BAK economic intelligence

# Cutting Edge Technology Profile for STRING

## Technological Strengths and Linkages

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# 1 Introduction

STRING is a political cross-border organisation, with eight regions and five cities as members, located in Norway, Sweden, Denmark and Germany. STRING is also a geographical area that comprises Oslo City and Viken, West Sweden, the Copenhagen-Malmö-Region (Øresund) and the region of Hamburg. The vision of STRING is to be a globally acknowledged green investment hub and a leading implementer of sustainable infrastructure to combat climate change while improving the lives of its citizens.[1]

Technological progress is key to ensuring competitiveness and future growth. To cope with global competition, European regions and cities must innovate. Innovation is also central to addressing global challenges like climate change.[2] About two-thirds of Europe's economic growth over the last decades has been driven by innovation.[3] However, the nature of innovation is changing and, therefore, also the ways in which regions compete.[4] The diffusion of technology advances is increasing. New technologies are spreading faster within society. It is expected that multidisciplinary approaches will become even more important because innovations that arise from the intersections of different fields are often more valuable. In addition, the importance of cooperation and communication among researchers and engineers is growing as innovations become more complex.

Although technological progress is decentralised and is mainly achieved at the company level, one method available for measuring these activities is through the international patent system. Together with the Swiss Federal Institute of Intellectual Property, BAK Economics has developed an approach that allows for the measurement, analysis and assessment of research and technology activities of companies and regions within a global comparison, based on patent analysis. Further, this approach allows BAK to analyse how research-intensive regions are and to evaluate the quality of these research activities. This technology approach also highlights research cooperation and technology combinations, i.e. patents that are relevant for more than one technology.

Cross-border regional cooperation aims to develop untapped growth potential of border regions. The goal of this study is:

- to identify technological strengths of the STRING region,
- to provide better reciprocal knowledge to facilitate collaboration in cross-border research and development,
- to identify existing cross-border research cooperation and
- to detect intelligent technology combinations leading to better research outcomes, regional competitiveness and growth prospects.

As green growth is a main strategic priority of STRING, special attention will be paid to green technologies.

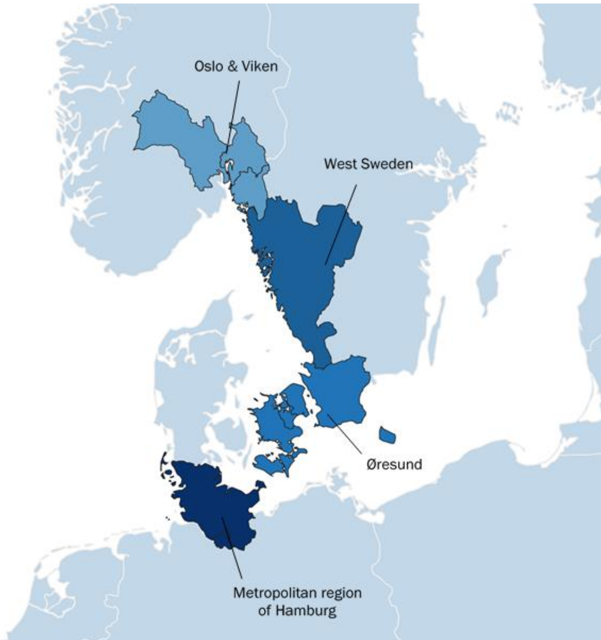
[1] https://stringnetwork.org/about/
[2] http://www.oecd.org/governance/regional-policy/regionalinnovation.htm.
[3] https://europa.eu/rapid/press-release_IP-19-2991_en.htm
[4] For the following see Council of Competitiveness 2005: Measuring Regional Innovation. A Guidebook for Conducting Regional Innovation Assessments, p. 8.

## 1.1 Definition of the STRING region and its benchmarks

Geographically, the STRING region consists of the Oslo region (Oslo-City and Viken[5]), West Sweden, Øresund (Zealand-Copenhagen-Malmö-Region) and the region of Hamburg (Hamburg and Schleswig-Holstein). Except for figures and tables where region abbreviations are used for the sake of visibility, this will be the terminology of choice throughout this report. With a population of 1.9 million, the Oslo region generated a GDP per capita of 64,000 US dollars in 2018. West Sweden has 2.0 million inhabitants, the largest city being Gothenburg, and a GDP per capita of 52,000 US dollars.[6] The Øresund region has slightly more than 4 million inhabitants, while its recent GDP per capita amounts to 56,000 US dollars. The Hamburg region, in turn, has 4.7 million inhabitants and a GDP per capita of 56,000 US dollars, similar to the Øresund region. In sum, the STRING region includes 12.6 million inhabitants and had an average GDP per capita of 58,000 US dollars in 2018.

This report compares the STRING region to Western Europe, which consists of Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom. In addition, the STRING region is compared to the average of the 50 most research-intensive countries in the chapter on technology combinations. For comparing green technologies, the San Francisco Bay Area has been chosen as a benchmark for the STRING region. This region is home to more than 8.7 million people and earned a GDP per capita of 103,000 US dollars in 2018.

**Fig. 1-1 The STRING Region**




Source: BAK Economics

[5] As per 01.01.2020, the regions Akershus, Buskerud and Østfold will be merged into the province of Viken.
[6] The following data are from BAK Economics Regional Economic Database 2019. All GDP per capita figures are of 2018 and adjusted for differences in purchasing power.

## 1.2 Regional innovation systems

For the definition and implementation of innovation strategies and policy instruments, cities and regions must analyse the strengths and weaknesses of their research and innovation systems. There are many different approaches to defining innovation and assessing performance.[7] One well-established instrument is the European Innovation Scoreboard (EIS), provided by the European Commission. The Regional Innovation Scoreboard (RIS) provides comparative assessment of the innovation performance of European regions and measures innovation performance in the same fields and categories as the European Innovation Scoreboard, but with a limited set of indicators.

The RIS assesses innovation performance in four categories:

- Framework conditions
- Investments
- Innovation activities
- Impacts

The category of **framework conditions** comprises the main drivers of innovation performance external to companies, such as human resources as measured by indicators such as lifelong learning. In addition, the attractiveness of research systems is measured with indicators such as international scientific co-publications.

The category of **investments** captures investments spent by both the public and the business sector with the two categories finance/support and firm investments. Indicators are, for example, R&D expenditures in the public sector (finance and support) and R&D expenditures in the business sector (firm investments).

The category of **innovation activities** summarizes different facets of innovation in the business sector: innovators, linkages and intellectual assets. The facet of innovators measures product or process innovations at the company (SME) level. The facet of linkages measures collaboration activities with indicators such as public-private co-publications or innovative SMEs collaborating with others. The facet of intellectual assets is assessed by patent, trademark or design applications.

The category of **impacts** depicts the efforts of a firm's innovation activities resulting in employment increases (employment impact) or sales of new-to-market and new-to-firm innovations (sales impacts). Together, these indicators form the Innovation Index that can be used to compare regional innovation systems.

A first impression of the innovation performance of the analysed regions is given in Table 1-1, reflecting the results of the RIS 2019. The RIS classifies the innovation performance of regions into different innovation categories. The first group consists of innovation leaders comprising regions with a performance above 120% of the EU average. The second group of strong innovators includes all regions with a performance between 90% and 120% of the EU average. Moderate innovators are regions with a score between 50% and 90% of the EU average, whereas modest innovators show a performance level below 50% the EU average. Innovation leaders are coloured in dark

[7] European Commission (March 2019): European Innovation Scoreboard. Exploratory Report A : What to measure and why ? Capturing mechanisms and emerging phenomena of innovation.

green, strong innovators are coloured in light green, moderate innovators in grey and modest innovators in light red in Table 1-1.

### Tab. 1-1 Regional Innovation Scoreboard 2019

| Category | Hamburg Region | Øresund | Oslo Region | West Sweden | STRING Region |
|---|---|---|---|---|---|
| **Human resources** | | | | | |
| Population with tertiary education | 71 | 150 | 162 | 140 | 120 |
| Lifelong learning | 84 | 282 | 199 | 298 | 198 |
| **Attractive research systems** | | | | | |
| Scientific co-publications | 111 | 151 | 136 | 129 | 128 |
| Most-cited publications | 97 | 117 | 92 | 117 | 105 |
| **Finance and support** | | | | | |
| R&D expenditure public sector | 110 | 135 | 131 | 114 | 120 |
| **Firm investments** | | | | | |
| R&D expenditure business sector | 83 | 131 | 107 | 153 | 113 |
| Non-R&D innovation expenditures | 84 | 75 | 130 | 110 | 94 |
| **Innovators** | | | | | |
| SMEs innovating in-house | 116 | 122 | 142 | 109 | 121 |
| Marketing or organisational innovators | 129 | 108 | 157 | 109 | 124 |
| Product or process innovators | 116 | 102 | 166 | 106 | 119 |
| **Linkages** | | | | | |
| Innovative SMEs collaborating with others | 65 | 108 | 166 | 86 | 99 |
| Public-private co-publications | 113 | 178 | 153 | 245 | 158 |
| **Intellectual Assets** | | | | | |
| Design applications | 129 | 122 | 29 | 109 | 107 |
| EPO patent applications | 102 | 174 | 96 | 157 | 133 |
| Trademark applications | 133 | 172 | 68 | 156 | 137 |
| **Employment impacts** | | | | | |
| Employment medium and high tech manufacturing & knowledge-intensive services | 106 | 115 | 116 | 140 | 115 |
| **Sales impacts** | | | | | |
| Sales of new-to-market and new-to-firm innovations | 49 | 78 | 92 | 96 | 72 |
| **Innovation Index** | 105 | 134 | 125 | 139 | 122 |

Modest Innovators | Moderate Innovators | Strong Innovators | Innovation Leaders

Performance in 2019 relative to the EU in 2019. The category Innovation Leaders includes regions with performance above 120% of EU average. Strong Innovators includes regions with performance 90% -120% of EU average. Moderate Innovators includes regions with performance 50%-90% of EU average. Modest Innovators includes regions with performance below 50% of EU average. The RIS provides data only at the NUTS 2, not the NUTS 3 territorial level. Therefore, RIS data are available for the following regions: Hamburg region = Hamburg and Schleswig-Holstein, Øresund region = Capital region Copenhagen, Zealand and South Sweden (Skåne and Blekinge), Oslo region = Oslo & Akershus and South-Eastern Norway (Østfold, Buskerud, Vestfold and Telemark), West Sweden. To account for the correct composition of the STRING region, performance values for Øresund, Oslo region and STRING region were measured as population weighted averages of the according NUTS3 regions they comprise.
Sources: BAK Economics, Regional Innovation Scoreboard 2019

As can be seen from the table, all regions depicted achieve good results. The Oslo region, West Sweden, and Øresund perform well in almost all indicators and are classified as innovation leaders. These three regions achieve particularly great scores in the area of human resources (population with tertiary education and lifelong learning). The Hamburg region scores slightly lower and is thus classified as a strong innovator. The Hamburg region has some weaknesses in sales impact, human resources, and firm investments compared to the other regions. The STRING region as a whole counts as an innovation leader. The STRING region scores well in every innovation category except for its sales impacts where it is regarded as a moderate innovator.

The following report is not intended to address all aspects of innovation when evaluating the regional innovation system in STRING. Instead, it focusses on the linkages and intellectual assets evident there. BAK assesses the innovation performance in these innovation categories by analysing patent data. Patents serve as a measure of research performance, which can lead to marketable products and increase productivity.

The following analysis tries to gain deeper insight concerning:

- The technological strengths of the regions
- Linkages between researchers within the STRING region
- Interesting linkages within technologies

## 1.3 BAK Technology Approach

The BAK Economics technology approach, developed jointly with the Swiss Federal Institute of Intellectual Property, breaks new ground by basing measurement on patent quality and refined technologies.[8] The underlying patent database is the OECD Regpat database which covers all patents that have been filed by at least one of the large international patent offices (EPO, USPTO or PCT).[9]

The definition of technology fields has been refined since the classical technological definition of technology fields by the World Intellectual Property Organization (WIPO) does not cover the latest technological trends anymore. Therefore, a new list of cutting-edge technologies that have an increasing impact on economic development in the coming years has been developed. It is possible to specifically show where STRING and its geographic regions are positioned in these cutting-edge technologies, which companies are technology leaders, and what the key technologies are.

In this study, the patents are identified and counted according to the reporting date concept – all active and published patent families and applications are counted at a specific point in time. This approach differs from other patent analyses (such as the RIS) where only new patent applications per year are counted. Whereas the latter concept focusses on the dynamics of patent development, the approach used in this study focusses on the absolute size and strength of a patent portfolio at a given date. For

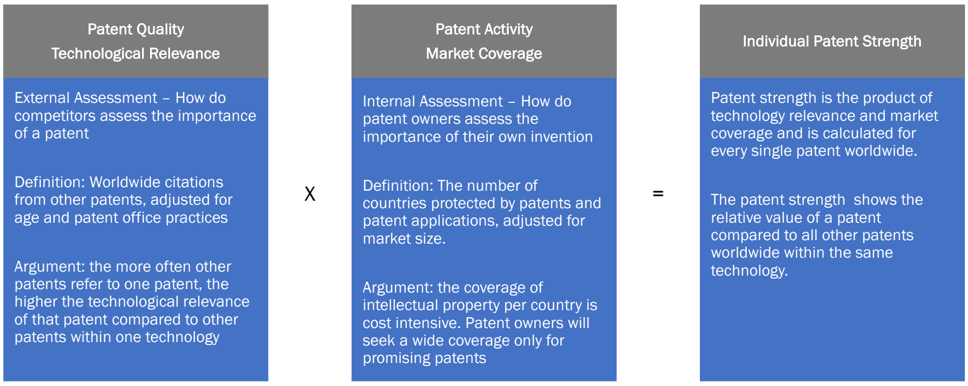
[8] Patents are analysed according to the researcher's address on the patent filed. This approach allows for the identification of the region where the research has taken place and circumvents the potential problems arising from international companies which apply for patent ownership via their headquarters.

[9] EPO: European Patent Office; USPTO: US Patent and Trademark Office; PCT: Patent Cooperation Treaty

example, the reporting date 2016 (31. December) includes all patents and pending applications up to this day. Still, active patents from all previous years are included.

When analysing the research capabilities of regions, it is important not only to look at the number of patents (= the quantity of research) but also to take the quality of research into account. The patent strength is evaluated for each individual patent worldwide and is comprised of two components: the patent activity and the patent quality.

### Fig. 1-2 Measuring patent strength: technological quality and market coverage




Source: BAK Economics, IGE, PatentSight

The patent quality corresponds to the relevance of the technology and shows how important an invention is in comparison with other patents in the corresponding technology (competitor's assessment) based on the references and citations by third parties.

The patent activity corresponds to the market coverage, i.e. the statutory coverage of the patent protection, and shows how companies assess the importance of their own inventions. Since international patent protection is costly, extensive international market coverage signals that a patent is promising (self-assessment).

Taken together, patent quality and patent activity comprise the overall evaluation of the patent or patent portfolio and can be evaluated according to specific technologies. The result is a rating in deciles where the top 10% of patents in the 50 most research-intensive countries in every technology are defined as world-class patents.

In today's research and technology environment, linkages and technology combinations play an increasingly important role in the innovation process, due to knowledge spillover and new dynamics made possible by digitization. The BAK technology approach can identify existing research networks and useful technology combinations.

A patent is the fruit of research usually carried out by more than one researcher, often by more than one company or institution. It must be noted that a university, research institute or company can only be identified as connected to a patent if it is named as (co-) owner of the patent. However, patenting strategy can differ quite substantially between research institutes and universities across countries.

Apart from shared ownership, many patents belong to more than one technology. This is because patents are often relevant for more than one technology. The International

Patent Classification (IPC) system currently consists of more than 70,000 classes. Technologies are defined by grouping relevant patent classes.

## 1.4 Structure of the analysis

In chapter 2, a technology profile is defined for the Oslo region, West Sweden, Øresund and the region of Hamburg as well as for the entire STRING region. The technology profiles of these regions are compared in order to identify common strengths and to discover technological differences. In addition, the top research companies and research institutes are listed. As a result, this first chapter gives a detailed overview of the intellectual assets in STRING.

Chapter 3 examines the research performance of STRING in green technologies. The technology profiles based on these technologies show which green technologies are important for STRING and the four analysed regions. The profiles also reveal which green technologies have experienced high patent growth rates in recent years and which technologies exhibit a high level of research efficiency. Moreover, the results of STRING are compared with the San Francisco Bay Area – an innovation leader in green technologies.

In the next part, the focus is on research interdependencies. First, the relevance of patents involving scientists from more than one of the four regions has been analysed. Moreover, patents with more than one owner have been filtered out to see whether co-ownership patents have a higher average quality than single-owner patents.

Promising technology combinations make up the chapter 5. Patents are often not only relevant to one specific technology, but rather two or more technologies. Therefore, some patents are counted in more than one technology field. It is assumed that innovations not only emerge from brand new technologies, but also emerge from the intelligent linking of existing technologies, among other ways.

Based on the focus technologies of the four regions and STRING, an analysis of potential combinations between technologies has been performed to identify which combinations lead to better results in terms of a better ranking of the respective patents.

The final chapter of the study consists of a conclusion based on the findings obtained.

# 2 Technology analysis of the four regions (Oslo region, West Sweden, Øresund, Hamburg region) and the entire STRING region

The results of the Regional Innovation Scoreboard (RIS) in chapter 1 show that STRING is rated as an innovation leader in the EU concerning intellectual assets. This chapter gives an overview in which specific technology fields the intellectual assets of STRING and the four regions (Oslo region, West Sweden, Øresund and Hamburg region) are located. To achieve this, technology profiles have been created that identify common strengths and show technological differences. Finally, a list of the top research companies and universities/research institutes in STRING is presented.

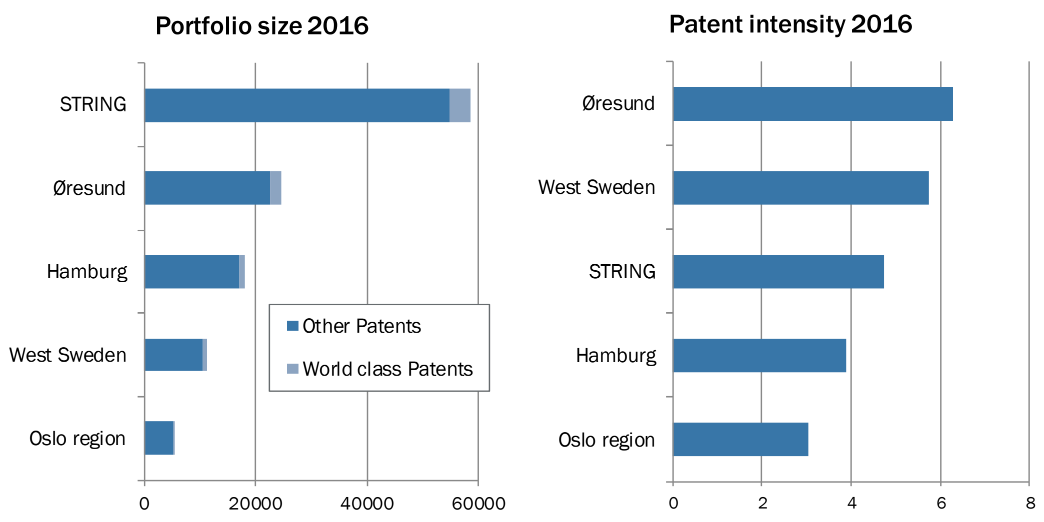
## 2.1 Overview

**Total patent numbers**

The regions of STRING are active in many different technology areas from transport technologies to Life Sciences to Clean Tech solutions. The research strength of STRING is reflected in its large and increasing patent numbers.

In 2016, there were almost 60,000 active patents in STRING according to the OECD Regpat Database. Øresund has the largest patent portfolio among the four analysed regions with a total of almost 25,000 active patents. The Hamburg region is in second place with a total of 18,000 patents. West Sweden (more than 11,000 active patents) and the Oslo region (more than 5,500 total patents) complete the list. Øresund also has the highest share of world-class patents, whereas the Hamburg region has the lowest share of world-class patents.

**Fig. 2-1 Portfolio size/Patent intensity**

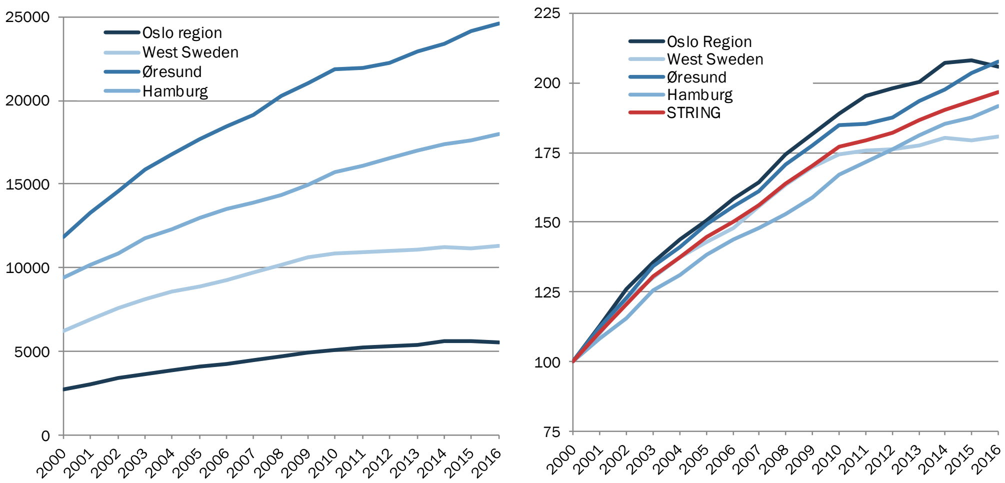



Portfolio size: Total number of active patents in 2016 by region
Patent intensity: Number of total active patents per 1'000 inhabitants in 2016
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

**Patent intensity**
The indicator of patent intensity measures the number of patents divided by the resident population. Øresund achieves the best results again. In 2016, there were 6.3 patents per 1,000 inhabitants in Øresund. West Sweden has the second-highest patent intensity with 5.8 patents per 1,000 inhabitants. In STRING in total, this number is 4.8. The Hamburg region, which is the largest region, has a patent intensity of 3.7 patents per 1,000 inhabitants. The Oslo region, which is the smallest region, also has the lowest patent intensity with 3.1 patents per 1,000 inhabitants.

