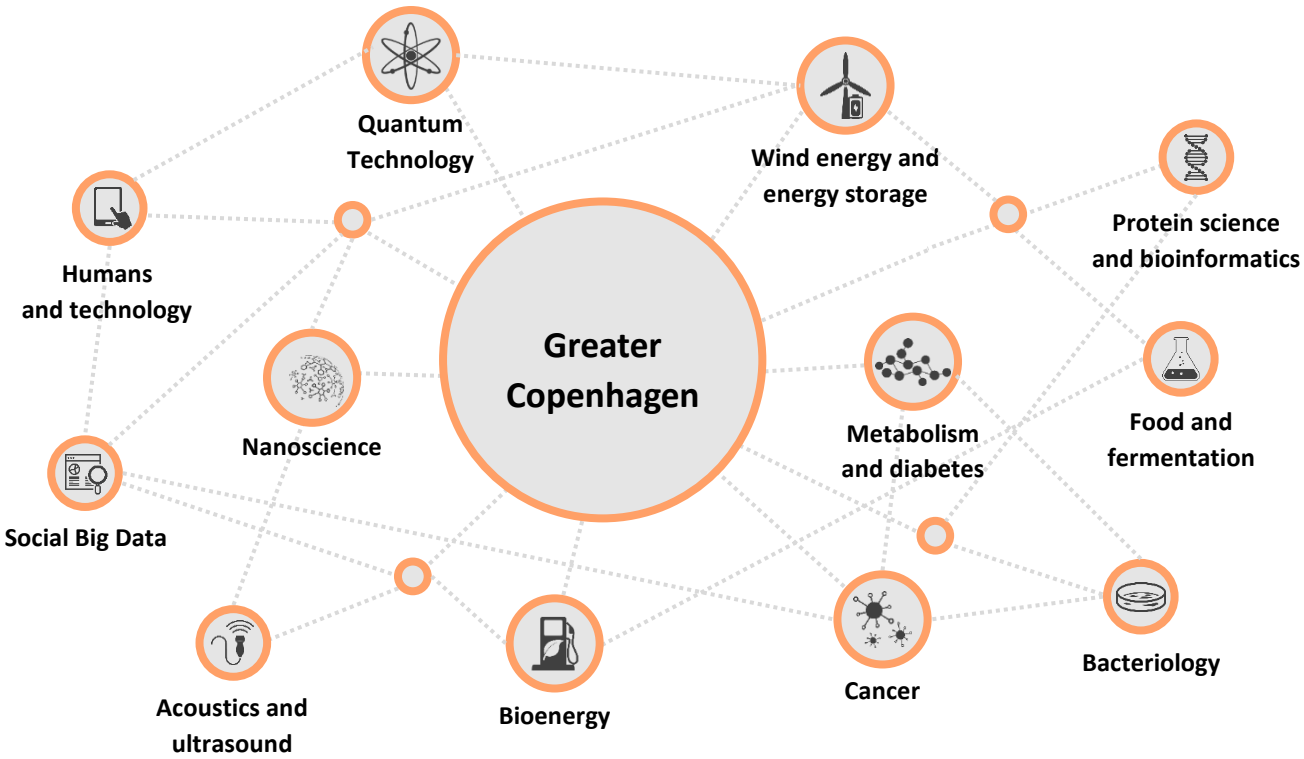
Research strengths of Greater Copenhagen with investment prospects

Background Report

November 2016



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Preface

Greater Copenhagen is among Europe's leading science cities. The region is home to numerous, absolutely world-class research environments.

Research provides answers and solutions to many of the societal challenges facing us worldwide. This relates for example to new types of treatment targeting diseases, which are spreading globally such as cancer, obesity and diabetes. It relates to the development and design of the sustainable energy systems of the future. And it provides methods and new insights that can help us reap the benefits of new digital technologies and products.

At the same time, companies and investors globally are seeking access to new cutting-edge science and technology that can prove crucial to the development of new products, services or new business models that can strengthen their position in intense international competition.

This report has identified research strengths in Greater Copenhagen from the perspective of investment promotion. What these research areas have in common is their ability to merge world-class science with a range of other value offerings that help attract foreign R&D investment to the region, such as a strong physical research infrastructure (labs, test facilities etc.), a large, competent pool of talent and well-developed university-industry relations.

Based on a combination of qualitative and quantitative methods, the report singles out 12 particularly promising areas of research with great potential for attracting investments to Greater Copenhagen. These areas are described in detail in 12 factsheets.

The 12 positions of strengths are wide-ranging, from research into new forms of treatment for life-threatening disease to quantum technologies that can constitute the basis for the supercomputers of the future.

Foreign investment in research and development leads to new jobs, growth and productivity, thereby providing an economic boost to the regions which succeeds in attracting it. Thus, Greater Copenhagen's special scientific strengths comprise an important starting point for efforts targeted at attracting investment.

We hope that the 12 selected fields of research constitute a strong basis for attracting future foreign investment to Greater Copenhagen.

This analysis has been compiled for the Capital Region of Denmark and Copenhagen Capacity in connection with the Capital Region’s growth and development strategy (ReVUS).

REGION The Capital Region of Denmark COPENHAGEN CAPACITY GREATER CoPENHAGEN

Chapter 1

Research strengths with investment prospects

1.1 THE COMPETITIVE SITUATION OF GREATER COPENHAGEN

Companies worldwide are increasingly investing in ground-breaking research that can lead to the development of the products and services of the future.

This could be the development of new supercomputers for processing big data as well as new individualised therapies that can cure life-threatening disease with very few adverse reactions. Or the development of new sustainable energy storage technologies that can stabilize the power supply when the wind is not blowing.

When companies decide on making physical investments in R&D-activities abroad, it is often to gain from a close proximity to leading research environments, access to specialists and talented personnel or to make use of special research facilities, such as laboratories or big-science infrastructure (e.g. the "super microscope", European Spallation Source (ESS), in Lund, Sweden).

States and cities compete globally to attract business R&D activities. Investments, which in many cases are accompanied by productive, well-payed labour, an influx of knowledge and increased economic activity. Greater Copenhagen participates in this competition, especially vis-à-vis other Northern European cities such as Stockholm-Uppsala, Amsterdam and Hamburg.

Greater Copenhagen performs strongly on several parameters that matters when seeking to attract research-related investment to the region. Generally, Danish research performs well in international comparisons. Greater Copenhagen is home to the greatest concentration of research institutes and higher education institutions in Scandinavia together with several world-leading research clusters, e.g. within life science and cleantech.

But competition among metropolitan areas to attract investments is intense. It is important for Greater Copenhagen to successfully differentiate itself and highlight the region's research strengths and their potential when it comes to developing breakthrough science and technology.

1.2 OBJECTIVE AND APPROACH

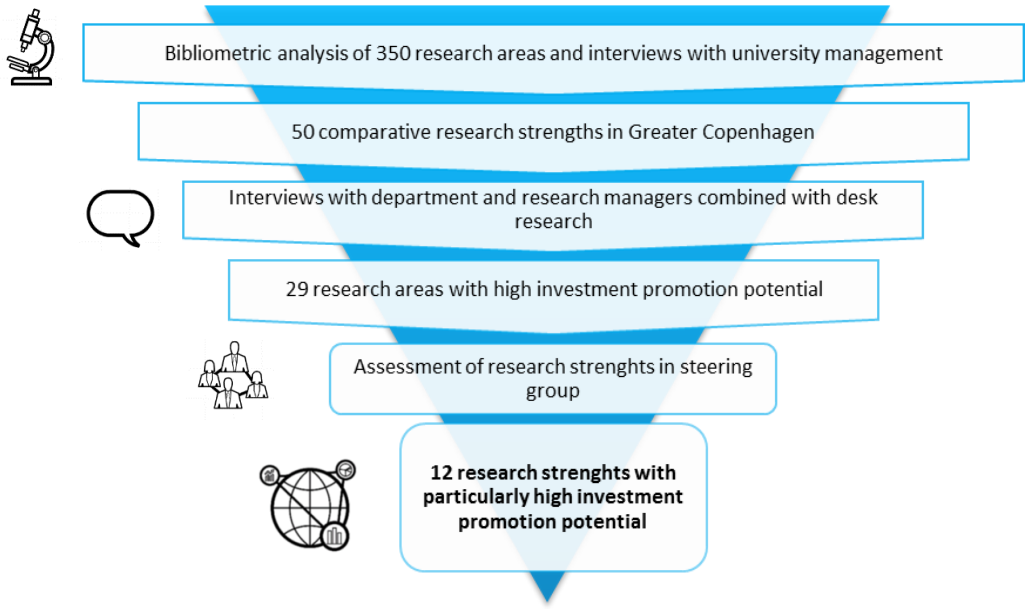
The aim of this report is to identify research strengths in Greater Copenhagen that carry significant prospects for attracting foreign investment.

The ambition has been to generate a strong foundation of fact-based knowledge that can serve as a basis for investment promotion and to provide new insights into what motivates foreign companies to collaborate with universities in Greater Copenhagen, e.g. for establishing R&D facilities in Denmark.

The analysis was conducted from April to November 2016 and resulted in the identification of 12 research areas with a particularly high potential for attracting investments. The 12 areas are described in detail in the factsheets that form the main output of the analysis. This report describes the analytical model and the methodological approach that led to the selection of the 12 areas.

The approach is based on a combination of a comprehensive bibliometric analysis, qualitative in-depth interviews with university management representatives, heads of departments, heads of research groups as well as companies. Furthermore, the analysis has drawn on an extensive desk research and accessible statistics. The figure below summarises the different phases of the process, which are elaborated in more detail in Chapter 2.

Figure 1.2 – Analytical process



The 12 research strengths have not only been selected on the basis of research quality (measured by proxy through bibliometrics). Importantly, the selection should not be construed as a *ranking* of Greater Copenhagen's many excellent research environments. Instead, the research strengths have been selected on the basis of a comprehensive assessment of a wide array of criteria, which are expected to carry weight for potential investors.

