SCIENCE|BUSINESS

Ten Tech Hubs
European wireless clusters that make industry and jobs grow

October 2016

Commissioned by

HUAWEI

It matters *where* you innovate

Innovation doesn't happen by accident. It takes smart and skilled people, good industry-university cooperation, strong financing and policy support – and a place for it all to come together. Always, despite the advancing power of digital tools that seem to connect us anywhere and nowhere at once, it's in a particular city or region that the right ingredients for innovation get mixed together and eventually go global. This could be in Boston or San Francisco, Bangalore or Shanghai – or London, Barcelona or Tallinn.

That's why a focus on innovative clusters has long been an important part of our efforts to speed up innovation, economic growth and social strength across Europe. For instance:

• The EU has been successfully advancing a "smart specialisation" strategy to target support for research and innovation where it can be best used to build local strengths. To this day, about 200 smart specialisation strategies have been developed in our regions, and a special platform for industrial innovation was launched earlier this year.

• Our policy has been to help local universities modernise and collaborate better with local industry – to train young entrepreneurs, to encourage student exchanges and internships in companies, to build what we have called Knowledge Alliances between education and business. These collaborations are also important for digital know-how and the kind of 'soft skills' – creativity, cultural awareness – that underpin many digital ventures these days.

• Building and inter-linking regional competences – in 'co-location' centres - has been a central aim of the European Institute of Innovation and Technology, which has created more than 300 spin-out companies to date. We already see that EIT graduates find jobs more quickly, earn more and create start-ups more often than their peers.

This Science|Business report, highlighting ten successful digital regions across the EU, is an important reminder of the importance of place and time in innovation. But what accelerates the economic growth and development of these regions is another factor: their openness to the world. Our universities are increasingly open to international cooperation, whether through exchange programmes like those offered by Erasmus+ or other strategic partnerships. Students who go abroad not only gain knowledge in specific disciplines. They also develop transversal skills such as problem solving abilities, creativity and tolerance. We therefore welcome the engagement of companies in working locally with our clusters, and encouraging international mobility of people and ideas.

Innovation happens where ideas and experiences collide – in the interaction of different branches of sciences, across national borders, and where people with entrepreneurial skills work side by side with those who have frontier knowledge. Together, we will work to build the clusters where these collisions occur, to build a more prosperous Europe – and world.

Tibor Navracsics
Commissioner for Education, Culture, Youth and Sport

Pioneering Europe's future ICT ecosystem

Information and communication technologies have become deeply integrated into our society. No longer simply an industry vertical itself, ICT has become an enabler of digital transformation across all sectors of the economy. To make this transformation a success, we need an open ICT ecosystem that works across regions and industry sectors worldwide. This ecosystem must be a community of interests, where all players contribute to and benefit from shared success.

Europe's leading wireless clusters illustrate perfectly how this can work in practice, and highlight examples of the numerous benefits this approach brings to all parties. In Europe's tech hubs, sustainable economic growth goes hand-in-hand with environmental protection, better services, strong connectivity, and groundbreaking innovation.

Huawei is actively involved in many of the clusters presented in this report. In Munich, we launched an "Openlab" to work on ICT innovation with partners such as Intel and SAP. The lab is focused on the Internet of Things (IoT), cloud computing, and big data to support safer and smarter cities. We have also built a 5G wireless technologies test environment, supported by the Free State of Bavaria, the city of Munich, the Technical University of Munich, and M-Net.

As a driver of future connectivity, 5G is a focus area for activity across European wireless clusters, and a priority for Huawei. We are researching 5G technologies at Surrey University's 5G Innovation Centre in Greater London –

another top cluster – where we will invest £5 million as part of the US$600 million the company has committed to our 5G research plan.

Stockholm, another tech hub, is home to Huawei's first R&D lab in Europe. Opened in 2000, the facility has about 350 staff working on cellular systems, including 5G technologies.

Huawei's European R&D network fosters win-win collaboration with European partners to push the global industry forward. The high level of expertise in a variety of strategic areas and the numerous opportunities for collaboration with universities, research institutes, and other industry players make Europe an ideal location for establishing R&D hubs. The latest addition to our growing network is the facility in Tampere, Finland, opened in September 2016. The unit is a part of Huawei's wider R&D hub in Finland for mobile device technology.

Huawei is committed to helping build an open ICT ecosystem in Europe, creating value together with our European partners, and sharing benefits with them. Our partnerships with academia and universities across Europe are a vital part of this effort.

Ms. Chen Lifang
Corporate Senior Vice President
Director of the Board
Huawei Technologies Co., Ltd.

> "A self-driving car makes a big difference. It doesn't get tired, or distracted by the children on the back seat, or look at its smartphone."
> MELANIE HENRIËTTE SCHULTZ VAN HAEGEN-MAAS GEESTERANUS, Minister of Infrastructure, The Netherlands.

> "5G provides the foundational technology for the digitalisation of everything. Homes, roads, factories, hospitals, cars will all be digitised,"
> RAHIM TAFAZOLLI, director of the 5G Innovation Centre at the University of Surrey.

> "We provide clean tech companies a local 'proving ground' for testing and demonstrating their technologies,"
> FRANK JENSEN, the mayor of Copenhagen.

Table of Contents
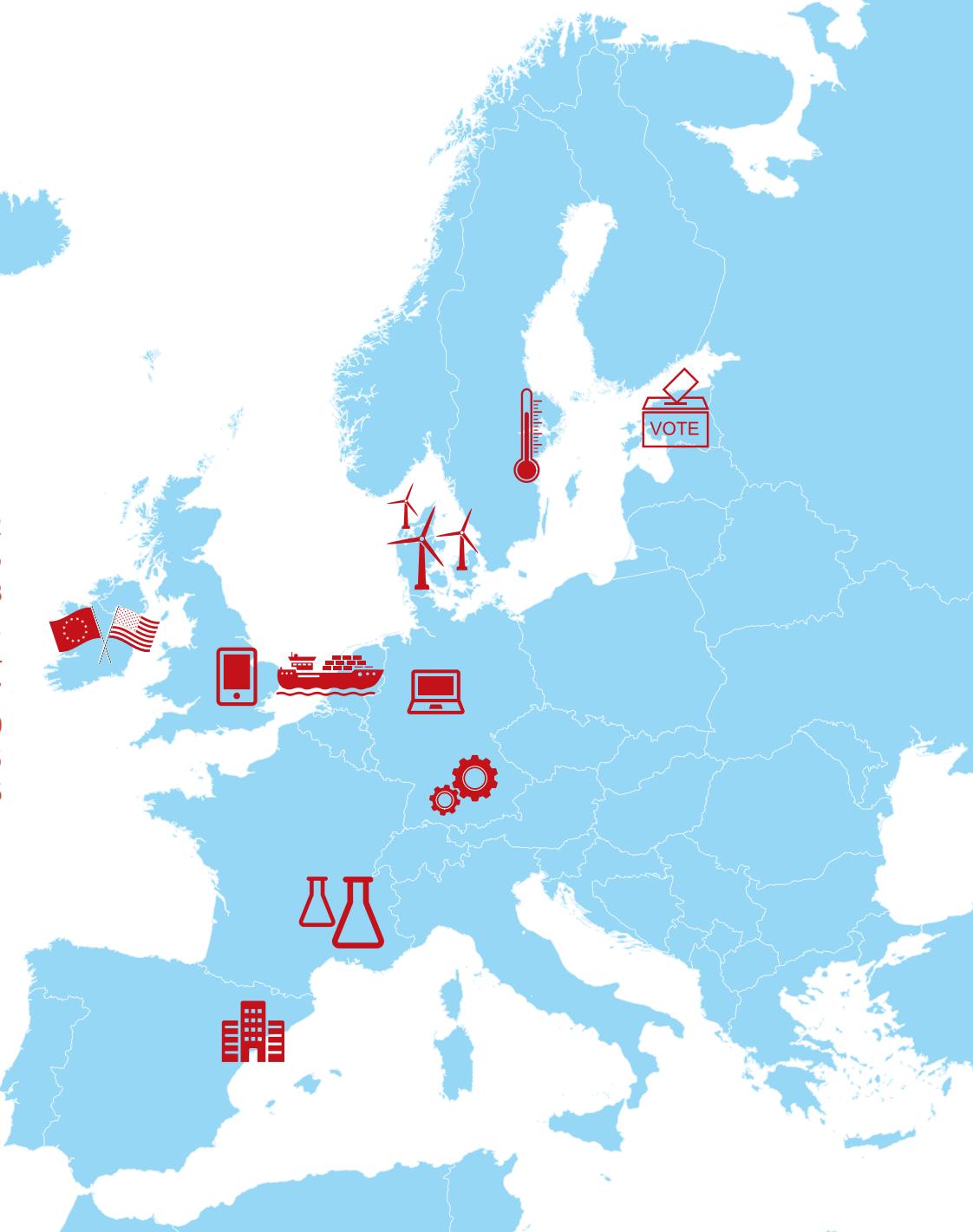
Ten Tech Hubs

European wireless clusters
that make industry and jobs grow

High-tech wireless clusters are springing up all over the EU, but the really valuable ones have companies, labs and academics that do more than write consumer apps: They make industry happen. They underpin new transport systems, make healthcare more effective and manage energy systems more efficiently. They are looking to harness 4.5G and 5G, the Internet of Things and Industry 4.0, and a range of related technologies. Their systems promise to transform companies across Europe, whether they be logistics specialists in the enormous Port of Rotterdam, niche manufacturers in Germany's *Mittelstand* or world-renowned perfumeries and aerospace factories on the Côte d'Azur. These wireless clusters are reimagining the way cities, such as Barcelona, are run, while delivering all-digital government in Tallinn, Estonia. Their code and networks help conserve energy, automate industry and manage transport across Europe.

In this special reference report, commissioned by Huawei, Science|Business examines 10 of these tech clusters. They provide case studies on the integration of information and communications technologies (ICT) into an economy, and of a region into the wider world. Some are big and famous, and some more specialised. European policy leaders need to know more about these successful clusters, to study their assets, skills and policies – local, national and pan-regional – that helped them grow. Propelling each forward is a productive cycle of collaboration among strong universities, big companies with local bases, smart regional-development agencies and intrepid entrepreneurs, operating in open, competitive markets. Is there a recipe to clone them? What role can EU policy play?

This special report profiles the ten clusters, analyses their success factors, and draws lessons for both national and EU policy makers. To that end, each profile scores the tech cluster on five areas of policy, drawing on Science|Business research, the relevant rankings of the World Economic Forum and data from Invest Europe (formerly the European Venture Capital Association) tracking the extent of public sector involvement in private equity. The cluster profiles also feature snapshots of key local players and relevant statistics, such as the proportion of the working population employed in high-tech jobs, enabling readers to compare one hub with another across a range of metrics. Finally, each profile includes an interview with a local visionary, yielding valuable insights into where Europe's tech hubs are headed next.

But this report is not intended as a ranking; there are many other promising regions across the EU. Rather, this is our effort to highlight some especially bright spots in the European digital landscape that we, as professional journalists who follow the field closely, think bear watching – either because they are already big and powerful, or because they are rising fast. They also show the wide range of policies, institutions and talents that have to come together to build a successful cluster.

To intervene or not to intervene

How can policymakers nurture the development of tech clusters?

How big a role has public policy played in creating Europe's leading tech hubs? The answer varies from a great deal to very little, depending on the hub. Whereas the development of the Côte d'Azur as a high-tech cluster has a lot to do with the sustained support of the French government, Berlin's position as the start-up capital of Europe is underpinned by a rich cultural and social life, together with a relatively low cost of living. While Estonia's digital government drive has made Tallinn a centre of cyber-security expertise, Munich's manufacturing acumen is largely down to the vision and determination of world-class companies, such as BMW and Siemens.

As they seek to define their role in fuelling innovation, policymakers need to tread carefully. There can be a fine line between creating the enabling conditions and supporting the development of standards (as the UK government did with GSM) and distorting the market, thereby constraining innovation: After splurging too much money on licenses to deploy 3G cellular technology, Europe's telecoms industry has been slow to deploy 4G.

In reality, most tech hubs emerge through a unique blend of entrepreneurialism, government enablement, smart regulation, cooperation on technical standards and commercial competition. Germany, for example, seems to be successfully combining these elements to lead the world in the development of so-called Industry 4.0 – smarter, data-driven manufacturing.

Pursuing excellence in education – in engineering and management

Perhaps the strongest lever available to policymakers is the education system. Nearly every cluster covered in this report is bolstered by the presence of universities with a strong track record in science, technology, engineering and maths (STEM) subjects, underpinned in Germany, the Netherlands and some other markets by good public schools.

However, STEM expertise isn't enough. "You need to invest in management education, as well," stresses Gill Ringland, CEO of SAMI Consulting and non-executive directive of Unlocking Foresight, noting that EU policymakers often overlook this dimension. As entrepreneurialism isn't ingrained in European culture, Ringland suggests that European governments should do more to entice émigrés back from Silicon Valley.

Supporting research – with money and public infrastructure

Another key policy measure in some of the leading clusters, notably Rotterdam, Barcelona and Copenhagen, is policymakers' willingness to support research, trials and pilots, and not just by providing funding. Crucially, they allow tests and experiments to be carried out using public infrastructure and in public places. "In the Netherlands, innovation in logistics is one of the priorities in Dutch economic policy," says Melanie Schultz van Haegen-Maas Geesteranus, Minister of Infrastructure and the Environment, who orchestrated the European Truck Platooning Challenge, terminating in Rotterdam.

Governments can go further still by pioneering new technologies in the public sector. By adopting new digital technologies to underpin its entire government infrastructure after it gained independence in 1991, Estonia has helped create an enviable tech cluster in Tallinn. In a similar vein, Denmark's aggressive decarbonisation targets have given its clean tech ecosystem assurances of long-term demand for its products and services.

Tax incentives – careful targeting is crucial

Another common tactic is to provide tax breaks for R&D. France, for example, has long used this lever to encourage North American and East Asian multinationals to establish R&D facilities in the country. Some governments go further still, using very low corporation taxes to attract both large and small companies. Ireland, a second home for Silicon Valley's finest, is a prime example – indeed, so much so that it has recently run afoul of European competition authorities, who are demanding it get Apple to pay back some €13 billion in tax breaks. Denmark is a counter example, preferring to offer a robust safety net to entrepreneurs that end up unemployed, rather than low taxes.

"Tax is a very tricky lever," cautions Karen Wilson, a senior fellow at think tank Bruegel and an expert on this topic. "You can very easily create the wrong incentive, as some of the R&D tax incentives can favour the large firms, rather than young entrepreneurial firms." Wilson recommends that policymakers follow the UK example and begin with a modest programme, evaluate its effectiveness regularly and refine it over time.