**Patent growth**
The comparison over time shows the dynamics of the regional patent portfolio. Since 2000, the number of active patents has more than doubled in Øresund and the Oslo Region. The Hamburg region and West Sweden performed below the average of STRING. However, between 2000 and 2016, they both still had total growth in patents of 85% and 75% respectively. It must be noted, nonetheless, that patent growth has somewhat slowed down in all regions in recent years. The main reason for this slowdown is that Life Sciences patent growth has decelerated noticeably in the same time period (see chapter 2.2 for more details).

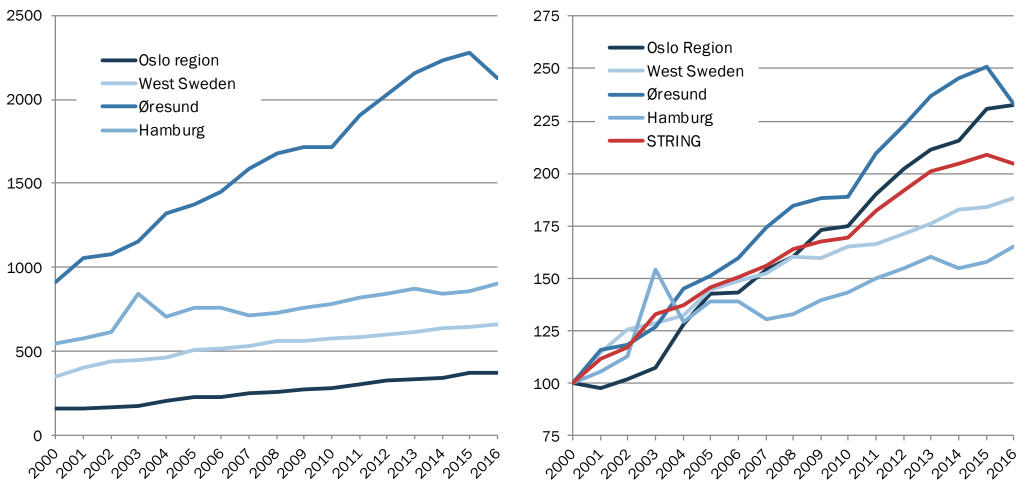
**Fig. 2-2 Total patent growth**




Left side: Number of total active patents from 2000 – 2016,
Right side: Patent growth between 2000 and 2016, 2000 = 100
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

Øresund and Oslo are also the two leading regions in terms of world-class patent growth. In the Hamburg region, the number of world-class patents has increased at a slower rate than the number of total patents. As a result, its share of world-class patents of total patents has decreased slightly, whereas it has risen in the other regions.

**Fig. 2-3 World-class patent growth**




Left side: Number of total active world-class patents from 2000 – 2016,
Right side: World-class patent growth between 2000 and 2016, 2000 = 100
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

## 2.2 Technology profiles

The technology profiles for STRING and its four member regions show the most relevant technologies in terms of patent numbers, their patent growth since 2010 and their research efficiency. These technologies are called "focus technologies" in the remainder of the text.

The focus technologies that make up the technology profiles are mainly based on the new BAK "cutting edge" technologies that were developed together with the Swiss Patent Office. These technologies are designed to highlight significant new developments. The cutting-edge technologies are a subset of the broader traditional WIPO[10] categories. In addition, the WIPO category of Transport was selected because it is a key technology field for STRING, and it is not covered sufficiently by the cutting-edge technologies.

**BAK Technology areas**
The BAK cutting edge technologies can be divided into five general technology areas: Life Sciences, Materials, Systems, Energy and Digital/IT.

**Digital/IT:** Digital technologies are an important and fast-growing component of the BAK cutting-edge technologies. From Digital Medtech to Fintech to Data Security to Machine Learning and to the Internet of Things, digital technologies are increasingly gaining relevance in various areas of the economy.

**Life Sciences:** Life Sciences is one of the most mature areas of cutting-edge technology and there are sizeable research activities in all analysed regions. This is reflected in

[10] WIPO: World Intellectual Property Organization: Concept of a Technology Classification for Country Comparisons (2008); https://www.wipo.int/export/sites/www/ipstats/en/statistics/patents/pdf/wipo_ipc_technology.pdf

the very high number of patents. Life Sciences include technologies that deal with the processes or structures of living beings.

The most important technologies in Life Sciences are Pharma, Biotech, and Medtech. Biotech is further subdivided in Biotech Red, Biotech Green, and Biotech White. Biotech Red refers to all medical applications of biotech such as regenerative medicine, gene therapy, cell therapy, and medicines based on biological molecules such as therapeutic antibodies. Biotech White involves the use of biotech in industrial processes (therefore sometimes also called industrial biotech) such as the production of new chemicals and materials or the development of new fuels for vehicles. Biotech Green includes all biotech applications related to agriculture, including the development of genetically modified organisms (GMOs) which are plants, animals or microorganism that are modified by using genetic engineering. GMOs are mainly used to create more fertile and resistant crops, seeds, or plants. The production of bio-fertilizers and biopesticides also belong to the Biotech Greenfield.

**Systems:** The area systems includes diverse technologies such as Autonomous Driving, Additive Manufacturing (with 3D-printing as the major application), Electric & Hybrid Vehicles, Drones, Sensors, or Hearing Aids. It also contains certain green technologies such as Recycling Waste Reuse and Wastewater Treatment.

**Energy:** The energy category consists of novel technologies that deal with the generation, conversion or storage of energy. For example, various types of batteries, but also Wind Energy technology, belong to this category. Clean Tech is another important Energy technology (see chapter Green Technologies for more details).

**Materials:** Materials include technologies that deal with the research, development, production, and use of novel materials. Material Science is a blanket term for these novel materials. These novel materials include, for example, smart polymers that change according to their environment, based on factors such as temperature or humidity. These polymers are used in many different applications including sensors, actuators, the production of hydrogels or drug delivery. Additive Manufacturing (3D-Printing) Materials is another materials technology.

These materials technologies are mostly in the early stages of their growth and this is reflected in the relatively small number of patents attributed to the segment. However, there are high expectations for growth in Material technologies and research activities are expected to intensify in the coming years.

The following table gives an overview of all cutting-edge technologies that were selected as focus technologies and/or green technologies for this report. A short description of all the different single technologies is included in the appendix.

**Tab. 2-1 Technology Overview**

| Technology Areas | Technologies |
|---|---|
| Digital/IT | Blockchain, Data Security, Digital Medtech, Electronic Gaming, Image Analysis, IoT: Smart Factory (Machine to Machine), IoT: Smart House, IoT: Smart City, FinTech Wealth Management, Machine Learning/Artificial Intelligence, Prevent & Predictive Maintenance, Process Automation, Quantum Computer, Speech Analysis |
| Life Sciences | Biotech Green, Biotech Red, Biotech White, Medtech, Pharma |
| Systems | Additive Manufacturing (3D Printing), Advanced Manufacturing, Autonomous Driving, Carbon Capture, Collaborative Robotics, Cosmonautics, Drones, Electric & Hybrid Vehicles, Hearing Aids, Nanostructures, Recycling Waste Reuse, Sensors, Wastewater Treatment, Wearables |
| Energy | Biomass Fermentation, Clean Tech, Energy Storage, Energy Conversion, Energy Generation, Fuel Cells, Lithium Battery/NiMH Battery, Smart Grid, Solar Energy, Organic Perovskite Solar Cells |
| Materials | Material Science, Smart Polymers, Additive Manufacturing Materials |

Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

**Selection of focus technologies**
In order to identify the focus technologies for each region, three selection criteria were used:

**- Number of patents**

**- Level of specialization compared to Western Europe**

**- Patent growth**

The top ten technologies in terms of patent numbers in 2016 were chosen for each region (blue colour in Tab. 2-1 and following). Second, five technologies with the highest specialization index, not already included because of their size, were selected (grey colour). The specialization index was calculated by comparing the share of each technology of total patents to the average in Western Europe. Values higher than one show above-average specialization, values lower than one reflect below-average specialization. Third, the five technologies with the highest average patent growth between 2010 and 2016, not already included due to the other two criteria, were added (red colour). In addition, the WIPO technology Transport was selected for all regions, because it is a key technology in STRING. The technology profile graphs in the remainder of this section exclude technologies that had less than 10 active patents in 2016.

### 2.2.1 Oslo Region

#### Tab. 2-2 Technology selection for the Oslo region

| Technologies | Category | Number of patents | Specialization Index | Growth p.a. |
|---|---|---|---|---|
| Transport | WIPO | 353 | 0.6 | 0.5% |
| Pharma | Life Science | 498 | 1.3 | 0.2% |
| Medtech | Life Science | 345 | 0.8 | 0.3% |
| Biotech Red | Life Science | 331 | 1.5 | 1.5% |
| Clean Tech | Energy | 301 | 0.7 | 2.0% |
| Sensors | Systems | 286 | 1.3 | 6.4% |
| Energy Generation | Energy | 136 | 0.6 | 1.2% |
| Energy Conversion | Energy | 94 | 0.8 | 8.8% |
| Data Security | Digital/IT | 93 | 0.9 | 2.9% |
| Image Analysis | Digital/IT | 78 | 1.0 | 6.0% |
| Nanostructures | Systems | 68 | 0.8 | 2.1% |
| Collaborative Robots | Systems | 1 | 2.2 | 0.0% |
| Advanced Manufacturing | Systems | 6 | 2.0 | -10.5% |
| Drone | Systems | 15 | 1.7 | 20.8% |
| Fintech Wealth Management | Digital/IT | 2 | 1.6 | 0.0% |
| Prevent & Predictive Maintenance | Digital/IT | 14 | 1.5 | 1.1% |
| Smart City | Digital/IT | 14 | 0.7 | 12.9% |
| Wearables | Systems | 21 | 0.9 | 11.2% |
| Quantum Computing | Digital/IT | 2 | 1.1 | 10.4% |
| Additive Manufacturing Material | Material | 2 | 0.2 | 10.4% |
| Autonomous Driving | Systems | 2 | 0.1 | 10.4% |

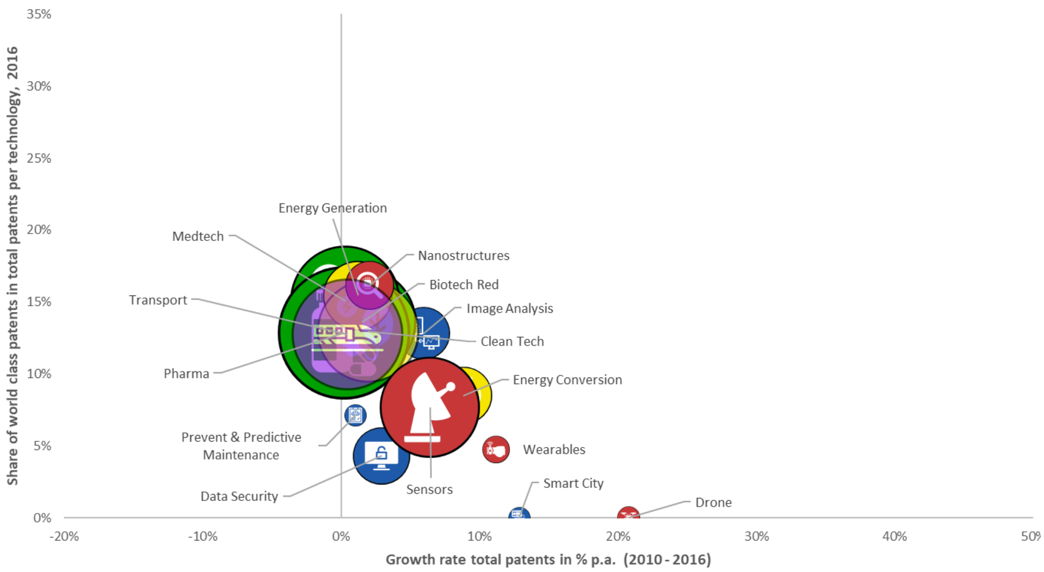
Focus technologies in the Oslo region, number of patents in 2016, specialization index in 2016, annual growth between 2010 and 2016
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

The table above shows the focus technologies for the Oslo region based on patent data. The largest technologies are Transport, Pharma, Medtech and Biotech Red. GE with its subdivision GE Vingmed Ultrasound is one of the leading research companies in Oslo that has developed many Pharma and Medtech patents. The company focuses on the manufacturing of radiographic X-ray, fluoroscopic X-ray, and therapeutic X-ray apparatus and tubes.

Other specialized technologies in Oslo are Advanced Manufacturing and Drones. Advanced Manufacturing technologies introduce network components to production machines (or industrial robots) along with other features from fields such as artificial intelligence, automatic programming, and smart grids. However, total patent numbers in both Advanced Manufacturing and Drones are still relatively small in the Oslo region.

The highest annual patent growth rates between 2010 and 2016 were recorded in Drones, Smart City, and Wearables. “Wearables” is a blanket term for electronics that can be worn on the body. Some of the most popular devices are activity trackers and smart watches. One of the major features of wearable technology is its ability to connect to the Internet, enabling data to be exchanged between a network and the device.

## Fig. 2-4 Technology profile of the Oslo region




Bubble size: Number of total patents in a technology in 2016
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

**Reading Example:**

A technology profile, like the one depicted in figure 2-4, can be read as follows: The vertical axis shows the share of world-class patents compared to the number of total patents in a technology. The higher the share, the higher the research efficiency. The horizontal axis shows the growth of patent numbers in a technology between 2010 and 2016 (per year in %). The bubble size represents the number of total patents in a technology in 2016.

For example: There are more patents in Sensors than in Drones. The research efficiency is higher in Sensors, however, the number of patents in Drones grew more robustly.

The technology profiles are coloured as follows: Life Sciences technologies are represented by green bubbles, Material technologies have orange bubbles, Systems are coloured red, the Energy Sector is represented by yellow bubbles, all Digital technologies are blue, and Transport is purple.

The key technologies in the Oslo region mostly belong to the Life Sciences and the Energy Sector. These technologies are also leading in terms of research efficiency, but patent growth was only modest between 2010 and 2016.

Another important regional technology is Transport. With a share of world-class patents of almost 13%, the Oslo region has the highest research efficiency in Transport of all the analysed regions in this report. The Oslo region is also a global leader in the adoption of plug-in and electric vehicles. The city of Oslo has the world's highest number of Electric Vehicles per inhabitant and is, therefore, often called the "EV Capital of the

World".[11] This development was supported by tax incentives for EVs in Norway as well as free parking, free charging and free tunnels in the city of Oslo.

A specific strength in the Oslo region is Sensors. With 286 patents in 2016, 5.2% of all patents in the Oslo region are Sensor patents, compared to only 3.1% in STRING. The most important research related to Sensors in the Oslo region has its roots in the oil and gas industry as can be seen by the top research companies Schlumberger, Petroleum Geo-Services, and Equinor.

Image analysis is another regional strength in the Oslo region. Patent growth in this technology was high between 2010 and 2016 and research efficiency is already above average. The top regional research companies in this field are Cisco, Idex ASA, and Hexagon.

The two technologies with the strongest patent growth are Drones and Smart City, with annual growth rates of 20.8% resp. 12.9% between 2010 and 2016. Smart cities use different types of electronic data collection sensors to supply information that is then used to manage assets and resources efficiently. This includes data collected from citizens, devices, and assets that is processed and analysed to monitor and manage traffic and transportation systems, power plants, water supply networks, waste management and other services. There are a wide range of Smart City projects in the Oslo region such as the Climate Dashboard that visualizes climate and environmental data, such as bicycle and pedestrian counts, use of charging stations for electrical vehicles, and air quality. The goal is to develop a more climate-friendly city, by referring directly to the statistics and trends.[12]

[11] http://news.trust.org/item/20180307114110-a0cqx/
[12] https://www.oslo.kommune.no/politics-and-administration/smart-oslo/projects/climate-dashboard/#gref

### 2.2.2 West Sweden

**Tab. 2-3 Technology selection for West Sweden**

| Technologies | Category | Number of patents | Specialization Index | Growth p.a. |
|---|---|---|---|---|
| Transport | WIPO | 1657 | 1.3 | 1.9% |
| Medtech | Life Science | 1159 | 1.3 | -1.5% |
| Clean Tech | Energy | 734 | 0.8 | 4.5% |
| Pharma | Life Science | 458 | 0.6 | -6.8% |
| Energy Generation | Energy | 358 | 0.8 | -0.1% |
| Material Science | Material | 351 | 0.9 | 4.3% |
| Biotech Red | Life Science | 275 | 0.6 | -3.2% |
| Sensors | Systems | 235 | 0.5 | 2.3% |
| Electro & Hybrid Vehicles | Systems | 155 | 1.7 | 16.3% |
| Smart Factory M2M | Digital/IT | 129 | 0.8 | 11.3% |
| Data Security | Digital/IT | 126 | 0.6 | 6.7% |
| Drone | Systems | 70 | 4.0 | 10.4% |
| Additive Manufacturing Material | Material | 54 | 3.0 | 17.0% |
| Autonomous Driving | Systems | 86 | 3.0 | 20.7% |
| Advanced Manufacturing | Systems | 9 | 1.4 | 12.3% |
| Smart City | Digital/IT | 50 | 1.2 | 7.1% |
| Prevent & Predictive Maintenance | Digital/IT | 16 | 0.8 | 21.9% |
| Smart Grid | Energy | 9 | 0.2 | 17.0% |
| 3D Image Modelling | Digital/IT | 17 | 0.4 | 13.5% |
| Energy Conversion | Energy | 123 | 0.5 | 12.5% |
| Image Analysis | Digital/IT | 74 | 0.5 | 11.3% |

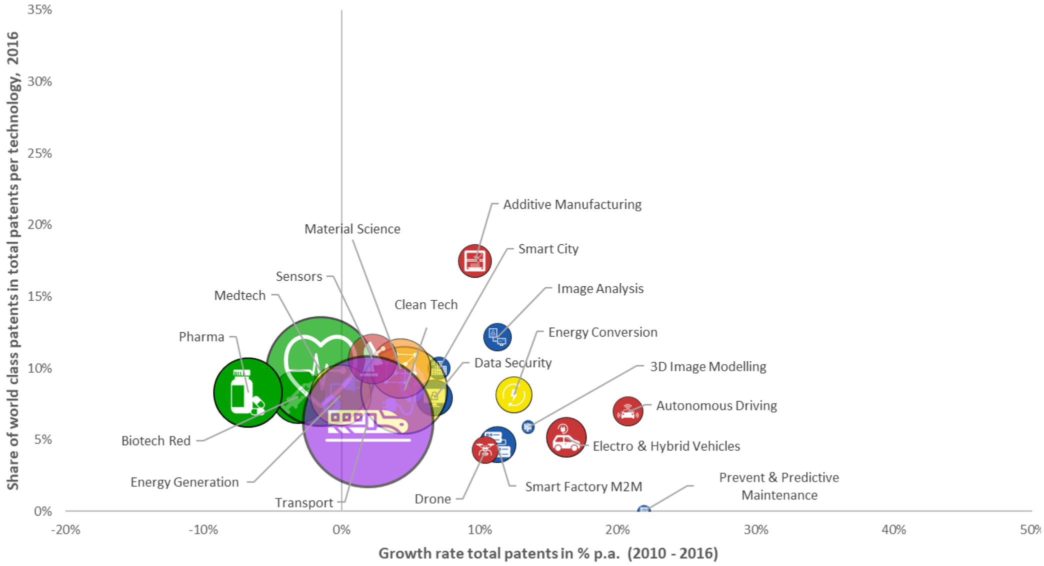
Focus technologies in West Sweden, number of patents in 2016, specialization index in 2016, annual growth between 2010 and 2016
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

The table above shows the focus technologies of West Sweden. Transport is by far the largest regional technology, followed by Medtech and Clean Tech.

Moreover, West Sweden is highly specialized compared to the Western European average in Drone, Additive Manufacturing (3D-Printing) Material and Autonomous Driving. The share of patents in these technologies of total patents is roughly four, respectively three times the size of the share of these technologies in Western Europe.

High annual growth rates are shown in the technologies Prevent & Predictive Maintenance, Smart Grid, Electro & Hybrid Vehicles, and Autonomous Driving.

## Fig. 2-5 Technology profile of West Sweden




Bubble size: Number of total patents in a technology in 2016
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

In West Sweden, Transport is the largest tech field with more than 1,600 patents in 2016. However, research efficiency in Transport is below average and patent growth was only moderate in recent years. Volvo, Geely (Owner of Volvo Cars) and Autoliv are key research companies in Transport in West Sweden.

Medtech is the second-biggest category with over 1,100 patents. But most Life Sciences technologies including Medtech have had negative patent growth rates in West Sweden in recent years. Hygiene and health company Essity currently holds most Medtech patents in West Sweden.