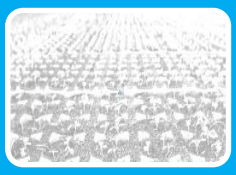
The figure below summarises the 12 fields of research identified in the process as well as the departments and centres in which the research is centred.

Acoustics and Ultrasound
Development of new advanced audio and hearing aid solutions. Application of ultra sound and 3D imaging for complex diagnosing.
Anchored: DTU Electrical Engineering (including Oticon Centre of Excellence for Hearing and Speech Sciences and Center for Fast Ultrasound Imaging).

Bacteriology
Solutions to counter antibiotic resistance and block biofilms. *Anchored*: Department of Biology, Department of Immunology and Microbiology, and Department of Veterinary Disease Biology at the University of Copenhagen, DTU Food.

Bioenergy
Application of enzymes, fermentation technology and the biochemical processes in developing 2nd generation biofuels. *Anchored*: Department of Geosciences and Natural Resource Management, Department of Plant and Environmental Sciences, Department of Chemistry, and Department of Biology at the University of Copenhagen. Chemicals Technology, Environment and Biosustain (NNF) at DTU. Center for Corporate Social Responsibility and BioBusiness Innovation Platform at CBS

Cancer research
Fundamental understanding of how cancer cells develop and spread, cancer diagnostics and strong environments focusing on developing and testing new drugs and new therapies. *Anchored*: Biotech Research and Innovation Centre (BRIC), DanStem stem cell center, Department of Immunology and Microbiology, and Department of Cellular and Molecular Medicine at the University of Copenhagen. DTU Bioinformatics, Copenhagen University Hospital.



Food and fermentation
Quality control of food using spectroscopic methods, food preservation, uptake of minerals in the body, nutritional research and food fermentation. *Anchored*: Department of Food Science and Department of Veterinary Disease Biology at the University of Copenhagen, DTU FOOD, DTU VET, DTU Bioengineering, DTU Chemical Engineering, Biosustain, and BioBusiness Innovation Platform, CBS.

Quantum Technology
Application of quantum properties of elementary particles in developing quantum-based supercomputers, ultra precise sensors and super fast communication. *Anchored*: Niels Bohr Institute at the University of Copenhagen, DTU Physics and DTU Photonics

Protein research and bioinformatics

Cutting edge research into the use of proteins for diagnostics using biological markers, new protein and sugar-based methods for drug delivery and personalised medicine. Anchored: Department of Cellular and Molecular Medicine and the Novo Nordisk Foundation Centre for Protein Research at the University of Copenhagen

Humans and technology

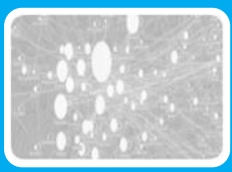
Understanding human interaction with, and use of, new technology. Anchored: Faculty of Humanities and Faculty of Social Sciences at the University of Copenhagen, Copenhagen Business School.

Metabolism and diabetes

Understanding metabolic processes and causes underlying life-style-related diseases such as obesity and type 2 diabetes. Anchored: Department of Biomedical Sciences, Novo Nordisk Foundation Centre for Basic Metabolic Research, and Department of Nutrition, Exercise and Sports at the University of Copenhagen, Department of Organization at CBS, Herlev Hospital.

Nanoscience

Manipulation of materials/substances at the molecular level, for example for developing materials with new properties, manipulation of the properties of plants, development of new therapies, for example in personalised treatments and new precise methods for drug delivery. Anchored: Nano Science Centre at the University of Copenhagen, DTU Nano and DTU Mechanical Engineering.



Social big data

Use of Big Data analysis to identify attitudes and trends amongst individuals and groups using algoritims that combine data from social media and registers. Anchored: Faculty of Humanities and Faculty of Social Sciences (including Department of Economics and Department of Anthropology) and Department of Computer Science at the University of Copenhagen, Department of IT Management, Department of International Business Communication and Department of Economics, CBS, DTU Compute.

Wind and energy storage

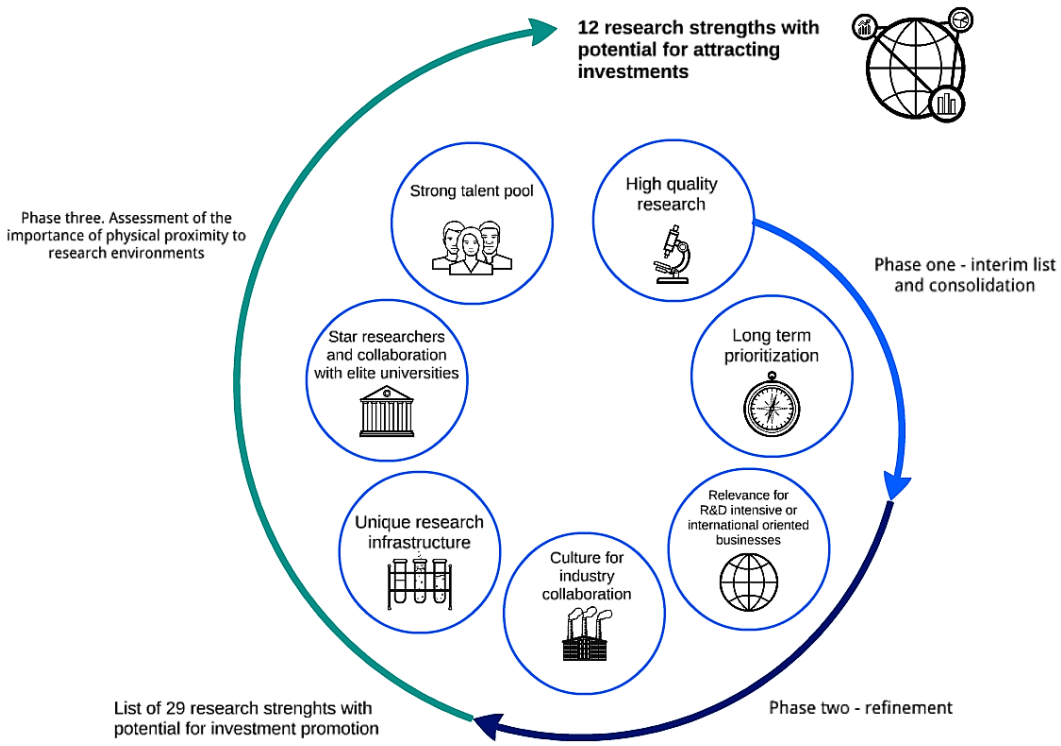
Development of wind turbines and new forms of energy storage such as flow batteries, electrolysis and fuel cells. Development of smart grid solutions for more efficient and even use of sustainable energy. Anchored: DTU Wind, DTU Energy, DTU Mechanical Engineering, DTU Electrical Engineering and DTU Compute.

1.3 RESEARCH STRENGTHS WITH INVESTMENT PROSPECTS

As part of the analysis of Greater Copenhagen's research strengths, IRIS Group developed a model for assessing the investment prospects for a specific research field. The model features seven key parameters that in many cases constitute important value offerings for companies considering locating R&D operations in another country.

The seven parameters are thus all reasons for companies to be geographically close to the research environments. We use these seven criteria to assess the investment potential of the research in Greater Copenhagen. The figure below illustrates the analytical model;

Figure 1.3 – Analytical model



High quality research is a fundamental precondition for a research area to attract investments to Greater Copenhagen. This spans excellent basic research as well as high-quality applied research. In many (but far from all) instances, high quality research is reflected in a high performance on bibliometric indicators, e.g. measuring the frequency of citations of research articles.[1]

Second, the decision to invest in Greater Copenhagen may be influenced by the extent to which the area is subject to a **long-term strategic prioritisation** by the university and/or national and regional actors. Strategic prioritisation sends out an important signal that a research field will maintain its current momentum in the years to come. This could, for example, be by way of long-term research funding (e.g. by the Danish National Research Foundation, the Novo Nordisk Foundation etc.), or by the internal priorities of a research institution, for example funding for special excellence centres. Such strategic priorities constitutes an important forward-looking supplement to the bibliometric data.

Third, the **research area has relevance for industries with a high level of R&D intensity and/or businesses with a high level of cross-border, international operations.** High-quality research may be of limited interest from an industrial perspective (at least in the short-term), for example if the research activities is oriented towards gaining new fundamental insights into a new field[2].

Fourth, **culture and tradition for industrial collaboration** is an important condition for attracting investments. E.g. though a tradition for co-publishing research results with industrial partners. Or environments that performs well with respect to technology transfer and commercialisation of research results, e.g. licensing or spin-outs. It is important to have a strong culture of industrial collaboration if an area is to be attractive to potential foreign investors. At the same time, a promising spinout may be the direct aim of foreign investors.

Fifth, for many companies, **access to unique research infrastructure**, such as facilities for trialling and testing, high-tech systems, equipment, specialized technical and scientific staff or big science facilities (such as ESS in Lund), is a strong reason for investing in Greater Copenhagen. Unique research infrastructure and access to researchers and specialists who know how to use it, may for example enable companies to test and demonstrate new materials or drugs.

Sixth, the **presence of elite researchers and/or researchers that collaborate with leading global environments in their field** can be a key reason for investing. This could for example be research teams that are international frontrunners in producing high impact research, or environments that are highly capable in transforming research into practice.

[1] Bibliometric indicators provide a retrospective picture of research strengths and is thus often inadequate for identifying new, upcoming areas. Bibliometrics is furthermore categorised according to pre-defined, journal-based headings that do not always provide a correct depiction of the content, interrelationship and properties of a particular strength.

[2] However, it is important to emphasize that is it is extremely difficult to establish a general relevance criterion for research from a commercial point of view. For example, industrial players with very long-term development horizons (e.g. in life science) are often highly interested in new fundamental discoveries.

It is also important for companies to be able to recruit younger talented scientists who have collaborated with international star researchers.

Seventh, **industrial access to talent** (highly qualified workforce/graduates/PhDs) from universities is an important driver for foreign investment. Access to a competent talent pool and specialists constitutes an important channel for transferring knowledge from research environments as well as an important source of recruitment for foreign companies.