Public venture capital – crowding out the private sector?

Another controversial measure is to try and pick winners, using public money to provide seed funding to promising entrepreneurs seeking to turn an idea into a commercial proposition. In many parts of Europe, private venture capital is in short supply, so there may be a case for using taxpayers' money in this way: Innovation Fund Denmark, for example, has DKK 1.25 billion (€168 million) to invest in start-ups.

In the wake of the financial crisis of 2007 and 2008, policymakers across Europe stepped in to shore up the venture capital market. Six years later, the market remains heavily reliant on public money. About 40 per cent of venture capital in Europe is from the public sector, up from 14 per cent in 2008, according to Wilson of Bruegel. "The question is whether the public sector is crowding out the private sector," she notes. Although Wilson believes there may be a case for governments co-investing with venture capitalists in some markets, she cautions the "jury is still out" on the effectiveness of this model.

EU integration – playing politics

The EU is trying to reduce the need for such interventions by building a single market in both venture capital and research. And some governments, such as Catalonia's, have ensured their tech clusters are well integrated into the EU framework and benefit from EU research and development funding. In practice, this can mean playing politics in Brussels, which can have drawbacks. The EU tends to measure the success of its R&D framework in terms of innovation, using such crude measures as the number of patents awarded, notes Ringland. As small companies may not have the resources to file for patents, this isn't necessarily the best measure of entrepreneurial activity and progress.

In summary, the 10 clusters in this report provide insights into the multiple ways in which policymakers can play a crucial role in fuelling high-tech innovation and economic activity. Choosing which levers to pull and when isn't easy, so it is important to assess exactly why some clusters thrive and others stagnate.

Copenhagen
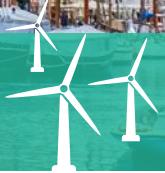
Facts and figures

R&D spend	Total intramural R&D expenditure per inhabitant	**€2,790 (Hovedstaden, 2013)**
Tech expertise	% of working population in high tech sectors	**9.7% (Hovedstaden, 2015)**
R&D base	% of active population employed in R&D	**5% (Hovedstaden, 2013)**
Local finance	VC investment as a % of GDP	**0.11% (Denmark, 2015)**
Connectivity	Average LTE download speed	**25 Mbps (Denmark, Q4 2015)**
Industrial base	Number of companies in the Forbes Global 2000	**11 (Denmark)**
Innovation	ICT patent applications to the EPO per million of the active population	**112 (Hovedstaden, 2012)**
EU Funding	H2020 funds	**€125 million**

Sources: Eurostat, OpenSignal, Forbes

Rethinking energy

Copenhagen, home to the European Environment Agency, was ranked as the greenest city in the world in 2014 by the Global Green Economy Index. Local policymakers are aiming to make the city of 1.2 million people the world's first carbon neutral capital by 2025. This will involve cutting greenhouse gas emissions in half and offsetting any remaining carbon use by producing more renewable energy. Looking further ahead, Copenhagen plans to transition to a clean economy entirely independent of fossil fuels by 2050.

More than 600 clean technology firms employing 77,500 people are based in Greater Copenhagen, according to Copenhagen Capacity, which promotes the city as a place to invest. The Danish capital is fast becoming one big sandbox, with dozens of 'smart city' pilot projects intent on doing away with the city's ageing tech.

Copenhagen is seeing a proliferation of co-working spaces, such as Startup Village, Rocket Labs, Founders House, Rainmaking Loft and Dare2Mansion, aimed at entrepreneurs. A noisy newcomer, #CPHFTW, which began life as a hashtag, has won plaudits from young companies. "Getting plugged into a great network of people helped me get the company going," says David Dizon, who runs M-PAYG, a pay-as-you-go solar company. Dizon's solar panels are being leased to homeowners in Tanzania for a fee of $5 a month, payable via a mobile phone. At the early-stage start-up incubator CIID Nest, Dizon received mentoring from experts specially flown in from San Francisco.

However, large companies, rather than individual entrepreneurs, are driving much of the clean tech activity. Copenhagen has relatively few high-flying start-ups per capita compared to other European capitals, according to the Global Entrepreneurship Monitor 2015. The European Digital City Index 2015, which ranks Copenhagen fifth in Europe, says "there is also a perception that large firms, rather than start-ups, drive the high innovation culture associated with Denmark."

As well as a strong industrial base, Copenhagen also boasts several leading universities. In the QS World University Rankings 2015/16, the city's flagship institution, the University of Copenhagen, is ranked at 69th, followed by the Technical University of Denmark at 112th.

History and policy

Green-minded Copenhagen, where cyclists have priority over cars, has long been at the cutting edge of clean-tech. According to a 2011 EU Joint Research Centre report, 22 per cent of all projects in the EU focused on the development of intelligent power grids were being conducted in Copenhagen.

But over the past five years, Denmark has embarked on a decisive new phase in its energy transition, helping to galvanise its clean-tech ecosystem. In 2011, a new centre-left government with ambitious energy and climate targets won the national elections. Three years later, the Parliament passed the Climate Change Act, establishing a framework to guide Denmark's decarbonisation toward 2050. By 2020 more than 35 per cent of the country's energy consumption must be renewable and greenhouse gas emissions 34 per cent lower than in 1990, while about 50 per cent of the electricity consumption must be supplied by wind power by 2050. These aggressive clean energy targets provide companies, entrepreneurs, and researchers with a clear sense of direction and the long-term assurance of demand for low-carbon solutions.

The Danish government also puts its money where its mouth is, having invested DKK 1 billion (€134 million) in energy-related R&D since 2010, while the City of Copenhagen plans to invest 2.7 billion DKK ($390 million) to achieve the 2025 Climate Plan. Moreover, Innovation Fund Denmark has an annual budget of DKK 1.25 billion (€168 million) to back promising start-ups in need of seed capital.

Although Denmark has some of the world's steepest income taxes, at up to 57 per cent, the government has shown itself sympathetic to the needs of start-ups. Before 2014, firms needed DKK 80,000 (€10,750) in capital to register a company, whereas today it is just one crown (about 10 euro-cents). Renting business space, although expensive, is still less than half of the price in Stockholm, according to the City of Copenhagen. The government does, however, take a big bite out of successful companies: capital gains tax is 27 per cent up to DKK 48,300 ($7,160) and 42 per cent on gains above that.

The World Bank ranks Denmark third in the world for ease of doing business. Entrepreneurs say the country's strong social system means the fear of unemployment or financial failure is lower than it might be elsewhere. Moreover, a new company can be incorporated and ready for business in only a few hours via the municipality's easy-to-follow website.

Copenhagen
Denmark

Policy Area

Bar chart — Score on a scale of 1–5 by policy area:

- Investment in education: 4
- Public support for research: 4
- Availability of public seed-funding: 4
- Favorable taxation: 1
- Integration into EU R&D framework: 3
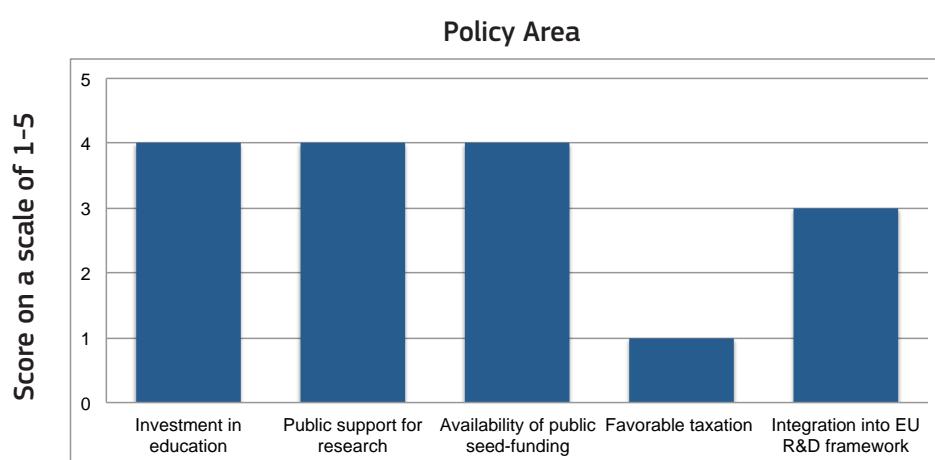
Copenhagen's mayor envisions more people and less pollution

With Copenhagen facing 20 per cent population growth between now and 2027, there's little alternative but to trial new, cleaner ideas, says **FRANK JENSEN**, the Social Democrat mayor of Copenhagen since 2010. "We provide clean tech companies a local 'proving ground' for testing and demonstrating their technologies. It's a huge challenge, but also an opportunity to create smart solutions," he adds.

A champion of all things green, Jensen says the country's clean tech sector outstrips all other parts of the Danish economy. And he's happy to take some of the credit. "A big part of the reason for the success of clean tech businesses in Copenhagen is the political willingness to invest in the sector and cooperate with businesses," he says.

The city administration is an assiduous collector of all kinds of data, which is readily available to enterprising folk with an idea for a new app or device. "We offer companies access to unique, high-quality figures and electronic registries dating back decades. This helps turn us into the preferred laboratory for smart city technologies to build, monitor and manage the data infrastructure of large cities," says Jensen.

Other cities are taking note of Copenhagen's leadership on climate change. "On our road to become the world's first CO2-neutral capital, big cities look to us for inspiration and we have successfully exported sustainable solutions to places like New York and Beijing," the mayor claims.

Jensen, an avid cyclist, takes pleasure in the environmentally conscious city he's helped to create. "It makes me proud, when I during the summer take my morning run along the Copenhagen harbour and see people swimming in the former industrial harbour," he says. "By cooperating with green businesses and investing in the complete modernisation of our sewage system the water quality improved and we were able to open the public harbour baths."

Snapshots of key players

Technical University of Denmark (DTU)

The country's largest technical university conducts specialised research on smart grids. The university's Centre for Electric Technology is undertaking research into electric energy systems and electric components, while Risø DTU National Laboratory for Sustainable Energy is one of Europe's leading research laboratories in its field. Fiber-optics is another speciality: In 2014, DTU students transmitted data over a single optical fiber at a speed of 43 terabits per second, beating the previous record of 32 terabits set by Germany's Karlsruhe Institute of Technology.

PowerLabDK

PowerLabDK is a test lab run by DTU to support the development of technologies that can help maintain the stability of energy supply and the balance between production and consumption. It houses Europe's largest grid simulator: researchers and companies that come to the lab can test innovations on the power grid of a whole island, called Bornholm, with a population of 2,000.

Danfoss

One of the largest industrial companies in Denmark, privately-owned Danfoss is heavily involved in the energy sector, developing district heating systems and space heating, including heat pumps, room controls, and under-floor radiant heating; air-conditioning components such as compressors, controls, and heat exchangers; pumps, compressors, and fans for electric motors; and solar inverters. Founded in 1933 by Mads Clausen, Danfoss now employs some 23,000 people in more than 50 countries.

Hitachi

The Japanese industrial giant is developing an integrated data service for smart lighting, sensor-based traffic management and intelligent building management for Copenhagen. It is building two applications: Journey Insight, which helps citizens in the region to track their transportation usage over time and understand the carbon footprint of their travel; and Energy Insight, which enables both households and businesses to see how much energy they use. Hitachi also runs Copenhagen's City Data Exchange, a website selling 1.7 billion bytes of data on everything from traffic snarl-ups to citizens' energy consumption.

Silver Spring Networks

Last year, Silver Spring Networks, a US smart grid networking firm, retrofitted Copenhagen's streetlights with a wireless network that can sense an approaching cyclist and shine extra light. The lights are remotely controlled from a central console, which can dim the illumination in the early morning hours to save electricity. The retrofitted lights consume nearly 60 per cent less electricity than those they replaced.

Denmark Outdoor Light Lab

In Albertslund in western Copenhagen, one square mile has been transformed into a kind of "outdoor living laboratory," where companies come and try out new gadgets. For example, vendors can test out sensors that gauge when rubbish containers need emptying and gizmos that measure the streets' temperatures, sending signals to warn pedestrians and cyclists of ice and the danger of slipping.

Tallinn

VOTE

Facts and figures

R&D spend	Total intramural R&D expenditure per inhabitant	€247 (Estonia, 2013)
Tech expertise	% of working population in high tech sectors	5.1% (Estonia, 2015)
R&D base	% of active population employed in R&D	1.5% (Estonia, 2013)
Local finance	VC investment as a % of GDP	Not available
Connectivity	Average LTE download speed	14 Mbps (Estonia, Q4 2015)
Industrial base	Number of companies in the Forbes Global 2000	0 (Estonia)
Innovation	ICT patent applications to the EPO per million of the active population	12 (Estonia, 2012)
EU Funding	H2020 funds	€58 million

Sources: Eurostat, OpenSignal, Forbes

Delivering digital government

Estonia is a world leader in digital government and banking. Today, 94 per cent of the country's 1.3 million people use an electronic ID, which allows for 95 per cent of tax declarations to be submitted online in less than three minutes. Moreover, 99 per cent of bank transactions are made online and 70 per cent of health records are digital, while 98 per cent of drug prescriptions are issued online. And doctors have secure digital access to their patients' medical history. Each citizen has its own log file kept by the government, where people can see who accessed their data.

Anyone who holds an Estonian electronic ID can sign a legally binding document over the Internet. Moreover, the government has started issuing e-residencies to individuals who want to build and run their businesses remotely, enabling both domestic and foreign entrepreneurs to register a company in less than 18 minutes, without having ever to set foot in Estonia. These services are widely used, says Janek Rozov, head of the Information Society Services Development Department at the Ministry of Economic Affairs and Communications. "Eighty per cent of Estonians use e-services to communicate with public institutions at least once a week," he adds.

But perhaps Estonia's biggest digital achievement has been the introduction of online democracy. Estonians can vote from the comfort of their living room, and are allowed to change their mind as many times as they want, as the system will always consider only the latest vote.

All of these advancements rely on the Internet X-Road. Some 170 online databases are connected to a digital highway, which enables more than 50 per cent of Estonian citizens to access information from over 2,000 services through the eesti.ee portal. Estonia is aiming for a once only rule, which states that any government agency should not ask for a piece of information from any citizen, if another agency already has it stored.

History and policy

After gaining its independence in 1991, Estonia had to build a government from scratch and going digital was the cheapest and fastest way to do it. "First, we started to build our banking system, because we had no check books and no credit cards," recalls Jaak Aaviksoo, rector of Tallinn University of Technology, who was minister for education and research from 2011 until 2014.