Autonomous Driving and Electro/Hybrid Vehicles are both fast growing technology fields in West Sweden. Volvo and Geely are the top research companies in West Sweden in these tech fields. Volvo Cars released its first all-electric vehicle in 2019 and promised that 50% of its cars will by electric by 2025. Moreover, Volvo Cars is planning to offer self-driving cars soon. The company is cooperating with Uber on autonomous driving. Moreover, Volvo Cars has struck a deal with Chinese technology giant Baidu to develop electric cars for use in a Chinese autonomous taxi fleet.

Borealis, which produces polyethylene (PE) and polypropylene (PP), is an innovator in Material technologies and enhances West Sweden's strength in Materials.

Additive Manufacturing (with its major application of 3D-Printing) and Image Analysis are two promising areas in West Sweden. While total patent numbers in these technologies are still modest, they are growing fast and have a very high research efficiency. GE and Danaher are top research companies in Additive Manufacturing in West Sweden.

### 2.2.3 Øresund

#### Tab. 2-4 Technology selection for Øresund

| Technologies | Category | Number of patents | Specialization Index | Growth p.a. |
|---|---|---|---|---|
| Transport | WIPO | 441 | 0.2 | 3.0% |
| Medtech | Life Science | 2459 | 1.3 | 2.5% |
| Pharma | Life Science | 2371 | 1.4 | -3.0% |
| Biotech Red | Life Science | 1755 | 1.8 | -0.6% |
| Clean Tech | Energy | 1217 | 0.6 | 5.6% |
| Biotech White | Life Science | 800 | 2.8 | 0.8% |
| Smart Factory M2M | Digital/IT | 772 | 2.1 | 9.9% |
| HearingAids | Systems | 747 | 8.5 | 9.3% |
| Biotech Green | Life Science | 591 | 2.8 | 1.0% |
| Material Science | Material | 464 | 0.5 | 1.8% |
| Data Security | Digital/IT | 450 | 0.9 | 5.5% |
| Wearables | Systems | 159 | 1.6 | 21.4% |
| Electronic Gaming | Digital/IT | 21 | 1.5 | 3.1% |
| Speech Analysis | Digital/IT | 159 | 1.4 | 7.0% |
| 3D Image Modelling | Digital/IT | 130 | 1.4 | 16.0% |
| Blockchain | Digital/IT | 13 | 1.4 | 14.6% |
| Additive Manufacturing Material | Material | 21 | 0.5 | 22.8% |
| Prevent & Predictive Maintenance | Digital/IT | 15 | 0.4 | 17.0% |
| Smart Polymer | Material | 6 | 1.0 | 17.0% |
| Electro & Hybrid Vehicles | Systems | 24 | 0.1 | 17.0% |
| Drone | Systems | 5 | 0.1 | 14.0% |

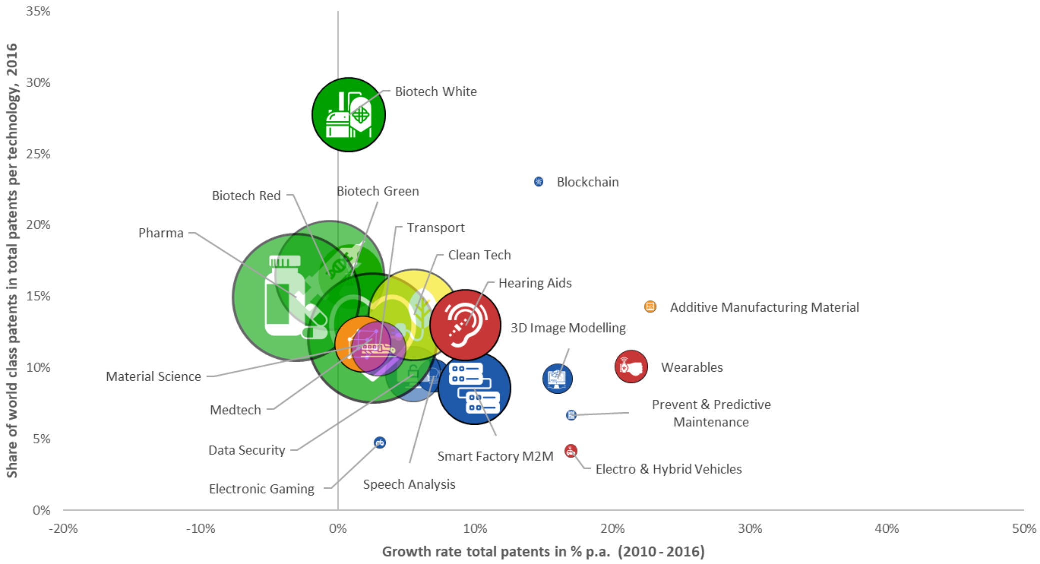
Focus technologies in Øresund, number of patents in 2016, specialization index in 2016, annual growth between 2010 and 2016
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

The table above shows the focus technologies for Øresund. The largest technologies are Medtech, Pharma, Biotech Red and Clean Tech.

Compared to Western Europe, Øresund is highly specialized in Hearing Aids, Smart Factory, all Life Sciences Technologies, Wearables, and Electronic Gaming.

The technologies with the highest annual growth rates between 2010 and 2016 were Additive Manufacturing Material, Wearables, Prevent & Predictive Maintenance, Smart Polymer, and Electro & Hybrid Vehicles.

**Fig. 2-6 Technology profile of Øresund**




Bubble size: Number of total patents in a technology in 2016
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

Øresund is outstanding in Life Sciences, especially in Medtech (2,459 patents in 2016), Pharma (2,371 patents), and Biotech Red (1,755 patents). In addition, Biotech White has by far the highest research efficiency. Novozymes and Novo Nordisk are Øresund's research engines in Biotech White. Novozymes produces industrial enzymes that help to reduce costs and improve productivity in manufacturing processes of various goods. Roche has developed many patents in Biotech Red (medical applications of Biotech) in Øresund. The Roche Innovation Center Copenhagen is a leader in the rapidly emerging field of RNA (ribonucleic acid)-targeted drugs. Coloplast and Cook Group are top Medtech research companies in the region. However, patent growth in most Life Sciences technologies was relatively weak between 2010 and 2016.

By contrast, some upcoming technologies such as Additive Manufacturing Material and Wearables saw robust patent growth.

Compared to the other analysed regions, Øresund is uniquely strong in Hearing Aids and Smart Factory. Both technologies have more than 700 patents each and grew almost 10% per year between 2010 and 2016. Moreover, there is a high regional specialization in Hearing Aids compared to the Western Europe average. The top research companies in Hearing Aids are Oticon, WS Audiology, and GN Store Nord.

Øresund also has many Data Security patents (450 patents in 2016). Due to the steady presence of major software and hardware companies such as Nokia, Motorola Solutions and Canon, Øresund has long been a hub for innovation in digital technologies.

The technology Wearables is another strength in Øresund. The top research companies in Wearables are BlackBerry, WS Audiology, and Oticon.

### 2.2.4 Hamburg Region

#### Tab. 2-5 Technology selection for the Hamburg region

| Technologies | Category | Number of patents | Specialization Index | Growth p.a. |
|---|---|---|---|---|
| Transport | WIPO | 2357 | 1.2 | 6.2% |
| Pharma | Life Science | 1701 | 1.4 | 0.7% |
| Medtech | Life Science | 1645 | 1.2 | 2.7% |
| Clean Tech | Energy | 1516 | 1.1 | 8.0% |
| Energy Generation | Energy | 753 | 1.1 | 9.0% |
| Material Science | Material | 595 | 0.9 | 6.2% |
| Sensors | Systems | 553 | 0.8 | 4.1% |
| Biotech Red | Life Science | 500 | 0.7 | 0.9% |
| Energy Conversion | Energy | 261 | 0.7 | 7.0% |
| Energy Storage | Energy | 180 | 1.0 | 6.6% |
| Nanostructures | Systems | 170 | 0.6 | 0.5% |
| Cosmonautics | Systems | 92 | 3.3 | 19.8% |
| Smart Grid | Energy | 117 | 2.0 | 9.3% |
| Security Printing | Systems | 157 | 1.5 | 0.1% |
| Additive Manufacturing Material | Material | 44 | 1.5 | 46.8% |
| Fuel Cells | Energy | 137 | 1.5 | 4.8% |
| Wearables | Systems | 43 | 0.6 | 21.5% |
| Additive Manufacturing | Systems | 129 | 0.9 | 20.5% |
| Smart Polymer | Material | 3 | 0.7 | 17.0% |
| Advanced Manufacturing | Systems | 6 | 0.6 | 17.0% |
| Drone | Systems | 9 | 0.3 | 12.3% |

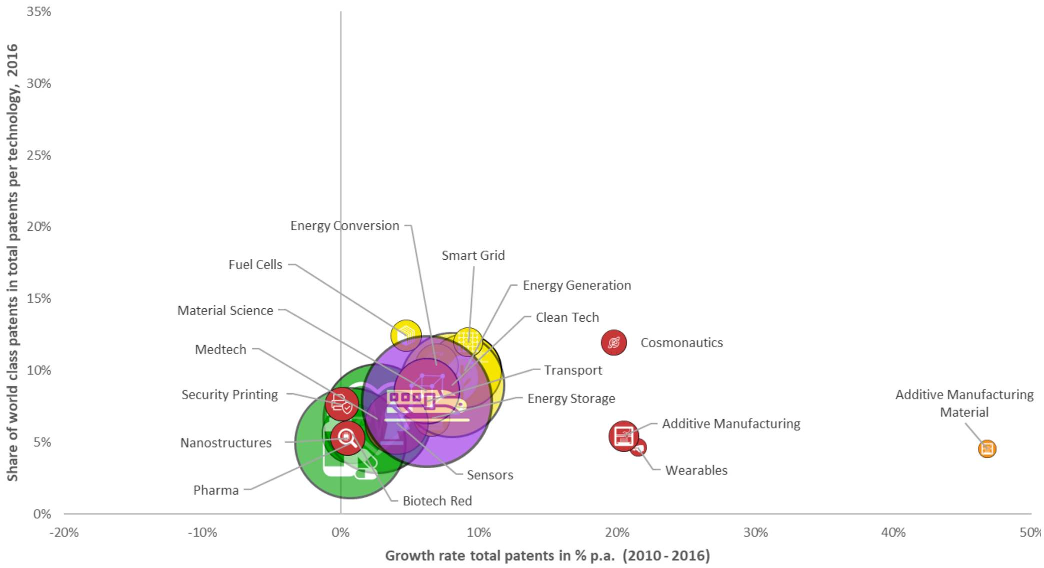
Focus technologies in the Hamburg region, number of patents in 2016, specialization index in 2016, annual growth between 2010 and 2016
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

The focus technologies for the Hamburg region are depicted in the table above. Transport, Pharma, Medtech and Clean Tech are the technologies with the highest number of active patents in the Hamburg region in 2016 with over 1,500 patents each.

The Hamburg region is highly specialized compared to Western Europe in Cosmonautics, Smart Grid, Pharma, Transport, Medtech and Clean Tech.

The technologies with the highest patent growth in the period between 2010 and 2016 were Additive Manufacturing Materials, Wearables, Additive Manufacturing and Cosmonautics.

**Fig. 2-7 Technology profile of the Hamburg region**




Bubble size: Number of total patents in a technology in 2016
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

Transport is the most important technology in terms of patent numbers. Airbus, Thyssenkrupp, Autoliv, and Jungheinrich are key companies. Hamburg is the largest German aviation industry hub and along with Toulouse, Europe's most important.

Energy patents rose annually by almost 10% between 2010 and 2016. There is also high research efficiency in Fuel Cells, Smart Grid and Energy Conversion. The top research companies in the Energy Sector are Airbus and Nordex.

The Hamburg region also has several companies/research institutes that are doing research in Material Science, such as Airbus, Beiersdorf, and Helmholtz Association.

The technology Additive Manufacturing Material stands out in the Hamburg region with its high annual growth rate of over 45% since 2010. The closely connected technology Additive Manufacturing (with its major application 3D-Printing) also developed dynamically. The top research companies in these two technologies are Airbus, SLM Solutions, and Siemens. Airbus is increasingly using 3D printing to produce aircraft components. By using 3D printing, certain parts can be produced quicker and less expensive than with conventional moulding techniques. Moreover, 3D-printed parts can be made lighter in weight. In the future, 3D printing is expected to gain further relevance not only in aviation, but also in areas such as Medtech and construction.

Another interesting technology in the Hamburg region is Cosmonautics. It is still a rather small technology, but it showed annual growth rates of nearly 20% between 2010 and 2016. Airbus Defence and Space is a division of Airbus responsible for defence and aerospace. The division is the world's second largest space company after Boeing.

Even though it is still a rather small technology and does not yet belong to the specialized technologies in the Hamburg region, Wearables showed strong growth in recent years. The research of Draegerwerk in Hamburg is one reason for this development

### 2.2.5 STRING

#### Tab. 2-6 Technology selection for STRING

| Technologies | Category | Number of patents | Specialization Index | Growth p.a. |
|---|---|---|---|---|
| Transport | WIPO | 4751 | 0.7 | 3.9% |
| Medtech | Life Science | 5498 | 1.2 | 1.5% |
| Pharma | Life Science | 4910 | 1.2 | -2.0% |
| Clean Tech | Energy | 3717 | 0.8 | 5.9% |
| Biotech Red | Life Science | 2799 | 1.2 | -0.3% |
| Energy Generation | Energy | 1579 | 0.7 | 4.7% |
| Sensors | Systems | 1442 | 0.6 | 4.4% |
| Material Science | Material | 1425 | 0.7 | 4.0% |
| Biotech White | Life Science | 1060 | 1.6 | 0.8% |
| Smart Factory M2M | Digital/IT | 1049 | 1.2 | 9.3% |
| Hearing Aids | Systems | 819 | 3.9 | 8.8% |
| Biotech Green | Life Science | 802 | 1.6 | 0.8% |
| Additive Manufacturing Material | Material | 118 | 1.3 | 24.1% |
| Drone | Systems | 98 | 1.1 | 11.8% |
| Cosmonautics | Systems | 97 | 1.1 | 13.9% |
| Wearables | Systems | 255 | 1.1 | 18.0% |
| Autonomous Driving | Systems | 101 | 0.7 | 17.3% |
| Smart Polymer | Material | 9 | 0.6 | 17.0% |
| Blockchain | Digital/IT | 16 | 0.7 | 12.5% |
| 3D Image Modelling | Digital/IT | 208 | 0.9 | 12.0% |
| Electro & Hybrid Vehicles | Systems | 284 | 0.6 | 11.5% |

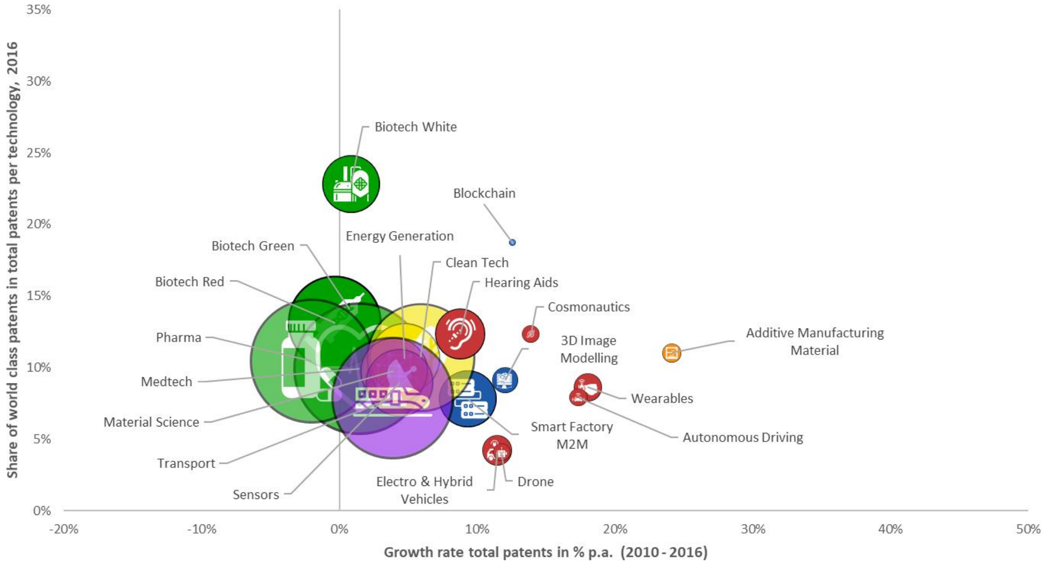
Focus technologies in STRING, number of patents in 2016, specialization index in 2016, annual growth between 2010 and 2016
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

The table above shows the focus technologies for STRING. Medtech, Pharma, Transport and Clean Tech are the technologies with the largest number of active patents in 2016.

There is a high specialization in STRING compared to Western Europe in all Life Sciences technologies as well as in Hearing Aids, Additive Manufacturing Material and Smart Factory.

The highest annual growth rates between 2010 and 2016 were recorded in Additive Manufacturing Material, Wearables and Autonomous Driving.

**Fig. 2-8 Technology profile of STRING**




Bubble size: Number of total patents in a technology in 2016
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

The technology profile of STRING shows a great number of patents in Medtech, Pharma, Biotech Red, Transport and Clean Tech. However, these technologies did not have high growth rates between 2010 and 2016.

The development of patents in Life Sciences technologies follows a clear pattern. While total patent numbers expanded rapidly between 2000 and 2010, they have stagnated or even decreased since then. This trend can also be observed in many other regions in developed countries. An explanation is that many Life Sciences patents were developed during the biotech boom related to the human genome project in the 1990s and at the start of the new millennium. Many of these patents have expired by now or have become obsolete due to technological advances. As patent protection is associated with annual costs, companies do not extend coverage for outdated patents. This has slowed down patent growth.

In terms of research efficiency, White Biotech is the top technology. White Biotech involves the use of biotech in industrial processes such as the production of new chemicals and materials or the development of new fuels for vehicles. The top research company in this tech field in STRING is Novozymes with 434 active patents in 2016.

While Life Sciences remains important in STRING, the development of patent numbers suggests that other technology fields have the potential to achieve higher growth in the coming years. For example, Additive Manufacturing Material, Wearables and Autonomous Driving all show very high patent growth. However, these technologies are still in their early stages.

## 2.3 Overview of top research companies and universities in STRING

What are the companies and research institutes behind these regional patent portfolios? The following tables list the top research companies and universities in STRING, according to patent numbers. The top 10 research companies among these are briefly introduced below:

Sony and Ericsson and their former joint venture Sony Ericsson mobile (operating until 2012) were a major research force in Øresund in the past, with a focus on Smart Factory and Data Security research. However, after Sony took full control of the joint venture in 2011, some research activities were shifted to locations in Japan and the UK. As the patents are regionally distributed by the scientists' addresses on the patent applications, Sony's patents still appear in the patent data for Øresund, even though research activities have been moved to other regions abroad.

Maxingvest is the holding company of Beiersdorf, which manufactures personal-care products and pressure-sensitive adhesives, and Tchibo, the German chain of coffee retailers. Maxingvest holds many patents in Pharma and Material Science.

The Airbus Group is the world's second-biggest aerospace and defense company. Hamburg is home to several Airbus sites (spares center, design office, production sites, final assembly line, training center). The Hamburg design office plays a pivotal role in the development and engineering of all Airbus aircraft. Airbus's main research priorities are Transport, Clean Tech, Material Science, and Cosmonautics.

The Danish pharma company Novo Nordisk has several research sites in Øresund. Its largest research center in Måløv houses early drug discovery laboratories, as well as facilities for production upscaling and formulation of lead medicine candidates. Novozymes is a global biotechnology company headquartered in Bagsværd outside of Copenhagen. It was founded in 2000 as a spin-off from Novo Nordisk. The company's focus is on research, development, and production of Biotech White applications including industrial enzymes, microorganisms, and biopharmaceutical ingredients.

Volvo is a Swedish manufacturing company with research sites in West Sweden (Gothenburg) and Øresund (Lund). Volvo's core activity is the production of trucks, buses and construction equipment. Its main research areas are Transport, Clean Tech and Energy Generation. Volvo Cars became independent from Volvo in 1999 when Volvo Cars was bought by Ford Motor Company. Later it was resold to the Chinese company Geely. Volvo Cars has developed many patents in Transport, Clean Tech and Autonomous Driving. A new research site was established 2013 in Gothenburg.

Essity AB is a global hygiene and health company, with headquarters in Stockholm and research sites in West Sweden. The company develops, manufactures and sells products and solutions within hygiene and health and has many patents in Medtech.

General Electric, or GE for short, is an American conglomerate that operates through the following segments: aviation, healthcare, power, renewable energy, digital industry, additive manufacturing, and oil and gas. GE Healthcare has research activities in the Oslo region (GE Vingmed Ultrasound) and has developed many patents in Pharma and Medtech. GE Vingmed Ultrasound focuses on the production of radiographic X-ray, fluoroscopic X-ray, and therapeutic X-ray apparatus and tubes.