Thus, it is not in itself sufficient for a particular research field to perform well according to bibliometric indicators for research quality. In the individual case, the various reasons for investing may carry more or less weight than in other cases. Furthermore, other factors may play a part such as cost of living, market access, airports, liveability in the region etc.

1.4 READING THE FACTSHEETS

The main outcome of the analysis are 12 factsheets, which provide a detailed description of a research field and its potential in an investment promotion context. The factsheets are structured in a standardised form:

The front page summarises the fact sheet with a brief introduction to the content, key environments and the investment attraction potential of research field.

The introduction provides an general description of the research strength, and highlight the key areas of high research quality as well as international collaboration.

The bibliometric key figures in the table illustrate some of the key bibliometric indicators that document Greater Copenhagen's leading position. This includes research output, level of excellence, industrial co-publication and Greater Copenhagen's ranking among the regions of comparison (see Sec. 2.1.2).

The section on key arguments for the area's investment promotion potential generally follows the figure above and emphasises the arguments for an area's potential by virtue of:

- The presence of star researchers and major scientific breakthroughs
- Talent pool
- Unique research facilities/infrastructure
- Strong collaboration with leading international research environments
- Extensive industrial collaboration

Finally, some of the factsheets provides examples of spin-outs or quotes emphasizing the potential of the area.

Chapter 2

Methodological approach

2.1 BIBLIOMETRIC ANALYSIS AND INTERVIEWS WITH UNIVERSITY MANAGEMENT

The first step in the process consisted of a comprehensive bibliometric analysis of a total of 334 pre-defined research fields. The aim of the bibliometric analysis was to narrow down the 334 fields to an interim list of approximately 50 areas, displaying high quality research.

The international research database Scopus was used for the bibliometric analysis. Scopus contains approximately 55,000,000 records of research articles, conference contributions and patents granted to researchers and research institutes worldwide.

2.1.1 Regions of comparison

The first task was to define a number of European metropolitan areas that would serve as regions of comparison vis-à-vis Greater Copenhagen. These regions were basically chosen as the European regions that Greater Copenhagen typically competes with in attracting foreign investment. These reference regions are listed in Table 2.1.

Table 2.1. Nine regions of comparison in the bibliometric analysis

Amsterdam	Geneva Lausanne	Munich
Berlin	Hamburg	Oslo
Dublin	Helsinki	Stockholm/Uppsala

Source: IRIS Group (2014).

In Greater Copenhagen, the analysis included the three big universities: University of Copenhagen (UCPH), Copenhagen Business School (CBS) and the Technical University of Denmark (DTU).

In all nine regions of comparison, the analysis covered a similar combination of technical universities, business schools and at least one classic university offering research in the humanities, social sciences, theology, etc.

Furthermore, research conducted in the regions' university hospitals was also included in the analysis.[3]

[3] Appendix 2 lists the research institutions covered by the analysis.

2.1.2 Key bibliometric indicators

Phase I consisted of defining relevant indicators for research output and quality research. The key indicators are briefly described below:

Research production: The target indicator used was scholarly output, covering published research in the form of articles, reviews and conference contributions. To ensure that only areas of research with a significant volume were included in the analysis, a minimum threshold was set at least 250 articles between 2005-2015.

Quality of research: The following two indicators were employed to measure quality research:

- *Research excellence:* The proportion of articles among the 10% most cited globally within the specific academic area in the period 2005-2015.
- *Field Weighted Citation Impact* (FWCI) measure the relationship between citations per publication in the research field, locally, and the average number of citations per publication in research field worldwide. FWCI is an index in which FWCI = 1 indicates that the average impact of a local field of research corresponds to the global average. FWCI >1 indicates that the impact is greater than the global average, whereas FWCI <1 indicates a lower average impact than the global average.

In **Phase II** the research fields were listed on the basis of research quality. First, we normalised the two indicators for quality research and merged them into one overall indicator for quality.

We furthermore calculated Greater Copenhagen's ranking, within each field, among the comparator regions for the three indicators of research output, number of highly cited articles and Field Weighted Citation Impact.

Next, we sorted all fields of research according to their scores on the consolidated quality indicator. We then reviewed the list from the top to assess the rankings of individual research fields according to scholarly output, number of highly cited articles (research excellence) and field weighted citation impact vis-à-vis the comparator regions.

The criteria for inclusion in the initial overall list were that the field of research:

1) Scored highly on the weighted quality indicators.
2) Ranked in the Top 3 among the regions of comparison and satisfied at least one of the three indicators (scholarly output, number of highly cited articles (research excellence) and field weighted citation impact).

In the first instance, we consolidated an overall list of about 70 research fields with high scores on the overall indicators for research quality and which, at the same time, were in the Top 3 among the regions of comparison with at least one of the indicators noted above.

2.1.3 Focus group interview with university managements

Subsequently, we conducted group interviews with university management representatives at each of the three universities (Copenhagen Business School, Technical University of Denmark and the University of Copenhagen). The aim of the focus group interviews was to qualify and refine the list of research strengths and potential areas of strength.

Initially, the overall list of (potential) strengths was submitted to university managements followed by a thorough discussion in order to qualify the list. The focus group interviews were structured according to the following overarching themes:

1) A review of the overall list of research strengths in order to assess the validity of the bibliometric findings and identify possible interrelated fields of research, which should be analysed as a consolidated, overall strength.
2) Identification of research strengths that did not appear in the bibliometric analysis.
3) Discussion of the underlying reasons for the university's strengths in the research areas identified in the bibliometric analysis.
4) Information about recent realised or planned investments in the identified fields of research, e.g. with excellence funding, etc.

The overall result of the bibliometric analysis and focus group interviews with senior university managements led to a consolidated list of about 50 research fields that could be potential candidates for a Top 10 listing of research fields with a high potential for attracting foreign investment.

2.2 INVESTMENTS IN RESEARCH FACILITIES AND TRADITION FOR INDUSTRY-COLLABORATION

The next step in the analysis was to screen the approximately 50 research areas on the interim list in order to assess their prospects for attracting investment.

- *First,* we sought to identify, whether the nature and content of research was relevant for R&D-intensive companies in sectors with a tradition for cross-border investment.
- *Secondly,* whether there was a culture and tradition for university-business collaboration within the specific research fields. For example, in the form of joint research projects with involvement from private companies, licensing agreements and spin-outs.

2.2.1 Interviews with heads of department

In order to gain a deeper understanding of the content of research and an overall assessment of the relevance of the research field with respect to foreign investments, we conducted interviews with relevant heads of departments, which have contributed with important research in the selected areas.

The relevant departments were singled out by initially identifying the most cited researchers from the University of Copenhagen, CBS and DTU within each research area, using the Scopus database, and subsequently investigated the departments at which the top researchers were employed.

Relevant heads of department were contacted for a telephone interview to discuss the fields of research on the overall interim list to which researchers in their department had contributed significant research.

Interviews with heads of department were structured in line with the following questionnaire:

Box 2.1. Themes for interviews with heads of department

a) Assessment of bibliometric findings

b) Brief introduction to the content of the research field

- Important commercial applications and potentials for attracting investment, including the significance of geographical proximity.
- Figures for FTE researchers in the specific environments as well as collaboration with other departments.

c) Excellence funding for the research environment over the past 3-5 years (Danish National Research Foundation, ERC grants, private foundations, etc.).

d) Collaboration with leading foreign research environments

e) Recent or planned research investments, e.g. in research infrastructure.

f) Talent - how many Master's graduates, PhDs and postdocs are trained on an annual basis?

g) Commercialisation and industrial relations, i.e. tradition for industrial collaboration with Danish or international companies, spinouts, etc.

Source: IRIS Group

The interviews with heads of department helped to provide a deeper understanding of the content and scope of research as well as identifying key elite researchers, major scientific breakthroughs and relevant future investments.

2.2.2 Supplementary desk research

Subsequently, we carried out supplementary desk research.

The first step focused on merging the listed research headings into coherent fields of research based on input from the heads of departments and by merging different research categories, featuring the same highly cited researchers, under common headings.

The second step in the research process focused on clarifying and assessing the research fields according to the following key parameters:

- Attraction of excellence funding (ERC grants, basic research funding, private foundations, etc.)
- Major, extraordinary research investments

- Tradition for industrial interaction (e.g. via organisational units for research-industry collaboration).
- International collaboration partners and ability to attract guest researchers, etc.
- Parameters that necessitate physical proximity to research, e.g. special laboratories and other research facilities, access to talent. etc.

The outcome was a consolidated general interim list of 29 research strengths and an overall assessment of the investment attraction potential of each of these areas. Appendix 1 shows the overall list of the 29 areas and an assessment of the areas' investment attraction potential.

2.3 PRIORITISING THE SELECTED STRENGTHS

The consolidated interim list, featuring 29 research fields was submitted to the project steering group, in which the three universities were represented. The steering group reviewed the fields and helped select 10-12 fields deemed to have strong prospects for attracting investments.

It was decided by the steering group to prioritise 12 areas of strength. Subsequently, detailed factsheets were compiled for all 12 areas, describing their potential for attracting foreign investment. Table 5.2 sums up the 12 prioritised areas.

Table 2.2. Research areas with a high potential for attracting investments to Greater Copenhagen

Bacteriology	Food and fermentation	Nanotechnology	Protein research and bioinformatics
Bioenergy	Metabolism	Quantum technology	Social Big Data
Cancer research	Humans and technology	Sound and ultrasound	Wind and energy storage

Source: IRIS (2014).

2.4 FACTSHEETS

An in-depth analysis was carried out in all 12 areas in order to achieve a thorough understanding of the potential of the areas for investment promotion. The aim was to increase awareness of the particular properties of the research fields, which are crucial for attracting investment, cf. Figure 1.2.

The analytical process comprised of the following steps:

- Phone interviews with research group managers and star researchers in the field

- Interviews with selected Danish and foreign companies with R&D operations within the research field and which know the environments in Greater Copenhagen.
- Supplementary quantitative indicators for the 12 areas:
    - Masters and PhD production
    - Inventions and spin-outs
- Identifying major research breakthroughs rooted in Greater Copenhagen's strong fields of research.