The decision to introduce an electronic ID card was inspired by Finland, which had implemented optional electronic IDs. But Estonia decided to make them mandatory for the entire population, creating a mass market for public and private e-services. "It was a crucial moment," remembers Aaviksoo. In 2005, Estonia held its first online elections. In 2008, Estonia's healthcare system went online.

In 2007, Estonia was the target of a series of cyber-attacks, in the wake of a diplomatic conflict with Russia over the relocation of a Soviet-era statue in Tallinn. The events prompted the Estonian government to prioritise digital security, establishing the Cyber Defence League, a network of volunteer hackers and IT specialists who identify security holes in Estonia's IT infrastructure. The Tallinn University of Technology is now organising the "Cyber-Olympics" to find and train white hat hackers who can protect the e-government and prevent cyber-attacks. Estonia's IT infrastructure has become so secure that NATO has set up its cyber-defence system in Tallinn.

The Estonian government is now looking to further streamline its e-services, says Janek Rozov of the Ministry of Economic Affairs and Communications. For example, a spouse changing her name after a wedding needs to go through seven different e-services to renew the electronic ID, passport, driver's licence, credit cards, and other vital documents. "We are now thinking about how to provide that through a unique service," says Rozov.

Organisations in the public sector are now tasked with pitching new ideas for e-services and digital strategies to the government twice a year. The quality of the proposals is increasing, as people in public institutions understand better how ICT can impact public services. "Three years ago we had 50 projects for developing

beta services, but we invested only in two," says Rozov. "Now we have two rounds of selection in September and in March, and for this September, we received 15 projects and all of them got the money," he added.

In the past three years, Estonia has dramatically changed its investment process in new e-services. Every government agency now has a strategy that explains how new digital services will improve the quality of public administration and how it will impact the lives of the citizens and the economy. "These strategies need to have measurable impact," says Rozov. By 2020, the Estonian government wants to offer 100,000 e-residencies worldwide, to convince the EU to introduce digital signatures to a fifth of Europe's population, and to build data embassies around the world. These embassies host copies of all data generated through Estonia's public e-services, and are placed abroad for security and defence reasons. "You can never occupy virtual Estonia," says Rozov.

Tallinn
Estonia

Policy Area

Bar chart — Score on a scale of 1–5:
- Investment in education: 4
- Public support for research: 3
- Availability of public seed-funding: 3
- Favorable taxation: 4
- Integration into EU R&D framework: 3
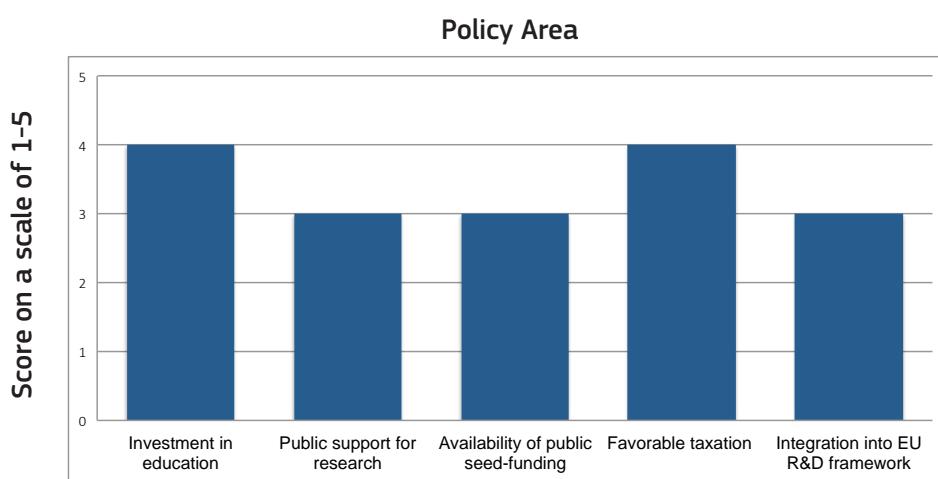
How public policy could become more personal

To what extent will big data drive public policy? JAAK AAVIKSOO, rector of Tallinn University of Technology, wants the Estonian government to use data mining to tailor services and policies based on individuals' behaviour. "We could rely more on data analysis when building policy," says Aaviksoo, who was minister for education and research from 2011 until 2014. He has first-hand experience at the Technical University of Tallinn, where students receive career advice based on data analysis. Aaviksoo envisions that governments could analyse anonymised data on health, education, income, and satisfaction with public services to devise smarter policies that address even the most trivial needs.

At the same time, Aaviksoo believes e-voting should be developed further. "It should become a government run open access platform for voting and decision making," he says, suggesting that an online decision-making platform, powered by the current e-voting system, could improve public policies and legitimacy.

Of course, delivering digital public policy depends on a digitally savvy population. Aaviksoo is also a longstanding advocate of embedding digital technologies into schools and incentivising children to learn to code at a very young age. He was one of the public figures at the forefront of Estonia's "Tiger Leap" policy in 1996, a national plan to create computer labs in all Estonian schools and connect them to the internet.

In Estonia, the Internet is now interwoven into the curriculum, as is digital security – "cyber-hygiene" is taught to all Estonian children as early as the age of five. "A national foundation was in charge of raising the money and implementing the project and by the end of the 1990s, all schools had computer labs connected to the Internet," recalls Aaviksoo, an award-winning scientist and a member of the Estonian Academy of Sciences.

"Trust and privacy are crucial," he adds, noting it is extremely important to inform the public about what the government is doing with all the data flowing among Estonia's e-services. It's all about "building trustworthy relationships between the government and the citizens," he says.

A lack of trust has been a roadblock for e-government initiatives in many developed countries. "It's the reason why in countries like the UK progress has been slow," says Aaviksoo. Before going fully digital, governments must address privacy and surveillance concerns, which are a "complicated psychological phenomenon," says Aaviksoo, noting individuals tend to trust Google and Facebook with their personal data, but not governments.

Snapshots of key players

Skype
Skype is the most famous product of Estonia's ICT industry. The innovative communications app was coded in 2001 by Estonian developers to enable people to make free voice and video calls via the Internet. In the first year after its launch, 19.8 million people were using the service. This success prompted Internet giant eBay to acquire Skype for $3.1 billion in 2006. Five years later, Microsoft bought Skype for $8.5 billion.

TransferWise
Co-founded by Kristo Käärmann and Skype's first employee, Taavet Hinrikus, TransferWise has developed a cheaper and simpler alternative to traditional bank transfers. Customers across the globe have transferred more than $3.5 billion through the service. After raising another round of investments this spring, some estimates value the company at $1.1 billion.

Estonian ICT Cluster
Stakeholders in both private and public sectors have come together to form the Estonian ICT cluster. The partners hope to create the ecosystems needed to replicate the success of Skype and TransferWise, and other Estonian ICT start-ups. Some 49 per cent of all Estonian ICT employees are working for partners of the cluster, who sell products and services in 115 countries and produce 75 per cent of the total turnover in the Estonian ICT sector.

Estonian HealthTech Cluster
More than 70 partners, including IT and medtech companies, R&D centres, hospitals, and patient organisations, have joined the Estonian HealthTech Cluster to speed up the digitisation of healthcare. Two members of the cluster, Quretec and Ignite are developing data management and analysis software that healthcare providers and insurers can use to deal with the large amount of health data that is collected through doctor-patient interviews, online questionnaires, and laboratory results. Other ICT-oriented healthcare companies in the cluster include Netiarst, Helmes, Nortal, Medisoft, and Cognuse.

Tallinn Science Park Technopol
There are 3,500 employees working for more than 200 companies in the Tallinn Science Park. The park's incubator is home to 25 start-ups that each have access to €10,000 worth of expertise in technology transfer, product development, and business. Start-ups can also access a special fund that provides equity finance for making prototypes.

EMT
Telecommunications operator EMT, owned by Sweden's TeliaSonera group, started testing 5G mobile technologies in the second half of 2016. TeliaSonera is working with equipment maker Ericsson to make Stockholm and Tallinn the two most connected urban areas in the world by 2018.

The Côte d'Azur

Facts and figures

R&D spend	Total intramural R&D expenditure per inhabitant	€754 (PACA region, 2013)
Tech expertise	% of working population in high tech sectors	4.1% (PACA region, 2015)
R&D base	% of active population employed in R&D	2% (France 2013)
Local finance	VC investment as a % of GDP	0.034% (France, 2015)
Connectivity	Average LTE download speed	18 Mbps (France, Q4 2015)
Industrial base	Number of companies in the Forbes Global 2000	61 (France)
Innovation	ICT patent applications to the EPO per million of the active population	102 (PACA region, 2012)
EU Funding	H2020 funds	€30 million

Fertilising ideas across sectors

Some ICT clusters are small and focused. Others are big and broad, enabling all kinds of industries. The Côte d'Azur is a high tech hub in the second, broadest sense – and a unique product of decades of deliberate French government policy.

Here, a sizeable ICT cluster particularly strong in semiconductors, telecoms, wireless, 3D image processing and security, rubs shoulders with clusters from other science-led industries, such as aeronautics and space, health and life sciences. Moreover, the region has major cosmetics and travel industries, which also draw on the local ICT expertise: The long-standing technology and science park at Sophia Antipolis houses more than 1,300 companies, as well as public research labs and university facilities. The presence of R&D facilities spanning these diverse industries is designed to seed the cross-fertilisation of ideas and concepts across different sectors.

Part of the Provence-Alpes-Côte d'Azur (PACA) region of France, the area includes the major city and transport hub of Nice, the upmarket resorts of Cannes and Saint-Tropez, and the world-renowned perfumeries of Grasse. Cannes is home to the headquarters of leading satellite systems player Thales Alenia Space; while Galderma claims it runs the world's largest

dermatology R&D centre in Sophia Antipolis. The science park also hosts major players in electronic design automation, Cadence and Synopsys, as well as Optis, a world leader in software solutions for simulating optics. Toyota established its European design headquarters in Nice in 1998.

Leading global ICT players, such as ARM, Gemalto, Huawei, Intel, Nvidia, Samsung Electronics, STMicroelectronics and Maxim Integrated Products, have a presence on the Côte d'Azur. The region is also making a major push into cleantech, creating the 10,000-hectare Eco-Vallée Operation of National Interest, as a hub for expertise in smart city solutions and sustainable development.

History and policy

The epicentre of the region's high tech sector, the science and technology park at Sophia Antipolis, was founded in 1969 to bring researchers, professors and companies together in an open and collaborative working environment. Today, Sophia Antipolis' development is managed by a complex public-private partnership.

Successive French governments over nearly half a century have played a big role in the cluster's development. Today, the

park and the wider region continue to benefit from France's tax policies. The local promotional body for the region, Team Côte d'Azur, says businesses can write off 30% of their R&D expenses with France's research tax credit. Jacques Lesieur, CEO of Team Côte d'Azur, describes the tax credit as "a key asset that attracts a lot of R&D centres, which then expand into other uses."

Such policies clearly achieve results, but they are also controversial. In a 2012 paper, Olivier Hueber, an associate professor at the University of Nice – Sophia Antipolis, argued that the French government's top-down development of Sophia Antipolis had failed to achieve one of its key objectives: strong relations between the firms based in the park, primarily because many of the occupants have their headquarters elsewhere. He contended that Sophia Antipolis' success in attracting foreign investment is largely due to the fact that "expatriate workers who arrive in France with their families can benefit from education and health systems virtually free."

As competition from other tech hubs has intensified, the Cote D'Azur has responded in two ways. Firstly, its policymakers are nurturing start-ups, as well as attracting the R&D labs of big companies. "350 starts-ups were created between 2012 and 2015," says Lesieur. Of course, many other regions in Europe are following the same strategy, and competing for EU money to support innovative SMEs.

The Côte d'Azur
France

Secondly, policymakers are now looking to combine and promote the strengths of the region, rather than individual 'brands', such as Nice, Cannes, Monaco and Sophia Antipolis. Local leaders say the PACA region is becoming more integrated both politically and economically, particularly with the election of Christian Estrosi as president of the regional council of the PACA region in December 2015. Estrosi is a high-profile and outspoken politician who has been a national minister and mayor of Nice. Lesieur says the PACA region is also creating its own representation in Brussels to attract greater EU support. "It is all about playing together," he adds.

Policy Area

Score on a scale of 1-5

Policy Area	Score
Investment in education	3
Public support for research	4
Availability of public seed-funding	2
Favorable taxation	4
Integration into EU R&D framework	2
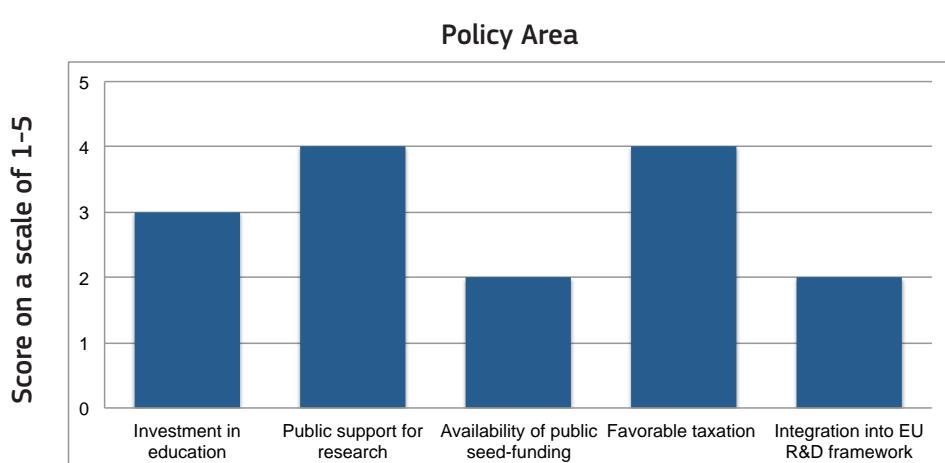
Can robots really see? A local visionary looks to 3D technologies

If they are to take over dangerous and demanding jobs from human beings, robots need to be able to see in three dimensions. While existing commercial robots use 2D sensors to perceive the world around them and plan their actions, Pixmap, a start-up based in the Sophia Antipolis technology park, is developing algorithms that combine data from multiple sources in real-time to enable drones and other machines to map and navigate their local environment in 3D.

ANDREW COMPORT, the chief scientific officer of Pixmap, embodies Sophia Antipolis' ethos of synergies between science and industry. A permanent researcher at CNRS (Centre National de la Recherche Scientifique), Comport grew up in Australia. He came to the Côte d'Azur in 2005 to do a post-doctorate, taking up a permanent position with CNRS in 2007.

