis, we employ 27 defined subject areas, known as All Science Journal Classification or ASJC, which are commonly used to categorize scientific articles published in journals [for further details on this classification, see Appendix A]. Although medicine leads Amsterdam's academic output, bio- and life sciences, social science, and computer science feature prominently, making it into the top five along with physics and astronomy.
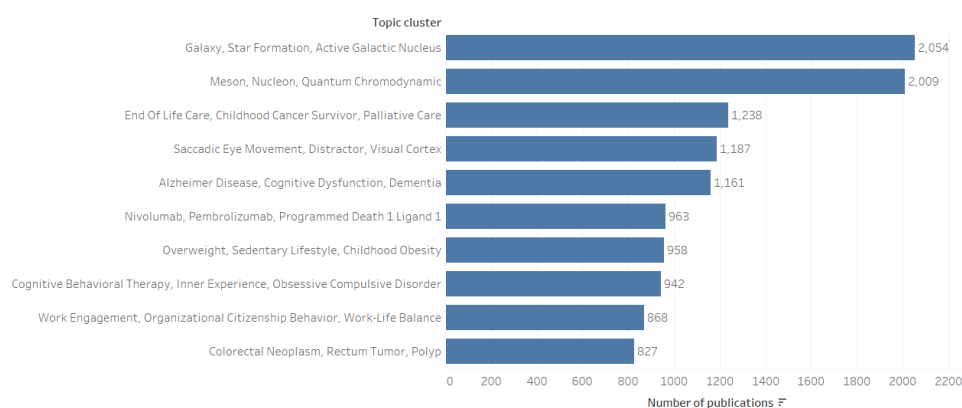
Topic cluster

Topic cluster	Number of publications
Galaxy, Star Formation, Active Galactic Nucleus	2,054
Meson, Nucleon, Quantum Chromodynamic	2,009
End Of Life Care, Childhood Cancer Survivor, Palliative Care	1,238
Saccadic Eye Movement, Distractor, Visual Cortex	1,187
Alzheimer Disease, Cognitive Dysfunction, Dementia	1,161
Nivolumab, Pembrolizumab, Programmed Death 1 Ligand 1	963
Overweight, Sedentary Lifestyle, Childhood Obesity	958
Cognitive Behavioral Therapy, Inner Experience, Obsessive Compulsive Disorder	942
Work Engagement, Organizational Citizenship Behavior, Work-Life Balance	868
Colorectal Neoplasm, Rectum Tumor, Polyp	827

Figure 1.11 *Number of publications from Amsterdam by top ten topic cluster, 2014-2020.*

These macro-subject categories can be further subdivided into micro-categories for a more rigorous bottom-up examination of a region's specialist expertise. Elsevier has categorized its entire citation database of Scopus-indexed publications and additional documents into over 96,000 precisely defined 'Topics', each of which represents a collection of publications sharing a common intellectual interest, as demonstrated by direct citation links among the publications [for further details, see Appendix A]. When Amsterdam's research output is categorized in these terms, it is noteworthy that while medicine still clearly dominates the top ten topic clusters, there is also strong expertise in related fields of health, well-being and behavioral sciences, as well as particle physics and astrophysics (Fig. 1.11).

Conclusions

- The normalized citation impact of Amsterdam's research output is on a par with the research powerhouses of Cambridge and Copenhagen, outperforming the wider Randstad region.

- Amsterdam is on a par with Berlin and Barcelona in the number of top 1% most cited publications, exceeded only by Cambridge, indicating the high impact of its research output.

- Amsterdam's research output in terms of the number of publications is on a par with Cambridge and Stockholm, with strengths in medicine, health and life sciences.

- Amsterdam boasts a depth of expertise in medicine, health and life sciences, behavioral science, particle physics, and astrophysics.

- Computer science now ranks as Amsterdam's fourth largest discipline in terms of number of publications.

Amsterdam's developing focus on artificial intelligence

Amsterdam's developing focus on artificial intelligence

AI is becoming increasingly ubiquitous and has the potential to offer innovative solutions across diverse scientific research disciples.

The Netherlands and Amsterdam have a long-standing global reputation as a powerhouse in medicine, health and life sciences. However, computer science now ranks as Amsterdam's fourth largest subject category of publications and is an area that is highly significant for future research and innovation. The city's research output in computer science has grown significantly over the last two decades[24], exceeding Amsterdam's overall research growth rate and ranking the city highly in terms of publications per capita in this field.

Artificial intelligence (AI), in particular, has been identified in recent years as a powerful approach for producing innovative solutions in many disciplines of scientific research. The use of AI, for example, in data analysis, computer vision, machine learning, decision making, and neural networks is becoming increasingly embedded in and vital to fields such as health sciences, social sciences, and agriculture.

However, defining a field like AI is a very complex undertaking. While computer scientists may prefer a relatively narrow and technical definition of AI, this report takes a broader approach based on keywords to describe the field and identify publications from other disciplines that apply its methods. Elsevier has characterized the field of AI research in a structured and comprehensive manner using approximately 800 specific keywords or concepts that, when applied to its own extensive publication datasets and public sources, generates a collection of some 7 million publications. In combination with machine learning techniques, a body of 700,000+ publications describing AI and its application in different fields can be defined. This approach ensures that AI-relevant publications from other fields such as medicine, social sciences or technological subjects are identified, as well as those in computer science, are considered in the analysis presented here.

Europe, as a region, produces a large scholarly output in AI and member states have come together under the 'European AI Alliance'[25].

"In the coming years, there are major challenges ahead, especially in the fields of climate change, healthcare and sustainability, where we will have to innovate. AI will play an important role in these developments."

Professsor Maarten de Rijke,
Distinguished professor of AI and
IR at the University of Amsterdam and
Founding Director of the Innovation Center for
Artificial Intelligence (ICAI)

[24] *Mapping Research and Innovation – Understanding Amsterdam's Competitive Advantage*. (2015). Elsevier and Urban Innovation Network. https://www.elsevier.com/__data/assets/pdf_file/0005/53483/UINAmsterdamReport.pdf
[25] European Commission. EU Member States sign up to cooperate on artificial intelligence. 10 April 2018. https://ec.europa.eu/digital-single-market/en/news/eu-member-states-sign-cooperate-artificial-intelligence

However, the region has a diverse focus and appears to be losing its share of publications and talent to other countries such as the US. China, meanwhile, has emerged in recent years as a global leader in AI, particularly in computer vision, supported by ambitious national policies such as its *New-Generation Artificial Intelligence Development Plan* and billion-dollar investments[26]. The US, which boasts global technology hubs in Silicon Valley and the Boston area, as well as the National Artificial Intelligence Research and Development Strategic Plan[27], remains a major contributor to AI research. Other countries such as India are also emerging as new players on the block. Consequently, AI is a high priority for policy makers, as well as industry and research leaders. In this chapter, we analyze the research output from Amsterdam and the Randstad region through the lens of AI.
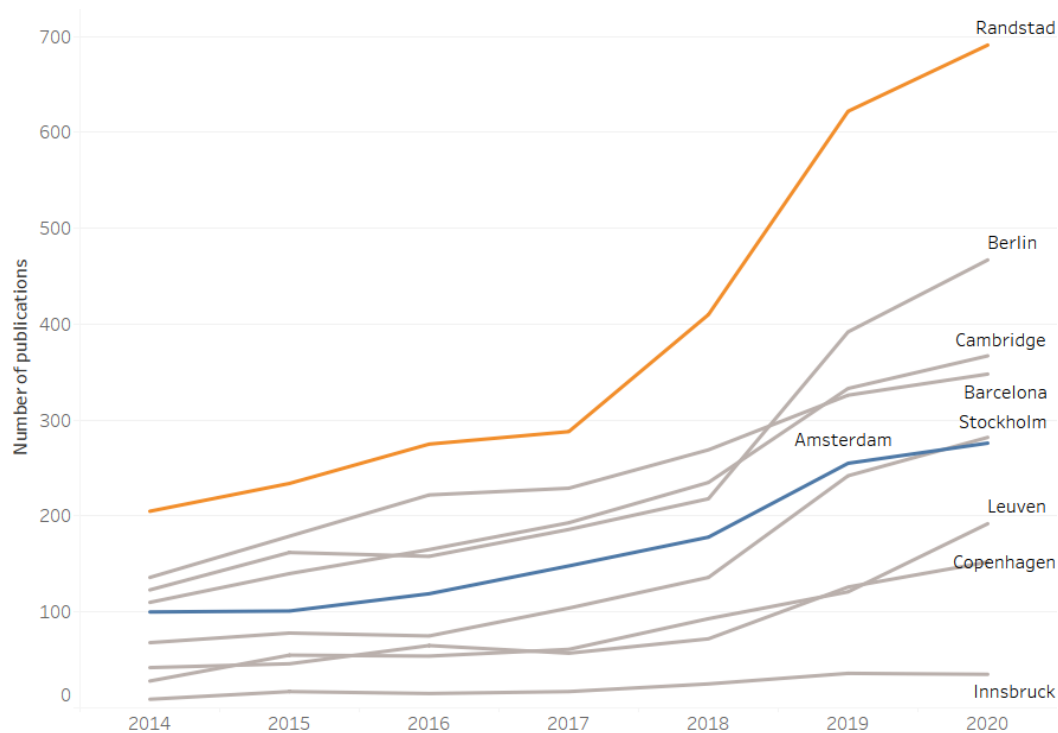

Figure 2.1 *Number of AI publications by city and for the Randstad region, 2014-2020.*

The volume of Amsterdam's publications in AI increased over the period of this report (Fig. 2.1), nearly tripling from 100 publications in 2014 to just under 300 in 2020. The boom is likely the result, at least in part, of the clear focus of knowledge institutions and the municipality on this topic through measures such as the AI Technology for People initiative[28], aimed at providing an ethical and responsible approach to AI that improves people's lives, and the ICAI, a national network aimed at developing talent and technology across knowledge institutes, industry, and government. Amsterdam and the Randstad's growth in AI publications can also be viewed in relation to other EU 28 cities, with the city on a par with Stockholm and

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[26] From5: The State Council. The People's Republic of China. China issues guidelines on artificial intelligence development. 20 July 2017. http://english.gov.cn/policies/latest_releases/2017/07/20/content_281475742458322.htm

[27] National Science and Technology Council, Networking and Information Technology Research and Development Subcommittee. The National Artificial Intelligence Research and Development Strategic Plan. October 2016. https://www.nitrd.gov/PUBS/national_ai_rd_strategic_plan.pdf

[28] https://www.iamsterdam.com/en/business/key-sectors/ai/ai-technology-for-people/what-is-ai-technology-for-people

behind only Berlin, Cambridge, and Barcelona. While the wider Randstad region is leading the way in Europe, demonstrating rapid growth, Berlin has also seen significant growth over this period.
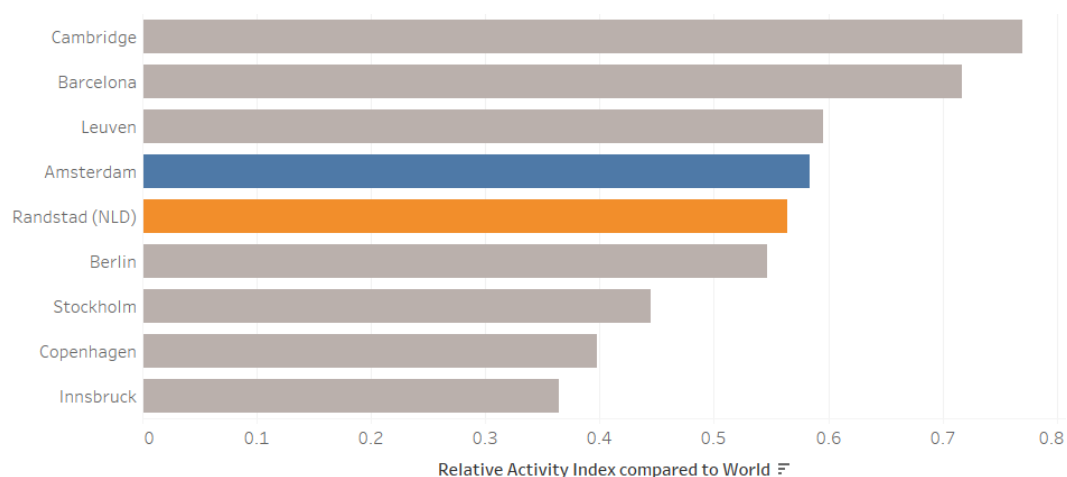

Figure 2.2 *Relative activity index compared with the world by city and for the Randstad region, 2014-2020.*

The relative activity index measures the share of an entity's (in this case, a city's) publications relative to the global share of publications in a given field. Typically, a value higher than 1.0 indicates a greater emphasis than the global average and a value lower than 1.0 a lesser focus. In the AI sector, global values are skewed by the dominance of the huge research efforts of China and the US. By this indicator, Amsterdam is on a par with Leuven and Berlin, outperforming the Scandinavian powerhouse research cities of Stockholm and Copenhagen in a field led Cambridge and Barcelona (Fig. 2.2). Our analysis indicates that Amsterdam has a slightly stronger emphasis on AI compared with the wider Randstad region. However, all the European cities analyzed in this report demonstrate activity indices well below China, which leads the world with a relative activity index of over 3 (data not shown).
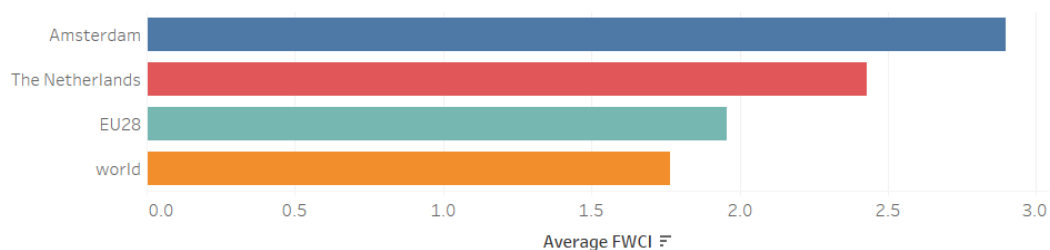

Figure 2.3 *Field weighted citation impact (FWCI) of AI publications from Amsterdam, the Netherlands, EU 28, and the world, 2014-2020.*