**Tab. 2-7 Top research companies**

| Company | Research Region | Patents in 2016 | Focus Technologies (Patents) | Patent Growth 2010 –16 p.a. |
|---|---|---|---|---|
| Ericsson | Øresund | 2835 | Smart Factory (356), Data Security (233) | 6.9% |
| Sony | Øresund | 1246 | Smart Factory (250), Data Security (90), Image Analysis (72) | 4.4% |
| Maxingvest | Hamburg | 1220 | Pharma (590), Material Science (107), | -0.4% |
| Airbus Group | Hamburg | 1167 | Transport (941), Clean Tech (394), Material Science (129) | 9.7% |
| Novo Nordisk | Øresund | 774 | Pharma (365), Biotech Red (347), Medtech (309) | -2.1% |
| Volvo | West Sweden, Øresund | 775 | Transport (433), Clean Tech (231), Energy Generation (127) | -1.4% |
| Novozymes | Øresund | 736 | Biotech White (434), Biotech Green (190), Clean Tech (118) | 1.2% |
| Geely (Volvo Cars) | West Sweden | 681 | Transport (502), Clean Tech (96), Autonomous Driving (56) | 6.2% |
| Essity | West Sweden | 606 | Medtech (467), Pharma (23) | -0.4% |
| GE | Oslo | 482 | Pharma (131), Clean Tech (89) Medtech (79) | 1.4% |
| Henkel | Hamburg | 408 | Pharma (374) | 2.4% |
| Autoliv | West Sweden, Hamburg | 403 | Transport (392) | 2.9% |
| Haldor Topsoe | Øresund | 352 | Catalysts (174), Clean Tech (137), Energy Storage (58) | 5.8% |
| Oticon | Øresund | 350 | Hearing Aids (323), Medtech (64), Speech Analysis (36) | 9.8% |
| Borealis | West Sweden | 293 | Material Science (133), Catalysts (68), Clean Tech (10) | 4.7% |
| Siemens | Hamburg, Øresund | 290 | Clean Tech (114), Transport (81), Wind Energy (53) | 6.6% |
| Thyssenkrupp | Hamburg | 289 | Transport (209), Clean Tech (32) | 10.0% |
| Coloplast | Øresund | 273 | Medtech (259), Pharma (27) | -0.2% |
| Schlumberger | Oslo | 262 | Sensors (96), Transport (30) | 3.7% |
| Centerbridge Partners | Hamburg | 248 | Wind Energy (241), Clean Tech (235), Energy Generation (234) | 12.5% |

**Continuation of Table 2-7**

| | | | | |
|---|---|---|---|---|
| ABB | Oslo,<br>West Sweden | 245 | Energy Conversion (51),<br>Process Automation (51),<br>Clean Tech (41) | 0.7% |
| GN Store Nord | Øresund | 228 | Hearing Aids (151),<br>Smart Factory (16),<br>Speech Analysis (15) | 16.8% |
| Salzgitter | Hamburg | 207 | Medtech (32),<br>Material Science (15),<br>Clean Tech (10) | 6.9% |
| Jungheinrich | Hamburg | 204 | Transport (113),<br>Battery Tech (40),<br>Electro & Hybrid Vehicles (34) | 5.3% |
| Danaher | West Sweden,<br>Øresund | 194 | Medtech (105),<br>Biotech Red (37),<br>Sensors (24) | -1.5% |
| Draegerwerk | Hamburg | 193 | Medtech (106),<br>Sensors (52) | 13.4% |
| Aker Solutions | Oslo | 191 | Transport (26),<br>Clean Tech (22),<br>Energy Generation (8) | 10.5% |
| Cook Group | Øresund | 191 | Medtech (191) | 8.6% |
| WS Audiology | Øresund | 191 | Hearing Aids (173),<br>Medtech (48) | 6.7% |
| VW Group | Øresund,<br>Hamburg | 181 | Transport (60),<br>Energy Generation (59),<br>Material Science (20) | 2.2% |
| Olympus | Hamburg | 166 | Medtech (164) | 20.1% |
| Astra Zeneca | West Sweden,<br>Øresund | 165 | Pharma (143),<br>Biotech Red (35),<br>Medtech (23) | -16.8% |

Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

**Universities/research institutes**

There are also many top research institutes in STRING. The leading research institutes in terms of patent numbers are depicted in Table 2-8.

In the Oslo region, the University of Oslo and the Oslo University Hospital both have developed many patents in Life Sciences technologies.

In Øresund, two universities, the Technical University of Denmark and the University of Copenhagen, have the largest patent portfolios. While the Technical University of Denmark is active in the Energy Sector with a focus on Clean Tech and Energy Storage, the University of Copenhagen focuses on Life Sciences, especially Pharma, Biotech Red (medical applications) and Biotech White (industrial applications).

Helmholtz Association and Fraunhofer conduct research in the Hamburg region. Fraunhofer's focus is on Micromechanics and Sensors, whereas Helmholtz Association has developed many patents in Material Science, Clean Tech and Biotech Red (medical applications of Biotech). For example, the Institute of Materials Research at the

Helmholtz Zentrum Geesthacht employs more than 160 employees that develop ultra-lightweight materials and innovative process technologies for application in the fields of air and ground transportation, implantology and regenerative medicine, as well as energy storage and conversion.[13]

**Tab. 2-8 Top research institutes/universities**

| University/ Research institute | Research Region | Patents (2016) | Focus Technologies (Patents) | Patent Growth 2010 – 16 p.a. |
|---|---|---|---|---|
| Technical University of Denmark | Øresund | 342 | Clean Tech (79), Energy Storage (45) | 13.0% |
| Helmholtz Association | Hamburg | 207 | Material Science (47), Clean Tech (30), Biotech Red (26) | 2.5% |
| Fraunhofer | Hamburg | 172 | Micromechanics (49), Sensors (24) | 5.3% |
| University of Copenhagen | Øresund | 102 | Pharma (42), Biotech Red (40), Biotech White (17) | 9.8% |
| University of Kiel | Hamburg | 55 | Pharma (11), Nanostructures (10), Sensors (9) | 8.0% |
| Oslo University Hospital | Oslo | 44 | Biotech Red (25), Pharma (14), Medtech (10) | 8.4% |
| University of Oslo | Oslo | 42 | Pharma (22), Biotech Red (17), Medtech (7) | 3.1% |
| Chalmers University of Technology | West Sweden | 3 | Data Security (1), Clean Tech (1) | -14.5% |

Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

However, it must be noted that a university, research institute, or company can only be identified as connected to a patent if it is named as (co-)owner of the patent. Patenting strategy can differ quite substantially between research institutes and universities across countries and some universities do not register patents for their inventions. Therefore, some notable research institutes are not represented in the OECD Regpat database because they either do not file patents or only file patents at national patent offices, which are not included in the OECD Regpat Database.

Some examples for this in West Sweden include RISE Sweden, Chalmers University of Technology, and the University of Gothenburg. RISE is a state-owned network of Research and Technology Organisations (RTOs) that collaborate with academia, industry, and society as a central part of the Swedish innovation system. Chalmers University of Technology is known as one of the best universities in the field of engineering and technology. It has a strong tradition of cooperating with regional industrial partners, such as with Ericsson in the ICT sector, with Volvo on the future of transport, and with SKF on sustainability and environmental concerns. The University of Gothenburg is

[13] https://www.hzg.de/institutes_platforms/materials_research/index.php.en

another renowned university that has sizeable research activities in the fields of Life Sciences and Medicine.

The Lund University within the Øresund region is one of Scandinavia's largest research universities. The Lund University performs research in many areas such as nanotechnology, climate change, and stem cell biology.

The University of Hamburg is also considered one of the top universities worldwide. It is associated with many research institutes, among them the Heinrich Pette Institute–Leibniz Institute for Experimental Virology, the Alfred Wegener Institute for Polar and Marine Research, and the Max Planck Institute of Meteorology.

Although these institutions are important research institutes, they don't have any or hardly any patents registered at the European patent office. Therefore, it is important to also look at other innovation indicators such as scientific publications when comparing and evaluating universities and research institutes.

The CWTS Leiden Ranking provides information on the scientific performance of nearly 1,000 major universities worldwide. It measures the number of scientific publications as well as the absolute number and share of publications that belong to the top 10 percent within their discipline. According to the CWTS Leiden Ranking for the period 2014-2017, the universities of Oslo, Lund, Gothenburg, Copenhagen, Hamburg, and the Technical University of Denmark are among the 100 best universities throughout Europe in terms of top 10 percent publications.

## 2.4 Summary

This chapter has aimed to provide in-depth knowledge of the specific strengths and weaknesses in STRING and its member regions concerning their intellectual assets.

There are certain **common strengths** in all analysed regions. First, all regions have sizeable research activities in Life Sciences technologies and are also mostly specialized in these technologies, compared to Western Europe. However, it must be noted that patent growth has slowed down in recent years in most Life Sciences technologies.

Moreover, Transport is a very important technology for West Sweden and the Hamburg region. By contrast, the Oslo region and particularly Øresund are not specialized in Transport technologies, compared to Western Europe. Patent growth in Transport was also relatively modest in recent years. This is not surprising, given that many transport technologies are mature technology fields. So, while these technologies remain crucial parts of the economies, other more dynamic technologies are likely to gain relevance in the future.

Each analysed region also has **unique strengths** in certain technologies of the future:

- **Oslo region** is particularly strong in Sensors thanks to research efforts by Schlumberger and Petroleum Geo-Services. In addition, the Oslo region has many excellent patents in Image Analysis.

- **West Sweden** has a unique location advantage in the technologies of Electro & Hybrid Vehicles and Autonomous Driving. In both technologies, local carmakers Volvo and Volvo Cars/Geely are the top research companies.

- **Øresund** is a top region in Smart Factory, Hearing Aids, and Wearables. The companies Oticon, WS Audiology, and GN Store Nord are responsible for Øresund's strength in Hearing Aids. Oticon and WS Audiology are also research leaders in Wearables because there are some overlapping elements in the technologies of Hearing Aids and Wearables.

- **Hamburg region** is the leader in energy technologies and is also highly specialized in Cosmonautics, due to Airbus's extensive research efforts. In addition, the Hamburg region is also strong in Additive Manufacturing (3D-Printing) and Additive Manufacturing Materials. Again, Airbus is the driving force behind this development.

These results highlighting specific regional strengths provide input for location promoters to foster information exchange and cooperation between companies and regions in STRING in the future.

# 3 Green Technologies in STRING

## 3.1 Overview

Climate considerations and green growth are a key focus of STRING, and sustainable infrastructure connectivity is key to strengthen greater collaboration and the labour force on green technologies in the region. STRING advocates for new cross-border connections like an Øresund Metro between Copenhagen and Malmö, a tunnel between Helsingborg and Helsingør, a new railway between Oslo and Gothenburg and works to maximize the benefits of the coming Fehmarn Belt Fixed Link.[14] These projects improve connectivity and boost economic development for cities and regions in the STRING region. Moreover, STRING continues to support the railway system as a sustainable and environmentally-friendly means of transport.

In this chapter, we focus on the intellectual assets in STRING concerning green technologies. We develop a technology profile for green technologies and analyse how STRING compares to the San Francisco Bay Area – one of the best green tech regions in the world. The analysis again uses the tech definitions developed by BAK and the Swiss Patent Office based on patent data from the OECD Regpat.

The following technologies were selected as green technologies because they contribute to reducing climate gas emissions, energy consumption, and waste production:[15]

| Green Technology | Category |
|---|---|
| Clean Tech | Energy |
| Battery Lithium | Energy |
| Biomass Fermentation | Energy |
| Fuel Cells | Energy |
| Organic Perovskite Tandem Photovoltaic | Energy |
| Smart Grid | Energy |
| Wind Energy | Energy |
| Solar Energy | WIPO |
| Geothermal Energy | WIPO |
| Carbon Capture | Systems |
| Recycling Waste Reuse | Systems |
| Wastewater Treatment | Systems |
| Electro & Hybrid Vehicles | Systems |

[14] https://stringnetwork.org/initiatives/

[15] Green Biotech was not included in the selected green technologies because a major focus of Green Biotech is the development of Genetically Modified Organisms to boost agricultural productivity. Whether or not these products are ultimately more environmentally friendly is a topic of debate.

### 3.1.1 Patent portfolio in green technologies

Table 3-1 shows the patent portfolio and the development of patent numbers between 2010 and 2016 of the Oslo region, West Sweden, Øresund, Hamburg region and STRING in the selected green technologies.

In the BAK technology classification, the technology Clean Tech refers to any process, product, or service that reduces negative environmental impacts through significant energy efficiency improvements, the sustainable use of resources, or environmental protection activities. This field comprises all eco-friendly technologies that are used, for instance, in renewable energy, materials, information technology, green transportation, and recycling. Consequently, Clean Tech represents an umbrella term for several green technologies (most of the patents from other green technologies such as Wind Energy or Wastewater Treatment are included in Clean Tech). Therefore, it is an approximation for green technologies in total. However, it should be noted that different definitions for Clean Tech also exist, for example in Sweden.

Clean Tech patents in STRING dynamically increased by 5.9% per year between 2010 and 2016. The Hamburg region has most Clean Tech patents with 1,516 active patents in 2016, followed by Øresund with 1,217 patents, West Sweden with 734 patents and the Oslo region with 301 patents. Øresund has the highest research efficiency (13.7% of its total patents are world-class patents).

Among the single green technologies, Wind Energy is a key green technology in STRING. The Hamburg region leads in this technology with almost 500 active patents. Nordex, an important wind turbine maker, is headquartered in Hamburg. With annual Wind Energy growth rates of 12.2% in Øresund and 9.2% in the Hamburg region between 2010 and 2016, this green technology recorded the fourth strongest growth among the green technologies in STRING. The research efficiency in Wind Energy is also high in Øresund with its world-class patent share of 16.1%.

The leader in patents in Wastewater Treatment is Øresund with 180 active patents in 2016. In addition, Øresund is highly efficient in research with a 22.2% share of world-class patents. The reason for Øresund’s advances in Wastewater Treatment stems from the amount of plastics and microplastics in the marine environment, which is a serious problem for the Øresund region. Since microplastics occur more often in environments close to cities and since the Øresund region of the Baltic Sea is a shallow strait between two densely populated, coastal areas of Sweden and Denmark, authorities in the Øresund region joined forces to reduce wastewater discharges and to financially support research in Wastewater Treatment. The top research companies in this sector in Øresund are Veolia and Novozymes.

**Tab. 3-1 Patent portfolio in green technologies (2016) and annual patent growth between 2010 and 2016**

| | Oslo | | West Sweden | | Øresund | | Hamburg | | STRING | |
|---|---|---|---|---|---|---|---|---|---|---|
| Technologies | Patents (world-class) | Growth | Patents (world-class) | Growth | Patents (world-class) | Growth | Patents (world-class) | Growth | Patents (world-class) | Growth |
| Clean Tech | 301 (39) | 1.9% | 734 (62) | 4.5% | 1217 (167) | 5.6% | 1516 (136) | 8.0% | 3717 (398) | 5.9% |
| Wind Energy | 27 (5) | 3.0% | 33 (2) | 6.0% | 143 (23) | 12.2% | 499 (49) | 9.2% | 695 (79) | 9.2% |
| Wastewater Treatment | 63 (5) | 2.2% | 43 (7) | -0.3% | 180 (40) | 0.4% | 95 (6) | 1.3% | 374 (56) | 0.7% |
| Fuel Cells | 9 (0) | -4.0% | 25 (1) | 4.0% | 141 (21) | 4.4% | 137 (17) | 4.8% | 307 (39) | 4.2% |
| Electro & Hybrid Vehicles | 6 (1) | -2.2% | 155 (8) | 16.3% | 24 (1) | 17.0% | 103 (2) | 6.8% | 284 (12) | 11.4% |
| Solar Energy | 34 (3) | -1.6% | 19 (3) | 2.5% | 86 (9) | 4.8% | 75 (4) | 6.3% | 211 (18) | 3.8% |
| Smart Grid | 25 (2) | 8.6% | 9 (1) | 17.0% | 38 (5) | 11.3% | 117 (14) | 9.2% | 188 (22) | 9.8% |
| Biomass Fermentation | 2 (0) | 3.7% | 18 (0) | 17.0% | 100 (17) | 12.1% | 37 (0) | 4.6% | 169 (17) | 9.1% |
| Battery Lithium | 2 (0) | -5.6% | 10 (0) | 38.9% | 25 (4) | 1.8% | 54 (11) | 18.0% | 91 (15) | 11.3% |
| Organic Perovskite Tandem Photovoltaic | 14 (1) | 1.1% | 4 (0) | 0.0% | 9 (0) | -1.5% | 7 (2) | 2.2% | 32 (3) | 0.0% |
| Recycling Waste Reuse | 1 (0) | -14.5% | 1 (0) | -9.4% | 8 (0) | 4.2% | 16 (3) | 6.9% | 26 (3) | 3.1% |
| Carbon Capture | 4 (0) | 4.2% | 3 (0) | 6.0% | 10 (0) | 25.8% | 7 (0) | 2.2% | 24 (0) | 9.2% |
| Geothermal Energy | 9 (1) | 12.3% | 4 (0) | 4.2% | 0 (0) | -100.0% | 2 (0) | -9.4% | 15 (1) | 3.2% |

Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

Fuel Cells is another important green technology in STRING with 307 active patents in 2016. A fuel cell is an electrochemical cell that converts chemical energy from a fuel into electricity through an electrochemical reaction of hydrogen fuel with oxygen or another oxidizing agent. Most of the Fuel Cell patents were developed in Øresund (141 active patents in 2016) and in the Hamburg region (137 active patents in 2016). While West Sweden and the Oslo region do not have many world-class patents in Fuel Cells, Øresund's share of 14.9% and Hamburg's share of 12.4% world-class patents both reflect their high levels of efficiency. The top research companies in Fuel Cells in

Øresund are Haldor Topsoe, the Technical University of Denmark, and Peugeot. In the Hamburg region, the top companies are Airbus Group, Thyssenkrupp, and Siemens.

Patent growth has been very dynamic in the technology of Electro & Hybrid Vehicles since 2010. In 2016, there were around 284 active patents in STRING in this area. Out of these, most patents were developed either in West Sweden (155 patents) or in the Hamburg region (102). Volvo and Geely (Volvo Cars) are the top patent companies in this technology in West Sweden, while Kion Group and Jungheinrich have developed the most Electro & Hybrid Vehicles patents in the Hamburg region. However, research efficiency in Electro & Hybrid Vehicles is relatively low in all STRING regions except for the Oslo Region. Despite having the world's highest number of Electric Vehicles per inhabitant in the city of Oslo, the total number of Electro & Hybrid patents is still small there, though.

In Solar Energy, there are around 210 active patents in STRING. Out of these, 86 patents were developed in Øresund, 75 in the Hamburg region, 34 in the Oslo region and 19 in West Sweden. Despite the Oslo region's rather small absolute number of patents, it is the leader in Solar Energy in terms of patents per capita. The government of Norway is investing in renewable and climate-friendly stationary energy technology. Its ambition is to develop and maintain a solar industry that is globally competitive. The government funds, among other things, SUSOLTECH, the research centre for sustainable solar cell technology, which cooperates with many companies, universities and research institutes.

A Smart Grid is an electricity network that is used to supply electricity to consumers via two-way digital communication. This system allows for monitoring, analysis, control and communication within the supply chain to help improve efficiency, reduce energy consumption and cost, and maximize the transparency and reliability of the energy supply chain. Electrical meters that record consumption of electric energy in real-time while simultaneously communicating the information back to the utility for monitoring and billing purposes is one example of such technology. The Hamburg region is a technology leader in Smart Grid. It has both the largest patent portfolio and the most world-class patents in Smart Grid technologies among the analysed regions. However, growth in patent numbers was stronger in West Sweden and Øresund.

Øresund has the largest patent portfolio in Biomass Fermentation. The term "biomass" refers to plant-based materials that are not used for food or animal feed, but as sources of energy. This energy is harnessed either directly via combustion to produce heat, or indirectly after converting the biomass to various sorts of biofuel. Among the analysed regions, Øresund is the only region in possession of world-class patents in this technology, and patent numbers have grown robustly in recent years. Only in West Sweden was a higher annual patent growth rate recorded. Novozymes and Veolia Environnement are the biggest research companies in Øresund.

The green technology with the second-highest annual growth rate in STRING is Battery Lithium. Lithium batteries stand apart from other batteries in their high-charge density (long life). Lithium batteries are widely used in portable consumer electronic devices as well as in electric vehicles ranging from full-sized vehicles to radio-controlled toys. West Sweden has seen the most dynamic patent growth with an annual growth rate of almost 39% between 2010 and 2016. However, the patent numbers in Battery Lithium in West Sweden are rather small. Geely, the owner of Volvo Cars, is the top research company in Battery Lithium located in West Sweden. Nonetheless, West Sweden does not have any world-class patents in Battery Lithium. In contrast, the Hamburg region and Øresund have high research efficiencies with shares of world-class patents of 20.4% and 16.0%, respectively.

Research activities in Organic Perovskit Tandem Photovoltaic, Recycling Waste Reuse, Carbon Capture, and Geothermal Energy are still limited in the analysed regions and, therefore, patents numbers remain relatively low.

### 3.1.2 Comparison with the San Francisco Bay Area

For the remainder of this section, the patent portfolio in green technologies of STRING will be compared to the portfolio of the San Francisco Bay Area, which is one of the world leaders in green technologies. For example, the San Francisco Bay Area ranks on the top spot in the US Clean Tech Leadership Index.[16]

As mentioned above, Clean Tech is an umbrella term for several green technologies and therefore, it has, among the considered green technologies, the highest number of patents both in STRING (over 3,700 active patents in 2016) and in the San Francisco Bay Area (almost 6,000 active patents in 2016).

In per capita numbers, the San Francisco Bay Area shows a patent intensity more than twice as concentrated as that of STRING. In 2016, the San Francisco Bay Area had 0.7 active patents per 1,000 inhabitants, while STRING only had 0.3 active patents in Clean Tech per 1,000 citizens.