With support from SATT, a new CNRS intermediary transfer company,, Comport co-founded Pixmap in 2015. Comport says Pixmap is working with big companies on the Côte d'Azur, such as Amadeus, which is interested in using the technology to map hotel rooms. "We have also sold licenses to Toyota and Airbus and we are talking with Magic Leap and Apple," he adds. "There are a wide range of applications."

At the same time, Pixmap is facing intense competition both from other local start-ups and from large players, such as Microsoft, Apple, Facebook and Google. Comport notes that some experts in this field have moved from the Côte d'Azur to Silicon Valley.

Through CNRS, Comport is also involved in a large EU-funded Horizon 2020 project, which is working with aircraft maker Airbus to develop humanoid robots that can do "hard and dirty" manufacturing work. Comport's team is supplying the visualization and location technology for the four-year project, which aims to enable robots to get into confined spaces and climb stairs, rather than being integrated into a traditional production line.

Snapshots of key players

Amadeus
Amadeus, a leading travel technology company, has its main R&D centre in Sophia Antipolis, developing products and solutions for travel agencies, airlines, hotels, railways, car rental companies, airports, cruise lines and ferry operators. In December 2014, the EU Industrial R&D Investment Scoreboard named Amadeus as the leading European investor in R&D for the travel and tourism sector.

The Secured Communicating Solutions Cluster
Based in Sophia Antipolis, the SCS (Secured Communicating Solutions) Cluster has almost 250 members, of which 75 per cent are SMEs, 25 international companies and 16 research and training establishments. The SCS says it has facilitated more than 450 collaborative R&D projects in health, tourism, security and logistics over the past ten years, 203 of which have received public subsidies in excess of €330 million.

Standards bodies W3C & ETSI
There are two major standards bodies based in Sophia Antipolis: ETSI, the European institute tasked with defining standards in telecoms, and the European office of the World Wide Web Consortium responsible for promoting the standardisation of web languages. ETSI is working with the European Institute of Innovation and Technology, which established a new centre in Sophia Antipolis in 2014.

SophiaTech Campus
Opened in 2012, the SophiaTech Campus accommodates 3,000 students and 800 research professors. The campus' Eurecom research lab focuses on networking and security, mobile and multimedia communications, while INRIA Méditerranée is working on machine-to-machine (M2M) communications and smart devices. The campus also houses two joint CNRS and Nice Sophia Antipolis University labs: LEAT (the electronics, antennae and telecommunications laboratory) and I3S (computing, signals and systems).

The Eco-Vallée Plaine du Var
The 10,000-hectare Eco-Vallée Plaine du Var is a new science and technology park dedicated to addressing environmental issues and sustainable urban development, building on Nice's position as a leading adopter of smart city solutions. Designated an Operation of National Interest by the French government, the project is overseen by a public development agency.

Com4Innov
Com4Innov is a real-scale testbed environment open to industrial companies and researchers working on next generation mobile, wireless and Internet of Things technologies, solutions and services. It provides tools to develop, prototype and test future products and services using 4G. Its partners include the SCS Cluster, Intel, Orange and the EU.

Berlin

Facts and figures

R&D spend	Total intramural R&D expenditure per inhabitant	€1,130 (Berlin, 2013)
Tech expertise	% of working population in high tech sectors	6.6% (Berlin, 2015)
R&D base	% of active population employed in R&D	2.6% (Berlin, 2013)
Local finance	VC investment as a % of GDP	0.025% (Germany, 2015)
Connectivity	Average LTE download speed	14 Mbps (Germany, Q4 2015)
Industrial base	Number of companies in the Forbes Global 2000	50 (Germany)
Innovation	ICT patent applications to the EPO per million of the active population	113 (2012)
EU Funding	H2020 funds	€182 million

Sources: Eurostat, OpenSignal, Forbes

Start-up city

A magnet for European entrepreneurs, Berlin has overtaken London to become Europe's leading recipient of venture capital: about 44,000 businesses are launched in the city each year, according to the Berlin Business Location Centre, with about a third of start-up staff coming from outside Germany.

In 2015, 183 Berlin-based companies received more than €2.1 billion in venture capital (VC) backing between them, up from €891 million in 2014, according to the EY Start-up Barometer Germany, representing about 70 per cent of VC investment in Germany. Four of the five biggest recipients of risk capital in Germany in 2015 are based in Berlin: Delivery Hero (total funding to date €586 million), Zencap, now merged with Funding Circle (€255 million), Foodpanda (€193 million) and HelloFresh (€185 million).

At the geographic heart of the continent, Berlin is well located to access European markets and talent. Also hosting large tech companies, such as Cisco, Deutsche Telekom, Microsoft, Siemens, IBM, Motorola, Oracle, SAP and eBay, Berlin has clusters of expertise in big data, the Internet of Things (IoT), mobile solutions, Industry 4.0, smart living, security, and open IT. This gives start-ups access to talent, partners and early adopters. There's a thriving local music, film, TV and games development scene, as well.

Berlin also has its own distinctive culture and freedoms, says Axel Manneking, head of internationalisation at incubator hub:raum, which is backed by Bonn-based Deutsche Telekom. "If you have some distance from the HQ, in a city that is still in development, where on any day some restaurants and clubs close and others open, in such an environment, the mindset of building things, starting things and stopping things is also different," he explains.

History and policy

Berlin's appeal to start-ups has more to do with its rich cultural and social life, its geographic position, low living costs and status as Germany's capital, rather than public policy. The city, once described by its mayor as "poor, but sexy", offers lower living costs than rival tech clusters, such as London. It's young: more than 40 per cent of its 3.6 million population is under 35. And migration boosted its population, by 48,000 in 2014.

Reinstated as Germany's capital in 1990 following reunification, Berlin is also a major centre of higher education. The city hosts four public universities; seven universities of applied science;

more than 30 private universities; and 22 technology parks and business incubators. In 2015, the city produced 18,500 graduates in the STEM (science, technology, engineering and maths) subjects and in 2014, 70 companies were spun out of the universities in the Berlin-Brandenberg area. It is also home to more than 70 non-university research institutions, including members of the Fraunhofer, Max Planck Society, Leibniz Association, and Helmholtz Association networks.

These factors have created a virtuous circle with the establishment of numerous incubators and accelerators, some backed by global companies, such as Axel Springer, Bayer, Lufthansa and Microsoft, that help start-ups to gain traction in their markets. Deutsche Telekom has chosen Berlin to host 5G:haus, an R&D lab for next-generation mobile technology; its incubator hub:raum; and a 5G test-bed. There are intermediaries to help start-ups, multiple sources of angel and venture funding and a rich variety of networks and partnering events.

But the city administration does play a significant role. The Berlin Partner for Business and Technology, a partnership between the state senate and 270 companies, promotes Berlin and works with Investitionsbank Berlin on shaping financial support packages. In 2015, companies supported by Berlin Partner attracted €723 million in investment. Berlin Partner also hosts the Berlin Startup Unit, dedicated to finding gaps in the city's offer to start-ups and ways to plug them.
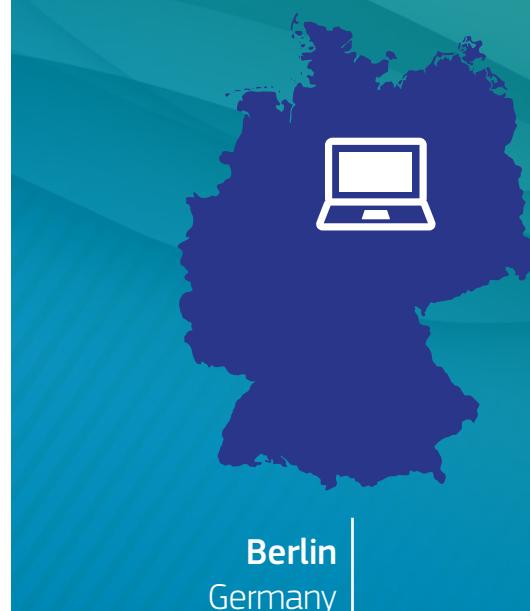
Berlin
Germany

Moreover, Berlin isn't resting on its laurels. The city has a ten-point plan to develop greater expertise in digital transformation, which includes hiring 30 more ICT professors; establishing a Digital Future centre with help from the Einstein Foundation; building a multisite 5G testbed; launching a CityLAB focusing on smart-city challenges; and creating an Internet Institute to consider societal impacts. Days after the UK voted to leave the EU, Germany's Free Democratic Party hired a van to circle London emblazoned with posters reading: "Dear start-ups, Keep calm and move to Berlin."

Policy Area

Policy Area	Score on a scale of 1-5
Investment in education	4
Public support for research	4
Availability of public seed-funding	3
Favorable taxation	3
Integration into EU R&D framework	2
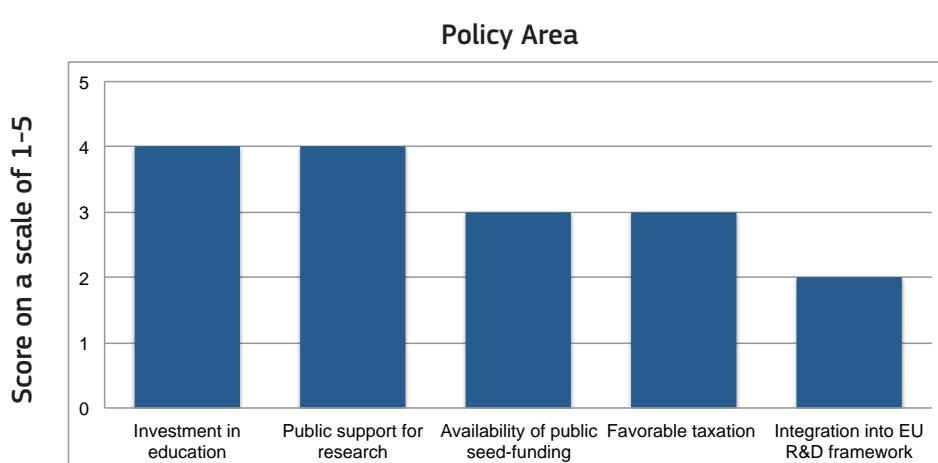
A vision of safe, secure, robust and trustworthy public services

In Germany, personal privacy is considered paramount. And the country's digital ecosystem is very sensitive to this issue. "We are in a revolutionary phase with ubiquitous digitalisation, and we should be very careful about what we do and what we leave out," says INA SCHIEFERDECKER, director of Berlin's Fraunhofer Institute for Open Communication Systems (FOKUS). FOKUS employs more than 430 people working on applications including mobility, digital public services, safety and security, and future media, as well as new technologies, such as software-based networks, quality engineering and visual computing.

Key projects included the development of KATWARN, a localised emergency warning app, that is already in use in many German municipalities, and an open data portal to help improve public decision making. That project has grown into a Europe-wide initiative. FOKUS also runs what Schieferdecker says is Germany's most important e-government center, with more than 80 partners, to improve governance processes. For example, FOKUS is exploring what facilities an electronic ID card should offer.

In her career to date, Schieferdecker has concentrated on the design, modeling and testing of communication systems for IT, automotive, telecoms and medical applications. She is also now considering societal issues, such as applying ICT to make cities smarter, and the contribution of networking technologies to the digital transformation of society, industry and living. Her work is both academic and practical: Schieferdecker has already been involved with three spin-offs from her research.

She is also supporting the implementation of Berlin's strategy and 10-point agenda to drive the digital transformation of its transport systems, healthcare, sustainable energy, resource use, industry and other sectors. "Contributing to these transformation processes is very important, and we're going to ensure that the technologies we develop are safe, secure, robust and trustworthy," says Schieferdecker, whose background also covers software quality.

Snapshots of key players

Berlin Startup Academy

Berlin Startup Academy is an independent start-up accelerator, linked to the German Tech Entrepreneurship Center, which runs intensive three-month programmes involving a group of Berlin's most experienced CEOs and investors, to help turn an idea into a start-up or to add entrepreneurial drive to an existing business.

Point Nine Capital

Point Nine Capital is an early-stage VC firm that backs start-ups with up to €1 million in seed funding. Although it is based in Berlin, it invests two thirds of its funds outside Germany, in software-as-a-service and online marketplace companies, such as Zendesk and Delivery Hero.

Rocket Internet

Rocket Internet wants to be the largest Internet platform outside the US and China. It is building companies that apply proven online business models to new markets, across five sectors: food and groceries, fashion, general merchandise, home and living, and travel. Its network of companies operates in more than 110 countries, and had more than 36,000 employees at the end of 2015.

SoundCloud

SoundCloud is an online platform for sharing music and audio privately or publicly through social media. It enables users to connect directly with artists, who can use the platform to share and make money from their content, as well as to receive detailed stats and feedback. Other app and platform developers can incorporate SoundCloud facilities into their offerings.

ResearchGate

ResearchGate is a social network, collaboration, feedback and research tool for scientists. It was founded in Berlin in 2008 by two virologists, and now has more than 250 employees, and over 10 million users from 193 different countries. Funders to date include Benchmark Capital, Founders Fund, and Bill Gates.

Zalando

An online fashion retailer that started in a shared apartment in Berlin in 2008, Zalando employed 10,000 people, had revenues of €3 billion and earnings before interest and tax of €107.5 million at the end of 2015. It has developed its own technology platform supported by a team of more than 1,000 people, some of which are based in Dortmund, Dublin and Helsinki. It now has 290,000m^2 of logistics space across three distribution centers in Germany.

hub:raum

Launched in May 2012 by Deutsche Telekom, the Berlin office of hub:raum has invested in 11 start-ups in the city to date and provides acceleration and incubation services, as well as seed funding. Areas of focus include the Internet of Things, cyber-security and big data, while successful applicants gain access to Telekom business units and customers.

Munich

Facts and figures

R&D spend	Total intramural R&D expenditure per inhabitant	€1,257 (Bavaria, 2013)
Tech expertise	% of working population in high tech sectors	7% (Oberbayern, 2015)
R&D base	% of active population employed in R&D	3.6% (Oberbayern 2013)
Local finance	VC investment as a % of GDP	0.025% (Germany, 2015)
Connectivity	Average LTE download speed	14 Mbps (Germany, Q4 2015)
Industrial base	Number of companies in the Forbes Global 2000	50 (Germany)
Innovation	ICT patent applications to the EPO per million of the active population	264 (Oberbayern 2012)
EU Funding	H2020 funds	€548 million

Home of Industry 4.0

Munich is at the forefront of the Industry 4.0 movement, which seeks to bring about a fourth industrial revolution driven by extensive data capture and analytics. The idea is that manufacturing and industrial plants will harness 'cyber-physical systems'. They'll be more intelligent and autonomous than today, with a greater sense of their operating environment, and will be driven by floods of data from machinery, production lines, and corporate IT systems. The vision is of more efficient, flexible and almost self-governing factories and supply chains, driven by data flows.