More significant, however, is the indicator that Amsterdam's AI publications are highly impactful when a normalized citation score (FWCI) is calculated, with the city's scores exceeding both national and global averages by some margin (Fig. 2.3). In fact, Amsterdam's AI publications are cited almost twice as often as the world average. While Amsterdam may not be producing volumes of AI publications as large as some other countries, the output is of high impact.
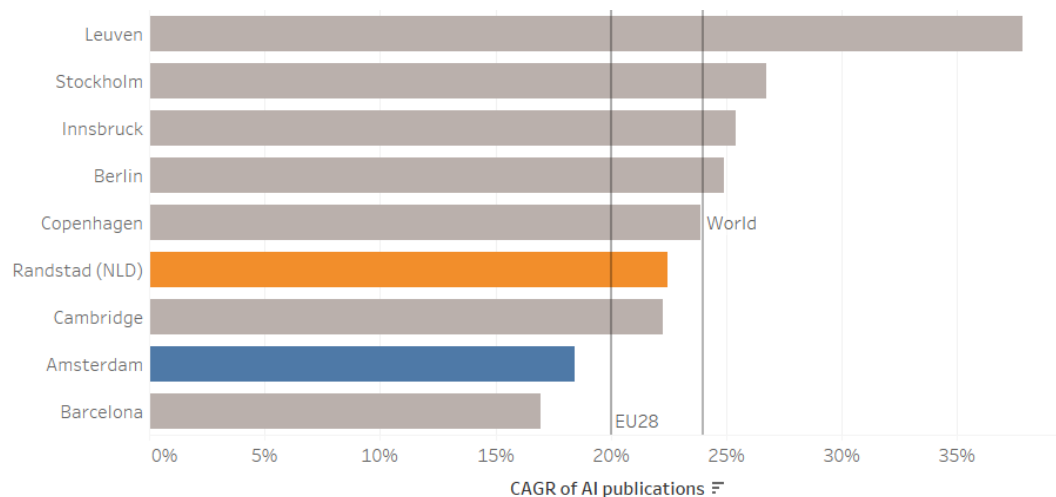
Figure 2.4 *Compound annual growth rate (CAGR) in AI publications by city and for the Randstad region, 2014-2020.*

Despite the high impact of Amsterdam's AI research, the compound annual growth rate (CAGR) indicates that the city's output in this field is growing at a slower rate than the world or EU 28 average and lags behind all comparator cities except Barcelona (Fig. 2.4). Globally, the number of AI publications has grown rapidly since 2014[29], driven primarily by China. However, Amsterdam saw less growth in the volume of its AI publications than the wider Randstad region over the same period, which achieved a CAGR above the EU 28 average and on a par with Cambridge. Our analysis indicates that other cities in the Randstad region, such as Leiden, Delft, and Utrecht, are performing better in this area than Amsterdam, indicating that there is an opportunity for the city to boost the scale of its research output in this field.
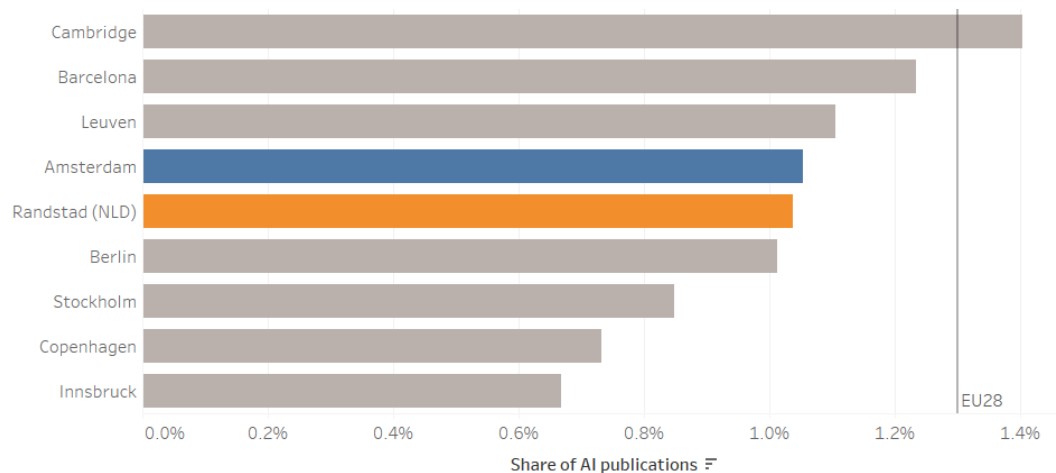

Figure 2.5 *Share of publications in AI out of the total number of publications by city and for the Randstad region, with the EU28 average, 2014-2020.*

[29] See Figure 3.1 from: *Artificial Intelligence Research Growth and Regional Trends*. (2018). Elsevier.
https://www.elsevier.com/?a=823654

Amsterdam and Randstad's shares of AI publications are less than the EU 28 average (Fig. 2.5), with only Cambridge of the European comparator cities analyzed here achieving a larger share of publications than the average. This is not unexpected as the UK leads the way in Europe in terms of AI research, in a field heavily dominated by China and the US. Cambridge's performance and expertise in AI could offer fertile ground for future collaborations for Amsterdam's universities and research institutions.
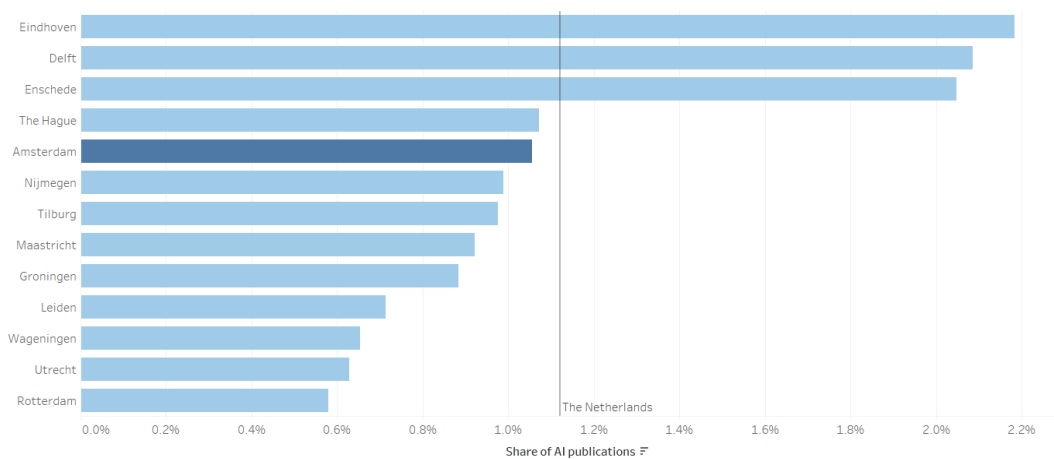

Figure 2.6 *Share of publications in AI out of the total number of publications by Dutch city, with the national average for The Netherlands, 2014-2020.*

The cities of Eindhoven, Delft, and Enschede all perform better than the national average in terms of their shares AI publications (Fig. 2.6). The broad applicability of AI is reflected in strong performance of these cities with their technical universities, namely the University of Twente, Delft University of Technology, and Eindhoven University of Technology. Similarly, the TNO, the Dutch national center of applied research and innovation, which is headquartered in The Hague, undoubtedly contributes significantly to this city's share of AI publications.

Although Amsterdam and Nijmegen appear to perform less well by this indicator, with their shares of AI publications just below the national average, the preponderance of comprehensive universities in these cities with activities in many disciplines makes it much more difficult for them to focus on a specific topic. In this light, Amsterdam performs remarkably well in AI, given the breadth of its research output.

Conclusions

- Amsterdam's research output in AI is highly impactful when normalized, with an FWCI close to 3, exceeding both national and world averages.

- The number of AI publications is growing, with Amsterdam's output on a par with Stockholm, behind only Berlin, Cambridge, and Barcelona.

- Amsterdam's share of AI publications is just below national and EU 28 averages, but it performs well given its preponderance of comprehensive universities.

- The cities of Eindhoven, Delft, and Enschede, which boast technical universities, outperform Amsterdam in terms of the fraction of their publications devoted to AI.

Sustainable development: how is Amsterdam meeting the United Nations' goals?
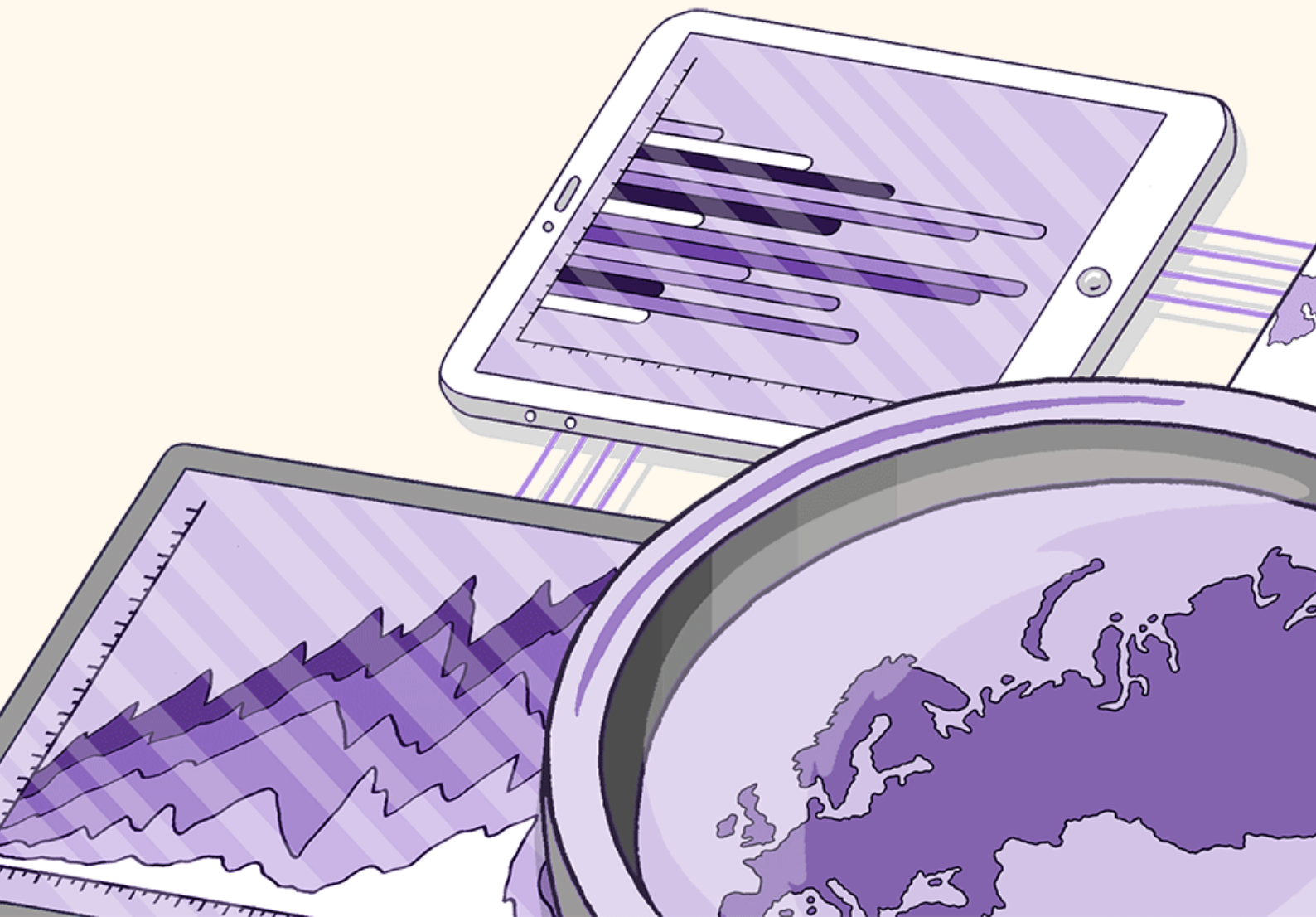
Sustainable development: how is Amsterdam meeting UN goals?

Amsterdam embraces the United Nations' Sustainable Development Goals as a framework for its research and innovation efforts.

The huge gains seen in life expectancy, poverty reduction, and health over the last century have been made possible in part by the efforts of global research and health communities. However, there is much more to be done, particularly considering the global challenges presented by climate change and the need for sustainability. The Netherlands, including Amsterdam and its universities and research institutions, has embraced the United Nations' Sustainable Development Goals (SDGs), established in 2015 as a framework around which to focus research and innovation efforts. The sustainability agenda is very broad and varied, encompassing research on climate, health, sustainable infrastructure, clean energy and water, responsible consumption and production, as well as justice and equality, and ending poverty and hunger [for further details see Appendix A]. With the 2030 deadline for these goals rapidly approaching, we analyze here the research output of Amsterdam in these terms.

"I believe knowledge institutions will be increasingly involved in larger societal issues such as the cost of healthcare and climate change. I am convinced that we can only resolve such issues with a systems approach."

Professor Arjen Brussaard,
Vice Dean Valorization of Research at Amsterdam UMC
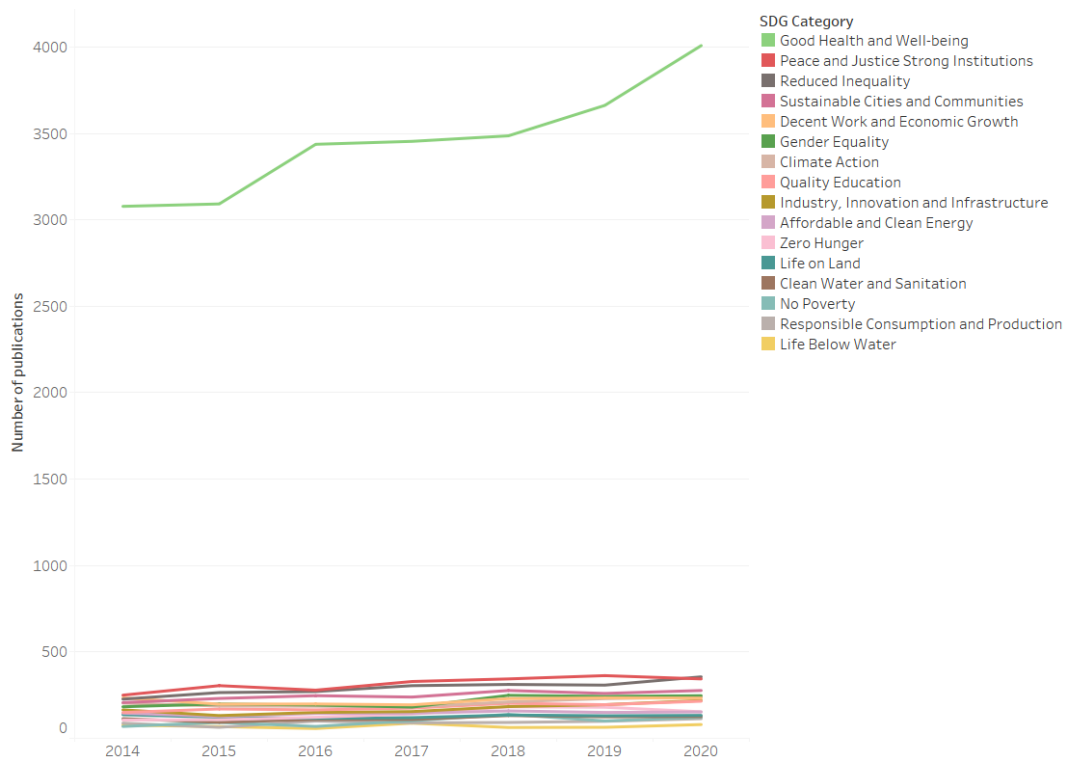and Scientific Director of Amsterdam Neuroscience