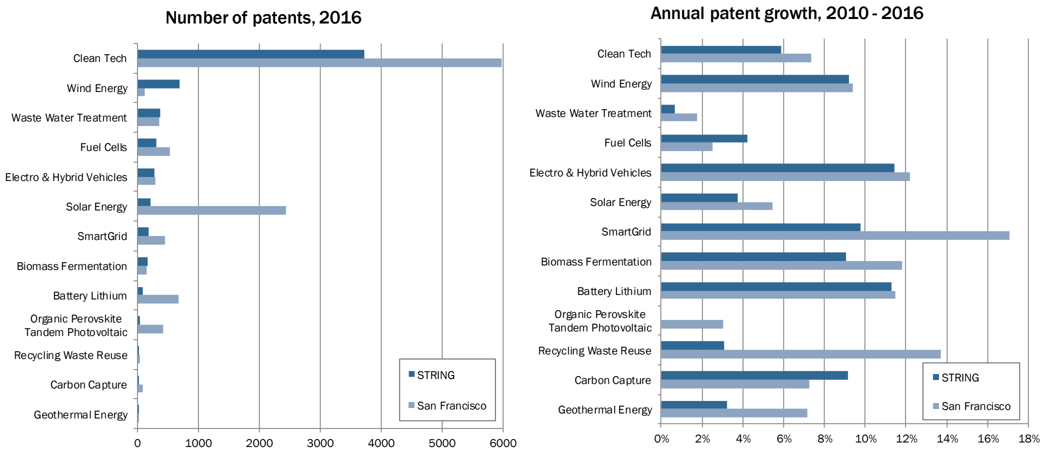
However, there are green technologies where STRING is clearly ahead of the San Francisco Bay Area. For example, Wind Energy is a key green technology in STRING with almost 700 active patents in 2016. In the San Francisco Bay Area, the patent portfolio in Wind Energy only amounted to 122 patents in 2016.

STRING also has slightly more patents in Wastewater Treatment (374 active patents in 2016) compared to the San Francisco Bay Area (362 active patents in 2016).

In the technology of Electro & Hybrid vehicles, STRING and the San Francisco Bay Area are on equal footing with a similar number of patents and similar patent growth rates.

[16] https://cleanedge.com/reports/2017-US-Clean-Tech-Leadership-Index

## Fig. 3-1 Size of green technologies/Patent growth in green technologies




Number of patents in green technologies: Total number of active patents in Green technologies in 2016
Annual patent growth in green technologies: Annual growth of patent numbers between 2010 and 2016
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

By contrast, the San Francisco Bay Area enjoys a lead in Fuel Cells with almost 530 active patents compared to only around 300 in STRING. However, between 2010 and 2016, patent growth in Fuel Cells was more dynamic in STRING. The only other technology in which STRING achieved higher patent growth compared to the San Francisco Bay Area was Carbon Capture.

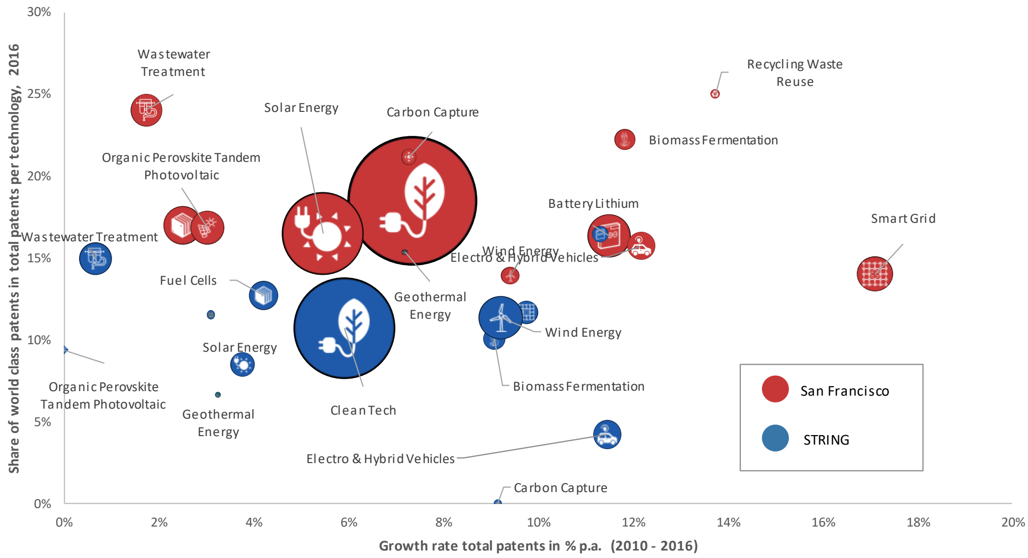
The green technology with the largest difference between STRING and the San Francisco Bay Area is Solar Energy. While there were more than 2,400 active patents in the San Francisco Bay Area in this technology, there were only 211 active patents in STRING in 2016. The City of San Francisco started in 2008 to give local incentives for the installation of photovoltaic systems. These incentives in combination with the favourable climate conditions increased the market size for producers of photovoltaic systems. This, in turn, has boosted regional research activities in Solar Energy.

Another technology with a rather large difference between STRING and the San Francisco Bay Area is Battery Lithium. STRING has only 91 active patents in Battery Lithium while San Francisco recorded 679 active patents in 2016. The top research companies in Battery Lithium in San Francisco are Intel and Bosch. Also, the recent development in electro-car manufacturing contributes to robust research activities. Tesla, with its headquarters in the San Francisco Bay region, also holds some patents in this technology and has shown high patent growth in Battery Lithium in recent years.

## 3.2 Green technology profile of STRING and San Francisco

Figure 3-2 shows the green technology profiles of STRING and the San Francisco Bay Area. The blue bubbles illustrate the green technologies in the STRING, while the red bubbles show the profile of the San Francisco Bay Area.

**Fig. 3-2 Green Technology profile: STRING vs. San Francisco**




Bubble size: Number of total patents in a technology in 2016. Blue bubbles represent STRING, red bubbles represent the San Francisco Bay Area
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

In total, the number of active patents in green technologies is higher in the San Francisco Bay Area which also enjoys, on average, higher research efficiency in green technologies compared to STRING. This means that a higher number of patents in the San Francisco Bay Area are considered world-class. Moreover, most green technologies in the San Francisco Bay Area recorded higher annual patent growth rates.

On the level of single green technologies, the San Francisco Bay Area outperforms STRING in Smart Grid, Organic Perovskite Tandem Photovoltaic, Battery Lithium and Solar Energy. Top research companies in the San Francisco Bay Area in these technologies are Enphase Energy, Cisco, and Total in Smart Grid, Total and Hanergy in Organic Perovskite Tandem Photovoltaic, Total, Lumileds and Apple in Solar Energy, and Intel, Bosch, and Energous in Battery Lithium.

However, there are also green technologies where STRING is on an equal footing or has even forged ahead of San Francisco. Both regions have a comparable patent portfolio size in Wastewater Treatment and Electro & Hybrid Vehicles and yet, STRING has many more patents in Wind Energy. The top research companies in the San Francisco Bay Area in these technologies are Thermo Fisher, Chevron, and Xerox in Wastewater Treatment, Tesla, and Bosch in Electro & Hybrid Vehicles, and Alphabet in Wind Energy.

## 3.3 Summary

STRING lags behind the San Francisco Bay Area in most green technology research areas and the latter region's lead is even more significant when patent numbers are adjusted for population size. Nevertheless, STRING's results are auspicious for the coming years. Clean Tech patents in STRING – an umbrella term that is an approximation for green technologies in total – increased by 5.9% per year between 2010 and 2016. This patent growth was more dynamic than what was seen for the average of future technologies analysed in chapter 2. The most important single green technologies in STRING are Wind Energy, Wastewater Treatment, and Fuel Cells.

Moreover, it should be acknowledged that the San Francisco Bay Area achieves outstanding scores in green technologies. If one compares STRING to the average patent growth/efficiency in Germany, Denmark, Sweden and Norway, the results for STRING are more compelling. For example, annual green technology patent growth between 2010 and 2016 in Germany was 5.1%, in Denmark 11.1%, in Norway 2.3% and in Sweden 6.1%, whereas patent growth in STRING reached 5.9%. In addition, research efficiency in STRING, which is at 11.1%, is higher, on average, than in the associated countries except for Denmark, where 14.6% of the patents in green technology are rated world-class. For comparison, green technology in Western Europe grew by 5.8% p.a. and only 8.6% of its patents in green technology are rated world-class.

However, it must be mentioned that there are notable differences in the distribution of intellectual assets in green technologies within STRING. According to the patent statistics, most green tech research activities take place within the Hamburg region and Øresund. The Hamburg region is particularly strong in Wind Energy and Fuel Cells, whereas Øresund excels in Wastewater Treatment and in Fuel Cells. Øresund also has the highest research efficiency. The patent portfolios of West Sweden and the Oslo region in green technologies are significantly smaller, even though West Sweden is the leader in Electro & Hybrid Vehicles. Considering these differences in the regional distribution of intellectual assets, stakeholders in all regions could benefit from increased collaboration in cross-border research and development.

# 4 Research interdependencies

## 4.1 Intra-STRING research interdependencies

This chapter focuses on linkages between the Oslo Region, West Sweden, Øresund and the Hamburg region. Regional growth and innovation studies stress that increased inter-regional cooperations and linkages enhance innovation.[17] Linkages are also analysed in the Regional Innovation Scoreboard (see chapter 1). In the RIS, linkages are measured by public-private co-publications and the number of innovative SMEs collaborating with others. We focus instead on research linkages in the development of patents. Patents are distributed geographically, based on the inventors' addresses. Therefore, patents can be linked to several regions because:

- scientists are commuting between regions,
- a large company develops a patent where scientists from different company departments and from different regions are involved,
- there are collaborations between companies/research institutes from different regions.

Table 4-1 shows research collaborations between the four analysed regions. The number of patents developed with researchers from other regions is relatively small in total. The number of co-researchers from other regions is generally somewhat higher in world-class patents.

The **Oslo region** is the second most interconnected region. About one-fifth of all patents in Fuel Cells and Additive Manufacturing are invented with scientists from at least one other region. Considerable collaborations between the Oslo region and the other regions take place in Nanostructures (13%), Energy Storage (10%) and Material Science (8%). There are also cooperations within the Life Sciences Industries, mostly in Medtech (8%), Pharma (8%) and Biotech Red (5%) and Biotech White (7%).

**West Sweden** is the most interconnected region. West Sweden has co-inventions in all Life Sciences Technologies from Biotech Green (21%), Biotech Red and White (12%), Pharma (15%) to Medtech (7%). One-fifth of the patents are co-invented with partners in Fuel Cells and Image Analysis. About 10% of the patents involve a researcher from the other regions in Transport, Energy Storage, Hearing Aids, Nanostructures, Additive Manufacturing, Speech Analysis, and 3D Image Modelling.

In **Øresund** most patents with co-inventors from other regions are active in transport-related technologies: Autonomous Driving (22%), Hybrid & Electric Vehicles (14%) as well as Transport (11%). 14% of the patents in Additive Manufacturing Material are co-invented with one researcher of other regions and 9% in Additive Manufacturing. Within the Life Sciences Industries, co-inventions are not very common in Øresund which may

[17] Summary of discussion for example in: Broekel, T. and Meder, A. (2008): The bright and dark side of cooperation for regional innovation performance, Jena economic research papers 2008, 053, University of Jena and Max-Planck-Institut für Ökonomik, Jena.

be due to the large Life Sciences cluster there. Almost 9% of the patents in Energy Generation are co-invented.

Research interdependencies are low between the **Hamburg region** and the other regions and mostly below 2%. Cooperation is only slightly higher in Biotech technologies. Most cooperations take place in Biotech Green (7%).

**Tab. 4-1 Regional Research interdependencies**

| | Oslo | West Sweden | Øresund | Hamburg |
|---|---|---|---|---|
| Total patents | 3.0% | 5.8% | 3.0% | 0.6% |
| World-class patents | 5.2% | 8.8% | 3.5% | 0.9% |
| Focus technologies | 4.4% | 6.7% | 3.8% | 0.8% |
| World-class focus Technologies | 8.8% | 10.0% | 4.5% | 1.2% |
| Transport | 2.4% | 3.2% | 11.1% | 0.3% |
| Medtech | 7.7% | 7.6% | 3.9% | 0.7% |
| Pharma | 7.8% | 15.5% | 4.9% | 1.2% |
| Biotech Red | 4.8% | 12.3% | 3.3% | 3.1% |
| Biotech Green | 1.8% | 20.8% | 3.6% | 7.0% |
| Biotech White | 6.7% | 12.7% | 1.7% | 2.8% |
| Clean Tech | 3.6% | 5.9% | 4.0% | 0.7% |
| Energy Generation | 3.2% | 6.9% | 8.8% | 1.1% |
| Energy Conversion | - | 0.8% | 0.5% | - |
| Energy Storage | 10.0% | 12.8% | 2.9% | - |
| Smart Grid | 4.0% | - | 2.6% | - |
| Fuel Cells | 22.2% | 20.0% | 2.1% | - |
| Material Science | 8.1% | 6.0% | 4.8% | 0.5% |
| Additive Manufacturing Material | - | 5.6% | 14.3% | - |
| Sensors | 0.7% | 3.2% | 1.6% | 0.2% |
| Hearing Aids | - | 10.4% | 0.7% | - |
| Nanostructures | 12.7% | 11.2% | 6.3% | 0.6% |
| Electro & Hybrid Vehicles | - | 2.5% | 14.8% | - |
| Autonomous Driving | - | 2.2% | 22.2% | - |
| Additive Manufacturing | 20.0% | 10.8% | 8.9% | 0.7% |
| Cosmonautics | - | - | - | - |
| Data Security | 1.0% | 6.5% | 2.1% | - |
| Smart Factory | 1.6% | 7.7% | 1.2% | - |
| Smart City | 7.1% | 2.0% | 7.7% | - |
| Image Analysis | 1.3% | 19.7% | 3.6% | 0.7% |
| Speech Analysis | - | 11.1% | 0.6% | - |
| 3D Image Modelling | - | 11.8% | 1.5% | - |
| Fintech | - | - | - | - |

Share of patents in a technology, which are also registered in at least one other region
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

The following tables show the share of patents in a region which are linked to one of the other analysed regions. For example, Table 4-2 lists the share of patents from the Oslo region in Biotech Red that also name scientists from Øresund on the patent application (3.8%). By contrast, Table 4-4 offers Øresund's perspective and lists the percentage of Biotech Red patents from Øresund developed together with scientists from the Oslo region (0.7%).

The selected technologies represent the 10 technologies with the most research interdependencies among the focus technologies of each region (see chapter 2).

**Tab. 4-2 Research interdependencies in the Oslo region[18]**

| Technologies | Patents | Øresund | Hamburg | West Sweden |
|---|---|---|---|---|
| Medtech | 339 | 3.8% | - | 3.8% |
| Pharma | 475 | 6.5% | 0.2% | 1.1% |
| Biotech Red | 316 | 3.8% | 0.6% | 0.3% |
| Biotech White | 60 | 5.0% | 1.7% | - |
| Energy Storage | 20 | - | - | 10.0% |
| Fuel Cells | 9 | - | - | 22.2% |
| Material Science | 37 | - | - | 8.1% |
| Nanostructures | 71 | 12.7% | - | - |
| Additive Manufacturing | 15 | 13.3% | - | 6.7% |
| Smart City | 14 | 7.1% | - | - |

Share of patents in a technology in the Oslo region, which are also registered in another region of the STRING region
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

The research interdependencies in the Oslo region are shown in Table 4-2. The most research interdependencies of all technologies were observed in Additive Manufacturing. 13.3% of the Oslo region's patents also list scientists from Øresund. Another 6.7% of the patents were created in cooperation with scientists from West Sweden. In Nanostructures, 12.7% of the Oslo region's patents were created in collaboration with Øresund. Pharma is a technology in which the Oslo region has research interdependencies with all other analysed regions.

[18] The tables on research interdependencies use patent data from 2017. Since not all patents from 2017 have been added to the OECD Regpat Database yet, we used patent data for 2016 for the patent portfolios in chapters 2 and 3 to avoid distortion of patent growth rates. As we are not focusing on patent growth concerning research interdependencies and technology combinations, we have used the latest data for 2017 for the following chapters.

**Tab. 4-3 Research interdependencies in West Sweden**

| Technologies | Patents | Øresund | Hamburg | Oslo |
|---|---|---|---|---|
| Pharma | 427 | 14.3% | - | 1.2% |
| Biotech Red | 253 | 11.9% | - | 0.4% |
| Biotech Green | 53 | 20.8% | - | - |
| Biotech White | 55 | 12.7% | - | - |
| Energy Storage | 47 | 8.5% | - | 4.3% |
| Nanostructures | 98 | 10.2% | 1.0% | - |
| Additive Manufacturing | 111 | 9.0% | 0.9% | 0.9% |
| Smart Factory M2M | 143 | 7.0% | - | 0.7% |
| Image Analysis | 76 | 18.4% | - | 1.3% |
| Speech Analysis | 9 | 11.1% | - | - |

Share of patents in a technology in West Sweden, which are also registered in another region of the STRING
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

Table 4-3 shows the research interdependencies of West Sweden. 20.8% percent of all Biotech Green patents that list a scientist from West Sweden on the patent also include at least one scientist from Øresund. There is also sizeable cooperation with Øresund in Image Analysis and Pharma.

**Tab. 4-4 Research interdependencies in Øresund**

| Technologies | Patents | Hamburg | West Sweden | Oslo |
|---|---|---|---|---|
| Transport | 433 | 0.5% | 10.4% | 0.2% |
| Pharma | 2228 | 0.8% | 2.7% | 1.4% |
| Biotech Red | 1667 | 0.8% | 1.8% | 0.7% |
| Biotech Green | 556 | 1.4% | 2.0% | 0.2% |
| Energy Generation | 352 | 2.3% | 6.0% | 0.6% |
| Energy Storage | 139 | - | 2.9% | - |
| Material Science | 437 | 0.7% | 4.1% | - |
| Electro & Hybrid Vehicles | 27 | - | 14.8% | - |
| Autonomous Driving | 9 | - | 22.2% | - |
| Additive Manufacturing | 135 | - | 7.4% | 1.5% |

Share of patents in a technology in Øresund, which are also registered in another region of the STRING
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

There is extensive research cooperation between Øresund and West Sweden in transport related technologies. In Autonomous Driving, 22.2% of the patents in Øresund also have inventors from West Sweden listed on the patent applications. In Electro & Hybrid Vehicles, Øresund shares 14.8% of its patents with West Sweden.

In Additive Manufacturing, most research interdependencies also take place between Øresund and West Sweden (7.4%).

**Tab. 4-5 Research interdependencies in the Hamburg region**

| Technologies | Patents | Øresund | West Sweden | Oslo |
|---|---|---|---|---|
| Transport | 2362 | 0.1% | 0.1% | 0.1% |
| Medtech | 1648 | 0.7% | 0.1% | - |
| Pharma | 1611 | 1.1% | - | 0.1% |
| Biotech Red | 490 | 2.7% | - | 0.4% |
| Biotech Green | 115 | 7.0% | - | - |
| Biotech White | 145 | 2.1% | - | 0.7% |
| Clean Tech | 1518 | 0.6% | - | 0.1% |
| Energy Generation | 747 | 1.1% | - | - |
| Material Science | 608 | 0.5% | - | - |
| Additive Manufacturing | 153 | - | 0.7% | - |

Share of patents in a technology in the Hamburg region, which are also registered in another region of the STRING region
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

The Hamburg region cooperates significantly in Biotech Green with inventors from Øresund.

## 4.2 Co-ownership of patents in STRING

This section examines research cooperation between companies and/or research institutes where at least one company is situated in STRING. The analysis is based on co-owned patents, which are created when companies cooperate on new inventions and decide to share the intellectual property.

Table 4-6 shows the top patent co-owners in STRING where at least one owner is based in STRING (Owner 1 in the table). There are some patent licensing companies that buy and hold patents together with other patent entities. However, we have focused only on companies/research institutes in STRING that are active in research and have really developed patents in connection with other companies/research institutes.

**Tab. 4-6 Top co-owners of patents in STRING**

| Owner 1 (average rating) | Region | Owner 2 (average rating) | Patents | Research focus | Rating of cooperation |
|---|---|---|---|---|---|
| Oticon (5.4) | Øresund | Sennheiser (4.7) | 23 | Hearing Aids | 4.7 |
| Airbus Group (6.4) | Hamburg | Helmholtz Association (4.7) | 11 | Transport, Clean Tech | 6.6 |
| Geely (4.8) | West Sweden | Bosch (4.3) | 9 | Transport | 2.2 |
| Technical University of Denmark (5.9) | Øresund | University of Copenhagen (5.3) | 9 | Biotech White, Medtech | 5.9 |
| Volvo (7.0) | West Sweden | Geely (4.8) | 9 | Transport, Clean Tech | 7.4 |
| Fraunhofer (4.7) | Hamburg | Charité (4.4) | 7 | Medtech, Image Analysis | 4.1 |
| Novo Nordisk (5.9) | Øresund | Innate Pharma (8.0) | 7 | Pharma, Biotech Red | 8.0 |
| Zealand Pharma (9.7) | Øresund | Boehringer Ingelheim (8.0) | 3 | Biotech Red | 9.7 |
| Airbus Group (6.4) | Hamburg | Fraunhofer (4.7) | 3 | Transport, Material Science | 7.0 |
| AstraZeneca (6.9) | West Sweden | Bayer (7.7) | 2 | Pharma, Biotech Red | 9.5 |

Top co-owners of patents in the STRING with average rating of the owners' patents, region of owner 1, number of co-owned patents, research focus and average rating of the co-owned patents. Patents are rated 1 to 10, where a rating of 10 means a patent is world-class.
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

In total, the number of co-ownership patents is relatively small. Because of bureaucratic difficulties, companies that cooperate often decide to register their co-created patents with just one company and instead deploy patent licensing or other remunerations for the research partner. Still, there are some interesting examples of research cooperations:

- Oticon, one of the world's largest producers of hearing aids from Copenhagen, has extensive research cooperation with German headphones manufacturer Sennheiser. Both companies belong to the William Demant Holding and hold 23 patents together in the technology of Hearing Aids.