Industry 4.0 is taking root in Munich's sophisticated manufacturing base, which incorporates a rich mixture of global and mid-sized companies, often family-owned (known as the *Mittelstand*), supported by research institutes and universities in the surrounding state of Bavaria. Among Munich's key industries are automotive, aerospace and financial services. According to the regional development agency, the automotive sector employs almost 200,000 people in Bavaria and includes 1,100 companies, such as Bosch Rexroth, Continental, and Webasto, as well as local offices for key international suppliers.

BMW (which also owns the MINI and Rolls-Royce brands) is headquartered in Munich, while Audi is based in nearby Ingolstadt. Other Munich natives include MTU Aero Engines, engineering giant Siemens, test and measurement company Rohde & Schwarz, lighting giant Osram and semiconductor maker Infineon Technologies. In Munich, Huawei has built a 5G wireless technologies test environment, supported by the Free State of Bavaria, the city of Munich, the Technical University of Munich and M-net.

"For an environment with large companies, a technology-savvy *Mittelstand*, research institutions and universities, the region around Munich is hard to beat," says Carlos Härtel, CTO and chief innovation officer, GE Europe, and director, GE European Technology Center, Munich. "Bavaria is very concentrated so it is easy to set up a meeting and to find world-class expertise just half an hour's drive away. Plus you have the weight of the large companies in the region."

History and policy

Over the past five decades, Germany has built a world-class, high-end manufacturing sector. Now, the German government is making a sustained push to digitise the country's economy and workplace. In March 2012, the German government announced its High-Tech Strategy 2020 Action Plan, designed to create lead markets, increase industrial/academic collaboration, and improve

conditions for innovation. One of its ten keystone projects focuses on Industry 4.0.

The Federal Ministry for Economic Affairs and Energy has followed up with its Plattform Industrie 4.0, a strategy for the manufacturing sector backed by three trade associations representing more than 6,000 companies. The Ministry has established five working groups focused on the legal framework, security, reference architectures and standards, among other things. The goal is to ensure Germany is both the leading supplier and the leading exponent of Industry 4.0 technology.

Munich, in particular, benefits from Bavaria's dual education system, which supports both academic and practical excellence, as well as being home to multiple universities and research institutes, including branches of the Max Planck Society, and the Fraunhofer Society. The city also hosts key global trade fairs such as Automatica, (automation and mechatronics), and Productronica (production equipment for electronics).

Munich's status as a high end manufacturing center, with a rich supporting ecosystem, means it already has both the market pull and technology push for Industry 4.0. Local academia and development bodies have long histories of supporting industrial innovation, and so there is also a tradition of organising local, regional and national networks, clusters and collaborations to enable it.

For example, Munich hosts one of the largest research sites of the DLR German Aerospace Center, and Munich Aerospace

Munich
Germany

promotes related interdisciplinary research and graduate education. There's a Bavarian Mechatronics and Automation cluster. And the MAI Carbon cluster links work in Munich, Augsburg and Ingolstadt on carbon fiber reinforced plastics, backed by corporate sponsors, such as Audi and BMW.

These clusters are bolstered by strong academic engagement. For example, the Mechatronics cluster is linked to the Institute for Machine Tools and Industrial Management at the Technical University of Munich, which also runs courses on Industry 4.0. At least two Fraunhofer Institutes in the city (Embedded Systems and Communications Technologies ESK, and Applied and Integrated Security AISEC) are also working on Industry 4.0 projects.

Policy Area

Score on a scale of 1-5

Investment in education	Public support for research	Availability of public seed-funding	Favorable taxation	Integration into EU R&D framework
4	4	2	3	4
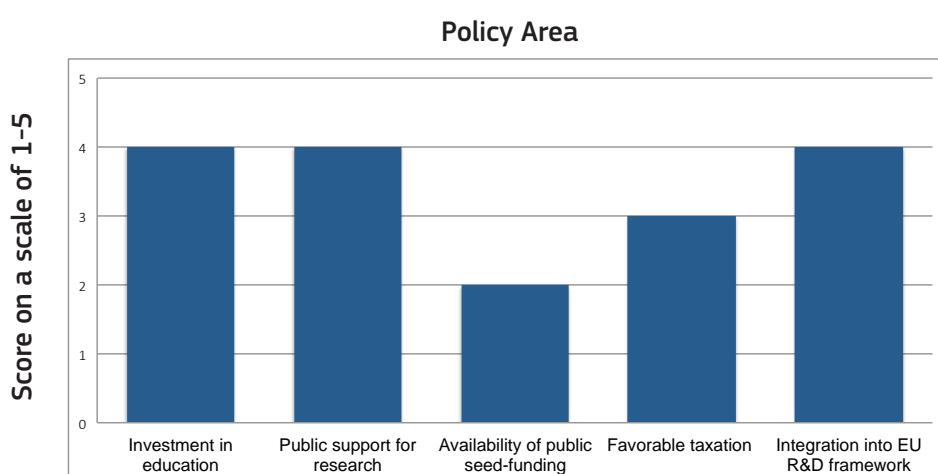
Imagining Industry 4.0: digital twins, interacting flocks and new business models

In future, large capital goods will have a digital twin – a virtual profile holding their operating history and component data. Using these twins, it will be possible to predict the lifetimes of individual machines, rather than relying on statistical forecasts. This is the vision of one of the leading players in the Industry 4.0 movement: CARLOS HÄRTEL, CTO and chief innovation officer, GE Europe and director of GE's European Technology Center in Munich. Härtel says these twins will be created by integrating multiple data sources onto a uniform, probably cloud-based, platform.

The second Industry 4.0 shift Härtel expects is to more systemic optimisation. For example, think of managing all the turbines in a wind farm as a mutually interacting flock (like geese in flight) so that they yield the highest overall output, rather than tuning each one as if it stood alone.

The third shift will be to new business models, using the mass of data flowing from equipment to reveal new opportunities. For example, running generators at a steady load makes them last longer – but doing so means passing up the chance to generate more power when spot energy prices are higher. Industry 4.0 analytics could enable operators to trade off a generator's lifespan for its ability to service profitable peak demand – so making more from their investment in less time. "How do you do the optimisation?" says Härtel. "You get the data and analyse it for operational excellence."

Härtel has a background in both academic research, at the German Aerospace Center and ETH Zurich, and industrial development at GE and Alstom. A mechanical engineer by training, he has published more than 50 papers and holds several patents.

"Most of Industry 4.0 is the same sort of systems that were expensive and complex to use in the past, which are now user friendly and can be deployed in more places," said Härtel. "They mean we can do analysis in near real-time because we can handle so much more data."

Snapshots of key players

BMW
Munich-headquartered BMW Group is one of the world's leading automotive companies with annual revenues of €92.2 billion. The BMW manufacturing plant in Munich, which has 7,800 employees from over 50 nations, produces 1,000 cars a day. BMW says the plant's advanced production systems mean customers can choose from a multitude of model variants and equipment options, tailoring their cars almost entirely to their personal specifications.

Celonis
Munich-based Celonis has just raised $27.5 million in first-round investment to fund the development of its 'process mining' tools, which analyse and visualise the process data saved in corporate IT systems to enable process flows to be understood and optimised. Celonis' 200 customers in 25 countries include Siemens, KPMG, Deloitte, Bayer and Vodafone.

GE Global Europe Research Center-Europe
GE Global Research Center-Europe employs 250 people at a facility on the campus of Technical University of Munich. Part of GE's 3,000-strong global R&D effort, the facility is researching fields as diverse as wind turbines, solar photovoltaics, robotics, diagnostic imaging, automated manufacturing of large components, and aero engines.

MAN Truck and Bus
Part of the MAN Group, MAN Truck and Bus AG is a leading supplier of commercial vehicles and transport solutions, with 36,500 employees and annual sales of €12 billion. Its corporate headquarters and a key manufacturing plant producing heavy trucks, cabs and driven axles, are in Munich.

Huawei Openlab Munich
In March 2016, Huawei launched an "Openlab" in Munich to work jointly on ICT innovation with partners, such as Intel and SAP. The Munich Openlab is focused in particular on the Internet of Things (IoT), cloud computing and big data to support safer and smarter cities. The Munich facility is one of ten inter-connected Openlabs set up by Huawei around the world.

Technical University of Munich
TUM is Germany's joint top university, according to the 2016 Academic Ranking of World Universities (ARWU) by the ShanghaiRanking Consultancy. Home to 39,000 students, it has multiple research groups, clusters and collaborations, in topics as diverse as protein science, photonics, nanosystems, catalysis, medical research, cancer treatment and more. TUM also has long-standing partnerships with Siemens, GE, BMW, Audi and other companies. Munich is also home to another of Germany's top universities, the Ludwig-Maximilians-Universität.

Siemens
Based in Munich, Siemens is one of the world's leading engineering companies, supplying components and systems for traditional and renewable power-generation and transmission, process automation, buildings, mobility and medical diagnosis. Its new headquarters in the heart of Munich, opened in June 2016, houses 1,200 staff from 40 countries and is a showcase for Siemens' renewable technologies.

Dublin

Facts and figures

R&D spend	Total intramural R&D expenditure per inhabitant	€600 (Ireland, 2013)
Tech expertise	% of working population in high tech sectors	6% (Ireland, 2015)
R&D base	% of active population employed in R&D	2.8% (Ireland 2013)
Local finance	VC investment as a % of GDP	0.041% (Ireland, 2015)
Connectivity	Average LTE download speed	14 Mbps (Ireland, Q4 2015)
Industrial base	Number of companies in the Forbes Global 2000	19 (Ireland)
Innovation	ICT patent applications to the EPO per million of the active population	44 (Ireland, 2012)
EU Funding	H2020 funds	€134 million

Silicon Valley satellite

Nine out of ten of the world's top information and communications tech companies and the full top-ten global 'born on the Internet' players have bases in Ireland, according to inward investment promotion agency IDA Ireland. That's significant in a country with a total population of just 4.6 million.

The presence of so much digital expertise has helped Dublin spawn hundreds of home-grown tech heroes. Two of the city's rising stars are DecaWave, which has developed technology that can locate indoor tagged objects to within 10 centimetres at distances of up to 300 metres, and Adaptive Mobile, which supplies security solutions that protect 1.4 billion mobile subscribers worldwide. Ireland is also becoming a leading test bed for Internet of Things (IoT) technologies, as Intel, Dell, EMC, Vodafone and others pilot new solutions across the country.

Three of Ireland's seven universities and four of its 14 institutes of technology are in Dublin. So there is a ready supply of graduates, research partners, incubation space and acceleration programmes. For example, Ireland produced 16,446 science, technology, engineering and maths (STEM) graduates in 2015, according to the Higher Education Authority.

Low corporation tax also plays a part in attracting multinationals to Dublin, and the recent European Commission ruling that Apple has benefited from an unfair tax break, could have a profound impact on all of this. The outcome of what's likely to be a prolonged legal battle is unpredictable – but Irish planners are working to make their development progress lawyer-proof.

What makes Dublin truly unique? Tech players point to remarkable levels of collaboration and communication. "Ireland's research system is probably the most collaborative in the world," claims Ken Finnegan, vice president for technology with IDA Ireland. "Dublin is a compact city and one of the friendliest in the world," adds Barry Napier, CEO of Cubic Telecom, citing access to people and places as reasons for maintaining Dublin as his company's headquarters.

History and policy

Dublin first saw a major influx of global tech players in the 1980s. They clustered around Sandyford in South Dublin and Leixlip, 12km from the city centre. Then in 2003, Google opened its EMEA headquarters in the Grand Canal district, creating Dublin's hottest new tech quarter. Dubbed Silicon Docks, Facebook, AirBnB and TripAdvisor, Amazon, Twitter, Etsy, HubSpot, Groupon, LinkedIn, Eventbrite and Stripe now have a presence there.

IDA Ireland, which promotes the country to foreign investors, attributes Dublin's success to its track record, its tax regime and its talent, together with Ireland's position as the only English-speaking country in the Eurozone and, with an imminent Brexit, ultimately the EU. Big names, such as Intel, HP and Microsoft, have been in Dublin and reinvesting since the 1980s. Ireland's tax package includes a 12.5% corporate rate, a 25% R&D credit and a new 6.25% preferential rate on income from intellectual property. The Irish government is appealing the recent EU ruling requiring Apple to pay the Irish government €13 billion in back taxes. Depending on the outcome, that dispute could affect the way tech companies perceive Ireland's tax regime. Dublin also has a young, well-educated population and is currently experiencing a major surge in inbound tech talent, according to a 2015 survey by LinkedIn.

Home-grown tech players are supported by Enterprise Ireland, the state agency tasked with helping indigenous companies to "start, innovate and scale". Through a well-regarded High-Potential Start-Up programme, each year Enterprise Ireland

Dublin
Ireland

identifies, funds and nurtures about 100 new start-ups with the best prospects of creating jobs and selling internationally.

Enterprise Ireland also invests in earlier stage start-ups and in seed and venture capital (VC) funds, making it one of Europe's largest VC investors. Moreover, the agency has a network of 32 overseas teams, which work with Irish-owned businesses to identify international opportunities, partners and buyers.

Science Foundation Ireland's research centres bring together research teams from across the country's universities and institutes of technology. Likewise, Ireland's Technology Centres bring multinationals and SMEs together in multi-institute research clusters.

Policy Area

Bar chart titled "Policy Area". Y-axis: "Score on a scale of 1-5", ranging 0 to 6. Categories: Investment in education (4), Public support for research (4), Availability of public seed-funding (4), Favorable taxation (5), Integration into EU R&D framework (5).
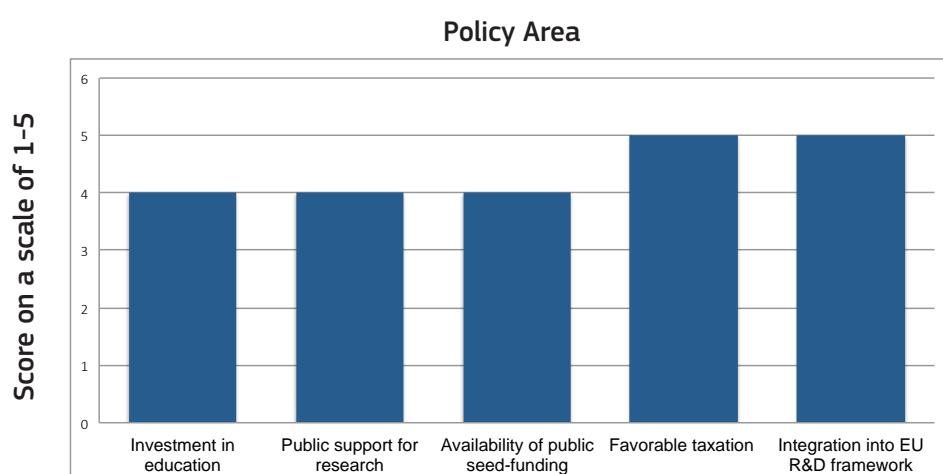
Building a smart and agile Dublin

"No one city has cracked it yet," says JAMIE CUDDEN. "But many things are now coming together. I think we are on the verge of seeing the smart city become a reality."