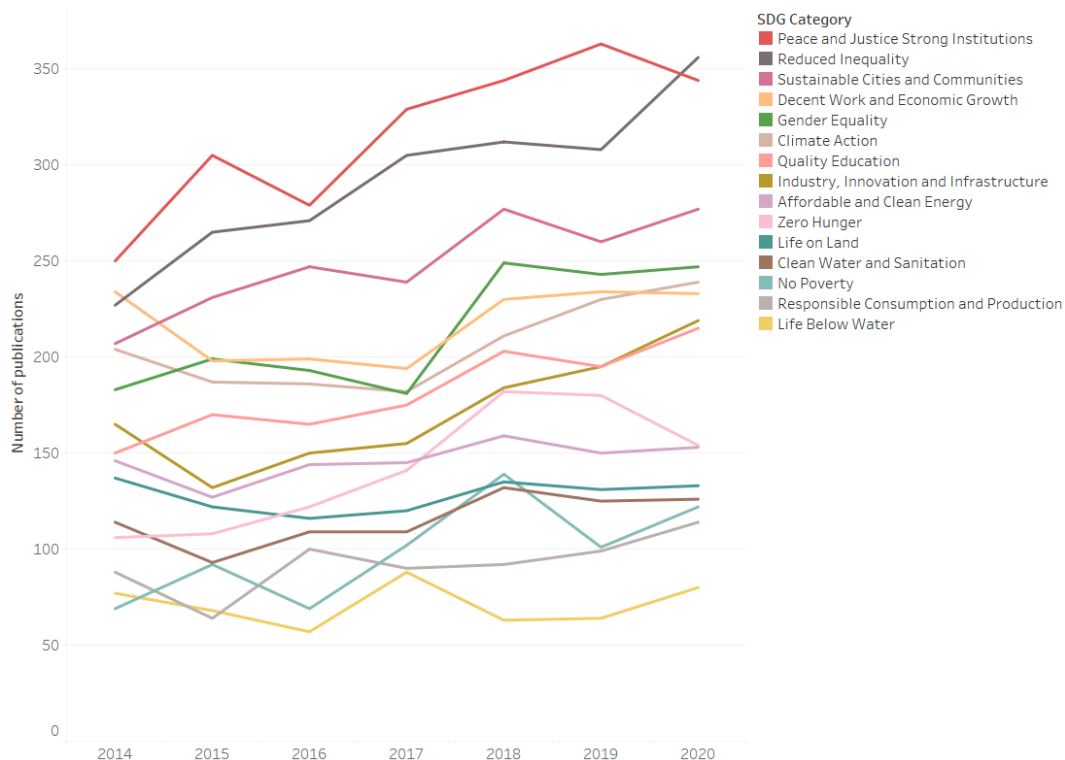Figure 3.1 *Number of publications from Amsterdam by SDG, 2014-2020.*

Figure 3.2 *Number of publications from Amsterdam by SDG, showing an expansion of the lowest 15 categories in Figure 3.1, 2014-2020.*

Amsterdam's research output in each of the SDG topics is shown in Figs. 3.1 and 3.2. The city's huge output in the field of 'Good Health and Well-being' is in a class of its own, reflecting Amsterdam's prowess in medicine, health and life sciences, and behavioral sciences. Homing in on the remaining categories reveals modest growth in publications in most categories across the board, reflecting the general upward trend in research output.
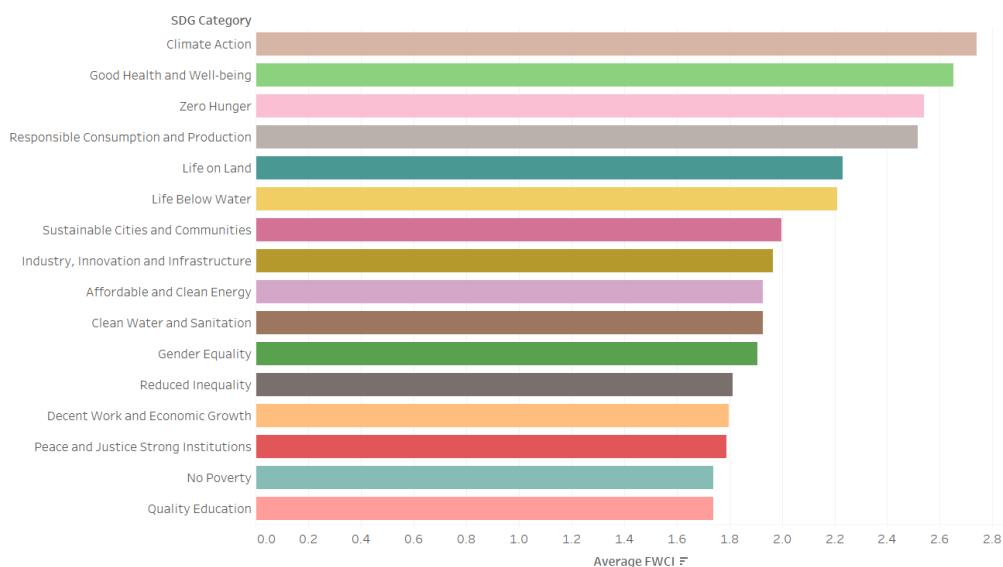

Figure 3.3 *Field-weighted citation impact (FWCI) per SDG category for Amsterdam, 2014-2020.*

Looking at the impact of Amsterdam's research output in these SDG categories in terms of the normalized citation impact (FWCI) reveals that 'Climate Action', 'Zero Hunger', and 'Responsible Consumption and Production' all perform better in terms of citations than the global average (of 1.0), indicating Amsterdam's strong performance in these fields (Fig. 3.3). It is worth noting the city's impact in 'Climate Action' where a relatively small number of publications generate a higher-than-average number of citations.
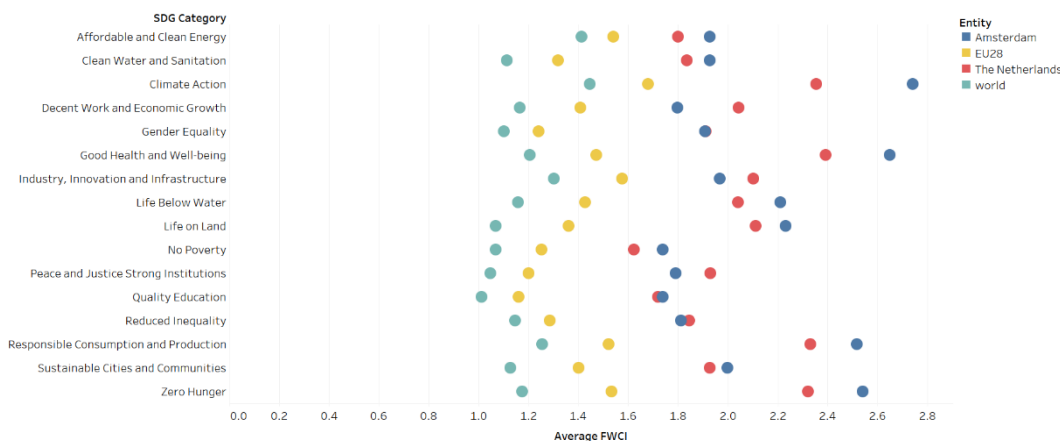

Figure 3.4 *Field-weighted citation impact (FWCI) per SDG category for Amsterdam compared with the Netherlands, EU 28, and the world, 2014-2020.*

It is clear from Fig. 3.4 that Amsterdam leads the way in most SDG categories in terms of the citation impact of its research compared with national, EU 28, and world averages. In particular, the normalized citation impact of Amsterdam's research in 'Climate Action', 'Good Health and Well-being', 'Responsible Consumption and Production', and 'Zero Hunger' is noteworthy compared with the rest of the Netherlands, EU 28 countries, and the world.
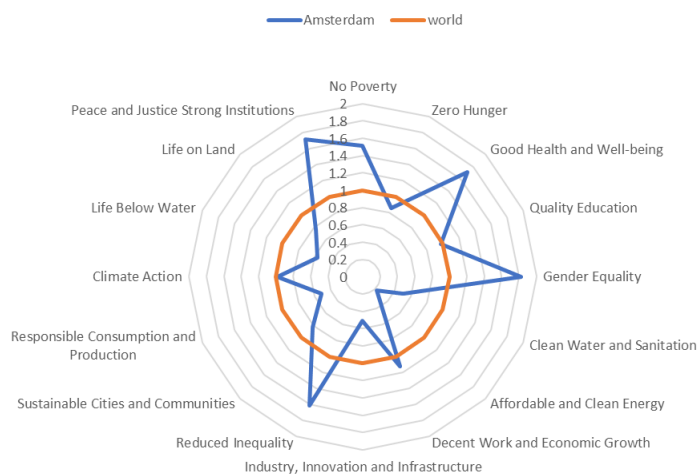

Figure 3.5 *Relative Activity Index per SDG category for Amsterdam compared with the world average, 2014-2020.*

Conversely, some of these high impact areas, such as 'Climate Action', 'Responsible Consumption and Production', and 'Zero Hunger' do not show above average levels of activity, with respect to the rest of the world (Fig. 3.5). Interestingly, those areas that do show above average activity levels include 'Gender Equality', 'Reduced Inequality', and 'Peace and Justice/Strong Institutions', as well as 'Good Health and Well-being.'
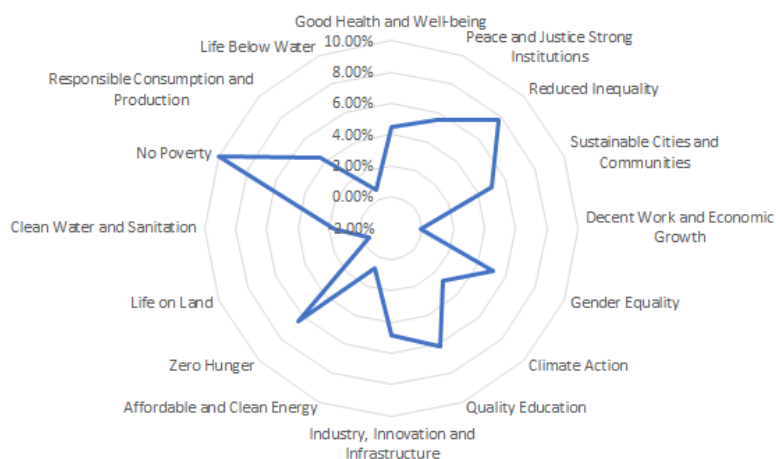

Figure 3.6 *Compound annual growth rate (CAGR) per SDG for Amsterdam, 2014-2020.*

Amsterdam's research output shows strong double-digit year-on-year growth in 'No Poverty' (10%) over the period of the report, while 'Reduced Inequality' (8%), 'Zero Hunger' (7%), 'Peace and Justice/Strong

Institutions' (6%), 'Quality Education' (6%), and Gender Equality (5%) all show significant growth, revealing the breadth of Amsterdam's strengths in SDG-related categories (Fig. 3.6). The city's output in 'Good Health and Well-being', meanwhile, which has seen a consistent increase in the number of publications from 2014 to 2020, achieves a CAGR of around 5%, consistent with Amsterdam's long-standing excellence in medicine, health and life sciences.

Amsterdam's research efforts excel on a global scale in a number of SDG categories, specifically 'Good Health and Well-being', 'Gender Equality', 'Reduced Inequality', and 'Climate Action'. It is worth noting that on the spider graphs, where an index value approaches 2.0, as it does for 'Gender Equality', the percentage of publications in that field is double the world average. Research in the field of 'Good Health and Well-being', meanwhile, although not showing the strongest CAGR, is still one of the most active areas of research in Amsterdam, thanks to the city's UMC, specialized hospitals, and medical research centers.

Conclusions

- Amsterdam's research output is cited more than expected with respect to EU28 and world averages in almost all SDG categories.

- In the category of 'Good Health and Well-being', the SDG with the highest number of associated publications by far, Amsterdam's output has increased significantly and ranks highly in terms of citation impact.

- Amsterdam is leading the way in terms of the impact of its research on 'Climate Action', a category which although small in volume and on a par with world activity levels outperforms all other areas including 'Good Health and Well-being' in citations.

- Amsterdam's share of publications in 'Gender Equality' is nearly double the world average and shows strong growth with high quality output.

International collaboration: how well does Amsterdam perform?

International collaboration: how well does Amsterdam perform?

Amsterdam is well placed in the Netherlands and Europe to foster international collaboration in its research.

Collaboration is a core element of research and innovation at the institutional, national, and international level. Geographically located close to a number of other research cities in the Netherlands, Amsterdam's skilled researchers can collaborate readily with colleagues in neighboring cities and further afield. The Randstad region, moreover, forms a natural conurbation of knowledge cities including Amsterdam, Delft, Leiden, Rotterdam, and Utrecht. Beyond its national borders, the Netherlands is centrally located within Europe, acting as a travel hub in the continent and the wider globe, facilitating international collaboration and drawing skilled researchers from around the world.

International collaboration – which we define here as the extent to which researchers from Amsterdam collaborate with others around the globe – is a useful and well-recognized measure of performance and an indicator of the reputation and global reach of research efforts. In this section, we look at the number of publications with at least one co-author located outside the Netherlands and compare Amsterdam's performance with other Dutch cities and European comparator cities. We also determine the proportion of international collaboration in Amsterdam's entire publication portfolio. Finally, we assess the impact of Amsterdam's international collaboration with respect to comparator European cities in terms of publication citations.

"The need and will to collaborate has increased significantly. We have seen interesting and positive developments among knowledge institutes, which have opened up to intensified collaboration."