Interviews with top researchers and companies focused on gaining a deeper understanding of the importance of active physical presence and operations in Greater Copenhagen in giving companies a competitive edge that they could not achieve elsewhere. This furthermore related to the importance of access to special expertise, talent, research equipment, data, etc.

The outcome of this phase was 12 factsheets with in-depth descriptions of the selected research strengths with strong prospects for attracting foreign investment, cf. the general model in Chapter 1.

Appendix 1

Overall list of 29 strengths following Phase II

2.5 INTRODUCTION

As described in Chapter 2, phase II led to 29 research strengths that are expected to carry a high potential for attracting investment. These are listed and described briefly in the table below.

In phase III, the broad list was narrowed down to twelve areas with particularly great investment attraction potential. Interlinkages and overlaps between the individual areas were identified through this process. It should be noted that the list it is an "intermediate product". The 12 factsheets include relevant elements of areas that did not in themselves give rise to a separate fact sheet.

The indicators used in the table are described in more detail in Chapter 2. The colours indicate our overall qualitative assessment of the presence of the listed factors that are significant for the areas' potential for attracting investment.

- Green indicates the clear presence of the factor
- Yellow indicates the partial presence of the factor
- Red indicates a weak or non-existent presence of the factor

Name	Overall assessment	Description	Impact rank	Top 10 ranking	Specialism	Output ranking	Excellence funding	Guest researchers	Major research efforts	Commercial collaborations	Requirement for proximity
Cancer	1	Covers basic research examining the causes behind the development and spread of cancer (including stem cells), as well as clinical research and testing. Biotech Research and Innovation Centre (BRIC), Novo Nordisk Foundation Stem Cell Center and Copenhagen University Hospital all contribute to the research strength. The interaction between medical and clinical research is emphasized as one of the regions' assets. Moreover, many researchers are being trained in a wide array of medical disciplines related to cancer. Early application of personalised medicine technologies is for example carried out at the Phase I Unit at Copenhagen University Hospital.	2	2	0.8	5					
Food research	1	Copenhagen has a strong position within food research. Research is undertaken at a wide range of departments and research environments e.g. the Department of Food Science, Department of Food and Resource Economics, Department of Public Health, Department of Sport and Nutrition, Department Veterinary Disease Biology at the University of Copenhagen as well as the National Food Institute at DTU and DTU Chemical Engineering. Particularly promising areas from an investment perspective include white biotechnology, including fermentation (with weighty industrial players such as Chr. Hansen, Carlsberg, etc., in the area), food safety, development of high value-ingredients such as probiotics, nutraceuticals as well as the application of mass spectrometry. The research is underpinned by new investments in state-of-the art facilities, e.g. DTU's Center for Hygienic Design, experimental animal housing at the University of Copenhagen's Faculty of Science, DTU Biosustain and DTU's coming building for Life Science and Bioengineering.	2-4	2-5	2.1	1					
Sound/ultrasound	1	Traditional Danish research strength, both with respect to hearing aids, sound technologies and ground-breaking ultrasound-technologies for medical applications. The majority of research is carried out at DTU Electrical Engineering. Important centres include the Center for Acoustical/Mechanic Micro Systems, Center for Hearing and Speech Sciences, Center for Applied Hearing Research and Center for Fast Ultrasound Imaging. The research constitutes the basis for Denmark's unique position within development and produc-	1	2	1.7	1					

		tion of hearing aids, as well as new medical applications. For example, the ultrasound research environments have made new breakthroughs in 3D-imaging, e.g. of blood-flows. They have also worked with BK Ultrasound to develop the most powerful ultrasound scanner in the world and has recently developed a compact, portable scanner, enabling new ultrasound applications for practitioners and paramedics.										
Metabolism and diabetes	1	Significant research strength focusing on the application of biochemical processes for the conversion of nutrients, and which form the basis for effective new therapies for obesity, Type-2 diabetes and other hormonal diseases. Novo Nordisk's successful product Victoza was based, among other things, on the University of Copenhagen's medical research. An important factor is the industrial engagement, as well as close general interaction between medical research and research at the Department of Sport and Nutrition and the Department of Public Health. The focus is on understanding the mechanisms of prevention, developing new drug candidates and large-scale randomised studies (medical treatments and studies of diets, etc.)	2-4	1	1.7	1-2					
Bioenergy	1	Greater Copenhagen's universities, especially DTU, is strong within the development of environmental recycling technologies (for materials/substances and energy-production, e.g. through incineration and biofuels). DTU Environment feature a range of strong environments, including Environmental Chemistry and Residual Resource Engineering. The Department's laboratories are used by companies for trials and jointly funded research projects. The Department collaborates with some of the strongest research environments in the world and has recently been awarded an ERC grant. DTU Biosustain is a Novo Nordisk Foundation funded institute with 260 researchers working with biochemical and biological processes in this field.	1	1	2.0	1					
Wind and smart grid	1	The Capital Region, and in particular DTU, performs strongly within research in wind energy and smart grid systems. DTU Electrical Engineering and DTU Wind, including the Center for Electric Power and Energy (CEE), are particularly strong in the area. The research is especially engaged in three main areas: designing wind turbines, energy storage and designing flexible electrical systems, including components and systems that can handle fluctuating power supplies.	4	4	1.7	1					
Bacteriology	2	Research strength within bacteriological research anchored at both DTU and the University of Copenhagen. There are particularly strong niches within 1) antibiotic resistant bacteria and 2) methods for interrupting biofilms, both of which have significant commercial importance. Research into antibiotic resistance is a matter of understanding	3	3	1.9	1					

		the genetic and bacteriological processes that lead to antibiotic resistance in bacteria and the development of new types of antibiotics. Methods for interrupting bacteriological films involve developing ways to interrupt the bacteriological films that make bacteria resistant - this is a problem for many different industries.										
Big Data	2	A highly interesting growth area, but also very broad and transversal. Links between the Niels Bohr Institute, ESS, the Department of Computer Science and DTU. The Department of Computer Science and the Niels Bohr Institute are generally highly competent in developing algorithms and machine learning. Big Data competency can be used in a many different fields of research from bioinformatics to social big data.	4	2	0.7	8					
Bioinformatics and protein research	2	The combination of protein research and bioinformatics' strives to gain a deeper understanding of the biological processes underlying the development of diseases and apply the knowledge to develop new drug candidates and therapies. Copenhagen DTU and the University of Copenhagen both have special strengths in using big data and bioinformatics to study gene and proteins. A particular research strength is the ability to link data from electronic patient records, biobank data and advanced methods for analysing molecular structures.	2	2	1.0	4					
Sustainable construction	2	Denmark is strong in this field. It covers construction, indoor climate, energy-efficient housing, urban development, etc., as well as architecture, urban development, GIS systems and climate change adaptation. DTU Civil Engineering, including the Center for Building Design, Center for Building Energy and Center for Internal Environment and Building Physics are all strong research environments in the area. Furthermore, the former SBi, which today is part of Aalborg University's Copenhagen branch. The field is being driven among other things by increasing global demand for energy and healthcare standards. The weakness is that construction markets are nationally-oriented due to tradition, differences in weather and climate, etc.	3	3-4	1.6.	1-2					
Cardiology	2	A strong cardiological environment derives among other things from the now closed Basic Research Centre (DARC). There is a relatively large group of young promising researchers studying the ion channels that govern the heart's contraction and the causes of arrhythmia and cardiac arrest. The research is now being moved to the new Maersk Building with its state-of-the-art facilities. The environment is characterised by a highly outward-facing commercially-oriented culture with considerable experience in commercial interaction and a significant number of licences and spin-outs. There are also collaborations with a highly qualified clinical hospital research environment.	4	3	1.0	5					

Quantum physics	2	Over the past century, Copenhagen has occupied a very strong position in the field of quantum physics. The Niels Bohr Institute has been awarded more ERC grants than all other departments at the University of Copenhagen - a total of 11 of which six relate to quantum physics. The field has attracted four Danish National Research Foundation grants to the Center for Quantum Optics, Center for Particle Physics, Center for Quantum Devices and Center for Stem Cell Decision Making. The Niels Bohr Institute has set up QUBIZ.dk in conjunction with DTU Physics, the University of Aarhus and 14 companies. The area carries great potential, but the weakness is that many companies regard quantum physics is very basic research-oriented.	3	3	0.8	5					
Nanoscience	2	Nanoscience relates the manipulation of particles between 1 - 100 nanometres. DK has a strong position by virtue of the Nano Science Center established in 2001 as a collaboration between the Niels Bohr Institute and the Department of Chemistry. Since then, the collaboration has expanded to include the Department of Biology, Department of Neuroscience and Pharmacology and the Faculty of Health Sciences. The Centre has 150 researchers and has received significant funding from the EU and the Danish National Advanced Technology Foundation. The Centre has also been awarded basic research grants for a Centre for Synthesis Biology and a Sino-Danish Center for Molecular Nanoelectronics.	-	-	-	-					
Plant science	2	Greater Copenhagen displays international top class within plant science. The field is made up by research at several Departments at both the University of Copenhagen and DTU, but is mainly centred at the Faculty of Science at the University of Copenhagen, including the Department of Biology and the Department of Plant and Environmental Sciences (PLEN). PLEN also works on energy production through reversed photosynthesis, synthesis biology, glycobiology and plant breeding. The University of Copenhagen's Plant Science Center is located at PLEN.	3-4	3	1.2	1					
Technology and people	2	Copenhagen is home to the largest anthropological environments in Europe and has a strong research profile focusing on interaction between technology and people. It was e.g. one of the first in Europe to focus on Business Anthropology. There is a strong interdisciplinary research collaboration on communication and computer use in everyday life at the Department of Media, Cognition and Communication, Department of Computer Science and the Royal Library. There is a tradition for collaboration between anthropology and companies within medtech, healthcare, the environment, etc. The field educates graduates for a growing consultancy sector providing advi-	4	5	1.5.	2					