As smart city programme manager at Dublin City Council, Cudden is leading Dublin's push to harness new digital technologies to improve city living. "The evolution of new technology and new business models offers huge opportunities," he says. "Consumers have powerful smartphones, allowing them to access all kinds of new business services. But the public sector is lagging behind. Cities need to be more agile in how they do technology. We need to start viewing our infrastructure – our fibre and street columns – as assets."

New wireless network technologies that bring connectivity to large numbers of battery-powered devices should help in this respect, making it viable to install sensors in everything from street lamps to garbage bins. Cudden sees the recent rollout of a Sigfox network across Ireland as a "game changer" in his vision to make Dublin a truly smart city.

Named one of 25 key people influencing the Internet of Things (IoT) in Ireland by Silicon Republic, Cudden has extensive experience working across industry, local and central government in Ireland and, before that, in London.

The Smart Dublin initiative brings together the four local authorities that control the greater Dublin area and industry partners – Intel, IBM and local company Kingspan Sensors – with national research centres specialising in connected networks, IoT and data analytics.

Cudden says practical implementation is the next step. "The problems of the city – noise, traffic congestion, carbon footprint – are universal, and Smart Dublin has set these out as the basis for collaboration," he explains. "We are working with Lero, the Irish Software Research Centre, to develop business models that enable the technology to make financial sense."

In addition, Smart Dublin has launched a €100,000 Small Business Innovation Research Challenge to promote cycling in the city. The aim, Cudden says, is to provide a model that will make it easier for small, disruptive tech start-ups to supply local authorities.

Snapshots of key players

Intel
Intel's Leixlip campus is one of Europe's leading semiconductor manufacturing locations, employing over 4,500 people. Once complete, the latest campus upgrade will bring Intel's cumulative capital investment in Ireland since 1989 to US$12.5 billion. Intel's Quark and Curie IoT chip were designed by the IoT Solutions Group in Leixlip.

Google
Google established its EMEA headquarters along Dublin's Grand Canal Docks back in 2003. Google Ireland now employs more than 6,000 people from 60 different countries. The sales teams support over 100 markets, while the engineering team is responsible for Google's fleet of data centres across Europe.

Trinity College Dublin
Founded in 1592, Trinity College Dublin is located right in the heart of the city, while its incubation space, Trinity Technology & Enterprise Centre, stretches along Barrow Street into Silicon Docks. Trinity is home to three Science Foundation Ireland ICT-focused research centres, encompassing digital content, advanced materials and future networks.

Movidius
Dublin-founded Movidius, which is now being acquired by Intel, has developed a pioneering low-power vision processing unit, the Myriad 2, designed for use in drones, smart cameras and IoT sensors. Google is using Myriad chips in Project Tango, which is designed to give phones and tablets a sense of space and 3D orientation, and is rumoured to be using Myriad in its upcoming virtual reality headsets.

Cubic Telecom
HP laptops and Audi cars use Cubic Telecom to provide always on, seamless connectivity across international borders. Cubic's SIM technology allows customers' hardware to access a single connection through Cubic's core network. This, in turn, is hardwired into the networks of mobile operators, with whom Cubic has forged leasing arrangements.

Davra Networks
The recent Rio Olympics used Davra Networks' RuBAN platform to provide Internet connectivity and real-time travel info on buses ferrying athletes to and from venues. It is also being used by Cisco to roll out Wi-Fi on yellow school buses in the US. The technology gathers data from vehicle fleets to help improve passenger safety, reduce fuel costs and optimise routes and maintenance.

Enterprise Ireland
A government-backed development body with an annual budget of €335 million, Enterprise Ireland says it has provided financial support to 217 start-ups. It has also invested €25 million in training business leaders, and spent a further €72 million on helping to commercialise research and development conducted in Ireland.

Barcelona

Facts and figures

R&D spend	Total intramural R&D expenditure per inhabitant	€396 (Catalonia, 2013)
Tech expertise	% of working population in high tech sectors	4.9% (Catalonia, 2015)
R&D base	% of active population employed in R&D	1.7% (Catalonia, 2013)
Local finance	VC investment as a % of GDP	0.01% (Spain, 2015)
Connectivity	Average LTE download speed	21 Mbps (Spain, Q4 2015)
Industrial base	Number of companies in the Forbes Global 2000	26 (Spain)
Innovation	ICT patent applications to the EPO per million of the active population	22 (Catalonia, 2012)
EU Funding	H2020 funds	€225 million

Pioneering smart city services

Named as the European Innovation Capital in 2014 and ranked as the smartest city in the world in 2015 by Juniper Research, Barcelona has a global reputation as an early adopter of digital and wireless technologies. Over the past two decades, the Catalan capital has positioned itself as a place where business and academia can test new concepts and technologies in a real urban environment and at scale.

For example, the publicly-funded €180 million 22@Barcelona project saw 100 hectares of industrial land on Barcelona's seafront transformed into a business district between 2000 and 2010. With the help of Cisco and other technology partners, the district has employed a myriad of smart city solutions, including temperature, humidity, dust, noise and gas sensors; a parking management system; connected waste containers; smart lighting, a connected watering system; and bus stops equipped with digital kiosks. Furthermore, Cisco and the Barcelona Super Computing Centre have just signed a collaboration agreement to research the Internet of Things, smart cities and data centers.

More broadly, Catalonia attracted 71 per cent of all foreign venture capital investment in Spain in 2015, according to the Spanish Venture Capital & Private Equity Association. And Barcelona is ranked as the fourth best European city for scientific production, according to Catalonia Trade and Investment.

Although it is a relatively small region (home to seven million people), Catalonia hosts 12 universities and 17 international schools, with more than 44,000 science, technology, engineering and maths (STEM) students, giving the region access to a strong talent pool and university research environment. The Barcelona Institute of Science and Technology (BIST), which brings together the six top research centers in the city, is coordinating a joint programme with ESADE Business School to evaluate opportunities for new business ventures.

History and policy

Barcelona's administration and the Catalan government have both made a sustained effort to establish the city as a benchmark technology hub for smart cities. The key element has been steady and constant support from public bodies over the past two decades. This long-term thinking is highlighted by the 10-year project to redevelop the rundown industrial Poble Nou area as a smart neighborhood. Since 2000, more than 3,500 businesses have moved into the district and there are almost 100,000 employees working there, according to real estate company shbarcelona.

Building on that project, Barcelona Activa, the public agency to promote local development, has recently established "Smart City Campus-22@" to bring together entrepreneurs, companies, universities and research centers to work on ICT, ecology, urban-planning and other strategic fields.

The Barcelona administration and Catalan government have played a very active role in attracting major ICT events, notably the Mobile World Congress, the biggest mobile industry event in the world, which the city will host until 2023, and the Smart City Expo, with over 15,000 visitors and around 560 cities showcasing solutions. The city administration provides attendees at the Mobile World Congress with free usage of public transport, for example.

Barcelona has also been successful in winning EU funding for its smart city projects: The city is part of the Smart Specialisation platform, a EU-funded effort to set priorities to develop and match each region's strengths with business needs. Its strong scientific institutions and advanced technological infrastructure helped Catalonia win 67 per cent of the financial aid given to Spain by the European Research Council in 2015, according to the Trade & Investment Office of the Catalonia Government.

Barcelona
Spain

Policy Area

Score on a scale of 1-5

Investment in education	2
Public support for research	4
Availability of public seed-funding	2
Favorable taxation	2
Integration into EU R&D framework	4
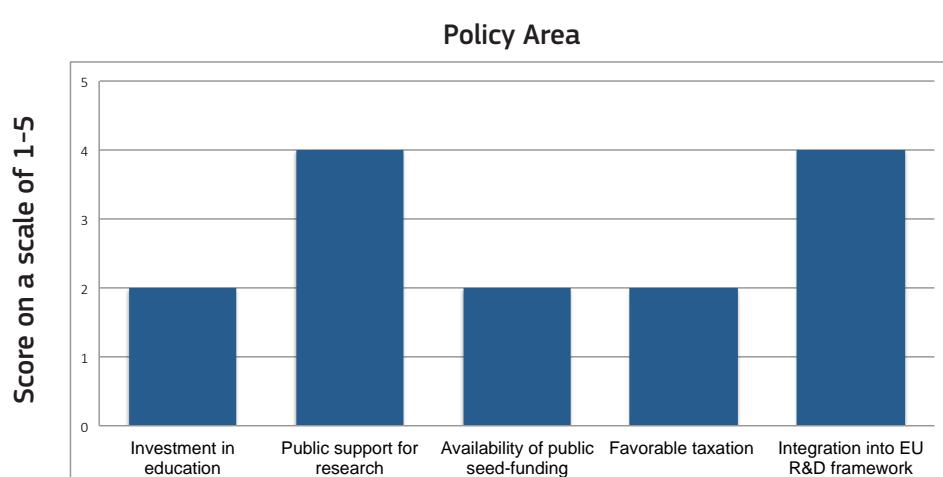
Paving the way to an urban operating system

Barcelona and other cities will ultimately be run using a single computer-style operating system that is able to capture and exchange data between different services and sectors. Centralised data analytics, underpinned by advances in artificial intelligence, will make city-wide coordination much easier, saving resources and increasing service effectiveness.

That's the view of **IGNASI VILAJOSANA**, the CEO of WorldSensing, a Catalan company developing sensors and software platforms for the Internet of Things (IoT) and smart city sectors in Europe. An alumnus of Harvard Business School and a former associate professor at the Polytechnic University of Catalonia, Vilajosana was anointed "Best Young Entrepreneur" in 2015 by the Catalan Association of Young Entrepreneurs.

Vilajosana says that Barcelona's smart city initiatives point to what is possible. "The city's administration has done a great job by centralising all the technological services in one place (and soon in one operating system) and big companies and SMEs have used this to develop their businesses," he explains. "What we have accomplished so far is incredible. We have seen how the public space has been digitalised and how this has fostered democratisation. With the new 5G networks this will grow exponentially, and connectivity will definitely consolidate as the fourth utility."

With recent advances in IoT technologies, city-wide connectivity will become a given. Vilajosana says it is the human component that needs attention now: "I don't think the big issues will be technological; in short term privacy issues, correct legislation and changing management traditions need our attention.[...] Right now it is the public sector responsibility to understand what is coming, and be prepared to offer their data in the best way possible".

Snapshots of key players

The Mobile World Capital Barcelona
A partnership between the GSMA, the global mobile trade association, and Barcelona's administration, the Mobile World Capital initiative is designed to drive the mobile and digital transformation of the city. It delivers "4 Years From Now", a major event for the startup and VC community, alongside the GSMA's Mobile World Congress, which attracts 100,000 industry executives to the city every February.

ICFO Innovation
Identified as the best research institute in photonic sciences by the Nature Publishing Index Global Ranking, the Institute of Photonic Sciences (ICFO) has more than 60 patent families and participates in industry collaboration initiatives in field sensors, energy efficient buildings, cancer diagnosis and other areas.

Telefónica I+D
In 2006, Spain's incumbent telco, Telefónica, made Barcelona the centre of excellence in the areas of Internet and multimedia for its research operation, Telefónica I+D. It is conducting research projects in smart cities, multimedia analysis, security and privacy and many other fields. It has secured more than 50 patents in the past five years.

Barcelona SmartCity
Established by the municipality, Barcelona SmartCity is a public agency that promotes the adoption of smart city solutions in the Catalan city and facilitates international cooperation with other cities. It also participates in 10 European projects focused on communications, mobility and other areas.

The Barcelona Institute of Science and Technology
The Barcelona Institute of Science and Technology is an alliance of the six top research centres in Barcelona. It aims to tackle scientific questions through a multidisciplinary approach. Together, the institutions combine 61 European Research Council grants and more than 1,000 publications in top scientific journals.

Fractus
Fractus has developed an award-winning geometry-based antenna technology that it sells to wireless device manufacturers in Europe, the US and Asia. With a portfolio of more than 120 patents, Fractus has been recognised by the European Patent Office for its innovative inventions.

Smart City Expo World Congress
Expanding since the inaugural edition in 2011, the Smart City Expo World Congress brought representatives from 568 cities around the world to Barcelona in 2015 to debate the future of urban development. The Congress is now holding regional spin-off events in Casablanca (Morocco), Istanbul (Turkey), Kyoto (Japan) and Puebla (Mexico).

Stockholm

Facts and figures

R&D spend	Total intramural R&D expenditure per inhabitant	€2,466 (Stockholm, 2013)
Tech expertise	% of working population in high tech sectors	7.9% (Stockholm, 2015)
R&D base	% of active population employed in R&D	3.3% (Stockholm, 2013)
Local finance	VC investment as a % of GDP	0.034% (Sweden 2015)
Connectivity	Average LTE download speed	13 Mbps (Sweden, Q4 2015)
Industrial base	Number of companies in the Forbes Global 2000	23 (Sweden)
Innovation	ICT patent applications to the EPO per million of the active population	316 (Stockholm, 2012)
EU Funding	H2020 funds	€152 million

The health hub

A well-established tech cluster, Stockholm is now at the forefront of the move to digitise healthcare. The Swedish capital is increasingly convening healthcare specialists, policymakers and ICT engineers. For example, this year Paul Beatus, the business development manager at the Stockholm Science City, and Ola Cornelius, a health and tech entrepreneur, cofounded the H2 Health Hub. It is a working space for researchers, companies and policymakers who want to collaborate on developing digital healthcare solutions. Stockholm is also home to FrogLeap, the first accelerator in Sweden to focus only on digital health.

The city also has a rich healthcare heritage: Stockholm's 200-year old Karolinska Institutet is ranked ninth worldwide for Life Sciences and Medicine faculties in the QS World University Rankings. There is also a wealth of local digital expertise. Stockholm is home to world-class software companies, such as music streaming service Spotify, online gaming company King Digital, Minecraft-maker Mojangc and web payments service Klarna. After Silicon Valley, Stockholm is the second-most prolific creator of unicorns – start-ups valued at more than $1 billion: It has created 6.3 billion-dollar companies per million people, compared to Silicon Valley's 8.1, according to a recent report from the investment firm Atomico.