Professor Mirjam van Praag, President of the Executive Board of Vrije Universiteit Amsterdam and Professor of Entrepreneurship
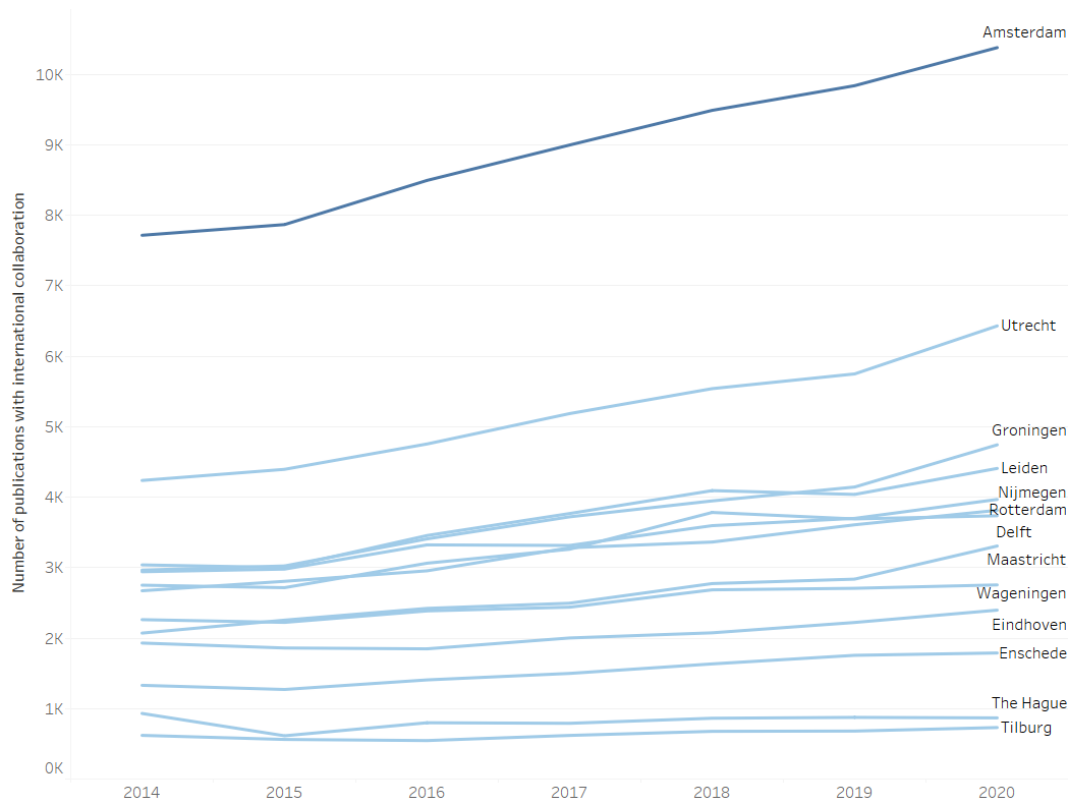
Figure 4.1 *Number of publications demonstrating international collaboration by Dutch city, 2014-2020.*

The number of publications from Amsterdam's universities and research institutions demonstrating international collaboration has grown steadily since 2014, reaching over 10,000 publications in 2020 (Fig. 4.1). Amsterdam produces far more publications of this type than any other single Dutch city, indicating a high level of international collaboration in its research efforts.
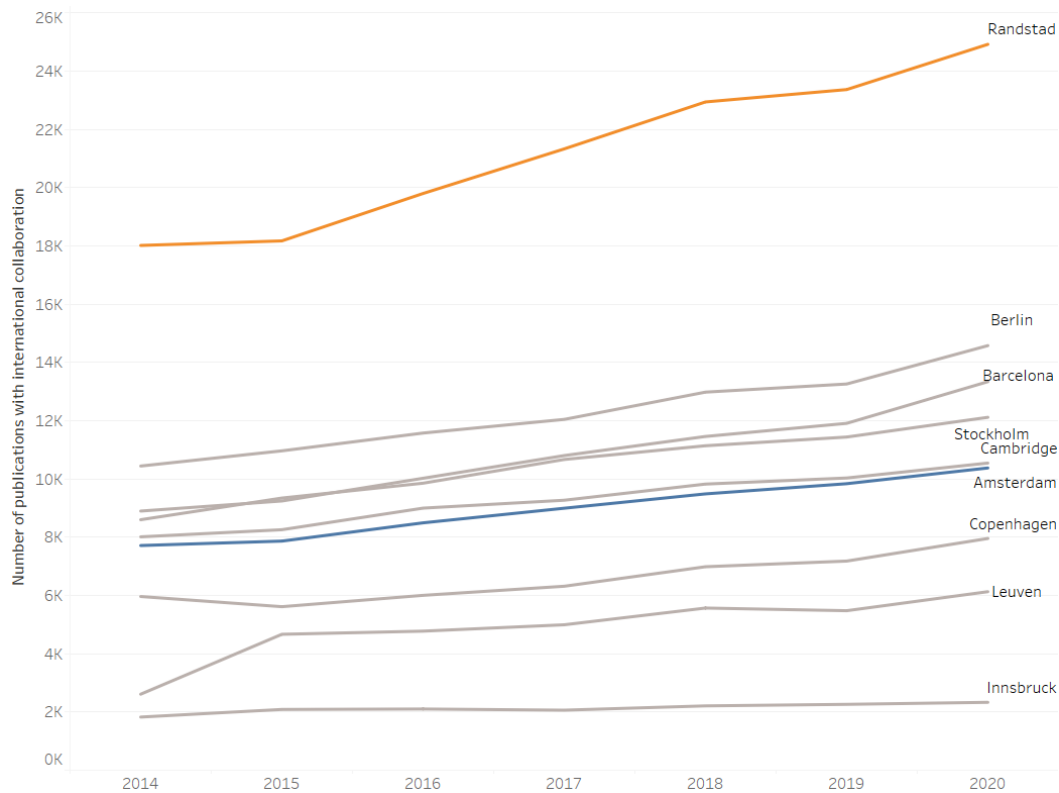
Figure 4.2 *Number of publications demonstrating international collaboration by city and for the Randstad region, 2014-2020.*

In comparison with other European cities over the same period, Amsterdam ranks fifth in terms of publications demonstrating international collaboration on a par with Cambridge but behind Berlin, Barcelona, and Stockholm, indicating some potential opportunity for improvement (Fig. 4.2). But when the wider and much larger Randstad region is considered, the volume of publications with at least one international co-author is greater than any of the other European cities analyzed here. The result is not surprising, given the size of the Randstad region, but nevertheless demonstrates the strong international ties in its research.
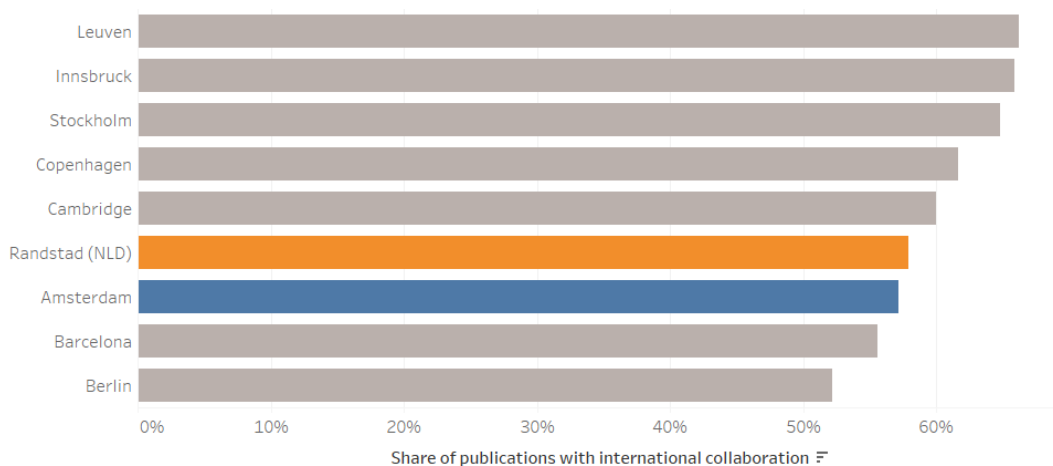
Figure 4.3 *Share of publications demonstrating international collaboration by city and for the Randstad region, 2014-2020.*

An informative indicator is the share of publications with at least one international co-author out of the total number of publications. By this measure, Amsterdam performs well above the EU 28 average, with international publications accounting for well over half (around 57%) of its total output and on a par with the wider Randstad region (Fig. 4.3). In fact, Amsterdam's share of publications in this category is over three times the EU 28 average. However, the comparator European cities analyzed in this report, namely Leuven, Innsbruck, Stockholm, Copenhagen, and Cambridge all perform even better than Amsterdam, with a larger share of publications demonstrating international collaboration, indicating that there is scope for the city's research to be more collaborative on a global scale.

Figure 4.4 *Field-weighted citation impact (FWCI) of publications demonstrating international collaboration by city and for the Randstad region, with the EU 28 average, 2014-2020.*

Finally, looking at the impact of publications demonstrating international collaboration in terms of citations provides a useful indicator of the reach and impact of Amsterdam's research efforts. Amsterdam's performance in this realm is impressive. Compared with the other European research cities analyzed in this

report, the normalized citation impact of Amsterdam's internationally collaborative publications is on a par with the research powerhouses of Cambridge and Copenhagen, ahead of the wider Randstad region and the EU 28 average. In fact, Amsterdam's publications with an international collaboration aspect are cited 60% more than the EU 28 average.
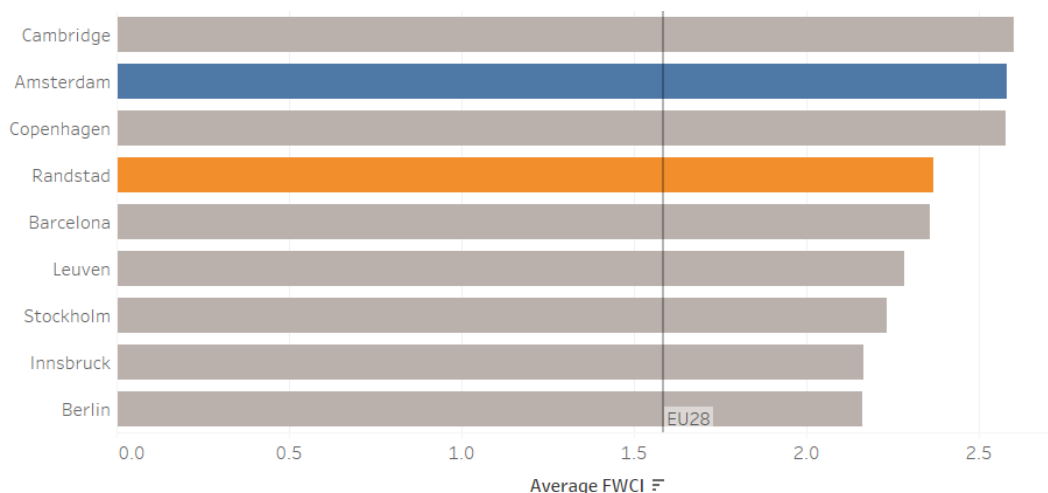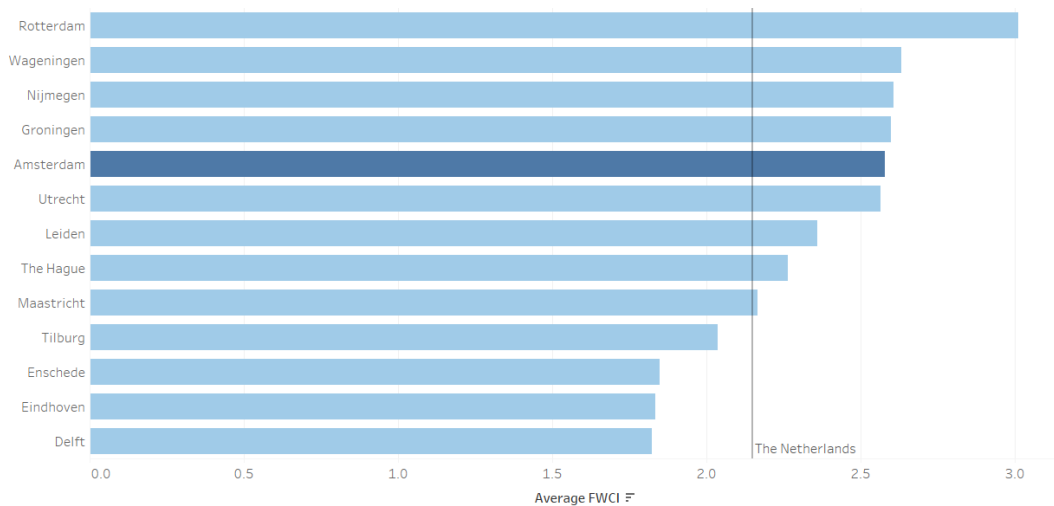

Figure 4.5 *Field-weighted citation impact (FWCI) of publications demonstrating international collaboration by and city, with the national average for The Netherlands, 2014-2020.*

At the national level, most of the Dutch cities analyzed in this report, including Amsterdam, perform well above world, EU 28, and national averages (FWCI values of 1.0, 1.6, and 2.2 respectively) (Fig. 4.5). Viewed within this competitive framework, Amsterdam's international collaborative efforts are among the most impactful, along with the cities of Rotterdam, Wageningen, Nijmegen, and Groningen. The Netherlands as a nation performs well above EU 28 and world averages, with its international publications cited more than twice the global average.

Conclusions

- The normalized impact of Amsterdam's internationally collaborative publications is on a par with Cambridge.

- Amsterdam's publications demonstrating international collaborations are amongst the most impactful in terms of citations, along with Rotterdam, Wageningen, Nijmegen, and Groningen.

- The Netherlands performs well above world and EU 28 averages in terms of citations, with its internationally collaborative publications cited over twice the global average.

- Amsterdam's publications demonstrating international collaboration have grown steadily since 2014, reaching over 10,000 in 2020.

- Amsterdam has a higher level of international collaboration than any other single Dutch city.

- While internationally collaborative publications make up over half of Amsterdam's total output – three times the EU 28 average, several cities in the Netherlands perform even better, indicating room for improvement.

Knowledge transfer: how does academia interact with industry?

Knowledge transfer: how does academia interact with industry?

Amsterdam and the Netherlands are home to many global companies, ideal for fostering effective knowledge transfer.

Knowledge transfer is the next piece of the research jigsaw, where new learning is transmitted from the academic sector into the realm of commercial and industrial development. There are many ways to assess the success of knowledge transfer from the research lab to the industrial production line including the number of startups or spinoffs or how many skilled graduates a company hires. However, this information resides with individual institutions or companies and does not provide a universal picture.

A more general and accessible measure of the transferability of academic research is to look at how well universities and institutions are connected to industry. In this section, we look specifically at how many publications from Amsterdam's universities and research institutes include authors from corporates, as well as how this connectivity compares with the wider Randstad region, nationally, with comparator European cities and the EU 28 average. In this report, we use an indicator known as 'academic-corporate collaboration', where every publication with at least one co-author from an academic institution and one from a corporate is counted, although this is only an indirect or proxy measure of overall levels of academic-corporate collaboration. In order to account for differences in the transferability and commercial potential of diverse research fields, we also calculate the FWCI of academic-corporate collaborations for Amsterdam and compare it with the wider Randstad region and other European cities. These measures enable us to build up a picture of how effectively Amsterdam's universities and research institutes are collaborating with corporates located in the city, the Netherlands or beyond, how much knowledge transfer is occurring, and to what extent new insights generated in a research setting are being adopted, used, and commercialized by industry.

Amsterdam already has a strong pedigree in knowledge transfer and is well positioned to capitalize on new opportunities. The city is home to a number of global companies such as ING Group and Philips, spanning a range of diverse sectors from finance to electronics and biotechnology, as well as unicorns such as Adyen, Booking.com, and MessageBird, and numerous SMEs. Many other global enterprises including Cisco Systems, Nike, Hewlett Packard, Adidas and General Electric have premises located in the region.