- Airbus and the Helmholtz Association started a cooperation with the DLR (German Aerospace Center) and Siemens on an electro-engine for planes. This cooperation started in 2016 and has already yielded 11 co-owned patents for Airbus and the Helmholtz Association. It is noteworthy that these co-owned patents are rated higher, on average, than the patent portfolios of either Airbus or the Helmholtz Association.

- Geely/Volvo Cars co-owns 9 patents of the German automotive supplier Bosch. The research focus lies in Transport technologies. However, the co-owned patents are rated relatively low.

- There are also cases where two universities cooperate and develop patents together. The Technical University of Denmark and the University of Copenhagen have developed 9 patents together with a focus on White Biotech and Medtech.

- Since 2009, Bayer has been collaborating with Ardea Biosciences Inc., a wholly-owned subsidiary of AstraZeneca. They develop small-molecule mitogen-activated ERK kinase (MEK) inhibitors for the treatment of solid tumors. The co-owned patents of AstraZeneca are rated very high (world-class patents) and significantly higher than the average of the patent portfolios of AstraZeneca and Bayer. Moreover, in 2011 they decided to share their knowledge to increase coverage of chemical space.

- Another interesting research cooperation in the Life Sciences area exists between Zealand Pharma and Boehringer Ingelheim. They have a longstanding partnership focusing on innovative peptide-based medicines for cardiometabolic diseases. Together they hold 3 patents in Biotech Red that are rated as world-class patents (decile 10).

## 4.3 Summary

In STRING, most research interdependencies can be found between Øresund and West Sweden. However, due to the geographical proximity, a sizeable share of common patents is due to commuters.

Concerning single technologies, there are certain tech fields where the level of interregional cooperation is already high. Good examples include Additive Manufacturing (research connection between the Oslo region, Øresund and West Sweden), Biotech Green (Hamburg region and Øresund) as well as Transport and car-related technologies between West Sweden and Øresund.

However, there are also important regional technologies where the amount of interregional cooperation is still very limited, such as Medtech or Clean Tech.

Overall, there are some hints that cooperations may, in fact, lead to better patent results given that the share of co-inventorships is slightly higher in world-class patents compared to the rest and some co-owner patents score better than single patents. However, the available data on co-owner patents are too small to give a conclusive answer in this regard.

# 5 Analysis of the potential of technology combinations

Patents are often relevant for more than one technology. This is because patents are generally categorized into several patent classes. Technologies are defined by grouping relevant patent classes and there are often overlapping technologies. Innovations often emerge not solely from discovering new technologies, but also from linking existing technologies intelligently. Therefore, combining technologies can lead to excellent research results. Patents that are assigned to multiple technologies are often rated higher than regular patents.

In this chapter, an analysis of technology combinations for the Oslo region, West Sweden, Øresund and the Hamburg region as well as STRING has been performed to identify which combinations lead to better results in terms of the respective patents achieving a better rating. The results for STRING have been compared to the results of the global average. Moreover, a heatmap for STRING regions was created to show which technologies in STRING already have an advanced level of digitization (patent combinations with a digital technology).

## 5.1 Technology combinations in STRING

In the following, a selection of two interesting technologies and the associated technology combinations is shown for each STRING region as well as for STRING as a single region. The selection was based on the key technological strengths of each region. In addition, only technologies with an established high-level of combinations present in STRING and combinations with a certain minimum level of patents were considered.

**Reading guide for the technology combination figures:**

The following figures concerning the technology combinations can be read as follows:

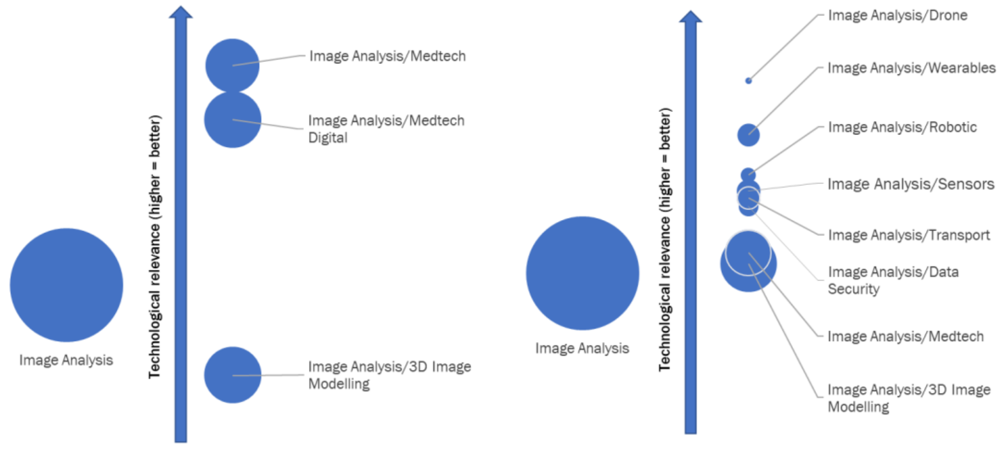
The left half of the graph shows the combinations within the named region. The left side of figure 5-1 for example shows the combinations in the Oslo region. The right side depicts the global combinations in the same technology under consideration.

Each half of the figure is constructed identically. The bubble on the left side of the arrow shows the average rating of all patents that are registered in the considered technology. On the right-hand side of the arrow, the average ratings for patents that are registered in the considered technology and one other technology are displayed. These patents are called technology combinations. Each patent counted on the right side of the arrow is also part of the bubble on the left side.

The size of the bubbles indicates the number of patents. The vertical position of the bubbles provides information on the rating of the patents. The higher up a bubble is located, the better the average patent rating is.

## 5.2 Oslo Region

### Fig. 5-1 Image Analysis: Oslo Region vs. World




Left side: Oslo Region; Right side: World
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

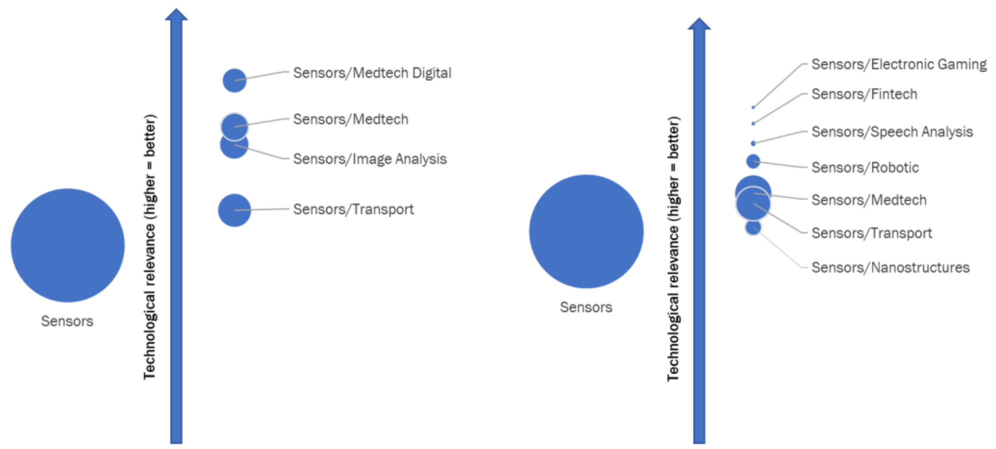
The term "image analysis" describes the extraction of information from images. The applications of digital image analysis are continuously expanding, and the technology is now used in countless areas of science and industry including astronomy, defence, machine vision, medicine, robotics and many more. In the medical field, image analysis plays an important role in tracking diseases and assessing treatment effects. Digital image analysis in the form of facial recognition is also used to improve security standards. Moreover, image analysis plays a crucial role in the development of autonomous vehicles.

The chart above shows the existing technology combinations in the Oslo region in Image Analysis compared to global averages. In general, Image Analysis is the strength of the Oslo region (see chapter 2). However, Image Analysis patents from the Oslo region are ranked, on average, slightly lower than the global average. Still, its patent ratings in image analysis are higher when compared to Western Europe.

The Oslo region achieves very good results when looking at technology combinations. Most image analysis combinations in the Oslo region take place with Medtech and Digital Medtech and in these combinations, patents from the Oslo region are rated significantly higher than the global average.

On a global level, there are many image analysis combinations with sensors, transports, and wearables. These combinations are not yet present in the Oslo region, but they could provide promising areas for future research in the region.

### Fig. 5-2 Sensors: Oslo Region vs. World




Left side: Oslo Region; Right side: World
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

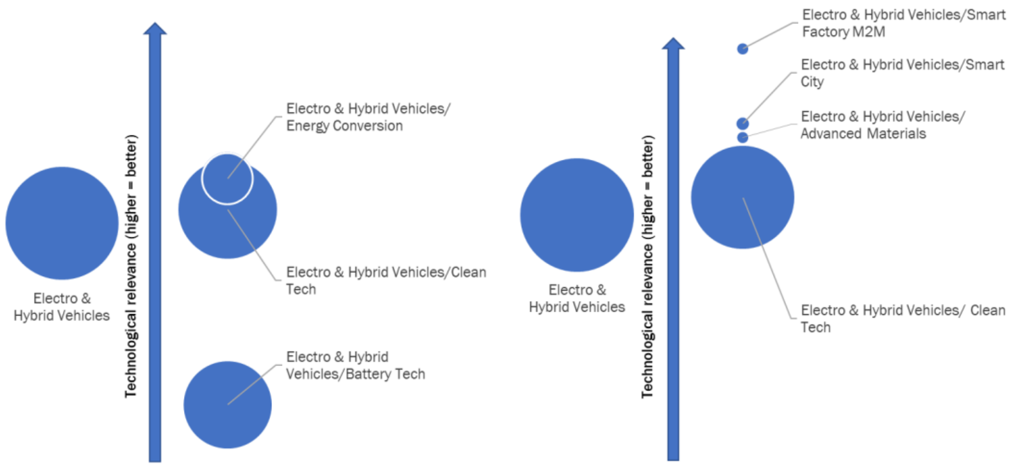
A sensor is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena. The output is generally a signal that is converted to a human-readable display at the sensor location or transmitted electronically over a network for reading or further processing.

As can be seen in the chart above, the technology of Sensors in the Oslo region is rated, on average, slightly lower when compared to the global average. However, it is interesting that all technology combinations with Sensors in the Oslo region are highly rated. The combination with Medtech Digital receives the best ratings.

Looking at Sensor combinations on the global level, the most common combinations are with Medtech and Transport. While Sensors/Transport is rated slightly lower in the Oslo region, the region has a clear advantage in Sensors/Medtech compared to the global average.

## 5.3 West Sweden

**Fig. 5-3 Electro & Hybrid Vehicles: West Sweden vs. World**




Left side: West Sweden; Right side: World
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

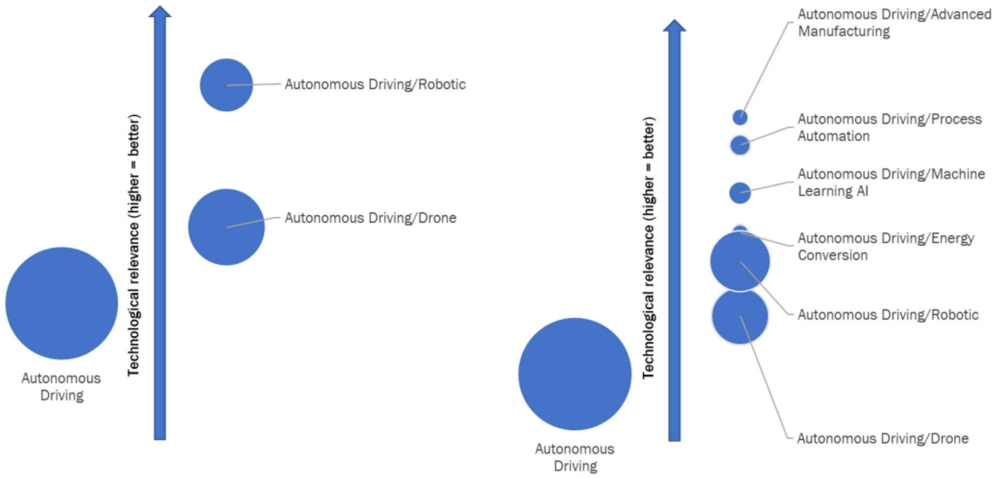
Electric vehicles, also called EV, use one or more electric motors or traction motors for propulsion. A hybrid electric vehicle is a type of hybrid vehicle that combines a conventional internal combustion engine system with an electric propulsion system. The number of EV and hybrid vehicles is expected to increase substantially in the coming years as carmakers are obliged to reduce the emissions of their fleets.

Electro & Hybrid Vehicles represent a key technology in West Sweden (see chapter 2) due to the presence of Volvo and Volvo Cars/Geely. Patents in Electro & Hybrid Vehicles are, on average, almost equally rated in West Sweden compared to the global average. Compared to Western Europe, Electro & Hybrid Vehicles patents from West Sweden are rated significantly higher.

Both in West Sweden and globally, the technology of Electro & Hybrid Vehicles has a large intersection with Clean Tech. Another important technology combination with Electro & Hybrid Vehicles in West Sweden is Battery Tech. However, this technology combination is rated quite poorly in West Sweden.

The combinations with Smart Factory M2M and Smart City are, globally, the highest rated combinations with Electro & Hybrid Vehicles.

**Fig. 5-4 Autonomous Driving: West Sweden vs. World**




Left side: West Sweden; Right side: World
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

The term Autonomous Driving describes vehicles (cars, buses, trucks) that are capable of driving to a destination without being controlled by a human driver, rather, by using information from radars, sensors and cameras. Today, many new cars already have semi-autonomous features such as assistance systems for parking, maintaining the lane or handling traffic jams, however, the driver is still responsible for controlling the vehicle.

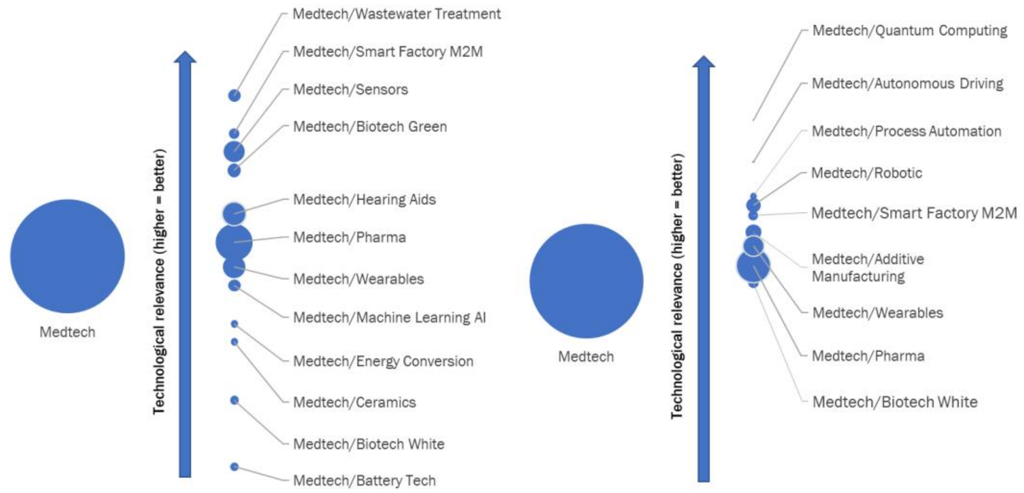
The above chart shows the technology combinations in West Sweden in Autonomous Driving compared to the global average. Autonomous Driving is a key technology for West Sweden (see chapter 2) and the region is highly specialized in this tech field. Moreover, Autonomous Driving patents from West Sweden receive a higher average rating compared to both the global average and to Western Europe.

Since the development of Autonomous Driving is still at a relatively early stage, there are not yet many technology combinations with Autonomous Driving available. Most patents in Autonomous Driving in West Sweden are combined with Drones and Robotics. These combinations, especially the combination Autonomous Driving/Robotics, are rated significantly higher in West Sweden when compared to the global average.

In the future, autonomous driving abilities will play an increasingly relevant role not only for self-driving cars, but also in several other areas such as agriculture (driverless tractors and drones), factories (self-driving transport vehicles), logistics (self-driving trucks) or smart cities (ride-hailing services). Therefore, it is promising that West Sweden already has many high-quality patents in Autonomous Driving.

## 5.4 Øresund

### Fig. 5-5 Medtech: Øresund vs. World



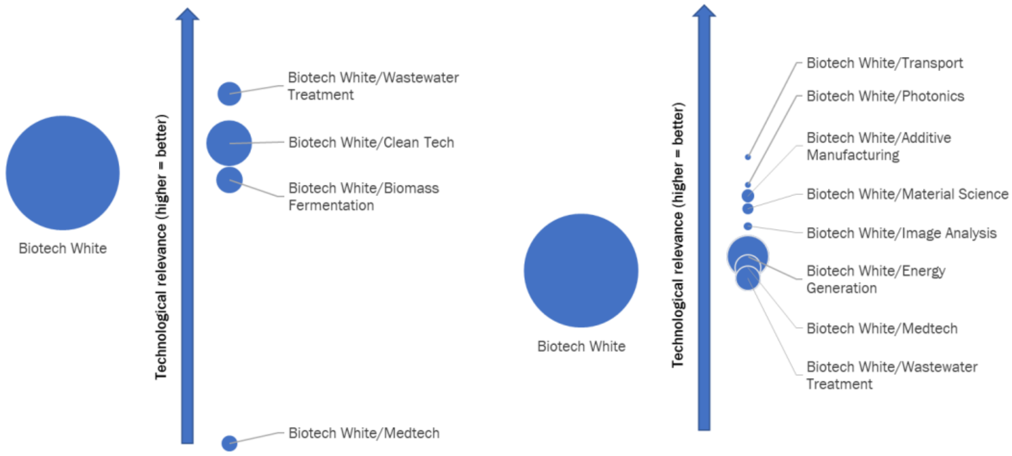

Left side: Øresund; Right side: World
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

Medtech is a key technology in STRING and particularly in Øresund. Medtech patents from Øresund without technology combinations are, on average, slightly higher rated than the global average. Western Europe is rated even lower than the global average.

When looking at Medtech technology combinations, it is noteworthy that there is a large range of existing results for combinations in Øresund. Some patent combinations such as with Battery Tech or with Biotech White are rated relatively poor, whereas other combinations such as with Wastewater Treatment and with Sensors achieve excellent ratings.

A look at global Medtech combinations reveals that combinations with Robotics and Additive Manufacturing are common and they also, on average, achieve good patent ratings. These combinations are not yet present in Øresund. This could be a promising research area in Øresund in the coming years.

**Fig. 5-6 Biotech White: Øresund vs. World**




Left side: Øresund; Right side: World
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

Biotech White involves the use of biotech in industrial processes (therefore also called Industrial Biotech) such as the production of new chemicals and materials or the development of new fuels for vehicles. The goal is to produce products that require less energy and resources and create less waste by using living cells from yeast, mold, bacteria, plants and enzymes.

The chart above depicts the Biotech White technology combinations in Øresund compared to the global average. Biotech White patents from Øresund are, on average, significantly higher rated than the global or the Western European average.

The most common combination in Øresund is Biotech White/Clean Tech. This combination is slightly higher rated than the average Biotech White patent. On a global level, this combination is not among the most frequent ones.

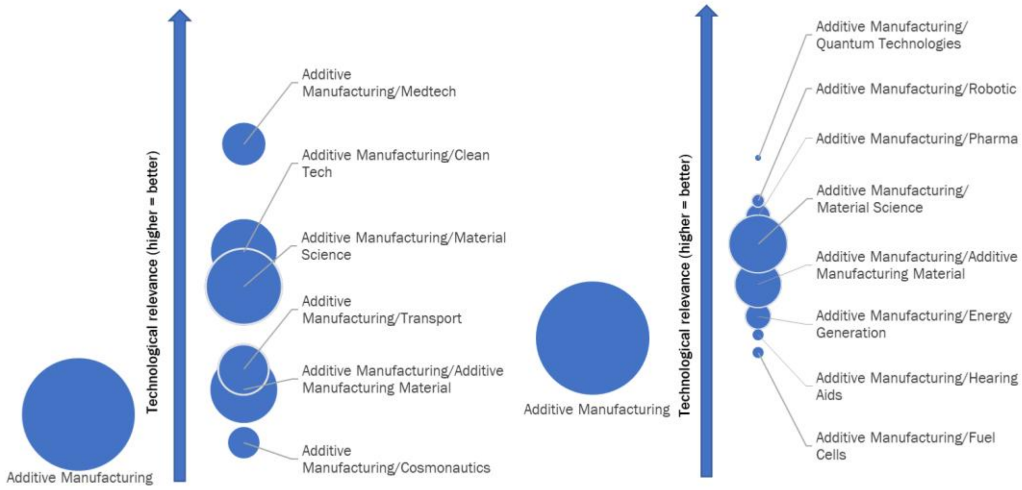
The technology combination with Medtech is the combination with the lowest rating in Øresund. This is surprising given that both technologies are strengths in Øresund (see chapter 2). For comparison, the global average of the Biotech White/Medtech combination is significantly higher than in Øresund.

The combination with Wastewater Treatment is the highest rated Biotech White combination in Øresund. This combination is globally rated much lower.

A look at global Biotech White combinations shows that combinations with Transport, Photonics and Additive Manufacturing are rated relatively high.

## 5.5 Hamburg Region

### Fig. 5-7 Additive Manufacturing: Hamburg Region vs. World




Left side: Hamburg Region; Right side: World
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

The term Additive Manufacturing (often also called 3D-Printing) subsumes production technologies by which products are constructed from sequential layers of liquid or powder. The basic materials used in the process are various metals, plastics and composites. One of the greatest benefits of this technology is the greater range of shapes which can be produced.