A city of 800,000 inhabitants, Stockholm has incubators, accelerators, start-up hubs and networking groups aplenty. Finance, notably venture capital, is also in plentiful supply. Although Sweden makes up two per cent of Europe's population, it receives 15 per cent of the total foreign direct investment into the European tech sector thanks to the strength of its capital city, according to the Wharton School of the University of Pennsylvania.

History and policy

The home of 150-year old telecoms equipment maker Ericsson, Stockholm prides itself on being one of the world's most connected cities. The Swedish government has long pursued a digital agenda. A government tax break on computer purchases helped Sweden to have one of the highest rates of PC ownership in the early 2000s. Moreover, a fast and extensive broadband infrastructure has also played a major role in spawning digital start-ups: a network of fibre optic cables reaches 98 per cent of homes in the city. Moreover, the government issued 3G licences for free, as long as the operator recipients got as many people as possible online and mobile.

With free university education and universal healthcare, entrepreneurs feel they have a safety net if their business

should fail. Childcare costs are subsidised by the government, making Stockholm a good environment for workers with young families. Sweden also welcomes foreign entrepreneurs. Data from the Swedish Agency for Economic and Regional Growth shows that 20 per cent of new businesses in Sweden are started by foreigners. Each year, approximately 2,500 Indian software programmers apply for visas to work in Stockholm.

These measures have paved the way for Stockholm to become a world-class hub for digital healthcare. The city is home to a lot of innovative med-tech companies and excellent private hospitals, which are key to the country's cost-effective healthcare system, as well as entrepreneurs who have already proven themselves in the digital domain. Indeed, it is Stockholm's well-established ICT community, rather than healthcare researchers, that is driving the development of digital healthcare solutions, according to Pär Hedberg, CEO of STING, a Stockholm-based incubator for ICT and cleantech start-ups. He claims that Stockholm has a good reputation in the venture capital market. "Investors don't get screwed. Entrepreneurs won't cross the street for a dollar more," Hedberg says. "Here the valuation levels are much lower than in London and Silicon Valley and investors can get a higher return on investment...[and] Swedish entrepreneurs think global from day one because the domestic market is so small."

Not everything works perfectly: a few things vex Stockholm's entrepreneurial crowd. "The home market in Stockholm for

Stockholm
Sweden

digital health services is still very small and it is difficult for SMEs to sell services to the public health services due to regulation around public procurement, patient data safety and reluctance to embrace new digital services," says Henrik Ahlen, founder of ehealth consultancy company Alfa Bravo.

Moreover, the cost of living is high, in terms of taxes and housing. Swedes face the second-highest tax burden in the world – after Denmark's – with an average of 48.2 per cent of GDP going to taxes. Employees who get stock options also face whopping tax bills, while finding a rental home in central Stockholm can be hard.

Policy Area

Score on a scale of 1-5

Investment in education	Public support for research	Availability of public seed-funding	Favorable taxation	Integration into EU R&D framework
3	4	4	1	3
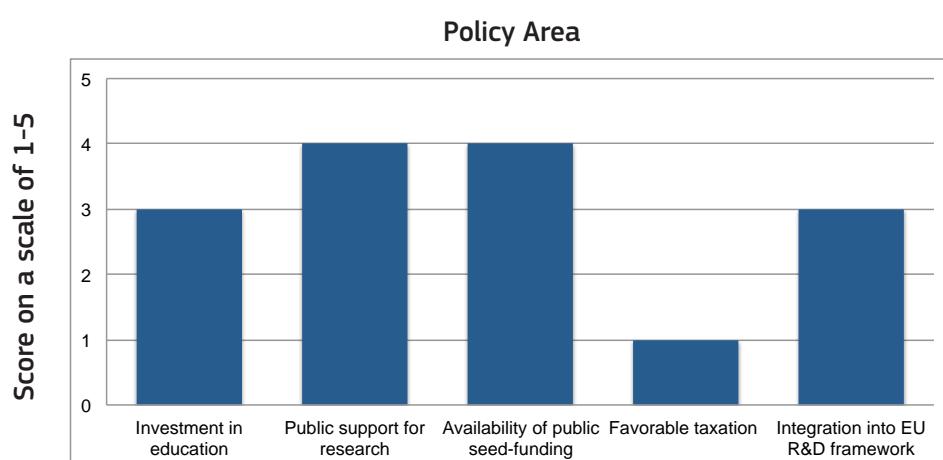
A digital diagnosis for predictive healthcare

Prevention is better than cure. For the world's stretched healthcare systems, this old adage is becoming a guiding principle as they seek to harness big data to reduce the number of people needing treatment by clinicians. Ideally, a digital assistant will be able to analyse an individual's likelihood of developing a particular illness and advise them to take preventative measures. CHRISTIAN GUTTMANN is trying to move healthcare in that direction. The professor in digital health with the Karolinska Institutet is heavily involved in the growing field of predictive analytics. "We're looking at the probability that a patient develops complications in the future," he says.

To do that, Guttmann and his colleagues need high quality data, but he says that companies and universities aren't always in the habit of sharing patient information. "We have these near perfect data registries, but the attitude is a bit conservative – I wouldn't say this is unique to Sweden though," he explains.

Following the entrepreneurial path taken by many of the university's graduates, Guttmann recently co-founded his own e-health company, Healthihabits, which is still in beta mode. "It's a search engine specifically geared towards healthy living," he explains. "Patients will be able to go there and discover more about their illness and find other patients experiencing what they are."

Guttmann, who previously worked with IBM, feels he's on the ground floor of many of the exciting digital health projects happening in Sweden. From his office window, he can look out and see a brand new hospital going up. "It's going to be the most advanced hospital in the world," he says.

Like many entrepreneurs in Stockholm, he's thankful for the opportunity to stand on the shoulders of some of the capital's giants. The people behind the big blockbuster digital successes are getting involved in digital healthcare and are very willing to share their knowledge, Guttmann says. "We have met great people at events hosted by Klarna and Spotify. These people have been through it, they know what we need. The CEO of Spotify is personally investing in new e-health startups," he adds. There's other great networking events. Guttmann mentions two: Stockholm Techfest and Nordic Life Sciences – "everyone is there".

Snapshots of key players

Lifesum
Fourteen million people have installed the Lifesum app, which was created by Martin Wählby and Tove Westlund in 2008. Lifesum is designed to make it simple to maintain a healthy lifestyle. After the user inputs their daily eating and exercise activities, Lifesum offers advice on how to lose or gain weight and become healthier, including healthy recipes and physical activities. Sweden's second-ever app designed for the iPhone, Lifesum has been recognised several times to be among the best apps both on the Apple's App Store (Editor's Choice 2014/15) and Google's Play Store (Editor's Choice 2016).

Stockholm Science City Foundation
The Stockholm Science City Foundation is coordinating 'Hagastaden', an urban development project planned for completion in 2025. Hagastaden will be a new neighbourhood containing a world-class science complex, called 'Stockholm Life', with ambitions to be one of the leading e-health hubs in the world. It will house the most important technology and health universities in the city, the Karolinska University Hospital, leading biotech companies and government agencies.

Karolinska Institutet
One of the oldest and most prestigious medical universities in the world, the Karolinska Institutet was established in 1810 and holds the ninth spot on the QS World University Ranking for Life Sciences and Medicine faculties. This university accounts for 40 per cent of the medical research conducted in Sweden – including the activities of the Karolinska University Hospital – and is where the Nobel Prizes of Physiology or Medicine have been decided since 1901.

KTH Royal Institute of Technology
Founded in 1827, KTH has grown to become one of Europe's leading technical and engineering universities, as well as a key producer of talent and innovation: It provides a third of Sweden's research and engineering graduates. One of the latest inventions to come out of a KTH lab is the 'Bio-patch', which measures bioelectrical signals through the skin, gathering data on different parts of the body. The patient can analyse the readings with their smartphone, or email the data to a doctor for diagnosis.

Huawei R&D lab
Global telecoms equipment maker, Huawei, chose Stockholm as the location for its first R&D lab in Europe. Opened in 2000, the facility has about 350 staff working on cellular systems, including 5G technologies. Each researcher has about a decade's experience in their field.

Swedish Institute of Computer Science (SICS)
SICS is a public research centre that aims for the total digitisation of products, services and business, with a view to improving the competitiveness of Swedish industry and the efficiency of the public sector. Founded in 1985, SICS includes six laboratories, one of them dedicated exclusively to digital health technologies.

Rotterdam

Facts and figures

R&D spend	Total intramural R&D expenditure per inhabitant	€821 (West Nederland, 2013)
Tech expertise	% of working population in high tech sectors	4% (Zuid Holland, 2015)
R&D base	% of active population employed in R&D	2% (Zuid Holland 2013)
Local finance	VC investment as a % of GDP	0.032% (The Netherlands, 2015)
Connectivity	Average LTE download speed	23 Mbps (The Netherlands, Q4 2015)
Industrial base	Number of companies in the Forbes Global 2000	22 (the Netherlands)
Innovation	ICT patent applications to the EPO per million of the active pop.	58 (Zuid Holland 2012)
EU Funding	H2020 funds	€53 million

The port of the future

By far the largest container port in Europe, Rotterdam is in the vanguard of the push to harness the Internet of Things (IoT) and other digital technologies to transform the logistics and shipping industries. Automated fork-lift trucks, crewless ships, smart containers, underwater and airborne drones, self-driving trucks and other connected equipment could dramatically increase the efficiency and flexibility of Rotterdam and other logistics hubs.

The Port of Rotterdam's advanced container terminals, such as TBA, ABB and Navis, are becoming increasingly automated, while the city is attracting specialist advisory, consulting, IT and engineering firms seeking to apply data to improve logistics. Nearby, Delft University of Technology and Erasmus University carry out cutting edge research into container operations, while The Hague, 20 kilometres away, is home to one of Europe's leading ICT security clusters. Earlier this year, the Dutch government organised a trial that saw convoys of semi-autonomous trucks travel across Europe to Rotterdam using Wi-Fi connections to maintain a safe distance between the vehicles.

This juxtaposition of logistics and digital expertise could transform the way in which goods travel by land and sea. "New sensor technology is enabling automated guided vehicles to be tested inside the domain of heavily-robotised terminals," says Bart Kuipers, senior researcher in port economics, urban, port and transport economics at Erasmus University. "Eventually, Rotterdam and other ports will be managing information, as much as containers," he adds. "In the future, the intelligent container will work its own way through the supply chain, deciding which transportation to use, enabling the integration of maritime operations with hinterland operations."

Today, the focus is more on connecting and automating the enabling infrastructure. For example, depth sounders at the Port of Rotterdam have been fitted with devices to connect them to a new network specifically designed for IoT applications that need low power, wide area connectivity. Dutch telco KPN launched this new network at the beginning of November 2015 in Rotterdam and The Hague. Schiphol Airport is now testing how the network technology can improve baggage handling and facility services, while Utrecht Central station is using the connectivity to monitor rail switches.

History and policy

As the Netherlands is a small and crowded country with a long history of international trade, a succession of Dutch governments have made improvements to transport and logistics a central plank of their economic policies. The government, which claims the quality of the Dutch infrastructure ranks among the top three in the world, encourages the use of public roads, waterways and other transport networks to test new technologies, as in the case of the European Truck Platooning Challenge. In its capacity as EU chair, the Dutch government organised the Challenge, bringing together truck manufacturers, logistics companies, road authorities, ministries and research institutes from several European countries, winning praise from ACEA, the European umbrella organisation representing the six truck manufacturers involved. The Dutch government is now planning further trials in partnership with Dutch transporters and shippers, such as Heineken, Unilever and Ahold.

In pursuit of economies of scale and greater efficiency, the Netherlands is also a very active proponent of European harmonisation of rules relating to new digital technologies and services. In Rotterdam, the municipality is also encouraging greater digitisation and innovation, but hasn't yet succeeded in fully integrating the big logistics companies that make use of the port with the innovative companies setting up shop in the city, according to Bart Kuipers of Erasmus University. "RDM Rotterdam is not very well connected to the rest of the city," he wrote in a recent paper. "The connection between hot spots like RDM and

Rotterdam
The Netherlands

other parts of the port and urban economy—and in particular other hotspots like the Merwe-Vierhaven-area (M4H), focused on facilitating start-ups—might become a new priority for the port and city ... replacing traditional concrete port infrastructure, like roads, pipelines and tunnels."

Kuipers also believes Rotterdam's Port Authority needs to become more proactive and aggressive in the development of new IoT infrastructure to help it compete with Hamburg, which is working with Cisco on the development of the "Internet of Everything". In particular, the Port Authority should play the role of a neutral IoT-infrastructure manager, Kuipers suggests.

Policy Area

(Bar chart — "Policy Area". Y-axis: "Score on a scale of 1-5", ranging 0 to 6. Bars: Investment in education = 4; Public support for research = 5; Availability of public seed-funding = 2; Favorable taxation = 4; Integration into EU R&D framework = 2.)
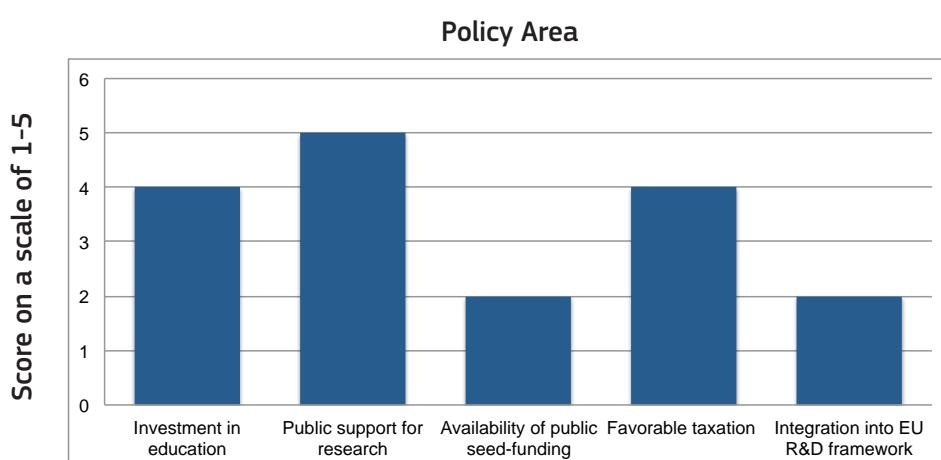
Steering the future of self-driving trucks

If the Dutch infrastructure minister gets her way, the long distance truck driver will eventually become an anachronism. "Self-driving vehicles have great international potential. We're at the start of a new era," says the minister, MELANIE HENRIËTTE SCHULTZ VAN HAEGEN-MAAS GEESTERANUS.