		sory services on products and business development, user understanding, etc. The field has attracted research funding from the Velux Foundation, the Carlsberg Foundation, Laurits Andersens Foundation, etc.										
Water	2	Greater Copenhagen has a range of strong competencies in water research and technology. Most of the research is done by DTU Department of Environmental Engineering, featuring three elements: Urban Water Systems, Water Resources Engineering and Water Technology. DTU also collaborates closely with DHI (Danish Hydraulic Institute). Copenhagen also features competencies within urban and landscape planning and climate adaptation at the University of Copenhagen Department of Geosciences and Natural Resource Management. One weakness with respect to commercial exploitation of water skills is the culture and regulation of the Danish water companies and significant national differences in water systems.	-	-	-	-					
Allergy	3	An exciting growth area in Denmark and in many other countries. The leading facility is the Danish Allergy Research Center at Gentofte Hospital, which is associated with the Department of Clinical Medicine at the University of Copenhagen. The centre has twice been awarded the Capital Region's Global Excellence Prize. The Environmental Protection Agency also established a knowledge centre for allergy in 2001, which carry out research in, and provides guidance on, substances that may cause allergy. So far there appears to be limited industrial interest in this field although there is close interaction with Leo Pharma Nordic and Lundbeck, among others.	3	3	1.3	3					
Automation, robotics and space	3	DTU Electrical Engineering and DTU Space display top class research. DTU Space is an alliance partner with both ESA and NASA and has played a significant role in sending a space probe to Mars. DTU Electrical Engineering has a strong Center for Automation and Control. The centre collaborates with the Maersk McKinney Møller Centre ate University of Southern Denmark. Both departments' research is relevant for developing fine measuring instruments and communication equipment.	1	4	0.7	4					
Bodytech	3	Bodytech covers research into prosthetics and endoscopy. The Danish capital has a strong medical environment. Prosthetics and implants are based at Bispebjerg Hospital, and endoscopy at Herlev and Gentofte Hospitals. The downside is the lack of Danish manufacturers.	-	-	-	-					
Energy conversion and storage	3	With DTU as the hub, Copenhagen is strongly positioned within a range of energy technologies, each of which has the potential to make significant contributions to a more coherent, sustainable energy system, through the use of fuel cells, electrolysis, batteries and plastic solar cells. At	3	3	2.0	2					

		DTU, research is especially being done at DTU Energy and DTU Electrical Engineering and especially into disruptive technologies. Their strength lies in their strong international position in selected technologies. The weakness is due to the fact that some environments in Germany, France, Korea and Japan are just as strong, and larger.										
Fertility and reproduction	3	This area relates to fertility, gynaecology, obstetrics, (paediatrics, neonatal patients (premature babies)), etc. Denmark is strongly positioned in this area, e.g. due to the research and treatment of patients at the Juliane Marie Center, Copenhagen University Hospital. The research at the centre is world-class, with Denmark's internationally acclaimed patient registers being a contributory factor. Another issue is that in most of the world, fertility treatment is private. Copenhagen University Hospital works closely with Lund University. There is a certain amount of commercial interest in this field.	1	1	1.4	2-3					
Materials technology	3	Materials Technology relates to materials and surface technologies and the development of polymers. Research is carried out at DTU Mechanical Engineering, DTU Nanotechnology and DTU Chemical Engineering, which has also established the Danish Polymer Center. Materials Technology is interdisciplinary and is based on a range of physical and chemical specialisms that have a wide range of commercial applications. There is strong commercial collaboration in this area, and one significant strength would be the new research opportunities arising in Lund with the recently opened MAX IV and the upcoming ESS. The weakness is the tough international competition in this field.	1.3	1-2	0.9	4-5					
Neuroscience	3	DK is strongly positioned within neuroscience, focusing on the development of brain cells, signalling mechanisms and ageing processes in the brain. The focus is also on a deeper understanding of energy levels and biological processes in the brain. Among other things, research addresses the underlying mechanisms for diseases such as Alzheimer's, dementia, etc. the University of Copenhagen has a range of strong research teams, but the University of Aarhus is also strong in this field and has established a top European research centre with funding, e.g. from the Lundbeck Foundation.	4	2	0.9	6					
Algebra/topology	4	A high quality international research environment in a broad range of mathematical disciplines, featuring strengths in algebra and topology located at the University of Copenhagen Center for Symmetry and Deformation. Generally high quality research and a significant amount of mathematical talent. The Department ranks in the International Top 50, although interest in commercial collaboration and investment is believed to be modest.	2	2	0.7	6					

Arctic research	4	Denmark feature high class Arctic research. The Niels Bohr Institute at the University of Copenhagen hosts the Centre for Ice and Climate, while the Department of Geosciences and Natural Resource Management hosts the Center for Permafrost that carries out basic research. DTU hosts the Center for Arctic Technology. Denmark's historical role in Greenland constitute the backdrop for these operations and in the longer term, there could be major commercial potential, for example for extraction of raw materials, maritime trading routes, etc.	1	1	1.4	2					
Geogenetics	4	The Natural History Museum of Denmark carry out world class research, which is the reason why they have been awarded a grant for basic research for establishing a new Center for Geogenetics. The centre furthermore received an ERC grant to study human migrations in the 2nd and 3rd millennia BC. The Department of Forensic Medicine at the University of Copenhagen also does some research here, although there is limited commercial interest.	3	2	1.1.	3					
International politics	4	The capital displays a leading international position for research in international politics. Research centres on the Department of Political Science at the University of Copenhagen. Special strengths within research in security and conflict resolution (Center for Advanced Security Theory and Centre for Resolution of International Conflicts at the University of Copenhagen), EU research (Center for EU Politics).	2	1-2	2.0	2					
Management and International business	4	CBS Management Research performs strongly internationally, especially by virtue of research in international business. The area is distributed across departments such as the Department for International Economics, the Department for Strategic Management and Globalization, and the Department of International Economics and Management. CBS interacts closely with the business sector.	2	1	1.5.	1					
Funding and finance	4	There has been a major improvement in the quality of research at the Department of Economics, University of Copenhagen over the past 10-20 years. Today, the Department is among the international Top 20 and collaborates with some of the best research environments in the world. At CBS, FRIC – the Center for Financial Frictions, Department of Finance, is an outstanding research environment. The Department of Economics at UCPH has been awarded two grants for basic research and two ERC grants. Graduates are in demand in the business sector, but the weakness from the point of view of attracting investment is that companies probably have little need for close physical proximity to research environments. As with international business, this area does have a significant complementary effect when it comes to attracting foreign investment.	4	4	1.7	1					

Appendix 2

Regions of comparison and institutions

Amsterdam	University of Amsterdam VU University Amsterdam Municipal Health Service of Amsterdam
Berlin	Technical University of Berlin Free University of Berlin Humboldt University of Berlin Helmholtz Centre Berlin for Materials and Energy Federal Institute for Materials Research and Testing Berlin Max Delbruck Center for Molecular Medicine Robert Koch Institute Max Born Institute 5 Leibniz Institutes Stuttgart State Museum of Natural History Weierstrass Institute for Applied Analysis and Stochastics Federal Institute for Risk Assessment Paul Drude Institut fur Festkorperelektronik (PDI) University Hospitals in Berlin Zuse Institute Berlin
Copenhagen	University of Copenhagen Technical University of Denmark Copenhagen Business School University Hospitals in the Capital Region
Dublin	University College Dublin Trinity College Dublin Dublin City University Maynooth University Dublin Institute of Technology Beaumont Hospital, Dublin Dublin Institute for Advanced Studies
Geneva/Lausanne	Ecole Polytechnique Federale de Lausanne (EPFL) University of Geneva University of Lausanne Business School Lausanne
Hamburg	University of Hamburg Deutsches Elektronensynchroton (DESY) Hamburg University of Technology Helmut Schmidt University Bernhard Nocht Institute for Tropical Medicine Hamburg Outstation

Helsinki	University of Helsinki Aalto University Hanken School of Economics Hospital District of Helsinki and Uusimaa Minerva Foundation Institute for Medical Research Helsinki
Munich	Technical University of Munich Ludwig-Maximilians University Munich Helmholtz Center Munich German Research Center for Environmental Health European Southern Observatory 7 Max Planck Institutes Bundeswehr University Munich Munich University of Applied Sciences Fraunhofer Institute for Embedded Systems and Communication Technologies ESK International Max Planck Research School for Molecular and Cellular Biology
Oslo	University of Oslo Norwegian University of Life Sciences Oslo University College Norwegian School of Sport Sciences BI Norwegian Business School
Stockholm/Uppsala	Karolinska Institutet Uppsala University Royal Institute of Technology Stockholm University Stockholm School of Economics Stockholm Environment Institute

Acoustics and ultrasound

Content and applications

Denmark and Greater Copenhagen has proud traditions in audio research and has for many years been a global leader in this area of research. This leading position is reflected in breakthrough research into audio-visual technologies for the hard-of-hearing, room acoustic modelling and noise reduction in buildings and cities. Research has also led to the development of revolutionary new ultrasound technologies that can revolutionise diagnostics of a wide array of diseases, including cardiovascular conditions and cancer, with a far higher precision and speed than before. Also new portable ultrasound devices will enable practitioners and paramedics to benefit more directly from ultrasound technologies.

Key environments and star researchers

DTU Electrical Engineering at the Technical University of Denmark (DTU), is the key environment in Greater Copenhagen's audio research. Among the key research environments is the Center for Applied Hearing Research, where researchers carry out interdisciplinary, audiological basic research and investigate how the experience of hearing aid can be augmented. The centre is led by Torsten Dau. At the Center for Fast Ultrasound Imaging, researchers are developing innovative ultrasound and imaging systems that could potentially revolutionise diagnostics and therapies in the health care sector. The centre is led by Jørgen Arendt Jensen.