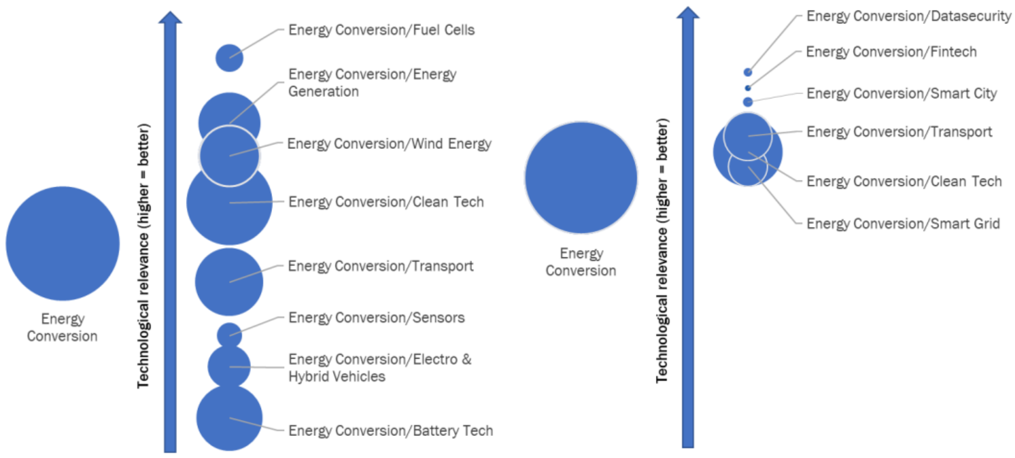
The chart above shows the technology combinations for Additive Manufacturing in the Hamburg region. In general, Additive Manufacturing patents have increased very dynamically in the Hamburg region (see chapter 2). However, Additive Manufacturing patents from the Hamburg region (left side bubbles) are rated, on average, lower than the global average.

The Hamburg region shows a variety of technology combinations with Additive Manufacturing. Many of these Additive Manufacturing combinations are with Material Science, Additive Manufacturing Material, and Clean Tech. However, these technology combinations are rated lower when compared to the global average. Medtech is one additive manufacturing combination that is rated significantly higher compared to the global average.

The Hamburg region also has several patents in the combination Additive Manufacturing/Cosmonautics whereas this combination is not very important on a global level. This combination is probably useful for Airbus in Hamburg since Additive Manufacturing methods can improve plane construction processes. However, this patent combination is not yet highly rated.

On a global level, the additive manufacturing combinations with Quantum technologies and with Robotics are rated quite high. However, there are not many patents with either of these combinations.

**Fig. 5-8 Energy Conversion: Hamburg Region vs. World**




Left side: Hamburg Region; Right side: World
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

Energy conversion technology refers to any system that converts energy from one form to another. Energy can be described in many ways, with different forms of energy including heat, work, motion, potential energy in the form of nuclear, chemical, elastic or gravitational, and radiant energy also known as light. All of these can be converted into useful energy, namely electricity, which is one of the most common and versatile forms of energy.

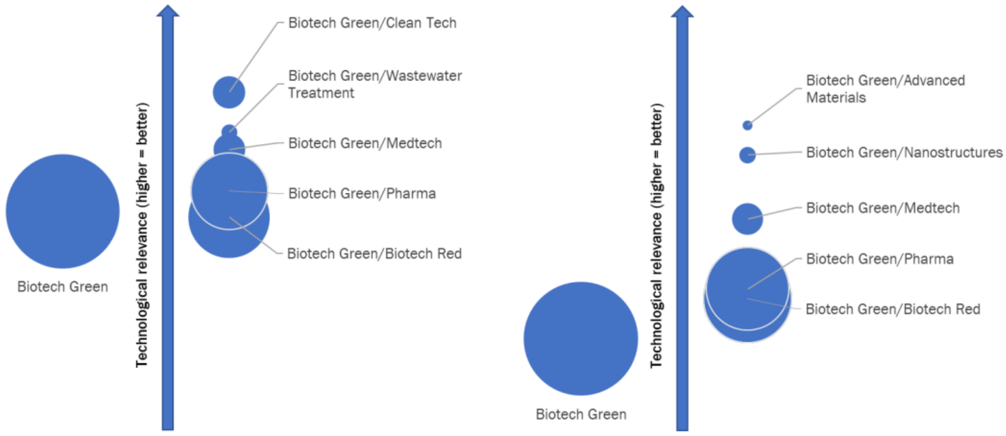
Energy Conversion is one of the ten largest focus technologies in the Hamburg region. However, patents in Energy Conversion are rated, on average, significantly lower in the Hamburg region compared to the global average.

The Hamburg region shows a large range of Energy Conversion combinations. The most common Energy Conversion combinations in the Hamburg region are with Clean Tech, Transport, and Battery Tech. While the combination with Clean Tech is rated slightly higher than the average Energy Conversion patent, the combinations with Transport and with Battery Tech are lower rated. The combinations with Fuel Cells, Energy Generation and Wind Energy are the top combinations in terms of patent ratings.

A look at the global Energy Conversion combinations reveals that the combinations of Energy Conversion with Data Security, Fintech and/or Smart City are rated relatively high. However, these combinations are not present in the Hamburg region yet.

## 5.6 STRING

### Fig. 5-9 Biotech Green: STRING vs. World



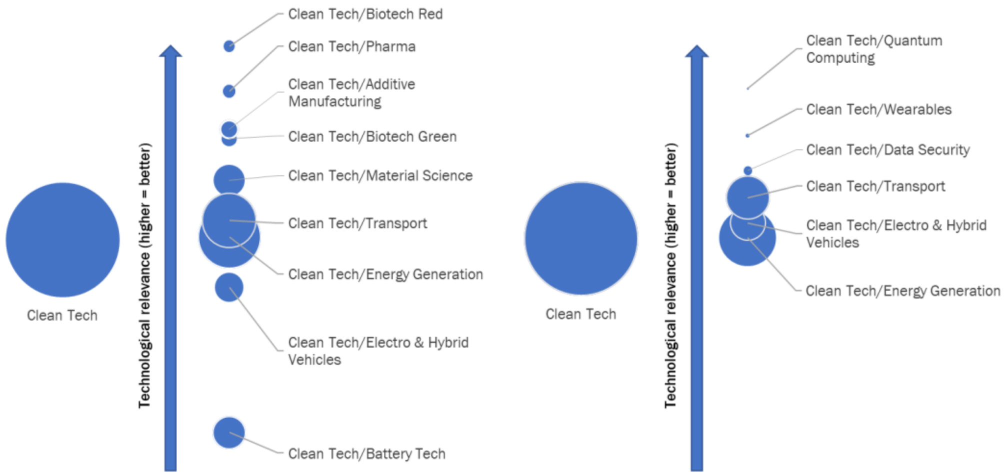

Left side: STRING; Right side: World
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

The technology Biotech Green includes biotech applications related to agriculture, including the development of genetically modified organisms (GMOs) to create more fertile and resistant grains, seeds, plants and resources.

STRING excels in terms of research efficiency in Biotech Green. The average rating of Biotech Green patents in STRING is higher than the global average and higher than in Western Europe. This is also true for Biotech Green combinations in STRING. The highest rated Biotech Green combinations are with Clean Tech.

On a global level Biotech Green/Nanostructures and Biotech Green/Advanced Materials are the best rated technology combinations. These combinations are not present yet in STRING.

## Fig. 5-10 Clean Tech: STRING vs. World




Left side: STRING; Right side: World
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

Clean Tech refers to any process, product, or service that reduces negative environmental impacts through significant energy efficiency improvements, the sustainable use of resources, or environmental protection activities. This field comprises all eco-friendly technologies that are used, for instance, in renewable energy, materials, information technology, green transportation, green chemistry, and recycling.

The chart above shows that patents in Clean Tech from STRING on average (left side bubble) have the same rating as the global average. Clean Tech in Western Europe is on average significantly lower rated compared to STRING.

The Clean Tech combinations with Transport and Energy Generation are common in STRING as well as in the world. While its rating of the combination with Energy Generation is the same compared to the global average, the research efficiency of its combination with Transport is below the global average.

It is also noteworthy that there is a large rating range of combinations in STRING. The technology combination with Battery Tech is rated relatively poorly. However, STRING's strength in Life Sciences shines through with relatively high ratings in the combinations with Biotech Red and Pharma.

When looking at global Clean Tech combinations, Clean Tech/Quantum Computing and Clean Tech/Wearables receive the highest rating patents. However, the number of patents with these combinations is still relatively small. Moreover, these combinations are not yet present in STRING.

## 5.7 Digitization in STRING

Digitization is becoming increasingly relevant for many economic areas from Medtech to finance to factories to autonomous driving. New digitization methods can be used to create new products or applications in order to remain competitive.

A good example is the digital technology Digital Medtech which encompasses many areas such as electronic health care, electronically supported disease management or telemedicine services. Concerning patent numbers, Digital Medtech is the fastest growing technology within Medtech. Due to the importance of data analyses in Digital Medtech, some IT/software companies are increasingly entering the Medtech market and gaining market shares. This shows that it is crucial for companies in almost all industries to keep up with the latest developments in digitization.

One way to measure how advanced regional research is in terms of digitization is to analyse patent combinations that merge a non-digital area (Life Sciences, Materials, Energy etc.) with a digital technology (Machine Learning, Cyber Security, Blockchain, Process Automation, etc.). Therefore, the heatmap below shows the share of patents in a non-digital technology like Biotech Red (Life Sciences) that simultaneously includes a digital technology – the digitization share. As a benchmark, the digitization share in Western Europe is listed and coloured yellow. When a region has a higher share of digitization in a technology, it is coloured green. If the degree of digitization is below that of Western Europe, the technology is coloured orange.

The combination of Medtech and Digital technologies is an area where the **Oslo region** excels. Almost every fifth Medtech patent from the Oslo region is a combination with a digital technology (compared to 17.8% in Western Europe). The Oslo region also achieves good results in Wearables, Additive Manufacturing, Sensors and Clean Tech.

**West Sweden** has an above-average level of digitization in some of its focus technologies such as Electro/Hybrid vehicles, Transport or Sensors. However, the digitization share of Medtech and Clean Tech is relatively low both compared to the other regions and the average of Western Europe.

**Øresund** is the leading region when it comes to digitization. Øresund particularly excels in Wearables, Drones, Autonomous Driving, Additive Manufacturing and Hearing Aids. However, the digitization share in Medtech – the region's largest focus technology – is slightly below the average in Western Europe. This lack of digitization might have contributed to the relatively low patent growth in Medtech in recent years.

In the **Hamburg region**, the degree of digitization is relatively low in most technologies. This is a risk for future growth potential. One exception is the tech field Energy Generation, where the Hamburg region's share of digitization is higher than the Western European average.

**STRING** achieves similar results to Western Europe. However, there are some regional focus technologies such as Hearing Aids, Additive Manufacturing, Electro/Hybrid Vehicles, and Sensors where the level of digitization is significantly higher than in Western Europe. However, a cause for concern is the relatively low digitization share in Medtech, given that there is a risk of technological disruption in certain Medtech areas due to new Digital Medtech solutions.

Tab. 5-1 Heatmap Digitization in STRING

| Technology | Oslo | West Sweden | Øresund | Hamburg | STRING | Western Europe |
|---|---|---|---|---|---|---|
| Transport | 2.4% | 6.0% | 7.6% | 3.9% | 4.9% | 4.8% |
| Medtech | 19.2% | 10.7% | 14.5% | 10.3% | 12.8% | 17.8% |
| Pharma | 0.2% | 0.9% | 0.4% | 0.1% | 0.3% | 0.6% |
| Biotech Red | 3.2% | 3.2% | 2.0% | 2.4% | 2.3% | 2.9 |
| Clean Tech | 14.8% | 5.1% | 9.4% | 4.5% | 6.7% | 7.3% |
| Energy Generation | 0.0% | 2.1% | 2.6% | 2.9% | 2.4% | 1.8% |
| Energy Conversion | 5.5% | 4.8% | 7.4% | 4.5% | 5.6% | 7.2% |
| Smart Grid | 16.7% | 10.0% | 16.7% | 5.1% | 9.1% | 22.0% |
| Material Science | 2.7% | 0.9% | 0.7% | 0.8% | 0.9% | 0.8% |
| Sensors | 14.5% | 11.6% | 14.2% | 8.5% | 11.6% | 9.4% |
| Hearing Aids | 0.0% | 8.5% | 20.1% | 0.0% | 18.8% | 15.2% |
| Nanostructures | 0.0% | 4.1% | 2.0% | 2.4% | 2.3% | 2.6% |
| Electro & Hybrid Vehicles | 0.0% | 8.0% | 7.4% | 2.9% | 6.1% | 4.1% |
| Autonomous Driving | 0.0% | 11.0% | 33.3% | 13.3% | 12.2% | 22.3% |
| Wearables | 52.4% | 27.9% | 55.8% | 16.7% | 46.2% | 47.4% |
| Drone | 6.3% | 9.7% | 33.3% | 5.6% | 9.6% | 17.3% |
| Additive Manufacturing | 26.7% | 15.3% | 26.7% | 8.5% | 17.5% | 11.3% |

Share of patents in a technology that are also registered in a digital technology. Only focus technologies, in which STRING has ten or more combinations with a digital technology are considered.
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

## 5.8 Summary

In this chapter, the goal was to identify existing technology combinations in selected focus technologies in the Oslo region, West Sweden, Øresund, the Hamburg region and STRING, to analyse which combinations lead to better results, and to compare the results to the global average.

In the **Oslo region**, Image Analysis is a technological strength and the region obtains very good results in associated technology combinations. Most Image Analysis combinations in the Oslo region take place with Medtech and Digital Medtech and in these combinations, patents from the Oslo region are rated significantly higher than the global average. On a global level, there are many Image Analysis combinations with Sensors, Transport and Wearables. These combinations are not yet present in the Oslo region, but they could display promising areas for future research in the region. In Sensor technology, all combinations in the Oslo region are rated highly. Sensors/Medtech Digital receives the best ratings.

Electro & Hybrid Vehicles and Autonomous Driving are technological strengths in **West Sweden**. While the region achieves average results in combinations with Electro & Hybrid Vehicles, it outperforms the global average in combinations with Autonomous Driving. Especially combinations between Autonomous Driving and Robotic, which are rated high, represent future potential for West Sweden for example for applications in Smart Factories.

In **Øresund**, technology combinations in Medtech and Biotech White were analysed. In Medtech, some combinations such as Medtech/Wastewater Treatment and Medtech/Sensors achieve excellent ratings. Biotech White patent combinations from Øresund are significantly better rated than the global or the Western European average. In particular, the combination with Wastewater Treatment obtains top results.

The **Hamburg region** shows a variety of technology combinations with Additive Manufacturing. The Additive Manufacturing/Medtech combination is rated significantly higher compared to the global average. The most common Energy Conversion combinations in the Hamburg region are with Clean Tech, Transport and Battery Tech. However, Energy Conversion/Fuel Cells is the top combination in terms of patent ratings.

**STRING** excels in terms of research efficiency in Biotech Green – average patent scores are clearly above global or Western European levels. Some Biotech Green combinations such as Biotech Green/Clean Tech and Biotech Green/Wastewater Treatment achieve even higher ratings. Clean Tech alone is an important technology priority in STRING (see also chapter 3). In this technology, STRING's strength in Life Sciences shines through with relatively high ratings in the combinations Clean Tech/Biotech Red and Clean Tech/Pharma.

In summary, these results regarding successful technology combinations provide indications for where it might be worthwhile to seek opportunities for research exchange between the different stakeholders in STRING.

In the second part of the chapter, a heatmap showed the level of digitization. The combination of Medtech and Digital technologies is an area where the **Oslo region** excels. The Oslo region also achieves good results in Wearables, Additive Manufacturing, Sensors and Clean Tech.

**West Sweden** has an above-average level of digitization in some of its focus technologies such as Electro/Hybrid vehicles, Transport or Sensors. However, the digitization share of Medtech and Clean Tech is relatively low both compared to the other regions and the average of Western Europe.

**Øresund** is the leading region when it comes to digitization. Øresund particularly excels in Wearables, Drones, Autonomous Driving, Additive Manufacturing and Hearing Aids. However, the digitization share in Medtech – the largest focus technology – is slightly below the average in Western Europe.

In the **Hamburg region**, the degree of digitization is relatively low in most technologies. This is a risk for its future growth potential. One exception is the tech field Energy Generation, where the Hamburg region's share of digitization is higher than the Western European average.

**STRING** achieves an average score compared to Western Europe. There are some focus technologies such as Hearing Aids, Additive Manufacturing, Electro & Hybrid Vehicles and Sensors, where the level of digitization is significantly higher than in Western Europe. However, a cause for concern is its low digitization share in Medtech.

# 6 Conclusion

Innovation is the key to productivity and competitiveness. For the implementation of innovation strategies, regions must analyse the strengths and weaknesses of their research and innovation systems. According to the Regional Innovation Scoreboard, STRING is an innovation leader in the EU in many performance categories, such as lifelong learning, public-private co-publications, EPO patent applications and Trademark applications.

The goal of this study was to deepen knowledge of STRING's innovation activities, specifically its intellectual assets and linkages by analysing its patent data.

In order to achieve this, technology profiles and research linkages were analysed for the Oslo region, West Sweden, Øresund, the Hamburg region and STRING to identify in which specific technology fields the intellectual assets of the different regions are located and how connected the regions are to each other. In addition, promising technology combinations and the level of digitization were identified and STRING's patent performance in terms of green technologies was analysed.

The results show that there are certain common strengths in all analysed regions. First, all regions have sizeable research activities in Life Sciences technologies and are also mostly specialized in these technologies. Moreover, Transport is an important technology for STRING. Apart from these common strengths, there are strengths and opportunities unique to STRING's member regions:

The **Oslo region** is particularly strong in Sensors thanks to research efforts by Schlumberger and Petroleum Geo-Services. In addition, the Oslo region has many excellent patents in Image Analysis. Moreover, the Oslo region is already well-connected with STRING and it benefits from an above-average research efficiency and an already high level of digitization in many technologies. In particular, the combination of Medtech and Digital technologies is an area where the Oslo region excels due to attractive technology combinations such as Image Analysis/Medtech. A weak spot in the Oslo region is the lack of patents in green technology.

**West Sweden** enjoys a unique location advantage in the technologies of Electro & Hybrid Vehicles and Autonomous Driving. In both technologies, Volvo and Volvo Cars/Geely are the top research companies. West Sweden is also the most connected region within STRING in terms of its research cooperations. A risk factor is its low level of digitization in important technologies such as Medtech and Clean Tech.

**Øresund** is a top region in Smart Factory, Hearing Aids and Wearables. The companies Oticon, WS Audiology, and GN Store Nord are responsible for Øresund's strength in Hearing Aids. Oticon and WS Audiology are also research leaders in Wearables because there are some overlapping elements in the technologies Hearing Aids and Wearables. Øresund is also a leader in digitization in many technologies and has many patents in green technologies such as Wastewater Treatment and Fuel Cells.

The **Hamburg region** is the leader in Energy technologies and is also highly specialized in Cosmonautics. The region is also strong in Additive Manufacturing (3D-Printing) and

Additive Manufacturing Materials. Airbus is the driving force behind this development. The Hamburg region also has the largest patent portfolio in green technologies in STRING with a strong focus on Wind Energy, Fuel Cells and Smart Grid. However, there is room for improvement in certain areas. First, its research cooperation with the other regions is low. Second, its degree of digitization is relatively poor in most technologies. This probably contributes to the below average research efficiency in the Hamburg region compared to the rest of the STRING region.

These results on regional strengths can provide valuable input for location promoters to encourage an exchange of information between regional stakeholders in STRING in the future.

A major goal of STRING is to foster sustainable growth. Green technologies will play an important role in this regard in the coming years. Patent growth in green technologies in STRING has been very dynamic in recent years. The Hamburg region and Øresund have particularly large patent portfolios in technologies such as Wind Energy, Wastewater Treatment, and Fuel Cells. However, the examination of green technologies reveals that STRING lags behind the San Francisco Bay Area in a number of green technologies in both quantity and excellence. San Francisco outperforms STRING in Smart Grid, Organic Perovskite Tandem Photovoltaic, Battery Lithium and Solar Energy. On the other hand, there are also some green technologies where STRING is on an equal footing or has forged ahead of San Francisco. Both regions have a comparable patent portfolio size in Wastewater Treatment and Electro & Hybrid Vehicles and STRING has many much more patents in Wind Energy.

While STRING has not yet caught up to San Francisco in most green technology research areas, its results are still auspicious for the coming years. If one compares STRING to the average patent growth/efficiency in Germany, Denmark, Sweden and Norway, the results for STRING regions are more compelling. Both patent growth and research efficiency are above average in STRING compared to these countries' averages or to the Western European average.