> *"The fundamental research that forms the foundation of innovations is increasingly conceived not in isolation but in collaboration between researchers [and] industry, users, patients, and entrepreneurs."*
>
> Professor Mirjam van Praag, President of the Executive Board of Vrije Universiteit Amsterdam and Professor of Entrepreneurship
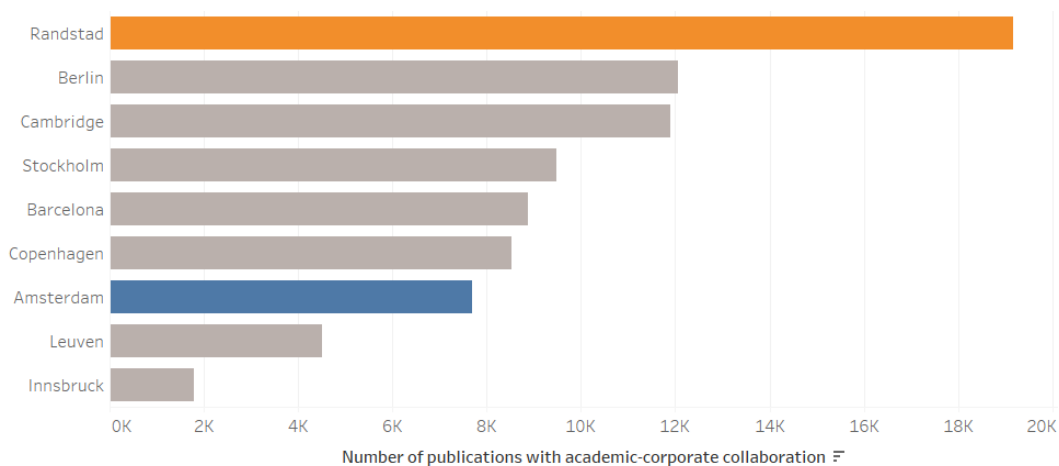
Figure 5.1 *Number of academic-corporate publications by city and for the Randstad region, 2014-2020.*

Amsterdam produced 8000 publications with at least one academic and one corporate author over the period of study, roughly on a par with Stockholm, Barcelona, and Copenhagen, but behind Berlin and Cambridge. Approximately 7% of Amsterdam's publications between 2014 and 2020 were co-authored by at least one academic and one corporate researcher (Fig. 5.1), a slight increase over the 5% calculated in a previous analysis[30].
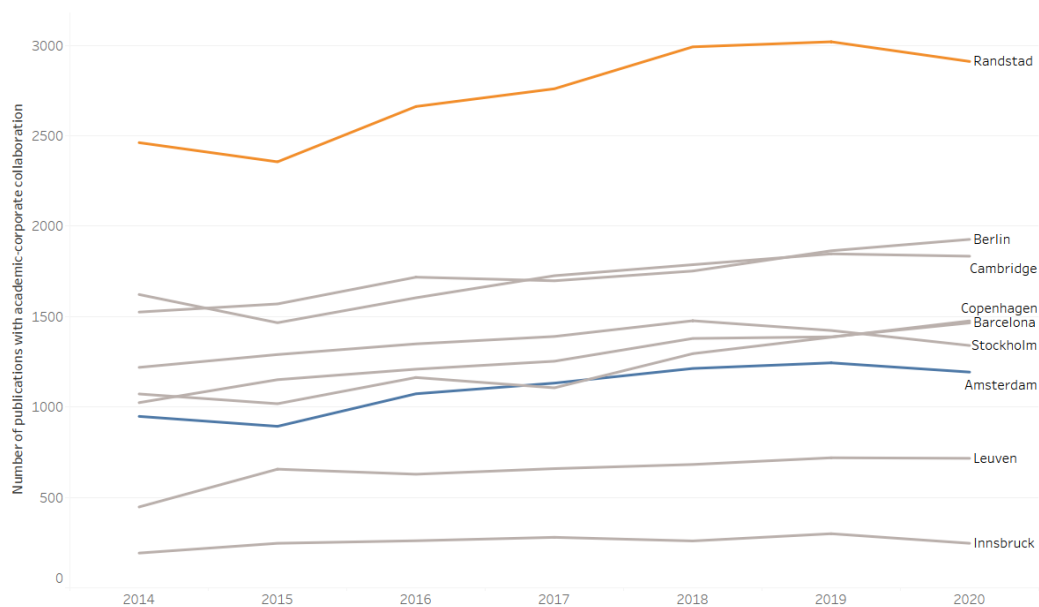
Figure 5.2 *Number of academic-corporate publications by city and for the Randstad per year, 2014-2020.*

[30] See p27: *Mapping Research and Innovation – Understanding Amsterdam's Competitive Advantage*. Elsevier in collaboration with Urban Innovation Network. (2015). https://www.elsevier.com/__data/assets/pdf_file/0005/53483/UINAmsterdamReport.pdf The share of academic-corporate publications is calculated assuming a total of 110,000 publications over this period.

Although the number of academic-corporate publications from Amsterdam has grown slightly from 2014 to 2020, the city does not produce as large a volume of this type of publication as other European cities analyzed in this report except Leuven and Innsbruck (Figs. 5.1 and 5.2).
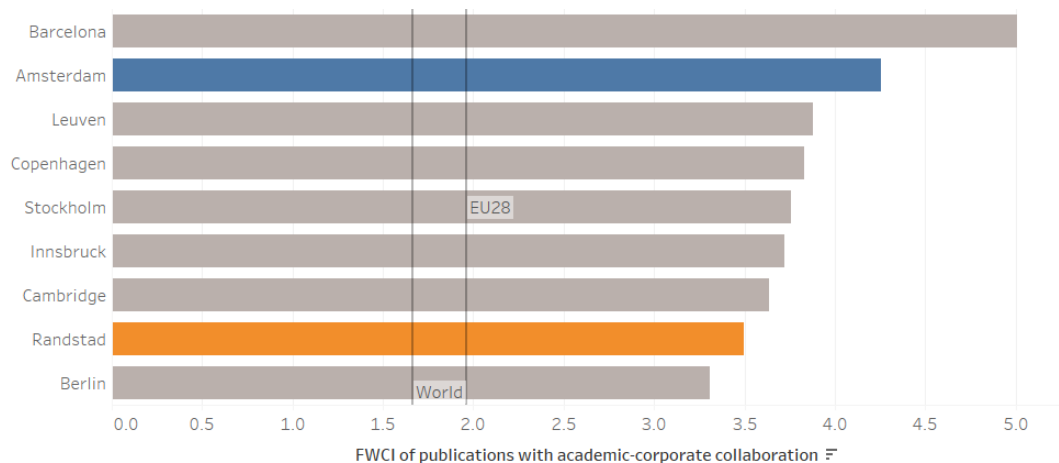
Figure 5.3 *Field-weighted citation impact (FWCI) of academic-corporate publications by city and for the Randstad region, with EU 28 and world averages, 2014-2020.*

However, a very useful comparison can be drawn from the FWCI indicator of academic-corporate output, which determines the relative citation impact of Amsterdam's research output when normalized by type of publication, subject area, year, and discipline. It is evident that Amsterdam's academic-corporate publications are highly impactful, performing well above world and EU 28 averages (1.6 and 1.9, respectively) (Fig. 5.3). In fact, among the comparator cities, Amsterdam ranks second only to Barcelona in terms of the citation impact of its academic-corporate publications. By this measure, while the wider Randstad region performs above both world and EU 28 averages, it lags well behind Amsterdam's outstanding performance.
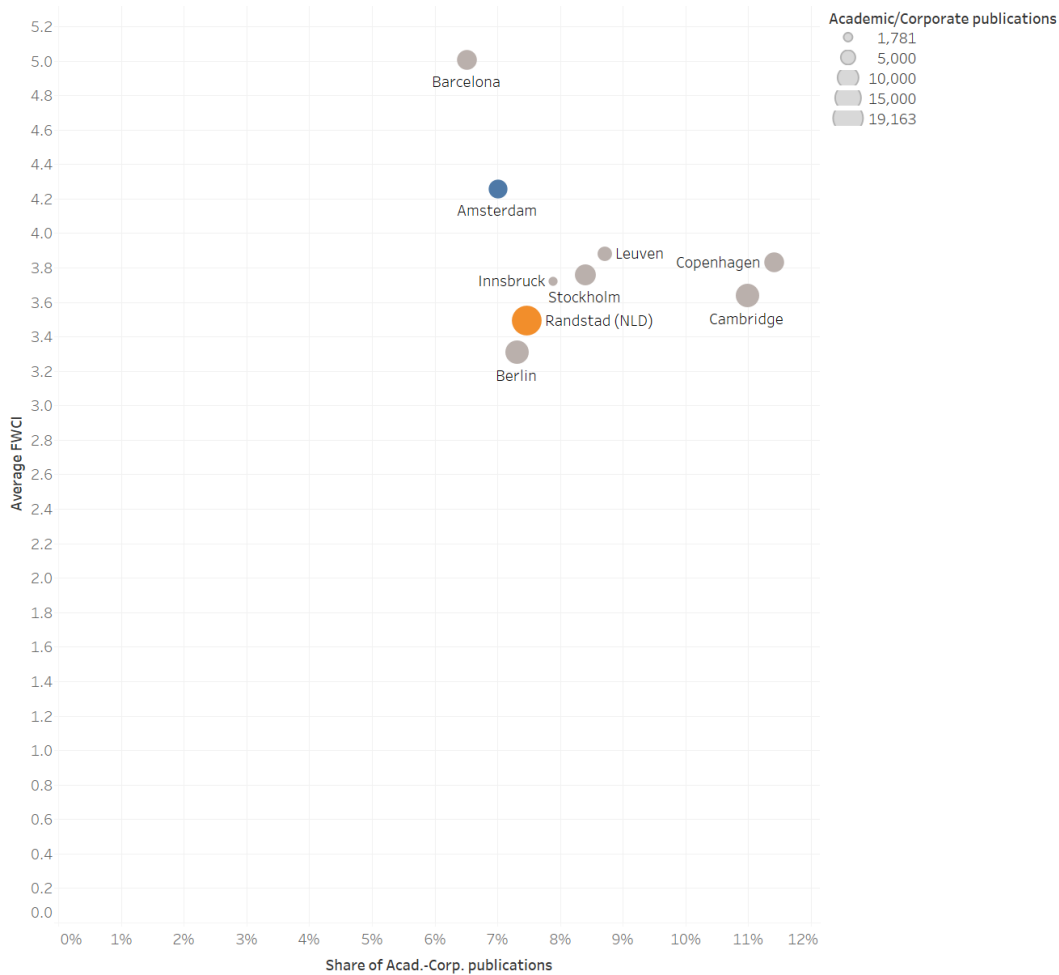
Figure 5.4 *Share of academic-corporate publications versus field-weighted citation impact (FWCI) by city and for the Randstad region, 2014-2020.*

This picture of Amsterdam's prowess in academic-corporate collaboration is reinforced by Fig. 5.4, which shows the share of academic-corporate publications out of the total number of publications compared with FWCI over the whole period. While the volume of Amsterdam's academic-corporate output is smaller than that of the Randstad region and other comparator cities such as Berlin and Cambridge, its impact is greater, second only to Barcelona. In other words, despite a smaller number of academic-corporate publications, those from Amsterdam are more influential in terms of citations.
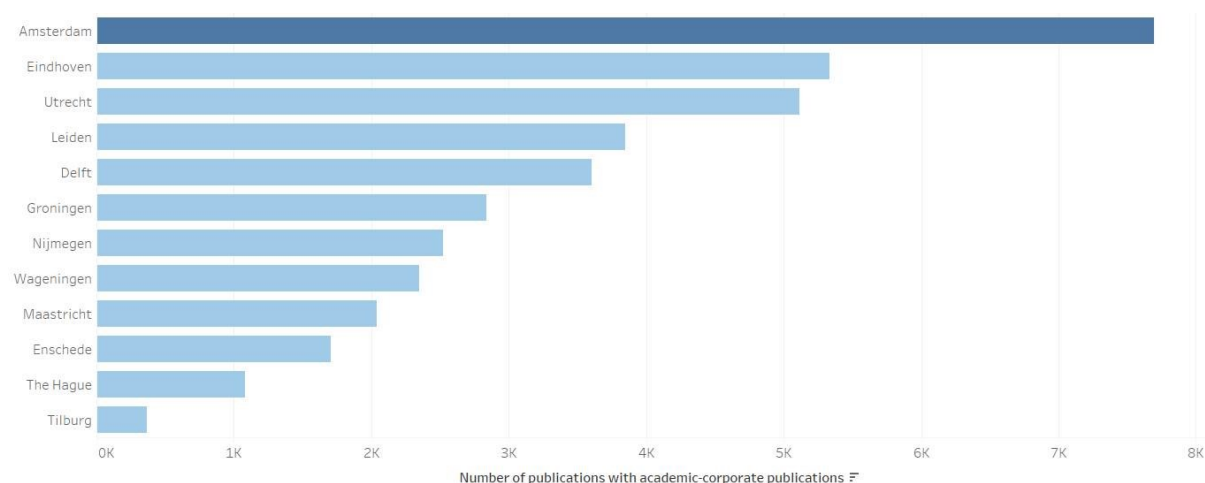
Figure 5.5 *Number of academic-corporate publications by Dutch city, 2014-2020.*

Looking at the national picture in more detail, Amsterdam produces far more academic-corporate publications than any other Dutch city by some margin (Fig. 5.5). While Amsterdam produced over 7500 academic-corporate publications over the 2014-2020 period, Eindhoven and Utrecht, the next largest producers, recorded only around 5300 and 5100 publications each, respectively.
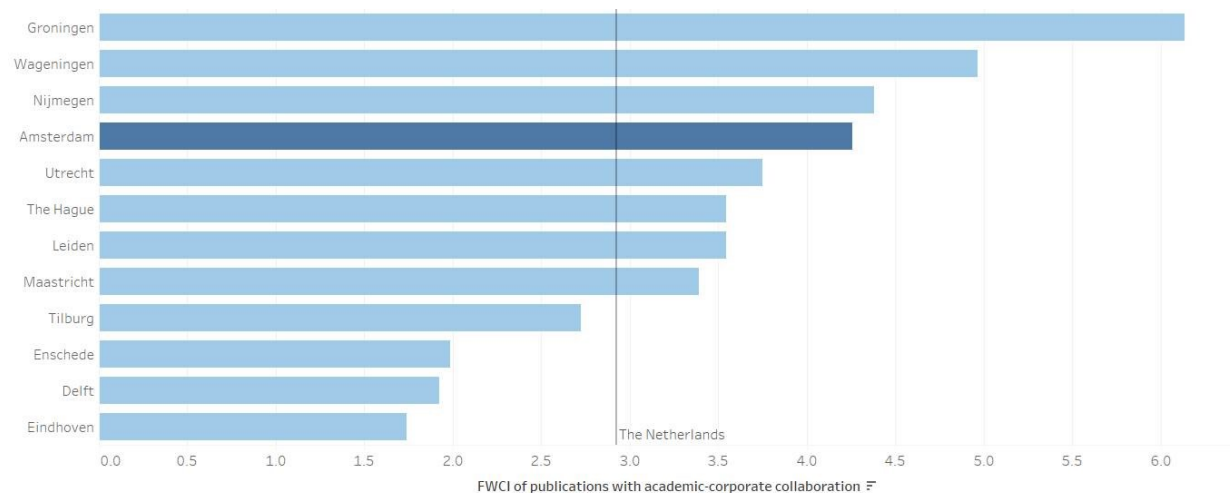
Figure 5.6 *Field-weighted citation impact (FWCI) of academic-corporate publications by Dutch city, with the national average for The Netherlands, 2014-2020.*

Interestingly, however, when we look at normalized citations for these publications, the picture is rather different (Fig. 5.6). By this indicator, Amsterdam, Nijmegen, and Groningen outperform national, European, and world averages (2.9, 2.0, and 1.6, respectively) by some margin, with academic-corporate publications from Groningen cited six times more and those from Amsterdam and Nijmegen citied over four times more than the global average. While all the Dutch cities analyzed here performed above the world average (of 1.6), Eindhoven, Enschede, Delft, and Tilburg performed below the EU28 average (of 2.0) and the national average (of 2.9).