Prospects for attracting investment

DTU and the associated Danish ecosystem for sound technology has significant potential for attracting investment. Greater Copenhagen has a well-established ecosystem in audiology, and the know-how within this area is absolutely world-class. The novel ultrasonic technologies, developed at DTU, carry a considerable potential for improving diagnostics and reducing costs in the healthcare sector. Right from the beginning, research has been characterised by a big industrial involvement and several large international companies employ software for ultrasound solutions developed by DTU.

Characteristics of the research area

Greater Copenhagen's stronghold within audio has deep historic roots. At the beginning of the 20th century, Valdemar Poulsen, an engineer, invented the arc generator and revolutionised wireless telegraphy and the development of the tape recorder. The first operational loudspeaker was invented in 1915 by a Dane, Peter L. Jensen. The Acoustical Laboratory at the College of Advanced Technology – what today is known as DTU - was established as early as 1941.

Audio research in Greater Copenhagen is absolutely world-class and is carried out in close collaboration with leading audio technology companies in the region, including Oticon, Widex and GN ReSound and BK Ultrasound, which develops revolutionary solutions for the health service.

DTU Electrical Engineering constitutes the centre of the region's research into audio technology. The research covers many different specialisations, such as acoustic technology, production and transmission of sound, noise control, advanced acoustic measuring technologies, modelling room acoustics and the effect of new construction materials on sound transmission. Greater Copenhagen also occupies a leading position in the field of audiology. Among other things, researchers at DTU Electrical Engineering investigate the development of better hearing aids using advanced signal processing and objective methods for measuring hearing.

Ultrasound research at DTU Electrical Engineering is one of the strongest environments in the world in the field. Over the years, researchers have developed the ultrasound solutions of the future for the health care sector, e.g. enabling imaging of cancer and analysis of the dynamics and speed of blood flow in 3D (for example in the heart) with far greater precision, speed and resolution than previously possible. Currently, this research underlies some of the world's most advanced ultrasound scanners from BK Ultrasound and Phillips, for example.

Researchers have also been engaged in developing new hand-held transducers that can be connected to smartphones or tablets, and which will make it possible for GPs or paramedics to make ultrasound scans quickly, cheap and with the option of transmitting information wirelessly and rapidly to hospitals, etc., via the internet.

Ultrasound technology has made it possible to make a better, cheaper diagnosis than previously possible for a whole range of health conditions. Research involves BK Ultrasound as well as other institutes and players, such as DTU Nanotech, the Alexandra Institute in Aarhus and researchers at Copenhagen University Hospital.

International top quality niches

The research done in Denmark on sound is world class. Top research covers the following environments:

ACT- Acoustic Technology - research in sound and vibration, including production and transmission of sound, noise control, transducer technologies, advanced measurement technology, room acoustics modelling and design, and the effects of new construction materials on sound transmission. Commercial applications include room acoustics and buildings, loudspeakers, concert sound and noise reduction in traffic and buildings. The area is headed by Prof. Finn Agerkvist.

CFU - Center for Fast Ultrasound Imaging - is DTU Electrical Engineering's centre for developing innovative new ultrasound technologies for the healthcare sector. The centre has been operating since 1998 and has developed new research tools and emerging technologies used by universities, companies and hospitals worldwide. CFU currently operates one of the largest projects being run by Innovation Fund Denmark aimed at developing the sustainable ultrasound scanners of the future. The centre is headed up by Jørgen Arendt Jensen.

CAMM - Center for Acoustical-Mechanic Micro Systems - is engaged in micro acoustics and the acoustic properties of materials at the micro level. Research at the Center is funded by Widex, GN ReSound and Oticon. This area is headed by Prof. Jakob Søndergaard Jensen.

Hearing Systems, comprising: 1) Oticon Centre of Excellence for Hearing and Speech Sciences, which is engaged in interdisciplinary, audiological basic research, including the treatment and diagnosis of hearing loss, and how the brain processes speech and music. The centre is headed up by Prof. Torsten Dau. 2) Center for Applied Hearing Research, which is characterised by a more application-oriented profile. The Centre is furthermore engaged in examining the perceptual implications of hearing loss, modelling how the brain processes and perceives sound, the use of modelling in hearing aids and measurements /testing of hearing aids.

Bibliometric key figures

The bibliometric indicators for research production and quality demonstrate that Greater Copenhagen is a clear leader in Europe with respect to research in acoustics and ultrasonics, cf. Table 1.

Over the past decade, researchers in the field have published 742 scientific articles in internationally recognised journals. This puts Greater Copenhagen into first place among the regions of comparison in terms of research output.

Greater Copenhagen is furthermore characterised by a strong specialisation, which means that sound research occupies a considerably greater proportion of the total research production in Greater Copenhagen, than is the case in the other relevant European regions of comparison.

Finally, Copenhagen take second place amongst the regions of comparison on quality of research, in terms of the percentage of publications figuring amongst the 10% most cited within the field of research globally.

Key bibliometric indicators

	Specialisation	Output ranking (No. articles)	Highly cited article ranking (%).	Co-publication ranking (%)
Acoustics and Ultrasound	1.72	1 (742)	2 (18.7%)	7 (3.8%)

Period: 2005 -2015. Regions of comparison: Amsterdam, Berlin, Dublin, Geneva-Lausanne, Hamburg, Helsinki, Munich, Oslo and Stockholm/Uppsala.

Specialisation is an expression of the size of a field of research compared to all research production at University of Copenhagen, DTU and Copenhagen Business School compared with its size in the regions of comparison. A specialisation level 1 indicates that Greater Copenhagen is on level with the regions of comparison. Specialisation of >1 indicates that Greater Copenhagen is more specialised in the field of research than the regions of comparison.

Output ranking measures Greater Copenhagen's position in the field concerned among the regions of comparison in terms of article production (with the absolute numbers of articles in brackets).

Highly cited article ranking indicates Greater Copenhagen's ranking in the regions of comparison for the proportion of articles in the field of research in Copenhagen that are among the 10% most cited worldwide (percentage in brackets).

Finally, co-publication ranking indicates Greater Copenhagen's rank among the regions of comparison for the proportion of articles in the field published jointly with the business sector (percentage of overall article production in Greater Copenhagen in brackets).

Key arguments for the research area prospects for attracting investments

Sound technology is an integral component in a wide range of solutions - from robot technology, via noise meters and sensors that can communicate with users, to digital teaching platforms. Sound also plays an important role as integrated technology in numerous solutions to the challenges facing society in the 21st century, for example in healthcare and welfare solutions or intelligent traffic and supply systems.

Greater Copenhagen has a clear strength in sound-related research. There is a considerable investment potential considering Denmark's strong sound-cluster, which includes well-established companies and start-ups working in audio and acoustics and hearing technology, together with its strong ecosystem. In 2014, the Danish Sound Innovation Network estimated that the 30 largest Danish sound companies had revenues amounting to more than DKK 30bn and that half of all the hearing aids in the world were made by Danish companies, such as Oticon, Widex and GN ReSound.

Greater Copenhagen is the undisputed global leader when it comes to developing audiology and hearing aids. The know-how accrued over many years and the world-leading research facilities available in this field are major assets for foreign companies engaged in innovation in hearing technologies.

Ultrasound research at DTU carries great potential with respect to revolutionising diagnostic methods in the health service, partly by way of much more precise, informative and cheaper methods for identifying and analysing such diseases as cancer and thrombosis, and as an aid in operations and analyses of biopsies. And also by way of developing new portable transducers connected to tablets that can accelerate the use of ultrasound diagnostics, for example in general practice or for paramedics in ambulances. All major ultrasound manufacturers (Phillips, GE, Siemens, Samsung, Sony and BK Medical, etc.) utilise simulation software developed by CFU.

Star researchers and major scientific breakthroughs

In the field of hearing aids, cutting edge research focuses on applying digital technology to improve hearing aids, including advanced algorithms and sensor technology. Researchers at DTU have worked closely with GN ReSound on developing ear-to-ear hearing aids that communicate wirelessly. This allows the left and right hearing aids to communicate with each other and automatically turn the volume up or down to give the clearest possible sound image in the hearing aid. These hearing aids can also be adjusted wirelessly using a smartphone.

Researchers at CAMM are studying how to optimise the complicated mechanical /acoustical connections in hearing aids. Researchers are also investigating how to improve the experience of hearing aids amongst other things by reducing acoustic feedback. Jakob Søndergaard Jensen is one of the lead researchers in this field. CAHR also study how to improve voice recognition using advanced signal processing, including the use of advanced algorithms that can filter out noise and feedback and improve the experience of using the hearing aids. Torsten Dau is one of the top researchers in the field.

CFU is an international leader in the field of ultrasonics and the centre's research has major medical/clinical significance. In contrast to traditional ultrasound scanners, health conditions in the body can be scanned and visualised from every direction in a single session, and with track changes over time (4D). This field of research has been awarded a total of DKK 250m in external funding, from research councils, Innovation Fund Denmark, private companies and foundations. CFU carries out translational research into advanced ultrasonics, including simulation, transducer technology, signal and image processing.
These technologies developed in collaboration with BK Ultrasound make it possible to investigate patients' anatomy and blood flow at very high resolution (down to the micrometre scale), speed (>1000 images /sec) and in 4D

- i.e. 3D imaging with data on changes over time.

For example, vortexes or differences in flow in blood vessels can be identified in real time. The technology significantly reduces the amount of time and resources spent in the clinic since ultrasound technology in many instances is cheaper and a better alternative than significantly more expensive MRI scanning.

CFU is also engaged in an Innovation Fund Denmark project aimed at developing the portable ultrasound scanners of the future, e.g. for use by nurses, doctors or paramedics, without the special training currently required to operate ultrasound scanners.

Nanotechnology and the use of advanced algorithms have improved the probe sensors used in ultrasonic systems, as these cut the number of calculations required and allow the probes to be portable, allowing for example general practitioners to be able to undertake preliminary investigations and transmit ultrasound images to hospitals or specialists. During operations, surgeons could use these scanners to investigate blood flow before suturing. Fundamentally novel ways of transmitting and processing ultrasonics are being developed to allow for data capture for subsequent processing by supercomputers.