# 7 Appendix

## 7.1 Definition of the STRING Region

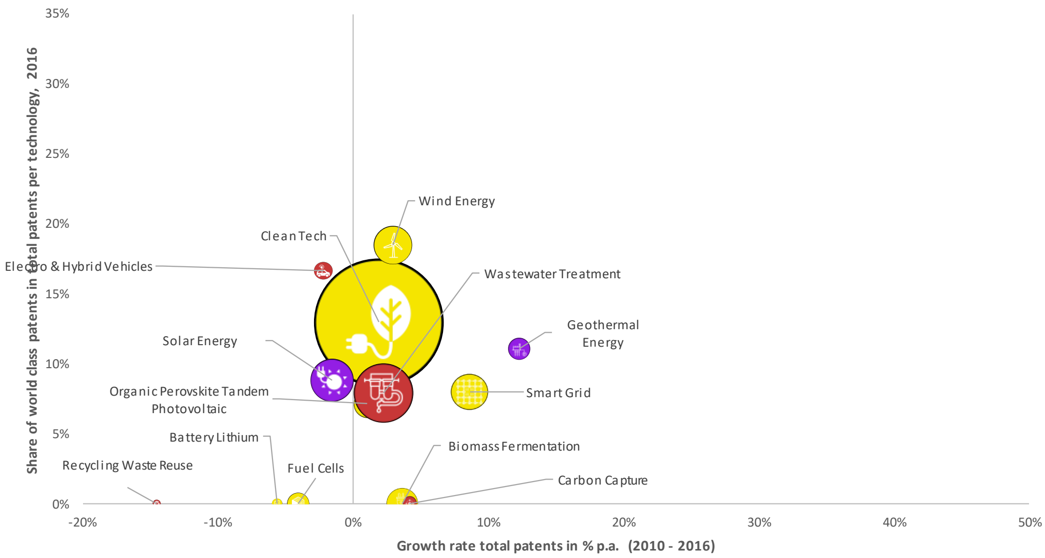
### Tab. 7-1 Definition of the selected regions

| Region | | Country | Core City | Region Type | Population (2016) |
|---|---|---|---|---|---|
| Oslo Region | Oslo and Akershus, Østfold and Buskerud | NO | Oslo | Metropolitan Region | 1,819,126 |
| West Sweden | Västra Götaland and Halland | SE | Gothenburg | Riksområden | 1,963,469 |
| Øresund | Capital Region, Zealand and Skåne | DK/SE | Copenhagen-Malmö | Border Region Copenhagen-Skane | 3,920,296 |
| Hamburg Region | Hamburg and Schleswig-Holstein | DE | Hamburg | Metropolitan Region | 4,646,124 |
| **STRING Region** | | **NO/SE/ DK/DE** | | **Border Region** | **12,349,015** |
| | **Benchmarking Region for green technologies** | | | | |
| San Francisco Bay Area | | US | San Francisco | Metropolitan Region | 8,571,458 |

Sources: OECD, BAK Economics

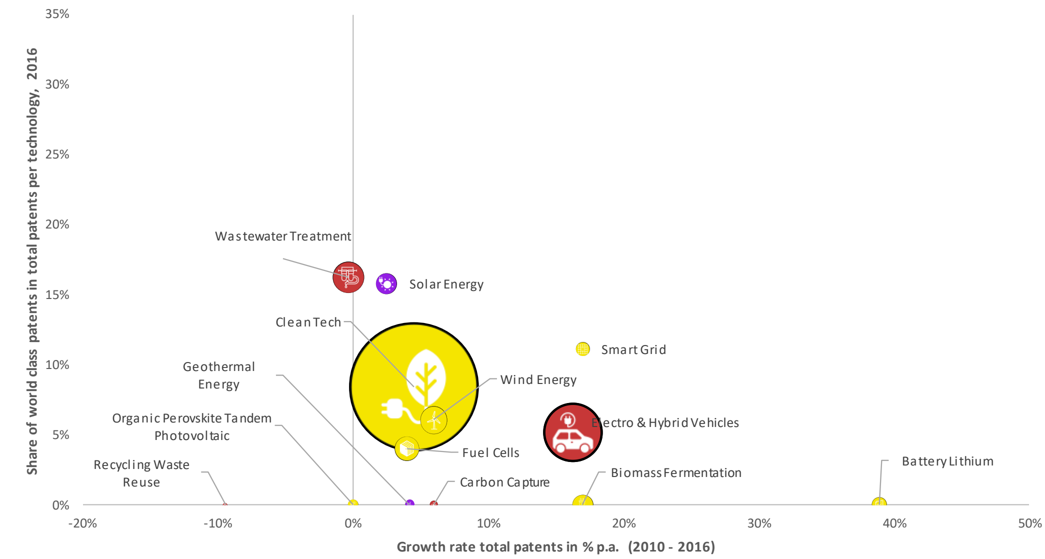
## 7.2 Green technology profiles of the Oslo region, West Sweden, Øresund and the Hamburg region

### Fig. 7-1 Technology profile with focus on green technologies of the Oslo region



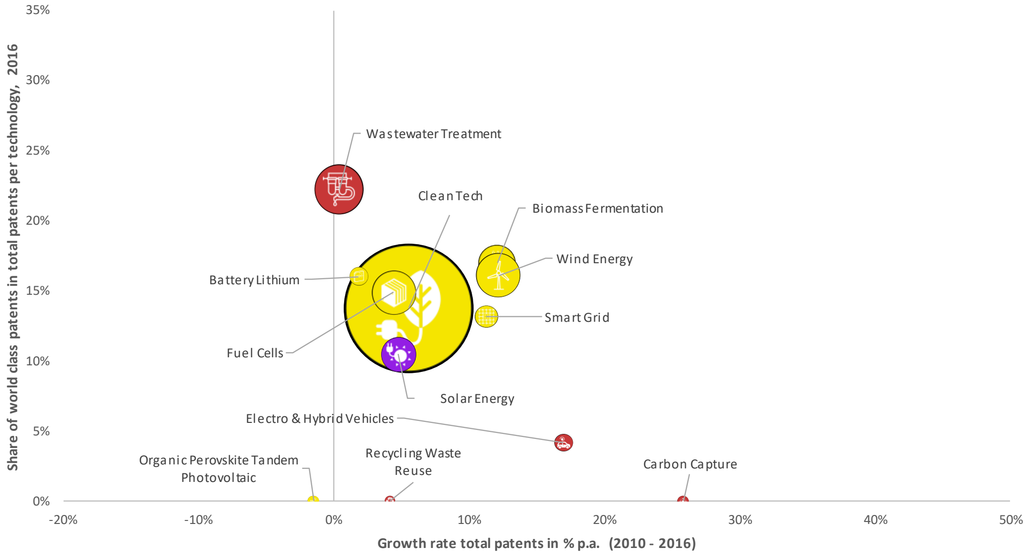

Bubble size: Number of total patents in a technology in 2016
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

### Fig. 7-2 Technology profile with focus on green technologies of West Sweden



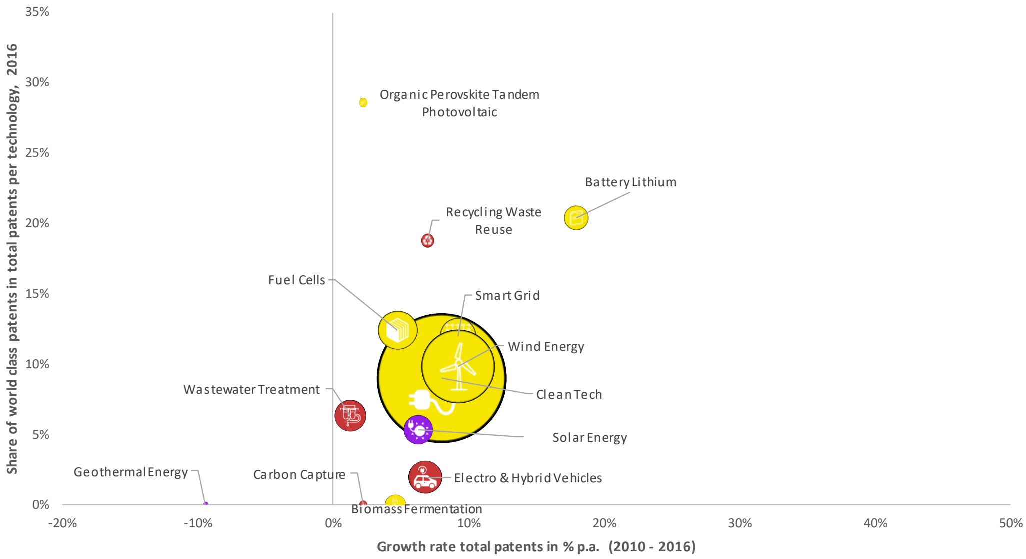

Bubble size: Number of total patents in a technology in 2016
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

## Fig. 7-3 Technology profile with focus on green technologies of Øresund




Bubble size: Number of total patents in a technology in 2016
No patents in Geothermal Energy (WIPO) in Øresund.
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

## Fig. 7-4 Technology profile with focus on green technologies of the Hamburg region




Bubble size: Number of total patents in a technology in 2016
Sources: BAK Economics, Swiss Federal Institute of Intellectual Property

## 7.3 Technology definitions

**Tab. 7-2 Definition of focus and green technologies**

| | Technology | Category | Description |
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| | Transport | WIPO | This field includes all types of transport technology and applications. Automotive technology dominates, but rail and air traffic play important roles. |
| | Geothermal Energy | WIPO | Geothermal energy is thermal energy generated and stored in the earth. Geothermal power is cost-effective, reliable, sustainable, and environmentally friendly, but has historically been limited to areas near tectonic plate boundaries. Recent technological advances have dramatically expanded the range and size of viable resources, especially for applications such as home heating, opening a potential for widespread exploitation. Geothermal wells release greenhouse gases trapped deep within the earth, but these emissions are much lower per energy unit than those of fossil fuels. |
| | Solar Energy | WIPO | Solar energy is radiant light and heat from the sun that is harnessed using a range of ever-evolving technologies. It is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. |
| | Pharma | Life Sciences | Pharma is based on the classical WIPO classification and includes processes, materials, and devices in the environment of drugs. |
| | Biotech Red | Life Sciences | Red biotech refers to medical applications of biotech. This includes the production of vaccines, the discovery and development of new drugs, molecular diagnostics techniques, pharmacogenomics, regenerative therapies or genetic engineering to cure diseases through genetic manipulation. |
| | Biotech Green | Life Sciences | Green biotech includes biotech applications related to agriculture to create more fertile and resistant grains, seeds, plants and resources, the production of bio-fertilizers and bio-pesticides or the evolution of disease-resistant animals. A very important part |

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| | | of this field is the production of genetically modified plants or crops. |
| Biotech White | Life Sciences | Involves the use of biotech in industrial processes (therefore also called industrial biotech) such as the production of new chemicals and materials or the development of new fuels for vehicles. The goal is to produce products that require less energy and fewer resources and create less waste by using living cells from yeast, mold, bacteria, plants and enzymes. |
| Battery Lithium | Energy | Lithium batteries are primary batteries that have lithium as an anode. They stand apart from other batteries because of their high-charge density (long-life). Lithium batteries are widely used in portable consumer electronic devices, and in electric vehicles ranging from full-sized vehicles to radio-controlled toys. |
| Biomass Fermentation | Energy | The term “biomass” refers to plant-based materials that are not used for food or animal feed, but are harnessed as an energy source in one of two ways: either directly via combustion to produce heat, or indirectly after having converted it into various sorts of biofuel. |
| Clean Tech | Energy | Clean Technology (Clean Tech) refers to any process, product, or service that reduces negative environmental impacts through significant energy efficiency improvements, the sustainable use of resources, or environmental protection activities. This field comprises all eco-friendly technologies that are used, for instance, in renewable energy, materials, information technology, green transportation, green chemistry, and recycling. |
| Energy Generation | Energy | Technologies that convert mechanical or thermal energy from primary sources such as fossil fuels, nuclear or renewable energy sources (sun, wind, water, and biomass) into electric energy. |
| Energy Conversion | Energy | Energy conversion technology refers to any system that converts energy from one form to another. Energy can be described in many ways, with different forms of energy including heat, work, motion, potential energy in the form of nuclear, chemical, elastic or gravitational, and radiant energy also known |

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| | | as light. All of these can be converted into useful energy, namely electricity. Electricity is one of the most common and versatile forms of energy. |
| Energy Storage | Energy | Energy storage is the capture of energy produced at one time for later use. A variety of technologies exist to store electricity, including batteries, compressed air and chemicals, but, by far, the most common technology to date is pumped hydro- storage. The growing need for flexibility in the energy system would benefit from new storage solutions and innovations. Some emerging storage technologies, including batteries and hydrogen, are gradually becoming competitive. |
| Smart Grid | Energy | A Smart Grid is an electricity network based on digital technology that is used to supply electricity to consumers via two-way digital communication. This system allows for monitoring, analysis, control and communication within the supply chain to help improve efficiency, reduce energy consumption and cost, and maximize the transparency and reliability of the energy supply chain. One example are electrical meters that record the consumption of electric energy in real-time while communicating the information back to the utility for monitoring and billing purposes. The technology can be used for remote load-balancing such as disabling non-essential devices at peak usage. |
| Fuel Cells | Energy | A fuel cell is an electrochemical cell that converts chemical energy from a fuel into electricity through an electrochemical reaction of hydrogen fuel with oxygen or another oxidizing agent. Fuel cells are different from batteries in requiring a continuous source of fuel and oxygen to sustain the chemical reaction, whereas in a battery, the chemical energy comes from chemicals already present in the battery. Fuel cells can produce electricity continuously as long as fuel and oxygen are supplied. |
| Organic Perovskite Tandem Photovoltaic | Energy | Organic photovoltaic cells and perovskite photovoltaic cells are two particularly promising areas of solar power research. These new cells have the potential to provide decent power conversion efficiencies combined with low production costs and more flexible applications. However, a downside of these cells is that their stability and life-spans are still |

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| | | | shorter than traditional silicon-based cells. Therefore, further research is necessary before perovskite and organic solar cells can compete with silicon-based cells on the commercial market. |
| | Wind Energy | Energy | Wind power is the use of air flow through wind turbines to provide the mechanical power to turn electric generators. Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, consumes no water, and uses little land. |
| | Material Science | Material | Creating properties never before seen in nature as well as restructuring existing materials are two of the most exciting prospects in this field. Subtopics from metamaterials with optical plasmonic properties to foam materials are paving the way for light-speed computing, subatomic microscopes, self-assembling structures with increased durability and lightweight hull designs. |
| | Additive Manufacturing Material | Material | Additive manufacturing subsumes production technologies by which 3D-objects are constructed from sequential layers of a material. The basic materials used in this process are various metals, plastics and composites. |
| | Smart Polymer | Material | The most prevalent use of smart polymers is for specifically-targeted delivery of drugs. Researchers employ them to control the release of drugs until the desired target has been reached. |
| | Sensors | Systems | A sensor is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena. The output is generally a signal that is converted to a human-readable display at the sensor location or transmitted electronically over a network for reading or further processing. |
| | Hearing Aids | Systems | Hearing Aids are an additive manufacturing application in the field of health care. The key advantage of additive manufacturing in health care is that this technology will soon allow the production of highly individualized health solutions in order to meet |

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| | | patients' needs in circumstances that require patient-specific implants or other devices. |
| Nanostructures | Systems | Nanostructures are defined as structures that range between 1 nanometer (molecular scale) and 100 nanometers in at least one dimension. Most nanostructures are synthetic and can be engineered to feature a wide range of physical properties. Common examples of nanostructures are nanotextured surfaces, nanofibers, nanotubes, nanosheets, nanoparticles and quantum dots. |
| Electro & Hybrid Vehicles | Systems | A hybrid electric vehicle is a type of hybrid vehicle that combines a conventional internal combustion engine system with an electric propulsion system. |
| Autonomous Driving | Systems | The term Autonomous Driving describes vehicles (cars, buses, trucks) that are capable of driving to a destination without being controlled by a human driver, rather, by using information from radars, sensors and cameras. In technical terms, a self-driving car is also a sort of robot. Today, many new cars already have semi-autonomous features such as assistance systems for parking, maintaining the lane or handling traffic jams, however, the driver is still responsible for controlling the vehicle. By contrast, a fully-autonomous vehicle will be able to drive itself without the need of a human driver to pay attention and control the vehicle. |
| Wearables | Systems | "Wearables" is a blanket term for electronics that can be worn on the body. Some of the most popular devices are activity trackers and smart watches. One of the major features of wearable technology is its ability to connect to the internet, enabling data to be exchanged between a network and the device. Augmented reality describes the integration of digital information with the user's environment in real-time. Unlike virtual reality, which creates a totally artificial environment, augmented reality uses the existing environment and overlays new information on top of it. Today, Google glasses and heads-up displays on car windshields are perhaps the most well-known augmented reality (AR) products for consumers. |

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| Drone | Systems | Drones, more formally known as “unmanned aerial vehicles” (UAV), are flying robots without a human pilot aboard. Drones can be under the control of a human operator or can fly autonomously through software-controlled flight plans working in conjunction with on-board sensors and GPS. At first, drones were primarily used for military applications, but they are increasingly used for other purposes such as surveillance, traffic monitoring, weather monitoring, agriculture and even delivery services. Drones are projected to provide productivity gains and cost savings in agricultural output, product delivery, as well as journalism and data gathering. |
| Additive Manufacturing | Systems | The term “Additive Manufacturing” subsumes production technologies by which products are constructed from sequential layers of liquid or powder. The basic materials used in the process are various metals, plastics, and composites. 3D- Printing is an example of Additive Manufacturing. One of the greatest benefits of this technology is the broader range of shapes which can be produced. |
| Cosmonautics | Systems | Cosmonautics encompasses technologies that are needed for navigation beyond Earth's atmosphere. Applications have to survive in extreme conditions because of restrictions to mass, temperature, and external forces. For example, space launch vehicles and satellites belong to the field of Cosmonautics. |
| Collaborative Robots | Systems | Collaborative Robots are industry robots that work together with humans. The robot apparatus is a method for direct physical interaction between a person and a general-purpose manipulator controlled by a computer. Sensors enable direct interaction without risking harm to people. |
| Carbon Capture | Systems | Wastewater Treatment, biomass and carbon capture are three technologies that play an important role in sustainable development. Carbon capture describes the process of capturing carbon dioxide from fossil fuel power plants and industrial sites, transporting it to a storage site, and depositing it. The goal of carbon capture is to reduce the release of CO2 into the atmosphere to counteract global warming. |

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| Recycling Waste Reuse | Systems | Recycling is the process of converting waste materials into new materials and objects. It is an alternative to "conventional" waste disposal that can save material and help lower greenhouse gas emissions. Recycling can prevent the waste of potentially useful materials and reduce the consumption of additional raw materials thereby reducing energy usage, air pollution (from incineration), and water pollution (from landfills). |
| Wastewater Treatment | Systems | Wastewater Treatment, biomass and carbon capture are three technologies that play an important role in sustainable development. The process of Wastewater Treatment is employed to remove contaminants from wastewater to make the water safe for discharge back into the environment. |
| Data Security | Digital/IT | The term Data Security (or "cyber security") refers to the body of technologies, processes, and practices designed to protect networks, devices, programs and data from attack, damage or unauthorized access. Cyber security is of growing relevance due to the increasing use of computer systems, wireless networks, the Bring Your Own Device (BYOD) trend and the growth of smart devices as part of the Internet of Things. Automotive security and medical device security are further examples of the cyber security market. |
| Smart Factory M2M | Digital/IT | Machine-to-machine, or M2M, is a label that describes any technology that enables networked devices to exchange information and perform actions without the manual assistance of humans. M2M technology was first adopted in manufacturing and industrial settings, and has since found applications in healthcare, business, insurance and more. It is also the foundation for the Internet of Things. |
| Preventive & Predictive Maintenance | Digital/IT | Predictive and Preventive Maintenance (short Pre-Maintenance) aims to avoid or mitigate failure of machines and installations. In the context of the Industrial Internet, it involves optimized repair and maintenance schedules based on several recent developments: the use of predictive algorithms, significant progress in sensor data availability from the production equipment maintained, advances in data analytics, storage of these data in clouds, and |

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| | | | automatic adjustment of production by the equipment itself. |
| | Smart City | Digital/IT | A Smart City is an urban area that uses different types of electronic data collection sensors to supply information to manage assets and resources efficiently. This includes data collected from citizens, devices, and assets that is processed and analysed to monitor and manage traffic and transportation systems, power plants, water supply networks, waste management, law enforcement, information systems, schools, libraries, hospitals, and other community services. |
| | Image Analysis | Digital/IT | The term “image analysis” describes the extraction of meaningful information from images. The applications of digital image analysis are continuously expanding, and the technology is now used in countless areas of science and industry including astronomy, defense, machine vision, medicine, robotics and many more. In the medical field, Image Analysis plays an important role in tracking diseases and assessing the effects of treatment. Digital image analysis in the form of facial recognition is also used to improve security standards. Moreover, Image Analysis plays a crucial role in the development of autonomous vehicles, since these vehicles need to be able to recognize driving patterns of human drivers and other cars. |
| | Speech Analysis | Digital/IT | Voice analysis is the study of speech sounds for purposes other than linguistic content, such as in speech recognition. Such studies include mostly medical analysis of the voice (phoniatrics), but also speaker identification. |
| | 3D Image Modelling | Digital/IT | 3D-modelling is the process of developing a mathematical representation of any surface of an object in three dimensions via specialized software. The science sector uses this process to create highly-detailed models of chemical compounds. The engineering community uses 3D-modelling in the design of new devices, vehicles and structures and has a host of other uses for it as well. |

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| Blockchain | Digital/IT | A decentralized register which allows the automated management of transactions without the need for a central entity (e.g. a clearing house). |
| Electronic Gaming | Digital/IT | Devices and processes for virtual reality, haptic displays, mobile functions, 3D-hardware-rendering, browser functions and artificial intelligence in the field of gaming. |
| Quantum Computing | Digital/IT | Quantum physics and quantum mechanics explain the behaviour and nature of matter and energy at atomic and sub-atomic scales which cannot be explained by classical physics. Quantum computing stands for extremely rapid computers and is an application of the new quantum technologies. |
| Fintech Wealth | Digital/IT | Applications of the so-called WealthTech include crowd-sourced investment ideas, real-time investment tracking and algorithm-driven portfolio advice. Robo-advisers use algorithms for low-cost, automated investment recommendations and manage customers' portfolios without depending on a human adviser. |