Conclusions

- Amsterdam's academic-corporate publications are highly impactful, receiving more citations than the EU 28 and world averages, second only to Barcelona.

- Groningen and Nijmegen also outperformed national, EU 28, and world averages in terms of the normalized impact of their academic-corporate publications, with Groningen's output cited six times more than the global average.

- Between 2014 and 2020, 7% of Amsterdam's publications had at least one corporate co-author, up from around 5% during the previous decade.

- Amsterdam produces a larger number of academic-corporate publications than any other Dutch city.

- The number of Amsterdam's academic-corporate publications grew steadily from 2014 to 2020 but lags behind other European cities in terms of volume.

- Most Dutch cities, including Amsterdam, perform above EU 28 and world averages except Eindhoven, Enschede, Tilburg, and Delft, which perform less well.

Amsterdam's technological strengths: research to commercialization
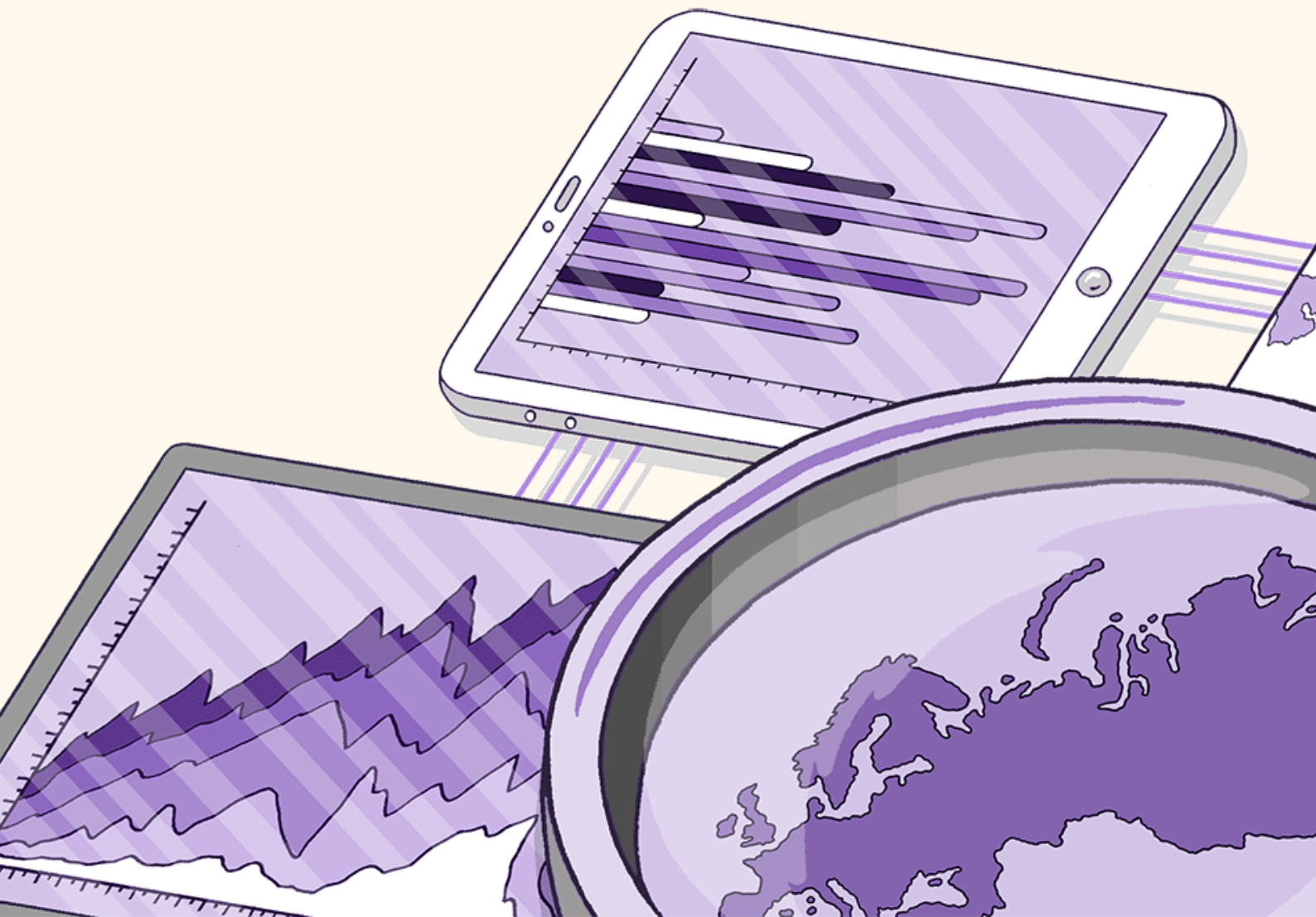
Amsterdam's technological strength: research to commercialization

Amsterdam's patent output demonstrates the city's technological strengths in transferring research from bench to plant.

Research is a major driver of economic development and there is a strong relationship between research strengths and economic value. When research and technological innovations move towards commercialization, in either the academic or corporate sphere, the work is typically patented. In the previous section, we looked at the extent to which Amsterdam's universities and research institutes collaborate with corporates and industry. Here, we take this analysis a stage further and look at patents as an indicator of the success of knowledge transfer, the commercial relevancy of research and innovation.

While a country or a city is not an 'inventor', it is useful to assess the originating location of a patent to determine the level of that country or city's success in knowledge transfer and technological innovation. Using LexisNexis' PatentSight database[31], which spans over 96 million records from over 100 patent authorities including the European Patent Office (EPO)[32], United States Patent and Trademark Office (USPTO)[33], and World Intellectual Property Organization (WIPO)[34], we can determine how many patents are filed and granted, as well as the number of academic publications cited in these patents. This measure gives an indication of how well research efforts are technologically aligned and focused on applications. However, when an innovation or invention is patented, it is typically filed with multiple patent authorities simultaneously to provide international protection. Therefore, in order not to double count patents filed with multiple authorities, we look at 'patent families', which represent a set of related patents associated with a single invention or innovation filed in multiple locations.

"Turning innovative research into concrete products faster, better, and more often... will have an enormous impact on our society."

Professor Mirjam van Praag,
President of the Executive Board of Vrije Universiteit Amsterdam and Professor of Entrepreneurship

[31] PatentSight: https://www.patentsight.com/en/
[32] European Patent Office: https://www.epo.org/
[33] United States Patent and Trademark Office: https://www.uspto.gov/
[34] World Intellectual Property Organization: https://www.wipo.int/portal/en/index.html
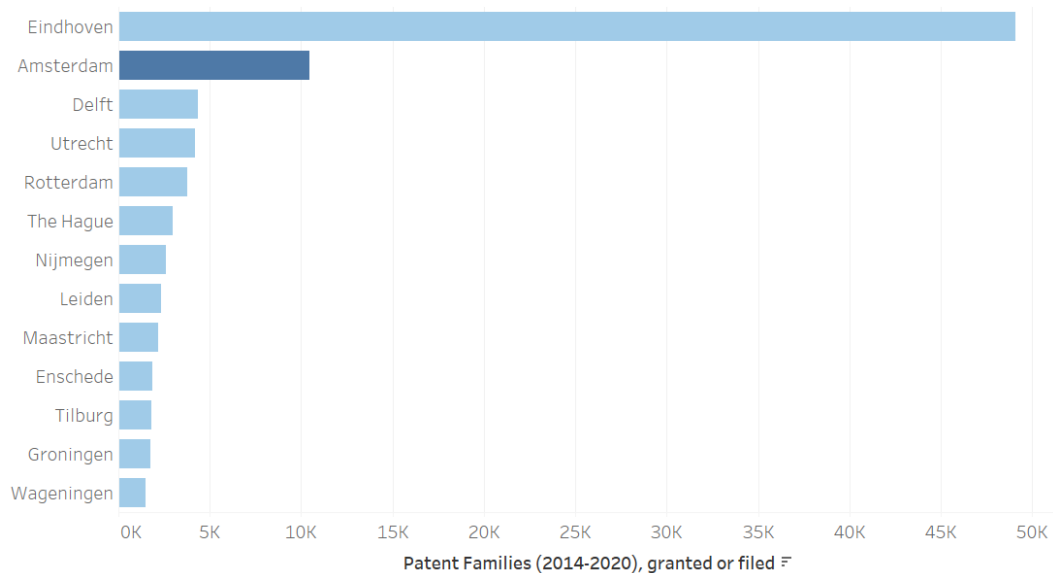
Figure 6.1 *Number of patent families granted to or filed by city of origin for the Netherlands, 2014-2020.*

Over the period of this report, more than 10,000 patent families were filed or granted with at least one inventor or co- inventor from Amsterdam (Fig. 6.1). While Amsterdam performs well by this measure nationally with its output over twice that of most Dutch cities, nearly five times as many patent families were granted to or filed by inventors or co-inventors from Eindhoven over the same period. This outstanding record is likely driven by the presence of Philips and other high-tech corporates in the city, as well as Eindhoven Technical University. Such a large volume of patent families puts Eindhoven on a par with much larger research cities elsewhere in Europe[35].
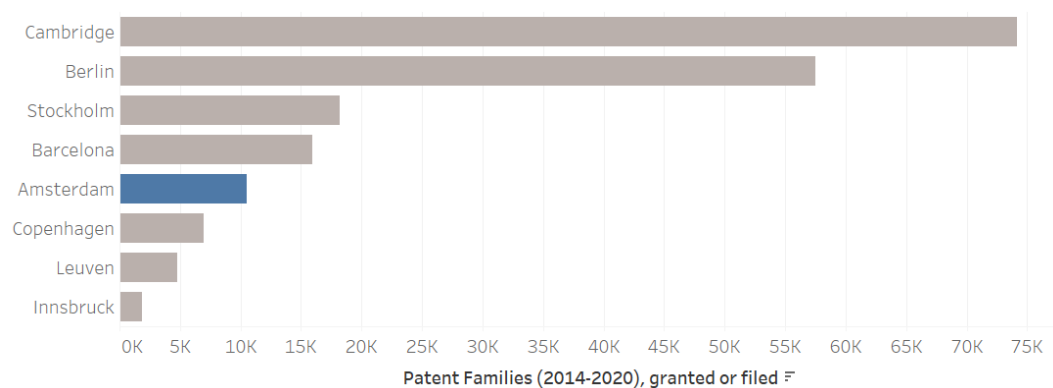
Figure 6.2 *Number of patent families granted to or filed by city of origin for Amsterdam and European comparator cities, 2014-2020.*

When compared with the other European cities analyzed in this report, Amsterdam's performance appears more modest (Fig. 6.2). Although its patent output is greater than Copenhagen, Leuven, and Innsbruck, Amsterdam performs less well than technological innovators Cambridge and Berlin. It is worth noting,

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[35] See p37: *Data and Insights on International Science, Technology, and Innovation – Comparative Research Report of 20 Global Cities (2016-2020)*. (2021). Elsevier. https://www.elsevier.com/?a=1156484

however, that if Eindhoven's patent output (Fig. 6.1) were compared with these European comparator cities (Fig. 6.2), it would rank behind Berlin and Cambridge, but ahead of the rest of the field.
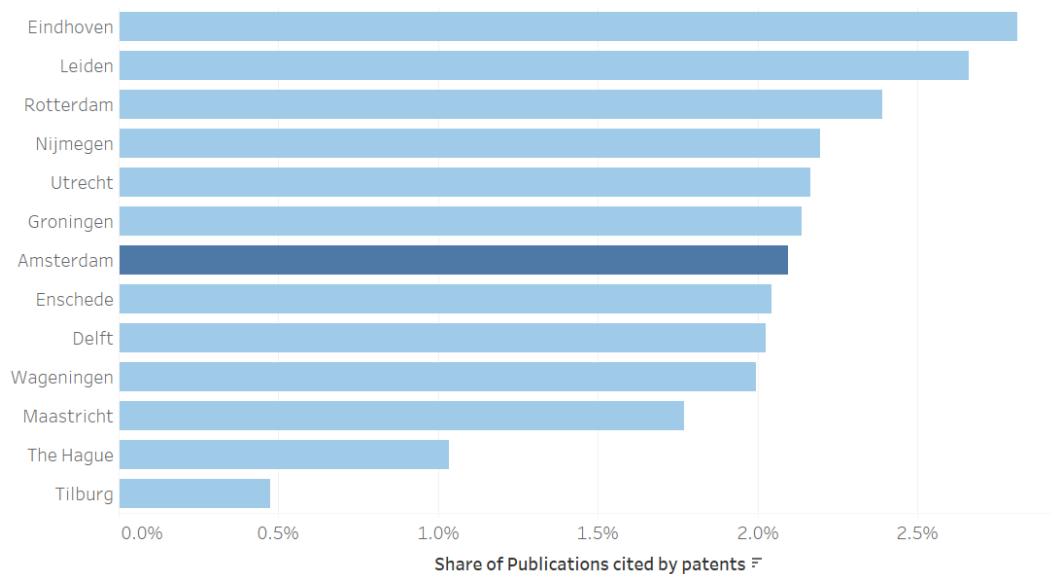
Figure 6.3 *Share of publications cited by patents by Dutch city, 2014-2020.*

By looking at the share of publications from individual cities cited by patents, we can get a clearer picture of the relevancy of that city's research to technological innovation and commercialization. At the national level, around 2% of Amsterdam's total research publication output was cited in patents between 2014 and 2020, in line with most Dutch cities scrutinized here (Fig. 6.3). Once again, however, Eindhoven takes the top spot with nearly 3% of its research publications cited in patents, likely reflecting the degree to which its research is aligned with industrial problems.
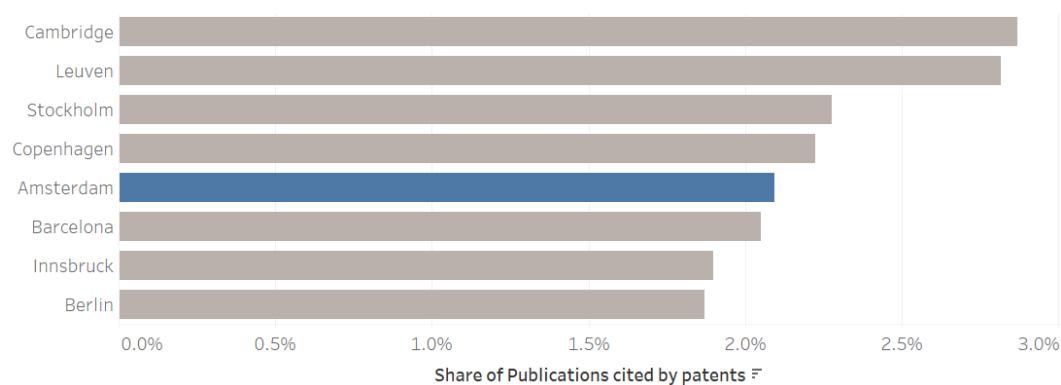
Figure 6.4 *Share of publications cited by patents for Amsterdam and European comparator cities, 2014-2020.*

When compared with other European cities, Eindhoven competes with the leaders Cambridge and Leuven in terms of the share of publications cited by patents, at just under 3% (Figs. 6.3 and 6.4). Amsterdam, however, ranks slightly further down the field behind the leading cities, as well as Stockholm and

Copenhagen, although still recording a creditable 2% of publications citied by patents. By this measure, Amsterdam performs on a par with Barcelona despite producing fewer patent families (Fig. 6.2). Research leader Cambridge both produces the greatest number of patent families and has the largest share publications cited by patents of the cities analyzed in this report. Conversely, while Berlin is second only to Cambridge in terms of the number of patents granted or filed, less than 2% of its publications are cited by patents, ranking lower than any other city shown here. This apparently contradictory finding could indicate either that patents filed or granted to inventors of co-inventors from Berlin may not be from the academic sector or that academic research in the city is less focused on applied topics.