Large talent pool

Every year, DTU trains about 20 engineers specialising in acoustics. In medicine and technology, around 30-40 graduates are trained every year, some specializing in ultrasound. DTU Electrical Engineering, Hearing Systems has about 22 PhD students and 11 postdocs. There are about 11 PhD students in Acoustic Technology. Since its establishment, CFU has trained 35 PhDs and currently has 10 PhD students.

Unique research facilities

At DTU, CHESS operates the Audiovisual Immersion Lab (AVIL) test facility, which makes it possible to test hearing technologies in a virtual sound environment. The laboratory features a sound-insulated, sound-dead room with 64 loudspeakers that can recreate audiovisual images, for example from restaurants, with background noise or crowded railway stations. The facility is funded partly by the Oticon Foundation, and partly by DTU's own resources for modernising research infrastructure. DTU also works closely with the DELTA GTS Institute in Hørsholm which has a whole range of test facilities for sound technologies.

CFU hosts one of the most powerful ultrasound scanners in the world, SARUS, developed in collaboration with BK Ultrasound and Prevas. This scanner can make 25,000bn calculations per second and can also be used to make 3D images of the entire heart's blood flow while also measuring flow speed and direction throughout the heart.

Strong collaboration with leading international research environments

The Oticon Centre of Excellence for Hearing and Speech Sciences has a large number of visiting audiology researchers. DTU also works with experts from universities including the Université Paris Descartes in France and University of California, Berkeley. CFU also has collaborations with Stanford University, Duke University, Lund University, Harriet Watts University and Institute Langevin in Paris.

Extensive corporate collaborations

There is a strong tradition of close collaboration between scientists and the corporate sector in the field of hearing aids (Widex, Oticon and GN ReSound), with the loudspeaker industry (e.g. B&O and Dynaudio) and in sound measurement and ultrasonics (Brüel and Kjær). Collaborations are characterised by a wide range of research and development projects and funding for major research efforts such as CHESS and CAMM.

CFU has a long-term, close collaboration with BK Medical and the simulation software for ultrasonic systems developed by the centre is used by all major ultrasound manufacturers.

Bacteriology

Content and applications

In the field of bacteriology, Greater Copenhagen is an international leader in two vital areas:

- Research into antibiotic resistant bacteria and ways of preventing bacteria from developing antibiotic resistance.
- Methods for preventing bacteria from creating biofilms, which are a major challenge for industry and for humans and can lead to life-threatening inflammatory conditions.

Key environments and star researchers.

Research is broadly anchored in a range of institutions in Greater Copenhagen. There are strong research environments at the Department of Immunology and Microbiology and the Department of Drug Design and Pharmacology at the University of Copenhagen, at Statens Serum Institute and at DTU Vet, DTU Food and DTU Bioengineering and DTU Biosustain at the Technical University of Denmark (DTU).

Star researchers include Prof. Michael Sommer and his team who have developed a new resistance principle that can cut the risk of antibiotic treatment leading to the development of resistant bacteria.

Potential for attracting investment

Antibiotic resistance is a global challenge. In Europe alone, every year about 25,000 people die as a result of infection with bacteria that have developed resistance. In domestic livestock and food production, biofilms and antibiotic resistance lead to enormous production losses. Researchers in Greater Copenhagen are amongst the world leaders in these areas which are very broadly anchored in the academic environment. Greater Copenhagen also offers unique research infrastructure, including facilities at Statens Serum Institute, Biosustain at DTU and from an international point of view, there are very special competencies at the Biofilm Test Facility at the Department of Immunology and Microbiology, University of Copenhagen.

Characteristics of the research area

Bacteriological research is strongly interrelated with a number of Greater Copenhagen's other research strengths, such as food and fermentation, bioenergy and protein research. This entails that the environment has a great deal of critical mass and has a strong presence at both the University of Copenhagen and DTU.

Special strengths include understanding the mechanisms that lead to bacteria developing resistance and research into methods for disrupting biofilms. Both fields address key socioeconomic challenges with global perspectives.

International top quality niches

Research in Greater Copenhagen into antibiotic resistant bacteria involves the medical and veterinary fields. Research focuses on understanding the microbiological changes that lead to resistance and how the risk of resistance can be reduced by changing the way agriculture, hospitals and general practitioners use antibiotics.

Research into biofilms seeks to understand the mechanisms that lead to the creation of biofilms in which bacteria clump together to form a biological film that makes it very difficult to fight the presence of bacteria. There are strong research environments at the Costerton Biofilm Center, which is an interdisciplinary research facility at the University of Copenhagen, and at the Biofilm Test Facility, also at the University of Copenhagen, which works closely with the commercial sector.

The presence of biofilms creates major problems in humans since they exacerbate wound-healing and can lead to chronic, life-threatening inflammation.

Biofilms are also a challenge in many places in the industry where bacteria form biofilms that make it difficult to comply with hygiene requirements. But biofilms can also have a positive impact, e.g. in effluent treatment.

Bibliometric key figures

Greater Copenhagen's research strengths in antibiotic resistance and biofilms are only partially reflected in the bibliometric analysis. This is due to microbiology and immunology being a relatively broad field of research, covering many different types of research. Applied Microbiology and Biotechnology are in the category of research that is closest to reflecting Greater Copenhagen's areas of strength, cf. Table 1.

This shows that over the past decade, researchers at the University of Copenhagen and DTU published around 1054 articles in recognized international scientific journals.

Greater Copenhagen has the greatest overall output amongst the comparator regions. The bibliometric indicators furthermore reveal that Greater Copenhagen is highly specialised in this field. A specialisation rate of 1.92 indicates that research accounts for almost twice the proportion of overall research in Greater Copenhagen than in the comparator regions.

Greater Copenhagen comes out on top for quality research, and the region comes third in terms of numbers of globally most cited articles. Amsterdam and Geneva-Lausanne are better ranked but their strengths lie in other areas of microbiology.

Greater Copenhagen is placed first in the regions of comparison in terms of percentage of research articles published jointly with private companies.

Key bibliometric indicators				
	Specialisation	Output ranking (No. articles)	Highly cited article ranking (%).	Co-publication ranking (%)
Applied Microbiology and Biotechnology	1.92	1 (1054)	3 (18.6%)	1 (12%)

Period: 2005 -2015. regions of comparison.: Amsterdam, Berlin, Dublin, Geneva-Lausanne, Hamburg, Helsinki, Munich, Oslo and Stockholm/Uppsala.

Specialisation is an expression of the size of a field of research compared to all research production at University of Copenhagen, DTU and Copenhagen Business School compared with its size in the regions of comparison. A specialisation level 1 indicates that Greater Copenhagen is on level with the regions of comparison.. Specialisation of >1 indicates that Greater Copenhagen is more specialised in the field of research than the regions of comparison..

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Finally, co-publication ranking indicates Greater Copenhagen's rank among the regions of comparison for the proportion of articles in the field published jointly with the business sector (percentage of overall article production in Greater Copenhagen in brackets).

Key arguments for the research area's prospects for attracting investments

Bacteria that develop resistance to known antibiotics are a serious global problem. WHO has demonstrated that multi-resistant bacteria have spread all over the world.

Bacterial resistance results in treatment processes being lengthy or more expensive and could in time lead to more people dying from simple infections. A UK report suggests that up to 10,000,000 humans globally could die from resistant bacteria if new breakthroughs and measures are not made in coming years.

The challenges arising from biofilms are also serious. The increasing use of artificial 'spare parts', e.g. hip prostheses, implants and implanted medical devices also means that an increasing number of people get infections in which the bacteria form biofilms that are drug resistant and lead to chronic inflammation in the body.

Star researchers and major scientific breakthroughs

Greater Copenhagen is home to various internationally acclaimed researchers specialising in bacteriology and resistance. At DTU one of them is Prof. Morten Sommer, who was recruited in 2010 from Harvard. He was employed as the youngest professor in Denmark at DTU Bioengineering with responsibility for creating a strong team to research bacteria, and also to focus on resistance.

At DTU Food, Prof. Frank Aarestrup's team investigates the connection between the use of antibiotics for livestock in agriculture and the implications for human health. Their research has contributed to the development of international practices for surveillance and detection of food-borne antibiotic-resistant bacteria. This unique knowledge has also helped make the National Food Institute (DTU Food) a reference laboratory for WHO and EU.

The University of Copenhagen has supported a EuroStars programme, focusing on resistance and has established a leading international center to study biofilms, the Costerton Biofilm Center. The centre is interdisciplinary and aims both to understand the fundamental mechanisms underlying the creation of biofilms and to develop new therapies to disrupt them, with a focus on preventing and treating chronic inflammation. The centre's internationally acclaimed researchers include Prof. Niels Høiby, who formerly headed up the clinical microbiology department at Copenhagen University Hospital and Prof. Michael Givskov, the Director of the Center.

Large talent pool

Greater Copenhagen has a great deal of research talent by way of PhDs and postdocs who are highly knowledgeable about the microbiological processes underlying multiresistant bacteria and biofilm development. Many departments at both DTU and the University of Copenhagen are engaged in medical and veterinary research in this area.

At the University of Copenhagen alone, over the past five years about 500 PhD students have been admitted to relevant departments such as the Department of Biomedical Sciences, Department of Immunology and Microbiology, Department of Drug Design and Pharmacology and the Department of Veterinary Disease Biology.

Many of these have been educated and trained under the leadership of the many international top researchers in the region in the field of microbiological and structural biological research.

Unique research facilities

Research into antibiotic resistance is based among other things on advanced mass spectroscopy to study the function of proteins in bacteria. At the national level, the Research and Innovation Agency decided to provide DKK 40m in funding to support the establishment of the national PRO-MS Platform, the Danish National Mass Spectrometry Platform for Functional Proteomics.

This effort will also enable DTU and the University of Copenhagen to purchase and use the most advanced mass spectrometers to study the chemical make-up of proteins.