Envisioning that truck platoons will eventually stream out of the Port of Rotterdam to deliver goods across Europe, Schultz van Haegen has become a vocal proponent of harnessing new technologies to improve logistics. "Automated and connected driving is cleaner and more efficient and uses less fuel," she says. "It keeps vehicles moving and leads to fewer traffic jams…I also support the disruptive innovation of other technologies, such as drones."

Schultz van Haegen believes digital technologies could dramatically reduce the number of accidents caused by human error. "A self-driving car makes a big difference," she adds. "It doesn't get tired, or distracted by the children on the back seat, or look at its smartphone."

A strong proponent of "learning by doing", Schultz van Haegen served as a director responsible for contracts with care providers with Achmea Zorg healthcare insurers between April 2007 and October 2010, giving her insights into both the private sector and the healthcare industry.

She is now pushing her counterparts in other European countries to develop a consistent pan-European policy framework for connected and autonomous vehicles. "My goal is to make agreements to facilitate the introduction of smart cars, to coordinate efforts and to come to a joint strategy to strengthen the European industry's global market position," she says.

Moreover, Schultz van Haegen has set a target to have all infrastructure managed by the state agency the Rijkswaterstaat – roads, waterways, flood defence systems, locks, sluices and bridges – to operate in a fully energy-neutral manner by 2030. The Rijkswaterstaat is even examining the potential to construct energy-generating roads in the Netherlands, allowing induction charging of electric vehicles as they move along the road.

Snapshots of key players

RDM Rotterdam
The former shipyard of the Rotterdamsche Droogdok Maatschappij (RDM) is now home to a cluster of private sector, education and research initiatives, backed by the Port of Rotterdam and the EU, among others. RDM houses 40 companies, such as Ampelmann, Franklin Offshore, Energy Floors and Urban Green, working on a range of innovations designed to create a smarter port and enable small-scale 'new manufacturing', such as 3D-printing and prototyping.

The Internet of Things Academy
In July 2015, Dutch telco KPN and RDM Maker Space opened the Internet of Things Academy in Rotterdam. The Academy offers companies, developers and students the use of a lab to prototype facilities and hack an IoT solution together.

The Port of Rotterdam
The Port of Rotterdam hosts several very advanced logistics operations, such as APM terminals, which uses wind-generated electrical power for cranes and other operations, and Rotterdam World Gateway. Experts say both these operators employ state-of-the-art facilities that also act as laboratories to test new logistics technologies.

The Hague Security Delta
The Hague Security Delta claims to be the largest security cluster in Europe with 400 security businesses employing more than 13,400 people. Twente Safety & Security touts its expertise in nano technology, safety, radar and sensor technology and the Dutch Institute for Technology Safety & Security, located in Brabant, focuses on camera and sensor technology.

Utility Connect
A joint venture between utilities Alliander and Stedin, Utility Connect has rolled out a specialist wireless data network for smart metre and smart grid applications across much of the Netherlands. Designed specifically for business-critical processes, Utility Connect serves energy grid operators Liander, Stedin and Westland Infra.

European Truck Platooning Challenge
In March 2016, the European Truck Platooning Challenge saw six columns of trucks drive from Sweden, Germany and Belgium to Rotterdam. In each column, two or three trucks connected by Wi-Fi travelled in convoy, with the first truck determining the speed and route. Organised by the Dutch state infrastructure agency Rijkswaterstaat, the challenge featured DAF Trucks, Daimler Trucks, Iveco, MAN Truck & Bus, Scania and Volvo Group.

Delft University of Technology
Delft University of Technology is renowned for its cutting edge research into transportation and logistics. For example, early in 2016, a TU Delft team secured second place (to MIT) in a competition run by Elon Musk, the founder of Tesla Motors and SpaceX, inviting teams of students to design capsules that can travel at the speed of sound between cities using the 'Hyperloop' concept.

Greater London

Facts and figures

R&D spend	Total intramural R&D expenditure per inhabitant	€829 (south east England, 2013)
Tech expertise	% of working population in high tech sectors	7.2% (south east England, 2015)
R&D base	% of active population employed in R&D	2.3% (south east England, 2013)
Local finance	VC investment as a % of GDP	0.032% (UK, 2015)
Connectivity	Average LTE download speed	15 Mbps (UK, Q4 2015)
Industrial base	Number of companies in the Forbes Global 2000	92 (UK)
Innovation	ICT patent applications to the EPO per million of the active population	91 (south east England, 2012)
EU Funding	H2020 funds	€554 million (London+Guildford)

The wireless megalopolis

Home to several leading telecoms companies and world-class engineering schools, Greater London has long been a hotbed for research into new mobile technologies and services. London hosts two of the world's top ten universities (Imperial College London and UCL), and 12 of the top 500, according to the QS World University Rankings 2015/2016. The south east of England also boasts two more top-ten institutions (Cambridge and Oxford). In London, 52,505 people are studying STEM (science, technology, engineering and maths) subjects in higher education, according to HESA, a government-sponsored statistical agency. Though the various cities in the south east of England are governed separately, in recent years they have been collaborating to attract investment.

Greenwich, a London borough, is working with the 5G Innovation Centre in Guildford, Surrey to develop a 5G and Internet of Things test-bed as part of its smart-city strategy, while nearby Cambridge is home to an extensive wireless networking organisation made up of 400 companies. More broadly, London is home to 23,000 ICT and software companies, supported by formal networks, such as Tech City UK, an accelerator based in east London.

London ranked second out of 40 global cities in a comprehensive June 2015 assessment by research firm Citie of cities' openness to new ideas and new businesses, willingness to optimise their infrastructure for high-growth businesses, and readiness to incorporate innovation into their activities. London also ranked first in the 2015 European Digital City Index, which gauges how well cities support digital entrepreneurs, and in an assessment of UK cities' smart-city strategies.

As the capital of the world's fifth large economy, London has a rich concentration of global companies, experienced entrepreneurs, technologists, academic, scientific and cultural institutions, policymakers, financiers, NGOs and regulators, with deeply interwoven formal and informal networks. These organisations can draw on a very large pool of talent: London's population of 8.7 million is larger than that of innovation-led national economies, such as Finland and Ireland.

History and policy

The UK has taken a leading role in the development of mobile networks since 1983, when Margaret Thatcher's government issued the UK's first two licences to the newly privatised British Telecom (BT) and what was to become Vodafone. Tension between the former state monopoly provider of communications services and this commercial upstart slowly gave way to cooperation on issues such as interoperability.

Even as first-generation services were launched, GSM, a pan-European digital standard, was under development. It was Stephen Temple, a senior British civil servant, who wrote the GSM Memorandum of Understanding and encouraged Margaret Thatcher to use the UK's presidency of the Council of the European Union in the second half of 1986 to advocate the standard's adoption across Europe, which followed in September 1987. In 1988, just three years after that first call on its network, Vodafone listed on the UK Stock Exchange at a valuation of £1.7 billion.

Radio spectrum underpins all wireless technologies, and Ofcom, the UK regulator, has proven adept at making sufficient spectrum available to meet rising demand for capacity, while driving competition between telcos. One pivotal decision, to make a higher-frequency band available for a parallel service to GSM, enabled further competition and drove the development of battery-powered, rather than vehicle-mounted, mobile phones, spreading their use beyond business people to consumers. However, UK policymakers have sometimes put short-term fundraising ahead of long-term development. Intensely competitive auctions of 3G spectrum, which raised £22.5 billion
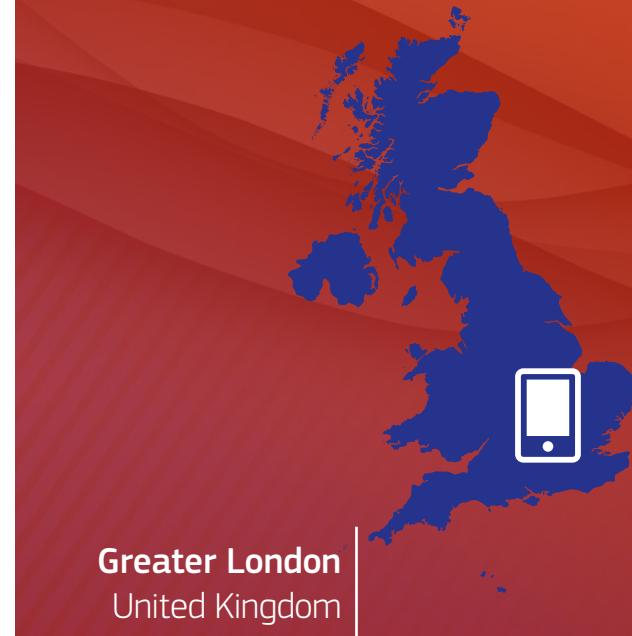
Greater London
United Kingdom

for the government in 2000, curbed the funds UK telcos had available for investment in networks, resulting in patchy mobile broadband coverage. Ofcom is currently working with European and global spectrum policymakers to decide which frequency bands should be used for 5G services, a decision that is driving another round of technological innovation.

This combination of entrepreneurialism, government enablement, smart regulation, cooperation on technical standards and fierce commercial competition, has ensured that the south east of England remains a key hub for the global cellular industry. The cluster now benefits from very deep reserves of experience: for example, Stephen Temple is now a visiting professor at the 5G Innovation Centre (see profile) and technical secretary of its Strategy Advisory Board.

Policy Area

Bar chart — "Score on a scale of 1-5":
- Investment in education: 3
- Public support for research: 4
- Availability of public seed-funding: 2
- Favorable taxation: 4
- Integration into EU R&D framework: 3
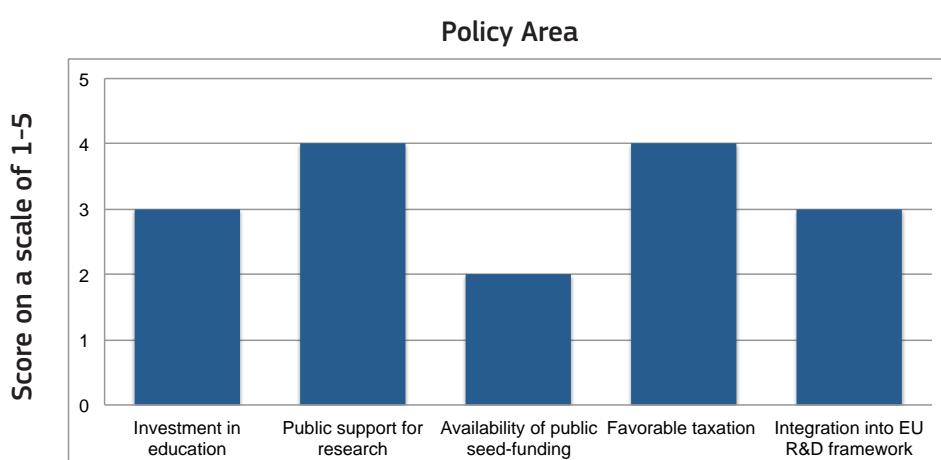
In pursuit of the digital ubiquity dream

What are we going to do with the 5G networks due to debut in 2020? **RAHIM TAFAZOLLI**, director of the 5G Innovation Centre at the University of Surrey, is working that out. "5G provides the foundational technology for the digitalisation of everything," Tafazolli says. "Homes, roads, factories, hospitals, cars will all be digitised."

5G is supposed to be 100 times faster than 4G and support 100 times more users, easing capacity and coverage issues at launch. Later, it will enable ultra-high capacity services over short distances – think on-demand action replay videos for everyone in a stadium at once. "It will give users the perception that they are in an infinite capacity environment," Tafazolli says.

5G's capacity will also be used to enable the Internet of Things (IoT), supporting autonomous cars that can communicate with each other and avoid collisions, and satellites controlled by smartphones, through to smarter utility meters in the home. Very responsive connectivity should also herald a new generation of augmented and virtual reality games, and eventually even 3D holographic images and video on mobile devices.

Tafazolli's vision of the future of digital communications is based on more than 25 years of teaching experience, over 500 research publications, and 30 granted patents. He has also been involved in UK studies on the IoT, 5G, smart cities and other issues that relate to communications policy – as well as being awarded the 28th KIA Laureate Award by Iran in 2015 for his contribution to communications technology.

The 5G standard is still being defined, and once launched, will continue to evolve for another 20 years – which makes predicting its ultimate uses a challenge. "When we defined 4G, we didn't think about something like the iPhone," says Tafazolli. "5G will provide a stepping stone to new devices, apps and services – and if we have the capability, the applications will come."

Snapshots of key players

5G Innovation Centre
The 5GIC at the University of Surrey is home to 170 researchers and a 4km2 advanced 4G network for trialling 5G concepts, validating standards and testing interoperability. The 5GIC is funded by £12 million from the Higher Education Funding Council for England and more than £68 million from industry and regional partners, including EE, Huawei, O2, Vodafone, the BBC, BT, Fujitsu and Samsung.

Cambridge Wireless
Cambridge Wireless (CW) is a global networking organisation linking nearly 400 companies working with wireless, mobile, networks, the internet, semiconductors and advanced software technologies. CW has special interest groups, led by champions, which run educational and networking events on topics, such as mobile broadband. CW also runs an influential annual Future of Wireless conference.

King's College London
The Centre for Telecommunications Research at King's College London was established in 1994 and hosts 50 researchers. Current research topics include the capacity, coverage and energy consumption of 5G networks, advanced approaches to networking, and intelligent information processing. The Centre partners with industry, and is a member of the UK's Virtual Centre of Excellence in Mobile & Personal Communications.

The Virtual Centre of Excellence in Mobile and Personal Communications (VCE)
VCE is a not-for-profit industrial-academic partnership undertaking industry-led strategic research, innovation and application of communications and information technologies. VCE began life in 1996 as a UK initiative, but has operated internationally since 2000, and also now includes SMEs among its members.

ARM Holdings
ARM was founded in Cambridge in 1990 to commercialise a design for an energy-efficient microprocessor. It took off when chip companies licensed the design for use in mobile phones, putting ARM at the heart of a rich global ecosystem of wireless semiconductor expertise. Today, almost all mobile phones and many tablets include chips based on ARM's designs. The London-listed company is now being acquired by Japan's Softbank for £24.4 billion.

Vodafone
Awarded one of the UK's first mobile licences in 1983, Vodafone launched a GSM network in 1991, cellular data services in 1994, 3G services in 2001, and 4G in 2013. It now has 444 million customers across 26 countries and has partnerships with operators in 55 more. Vodafone generates revenues of about £41 billion and spends more than £8.5 billion in capex each year