Conclusions

- Between 2014 and 2020, more than 10,000 patent families were filed by or granted to researchers from Amsterdam.

- Amsterdam's patent output is the second largest in the Netherlands, surpassed only by Eindhoven, which produced nearly 50,000 patent families over the same period.

- Amsterdam's performance is average compared with technological leaders Cambridge and Berlin, on a par with Stockholm and Barcelona, but outperforms Copenhagen, Leuven, and Innsbruck.

- Eindhoven's patent output is comparable with much larger European cities.

- Around 2% of Amsterdam's research publications were cited in patents between 2014 and 2020, compared with nearly 3% of Eindhoven's output.

- Eindhoven competes with frontrunners Cambridge and Leuven in terms of its share of publications cited by patents, while Amsterdam lags behind Stockholm and Copenhagen.

Conclusions

Amsterdam is a center of world-class research and innovation. The impact of the city's research is on a par with other European powerhouses, and it performs strongly in sustainable development. AI is growing in significance and the city is well placed to transfer its research knowledge and expertise into technological innovation.

Research output

Amsterdam's research output is cited as often as that of the research powerhouses of Cambridge and Copenhagen, when normalized, outperforming the wider Randstad region.

Amsterdam is on a par with Berlin and Barcelona in terms of the top 1% most cited publications, exceeded only by Cambridge, indicating the high impact of the city's research output.

Amsterdam's research output in terms of the number of publications is on a par with Cambridge and Stockholm.

Amsterdam's research output in medicine, health and life sciences is substantial and growing.

Computer science is Amsterdam's fourth largest discipline in terms of number of publications.

Artificial intelligence

Amsterdam's research output in AI is highly impactful, with a field-weighted citation impact (FWCI) of close to 3, exceeding national and world averages.

"This report shows us what we are really good at: technology and people. We should use our knowledge infrastructure to create a better world through technology."

Nina Tellegen,
Executive Director of the Amsterdam Economic Board

The number of AI publications is growing, with Amsterdam's output on a par with Stockholm, behind only Berlin, Cambridge, and Barcelona.

Amsterdam's comprehensive universities generate a lower-than-average but surprisingly competitive share of AI publications compared with national and EU 28 averages, indicating an opportunity for expansion.

Eindhoven, Delft, and Enschede, with their technical universities, boast larger shares of AI publications.

Sustainable development

Amsterdam's research output is cited more than EU 28 or world averages in almost all the UN's Sustainable Development Goals (SDG) categories.

In the category of 'Good Health and Well-being', the SDG with the highest number of associated publications by far, Amsterdam's output is increasing significantly and ranks highly in terms of citation impact.

Amsterdam leads the way in the impact of its research on 'Climate Action', which although small in volume and on a par with world activity levels outperforms all other areas.

Amsterdam's share of publications in 'Gender Equality' is nearly double the world average and shows strong growth in high quality output.

International collaboration

The impact of Amsterdam's publications that demonstrate international collaboration is on a par with Cambridge, with the cities of Rotterdam, Wageningen, Nijmegen, and Groningen also performing well.

The Netherlands performs well above EU 28 and world averages in terms of citations, with its international publications cited over twice the global average.

Amsterdam's international publications are growing steadily, reaching over 10,000 in 2020, and the city has a higher level of international collaboration than any other in the Netherlands.

While over half of Amsterdam's publications are international, nearly three times the EU 28 average, several cities perform better indicating potential for improvement.

Knowledge transfer

Amsterdam's academic-corporate publications are highly impactful, cited more than world and EU 28 averages, second only to Barcelona.

The impact of academic-corporate publications from Groningen and Nijmegen also outperforms national, EU 28 and world averages, with Groningen's output cited six times more than the global average.

Between 2014 and 2020, 7% of Amsterdam's publications had at least one corporate co-author, up from around 5% over the previous decade.

Amsterdam produces a larger number of academic-corporate publications than any other city in the Netherlands.

Between 2014 and 2020, the number of Amsterdam's academic-corporate publications grew steadily but still lags behind the other European cities analyzed here.

Most Dutch cities, including Amsterdam, perform above EU 28 and world averages except Eindhoven, Enschede, Tilburg, and Delft.

While Amsterdam scores highly on the impact of its academic-corporate collaborations, the number of such publications is less than other European research cities indicating an opportunity for expansion.

Technological strengths

Between 2014 and 2020, more than 10,000 patent families were filed by or granted to researchers from Amsterdam.

Amsterdam's patent output, which is the second largest in the Netherlands, is dwarfed by Eindhoven, which produced nearly 50,000 patent families over the same period.

Eindhoven's patent output is comparable to European leaders and major cities such as Paris.

Amsterdam's performance in generating patents is average compared with technological leaders Cambridge and Berlin, on a par with Stockholm and Barcelona but outperforming Copenhagen, Leuven, and Innsbruck.

Around 2% of Amsterdam's research publications were cited by patents between 2014 and 2020, with nearly 3% of Eindhoven's cited.

Eindhoven competes with Cambridge and Leuven in terms of patent citations, while Amsterdam lags behind the frontrunners Stockholm and Copenhagen.

Conclusions and recommendations

This report uses bibliometric indicators to provide an insight into Amsterdam's research and knowledge transfer landscape. The city is world class in some fields of research, like medicine, health and life sciences, and is leading the way in its approach to sustainability.

However, we can identify some areas where Amsterdam could maximize its potential and expand its impact. In AI, for example, the city could focus on growing the volume of its publications based on a strong foundation of high-impact output.

"We need a clear and unique story. With this, we will be able to improve and intensify our collaborations in the future."

Nina Tellegen,
Executive Director of the Amsterdam Economic Board

Well over half of Amsterdam's research publications have international co-authors, but other research powerhouses in Europe boast even higher proportions, indicating the potential for the city to explore new global collaborations.

While the impact of Amsterdam's publications demonstrating academic-corporate collaboration is high, the volume of these publications is low compared with other European research cities, offering an opportunity for growth in the future. The city could focus future efforts on encouraging the transfer of its research excellence into patents to develop its technological strengths even further.

Amsterdam is already a research powerhouse in Europe, particularly in medicine, health and life sciences, and shows great potential to grow and develop in this and other emerging disciplines such as AI in coming decades. Despite being one of Europe's smaller cities, Amsterdam boasts serious strengths in research and innovation with the potential for growth.

Interviews with key opinion formers
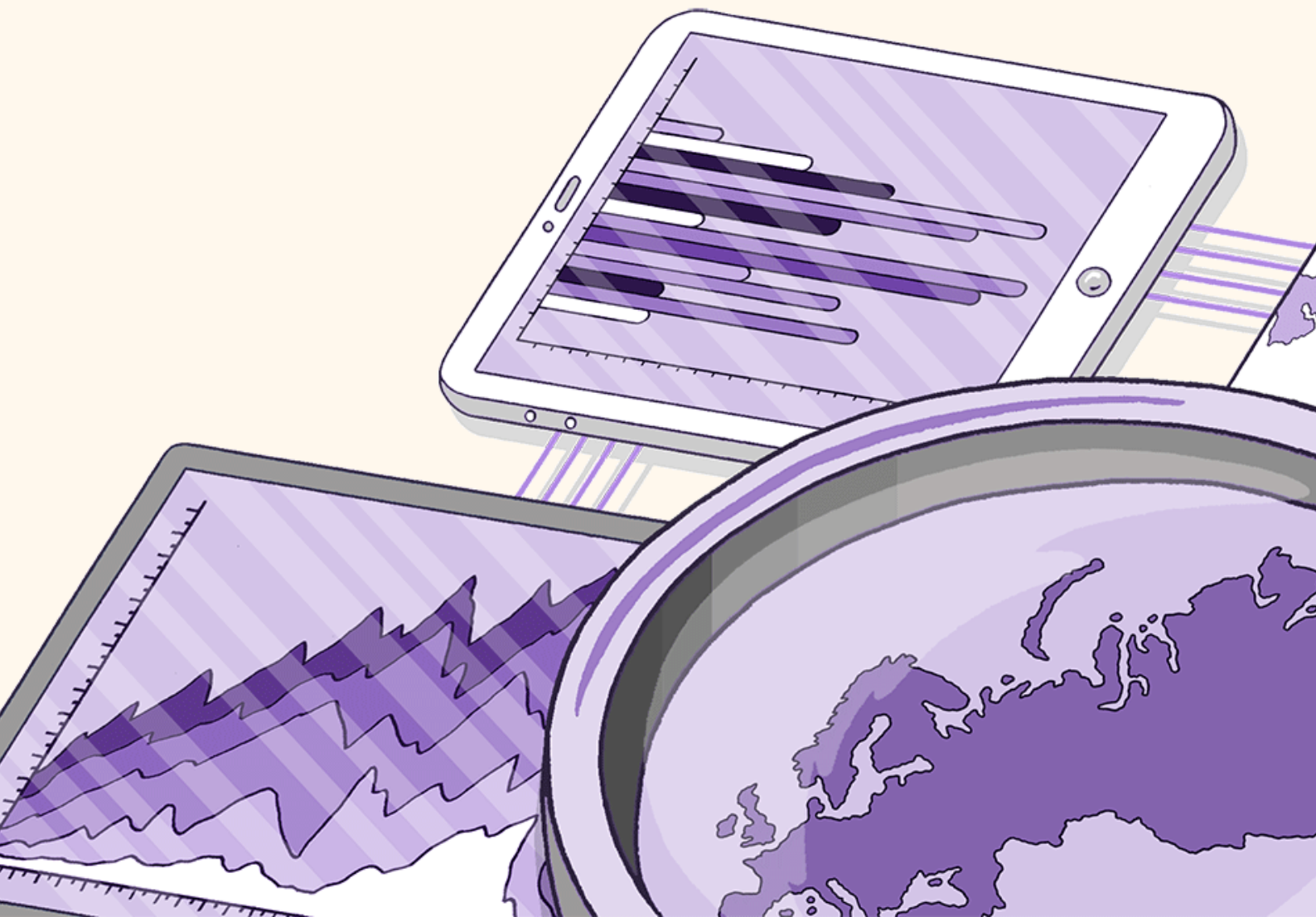
Interviews

Professor Arjen Brussaard

Vice Dean Valorization of Research at Amsterdam UMC and Scientific Director of Amsterdam Neuroscience

Professor Mirjam van Praag

President of the Executive Board of Vrije Universiteit Amsterdam and Professor of Entrepreneurship

Nina Tellegen

Executive Director of the Amsterdam Economic Board

Professor Maarten de Rijke

Distinguished Professor of AI and IR at the University of Amsterdam and Founding Director of the Innovation Center for Artificial Intelligence (ICAI)

Professor Arjen Brussaard

**Vice Dean Valorization of Research at Amsterdam UMC and
Scientific Director of Amsterdam Neuroscience**

Q: What value do data, such as contained in this report, offer policymakers, institutional leaders, and the research community and why?

AB: This report provides evidence-based insights [about research and innovation in Amsterdam and the Netherlands] to which I largely subscribe. Data such as this can support our future strategy.

Q: What initiatives or policy developments have emerged and been the most significant for Amsterdam and the Netherlands over the last five years?

Over the last couple of years, Amsterdam's knowledge institutes have established firm commitments in the fields of artificial intelligence (AI), health and life sciences, and sustainability. Of these three areas, health and life sciences is the most well developed.

The merger of Amsterdam's Academisch Medisch Centrum (AMC), the hospital affiliated with the University of Amsterdam, and Vrije Universiteit's Medical Center (VUMC) has had a major impact. Amsterdam UMC (Universitair Medische Centra or University Medical Centers) is now the largest academic medical center in the Netherlands, providing 22% of the country's academic medical care.

Q: What R&I priorities do you think should be the focus for Amsterdam and the Netherlands over the next five years?

AB: I believe knowledge institutions will be increasingly involved in larger societal issues, such as the cost of healthcare or sea-level rise. I call these 'wicked problems' and I am convinced that we can only resolve such issues with a systems approach. In recent years, Amsterdam has made a deliberate choice to focus on a limited number of areas on which we collaborate more intensively than before. The results of these investments will become visible in the near future, and I am looking forward to what Elsevier's report will look like in five years' time. Will we succeed in our ambition to maintain our focus on the three areas of artificial intelligence, health and life sciences, and sustainability? How many private-public partnerships will we successfully establish? How many Apps will we build?

Q: What future research in what fields do you find the most thought-provoking and would like to see? Are there any fields where you think there is underinvestment and room for improvement?

AB: Within my field of medicine, I believe we will see further development of translational and precision medicine in which partnerships with many different of fields of expertise will be required. Our overall aim is to transform our fundamental understanding of human well-being and disease into effective, patient-centered, and affordable health measures. If, one day, we publish less but have more impact with our work, it would be a great achievement.

Professor Mirjam van Praag

President of the Executive Board of Vrije Universiteit Amsterdam and Professor of Entrepreneurship

Q: What value do data, such as contained in this report, offer policymakers, institutional leaders, and the research community and why?

MvP: The data in this report are extremely valuable for the city of Amsterdam and our university. It is crucial to be able to support our strategy with data. The figures presented here fill me with pride: as a city we are on the right track. For example, the main areas of focus of the Amsterdam Valorization Strategy[36] are artificial intelligence (AI), health and life sciences, and sustainability, which coincide with the joint impact strategy of Amsterdam's knowledge institutes.

Q: What information in this report is most insightful and useful to you, and why? Were there any data that surprised you and if so, why?

MvP: Apart from physical data, numbers, and graphs, we must pay attention to other criteria to complete the picture of the research performed by Amsterdam's institutions. Society's contemporary and future demands require a narrative alongside the physical data that elaborates on processes and partnerships, on learning and success.

Q: What initiatives or policy developments have emerged and been the most significant for Amsterdam and the Netherlands over the last five years?

MvP: Since the publication of Elsevier's last report on Amsterdam in 2015[37], the need and will to collaborate has increased significantly. Science in general enjoys greater appreciation than before and financial support has grown. Simultaneously, we have seen interesting and positive developments among knowledge institutions, which have opened up to intensified collaboration, and corporates, who see new opportunities in collaborating with knowledge institutions. For example, the Biotech Booster program[38] has been awarded a grant of EUR 250 million from the Dutch National Growth Fund with the aim of turning innovative research into concrete products faster, better, and more often. This will have an enormous impact on our society.

Q: What R&I priorities do you think should be the focus for Amsterdam and the Netherlands over the next five years?

MvP: The fundamental research that forms the foundation of important innovations is increasingly conceived not in isolation but in collaboration between researchers from various disciplines and with industry, users, patients and/or entrepreneurs. The promotion of this kind of teamwork requires the establishment and/or support of topic-related communities where stakeholders meet, exchange knowledge and information, and build trust. The scientific basis of the report is an excellent foundation on which to build such efforts and we will reap the rewards in the coming years.

[36] https://www.ixa.nl/
[37] *Mapping Research and Innovation – Understanding Amsterdam's Competitive Advantage.* (2015). Elsevier and Urban Innovation Network. https://www.elsevier.com/__data/assets/pdf_file/0005/53483/UINAmsterdamReport.pdf
[38] https://vu.nl/en/news/2022/boost-for-biotechnology

Nina Tellegen

Executive Director of the Amsterdam Economic Board – a network in business, education, and government that works on large-scale social ambitions

Q: What value do data, such as contained in this report, offer policymakers, institutional leaders, and the research community and why?

NT: This report gives us important information about the areas in which we excel. These data support us in overcoming our main struggle as a city: we find it very hard to choose. Amsterdam has, unlike other cities such as Utrecht or Eindhoven, a tradition of wanting to do it all.

Q: What information in this report is most insightful and useful to you, and why?

NT: This report shows us what we are really good at: technology and people. These strengths fit beautifully with the social side of the region: we always pay attention to the human dimension. We should, therefore, use our knowledge infrastructure to create a better world through technology, as we do with the AI Technology for People initiative[39]. This is a unique collaboration between Amsterdam's universities, research centers, the Amsterdam Economic Board and municipality to share knowledge and skills in the field of AI in the design and deployment of technology in an ethical, responsible way that improves people's lives.

The report makes clear it that we score extremely well on research output and impact, but also reveals that we need to work harder on public-private partnerships. While we have excellent connectivity between the public sector and many different types of company in the region, some of the newer, very successful Amsterdam-based companies are not as well connected with the work we do on major societal issues. Exciting projects and results can come from such partnerships like the numerous public-private collaborations that we see at the Innovation Center for Artificial Intelligence (ICAI)[40] and within the Amsterdam Economic Board's program TechConnect[41], for example.

Q: What initiatives or policy developments have emerged and been the most significant for Amsterdam and the Netherlands over the last five years?

NT: In the last five years, we have seen an increase in the number of academic-corporate-government cooperative initiatives, which strengthens the need for choice.

Q: What R&I priorities do you think should be the focus for Amsterdam and the Netherlands over the next five years?

We need a clear and unique story. This issue is high on the agenda of the Amsterdam Economic Board. We, together with our partners, are currently working on an overarching agenda for the Amsterdam Metropolitan Area to sharpen our distinctive narrative. With this unique story, we will be able to improve and intensify our collaborations in the future. I hope all stakeholders will give each other space to prosper, so that we can achieve even more together.

[39] https://www.iamsterdam.com/en/business/key-sectors/ai/ai-technology-for-people/what-is-ai-technology-for-people
[40] https://icai.ai/
[41] https://amsterdameconomicboard.com/en/programmas/techconnect/

Professor Maarten de Rijke

Distinguished Professor of AI and IR at the University of Amsterdam and Founding Director of the Innovation Center for Artificial Intelligence (ICAI)

Q: What value do data, such as contained in this report, offer policymakers, institutional leaders, and the research community and why?

MdR: The report supports my observations that we produce influential research, and our research has significant impact.

Q: What information in this report is most insightful and useful to you, and why?

MdR: The last five years have shown a tripling of research output in AI and that is a great development.

Q: What R&I priorities do you think should be the focus for Amsterdam and the Netherlands over the next five years?

MdR: In the coming years, there are major challenges ahead, especially in the fields of climate change, healthcare and sustainability, where we will have to innovate. AI will play an important role in these developments. When we think of greening processes, discovering new materials and molecules, increasing the effectivity of alternative sources of energy, for example, AI will enable these different fields to innovate and make progress. But the public and private sectors will need to improve their cooperation. The closer the links between different stakeholders, the better the ability to control risks. An important precondition for success is to have real shared ownership of technology, social problems, and the solutions to those problems.

At the Innovation Center for Artificial Intelligence (ICAI) we facilitate and strengthen these processes. We are a network aimed at technology and talent development between knowledge institutes, industry, and government. We boost AI-based innovation in the ICAI labs where we train talent and support learning by doing. We facilitate a framework within which an individual can experiment.

Q: What future research in what fields do you find the most thought-provoking and would like to see? Are there any fields where you think there is under investment and room for improvement?

MdR: The city of Amsterdam has produced beautiful examples of utilizing technology for solving social problems instead of merely using technology because we have it to hand. To develop this further, it is key that people become technologically savvy, to be able to work independently of external consultants.

Another wish I have for the near future is that we will transform our campuses into real innovation centers. Amsterdam Science Park and Amsterdam Zuid Oost are on their way, but at Amsterdam ZuidAs[42], for example, one literally enters the business district when leaving Vrije Universiteit Amsterdam. I believe creating a natural transition between science parks, businesses, and society still has huge potential for innovation.

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[42] https://zuidas.nl/en/

Appendix A
Methodology

Bibliometrics

The quantitative data in this report are analyzed using bibliometric techniques, which extract information from databases indexing records of scientific publications and patents. This report uses Scopus[43], Elsevier's database of publication abstracts and citations, to interrogate the research output of Amsterdam and the Randstad region with respect to other cities in the Netherlands, a selection of leading European research cities, the EU 28 group of countries, and the world average. The data set covers the period from 2014 to 2020.

Scopus contains abstract and citation content from over 7,000 publishers, totaling over 84 million items from more than 26,000 serial titles, 240,000+ books and 10.4 million+ conference papers connected through a robust data model including over 94,000 affiliation and 17 million author profiles. Scopus coverage is multilingual and global: approximately 46% of the titles in Scopus are published in languages other than English (or published in both English and another language). In addition, more than half of Scopus content originates from outside North America, representing countries across Europe, Latin America, Africa, and the Asia-Pacific region.

We report on the absolute number of publications from Amsterdam, the Randstad region, and European comparator cities over the period 2014-2020; the number of publications receiving the top 1% of citations; the share of top cited publications out of the total; and the field-weighted citation impact (FWCI), which is an indicator of the citation impact of a publication. We also determine the compound annual growth rate (CAGR), which is defined as the year-over-year constant growth rate over a specified period.

Field-Weighted Citation Impact

The field-weighted citation impact (FWCI) is the ratio of the total number of citations received and the total citations that would be expected for a publication of the same type, subject area, and year, based on the average. An FWCI of:

- Exactly 1 means that the output performs as expected for the global average;

- More than 1 indicates that the output is cited more than expected according to the global average. For example, 1.48 means 48% more cited than expected;

- Less than 1 means that the output is cited less than expected according to the global average, for example, an FWCI score of 0.87 means the publication has been cited 13% less than the global average.

This measure is particularly useful for comparing data that covers a number of different fields.

Relative activity index

In this report, we also calculate the relative activity index (RAI) indicator, which is defined as the share of a country's publication output in a topic cluster relative to the global share of publications in the same topic

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[43] For further details: www.scopus.com

cluster. A value of 1.0 indicates that a country or region's research activity in a field corresponds exactly with the world activity level in that field, a value higher than 1.0 implies a greater emphasis, while a value lower than 1.0 suggests a lesser focus.

Research topic

This report also looks at research output by subject area, which we do by categorizing publications into different 'Topics'. A Topic is a collection of publications with a common intellectual interest and can be large or small, new or old, growing or declining. Topics are dynamic over time, new Topics will surface, and they will evolve. A publication can belong to only one Topic and a Topic can belong to only one Topic Cluster.

We take the entire citation network – over 1 billion citation links between 55+ million Scopus-indexed publications from 1996 onwards and an additional 20+ million non-indexed documents that are cited at least twice – and break that network into roughly 96,000 Topics. A Topic is created where the direct citation linkages within the Topic are strong and the direct citation linkages outside the Topic are weak. Only the indexed publications are included in Topics.

Topic Clusters are formed using the same direct citation algorithm that creates Topics. When the strength of the citation links between Topics reaches a threshold, a Topic Cluster is formed. A Topic Cluster is an aggregation of Topics with similar research interest into broader, higher-level areas of research. These Topic Clusters can be used to get a broader understanding of the research being done by a country, institution (or group) or researcher (or group), before drilling into the more specific or niche underlying Topics.[44]

Collaboration and connectivity

Central to the research effort is collaboration with other researchers within an institution, nationally, internationally, and with the private sector and industry. In this report, we measure research collaboration on global scale or international connectivity by counting the number of publications with authors from two or more different countries or regions. We determine collaboration between academic and corporate partners by scrutinizing the affiliations listed by the authors of a publication.

Knowledge transfer and patents

The final transfer of research innovations into applications and commercialization can be measured in different ways, but in this report we focus on the following indicators of knowledge transfer:

- Academic-corporate collaboration: the number of publications with co-authors from academic and at least one company or industrial partner, as described above; and

- Academic-corporate collaboration FWCI: there will naturally be higher levels of academic-corporate collaboration in some fields compared with others in absolute terms (medicine versus the arts & humanities, for example). To take into account these discrepancies (normalize) between subject areas, FWCI calculates the relative share of citations with respect to the expected number, based on the world average rate of academic patent citations for that subject area;

- Patent families: we record the number of patent families, which are sets of related patents that are filed at multiple patent authorities to protect the same invention in more than one country;

[44] More information on topics is available at:
https://www.elsevier.com/solutions/scival/releases/topic-prominence-in-science
https://service.elsevier.com/app/answers/detail/a_id/28428/

- Share of publications cited by patents: the citation of a publication by a patent is a relatively rare event compared with a citation by another scientific publication. Citation by a patent also takes longer because of the time required to develop an invention to the point where it is ready to be patented. Patent applications are filed with a patent office, which then "publishes" the patent at a later date. The granting of a patent takes even longer. In this report, we count citations from patents that have reached the point of publication. The measure is an indicator of the successful transfer of knowledge from the lab to the point of commercialization.

In this report, data on patent families was extracted from LexisNexis PatentSight[45], a powerful and easy-to-use analysis platform that provides quick access to patents in a wide array of application areas. The software and its underlying data enable the evaluation of companies and technologies, comprehensive analysis for strategic decision-making, as well as searching and viewing individual patents and patent details. PatentSight compiles bibliographic patent data from over 95 authorities worldwide (utilizing DOCDBN, the European Patent Office's master documentation database with worldwide coverage) and has the most comprehensive full-text patent data, with over 100 million patent documents in English, approximately 700 million drawings and illustrations of inventions, and nearly 100 million PDFs that are searchable (via OCR) and quickly downloadable. For this analysis, patent families were selected by extracting granted patents where the patent author is affiliated with the city in question.

Definitions of cities

Where we discuss cities in the report, we use the following definitions:

- **Amsterdam** is defined as the Greater Amsterdam area including Amsterdam, Amstelveen, and Diemen.

- **Stockholm** is defined as the Greater Stockholm area including Stockholm, Solna, Huddinge, and Kista.

- **Berlin** is defined as the Greater Berlin area including Berlin, Golm, Potsdam, and Tentow.

- **Copenhagen** is defined as the Greater Copenhagen area including Copenhagen and Frederiksberg.

- **Barcelona** is defined as the Greater Barcelona area including Barcelona, L' Hospitalet de Llobregat, Mataró, Sabadell, Santa Coloma de Gramenet, and Terrassa.

- **Randstad** is defined as the conurbation including Almere, Amersfoort, Amstelveen, Diemen, Amsterdam, Delft, Dordrecht, Haarlem, Leiden, Rotterdam, Utrecht Zaanstad, and Zoetermeer.

For this analysis, all towns with less than 15 publications in the 2014-2020 period were ignored.

The analysis also considers the different spellings of city names used by authors as their primary affiliation, for example Copenhagen, Kobenhavn, and København; The Hague, Den Haag and 's-Gravenhage; Leuven and Louvain, etc.

For the purposes of this report, we define EU 28 countries as: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom, although the latter is no longer part of the EU.

United Nations' Sustainable Development Goals (SDGs)

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[45] For further details: https://www.patentsight.com/en/

The United Nations defined 17 Sustainable Development Goals (SDGs) in 2015 as part of its 2030 Agenda for Sustainable Development. SDGs are designed to serve as a "blueprint to achieve a better and more sustainable future for all", by addressing the global challenges we face, according to the UN. Of the defined goals, 16 are subject specific with the final goal relating to processes to realize the goals.

The SDGs are defined as follows:

- Good health and well-being

- Peace and justice, strong institutions

- Reduced inequality

- Sustainable cities and communities

- Decent work and economic growth

- Gender equality

- Climate action

- Quality education

- Industry, innovation, and infrastructure

- Affordable and clean energy

- Zero hunger

- Life on land

- Clean water and sanitation

- No poverty

- Responsible consumption and production

- Life below water

- Partnerships for the goals

To support the research community in working toward these goals, Elsevier and its data science teams have joined forces with experts to create a Scopus search query for each SDG[46]. These in-house designed queries take a targeted and expert-informed approach in order to generate the most accurate and valid queries. Each Scopus search query can then be used to generate pre-defined research areas in SciVal to describe the work being carried out by institutions and universities on each SDG and its outcomes. The combination enables SciVal users to analyze and benchmark SDG research globally in detail.

[46] The methods and queries for the SDG publication sets are available here:
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United States Patent and Trademark Office (USPTO): https://www.uspto.gov/

World Intellectual Property Organization (WIPO): https://www.wipo.int/portal/en/index.html

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