In international biofilm research, the Biofilm Test Facility at the University of Copenhagen provides unique research infrastructure. The test facility has also established strong competencies in producing biomaterials for the use of researchers at universities and a whole range of pharmaceutical companies that see biofilms as a new business area.

Strong collaboration with leading international research environments

The global leading research institutions in this field include such top American universities as Harvard and MIT, and leading agricultural universities such as INRA in France. DTU and the University of Copenhagen are in the world's Top 25 in this field.

International research collaborations have been established between environments in Greater Copenhagen and top environments in USA, including Harvard University. There is also close collaboration with the leading veterinary research environments, including researchers at Lund University which is also strong in this field. The Biofilm Center Works closely with the Singapore Centre of Environmental Life Sciences Engineering.

Extensive corporate collaborations

Extensive commercial collaborations have been established in this field and there has been corporate veterinary collaboration for years. Nowadays, there is extensive interaction amongst other things on developing methods for limiting the use of antibiotics in livestock production.

The Biofilm Test Facility collaborates with various pharmaceutical companies.

Bioenergy

Content and applications

Bioenergy is generated from organic matter such as waste or plant residues. Biomass can be incinerated or used to create biogas, which can then be used for heating or in gas engines, for example in large district heating stations or for refined energy products such as bioethanol that can be blended with petrol. Researchers in Greater Copenhagen based at the University of Copenhagen and the Technical University of Denmark (DTU) are among the best in the world and they can provide a significant contribution to making bioenergy cheaper by optimising all the sub-processes involved in converting waste or plants into fuel. DTU Bioinformatik

Key environments and star researchers.

In the field of bioenergy, Greater Copenhagen hosts a strong research environment. At DTU this is based at DTU Chemical Engineering and DTU Environment. At the University of Copenhagen there are strong environments at the Department of Geosciences and Natural Resource Management, the Department of Plant and Environmental Sciences and the Departments of Biology and Chemistry. The Department of Plant and Environmental Sciences is also home to the Copenhagen Plant Science Center. One major theme researched at Copenhagen Business School (CBS) is the link between sustainability, biotechnology and business development.

A possible game-changer in the field of bioenergy could be the discovery of 'reverse photosynthesis' in the spring of 2016 by a group of leading researchers, including Prof. Claus Felby of the Department of Geosciences and Natural Resource Management, Prof. Morten Bjerrum of the Department of Chemistry and Prof. Poul Erik Jensen, Director, Copenhagen Plant Science Center. This discovery is one of a series of examples of new technologies from researchers in Greater Copenhagen that could have major implications in the future.

Potential for attracting investment

The area is highly relevant for attracting investment. Danish companies and researchers are among the best in the world in developing efficient processes for incinerating biomass and have also been involved in the first bioenergy plant to be set up in Europe in recent years. Various states nowadays require biofuels to constitute 5.75% of petrol and diesel. So-called 1st generation biofuels (made from plant matter) currently account for most of the biofuels. But Danish research is aimed at developing 2nd generation biofuels (made from waste or plant residues) and these are making progress.

Characteristics of the research area

In Greater Copenhagen, research is done in small teams at the University of Copenhagen and DTU. The key environments at the University of Copenhagen are the Department of Geosciences and Natural Resource Management, Department of Plant and Environmental Sciences and the Departments of Biology and Chemistry. In addition DTU has two strong environments - DTU Chemical Engineering and DTU Environment.

Researchers in these environments collaborate on a range of projects and combine different academic disciplines and areas. Total researcher headcount in the area amounts to around 200 permanent professors and associate professors.

CBS also does broadly-based commercially-oriented research into sustainable business development and support for bio-based entrepreneurship. This also involves the Center for Corporate Social Responsibility and Sustainability Platform which is engaged in wide-ranging aspects of green business development and sustainable business management and the BioBusiness Innovation Platform (a collaboration between CBS, DTU and University of Copenhagen), which focuses on bio-based entrepreneurship.

International top quality niches

There are several complementary tracks in bioenergy research. One track is efficient processes for incinerating biomass – a complicated challenge as biomass combustion also forms various residues that can corrode the combustion chamber, and which have to be dealt with using chemical processes. Another track is the conversion of plant residues and other organic matter using enzymes and fermentation processes. Then there are technologies based on catalysts, which in addition to generating bioenergy, can also produce bio-based chemicals. Finally, there are various chemical techniques and processes to extract waste products that have an adverse effect on biological processes or which can be extracted for use elsewhere.

There are several alternative links in the value chain mastered by Danish researchers and companies. Methane is produced from fermentation of waste and plant residues. Methane can be used in gas engines, for heating or as a precursor for producing biomethanol (by an oxidation process). Likewise bioethanol produced by a fermentation process of the biomass derived sugars can be used in combustion engines, especially for transport. Bioethanol is nowadays used in ordinary vehicle engines as a component of petrol.

Both fuels currently cost more per litre to produce than petrol or diesel, but will form an essential part of future energy supplies when international climate agreements take effect and when EU quota prices for CO_2 increase.

The EU VE Directive provides that 10% of energy for all land-based transport is to be sustainable by 2020. It has not yet been finally determined how this target in reality is to be met. It is expected that the efforts of reaching the target will involve 2nd generation biofuel. From the point of view of attracting investment, this places Danish research competencies in this field in the limelight.

Bibliometric key figures

The bibliometric indicators for research production and research quality indicate that Denmark has a leadership position in the field. The bibliometric figures provide an indication, but the indicators are not precise because 'bioenergy' or 'biofuel' is not a separate category when searched in the database. Greater Copenhagen is well-placed in the categories of Environmental Engineering, General Energy and Bioengineering. With a total volume of 2414 articles, this gives an overall first place among the eight regions of comparison. But in terms of excellence, too, research in Greater Copenhagen also takes the first place.

The high volume of co-publications reflects the high level of corporate involvement in research at the Departments of the University of Copenhagen and DTU noted above.

Key bibliometric indicators				
	Specialisation	Output ranking (No. articles)	Highly cited article ranking (%).	Co-publication ranking (%)
Environmental engineering	1.98	1 (948)	1 (24.7%)	1 (4.6%)
General energy	1.13	1 (502)	1 (28.1%)	1 (9.7%)
Bioengineering	1.16	2 (964)	2 (24.9%)	1 (10.4%)

Period: 2005 -2015. Regions of comparison: Amsterdam, Berlin, Dublin, Geneva-Lausanne, Hamburg, Helsinki, Munich, Oslo and Stockholm/Uppsala.

Specialisation is an expression of the size of a field of research compared to all research production at University of Copenhagen, DTU and CBS compared with its size in the regions of comparison. A specialisation level 1 indicates that Greater Copenhagen is on level with the regions of comparison. Specialisation of >1 indicates that Greater Copenhagen is more specialised in the field of research than the regions of comparison.

Output ranking measures Greater Copenhagen's position in the field concerned among the regions of comparison in terms of article production (with the absolute numbers of articles in brackets).

Highly cited article ranking indicates Greater Copenhagen's placing in the regions of comparison for the proportion of articles in the field of research in Copenhagen that are among the 10% most cited worldwide (percentage in brackets).

Finally, co-publication ranking indicates Greater Copenhagen's rank among the regions of comparison for the proportion of articles in the field published jointly with the business sector (percentage of overall article production in Greater Copenhagen in brackets).

Key arguments for the research area's potential to attract investment

Bioenergy research is highly relevant to society. The green transition to a non-fossil society demands that new energy technologies should be developed and made cheaper. Denmark is already a frontrunner in the green transition process and will continue to be so. In the coming years, when EU targets for discharging less CO_2 and increasing the proportion of sustainable energy take full effect, other countries will also increase the amount of bioenergy used in overall energy consumption, especially in the transport sector. By being located in Denmark, businesses can get first-hand access to the Danish experience and benefit directly from the competencies of Danish researchers and companies.

Star researchers and major scientific breakthroughs

Lead researchers at the University of Copenhagen include Prof. Claus Felby of the Department of Geosciences and Natural Resource Management and Prof. Morten Bjerrum of the Department of Chemistry, both key members of the team that announced their so-called 'reverse photosynthesis' discovery in 2016. This is one of a series of technologies that could provide a significant boost to the field of bioenergy.

The team discovered a natural process by which the sun's rays are used to break down plant tissue instead of generating it, as is usually the case in photosynthesis. The plant's chlorophyll and an enzyme use the energy of the sun's rays to break down plant biomass into chemical substances, for example, biofuel or other high value products which would otherwise take a long time to produce. The discovery could boost industrial production of bioenergy by increasing the speed of production and reducing contamination.

At the Department of Plant and Environmental Sciences, University of Copenhagen, Poul Erik Jensen, who was also a member of the photosynthe-

sis team, is also a key person in heading the Copenhagen Plant Science Center and as a professor in molecular plant biology.

DTU also has a range of key researchers. At DTU Environment, Irini Angelidaki is the most cited researcher in the world in the field of biosystems engineering and biogas - an area that also includes biorefineries. Thomas Fruergaard Astrup is another researcher investigating waste and resources. He is the head of the Center for Residual Resource Engineering.

The lead researchers at DTU Chemical Engineering are Prof. Anne Strunge Meyer (enzymes, silage and fermentation processes), Prof. Anker Degn Jensen (catalysis), Prof. Peter Glarborg (combustion and gasification) and Prof. Kim Dam-Johansen (combustion and pyrolysis). DTU Chemical Engineering has also helped develop processes that use pyrolysis to convert straw to biofuel in small, decentralised units that considerably cut the cost of transporting straw. In 2008 Kim Dam-Johansen was found the worlds most cited researcher in combustion based on work to a large extent directed to the utilization of biomass to replace coal for power production. A significant part of the research was performed in cooperation with DONG Energy A/S.

At CBS' Sustainability Platform, research is focused on green innovation and new sustainable business models, including how companies can optimise their consumption of resources and transform their business models in the light of rising raw material prices and climate change.

Large talent pool

The University of Copenhagen and DTU both educate and train a considerable number of talented scientists in this field. The departments involved at the University of Copenhagen educate and train several hundred Masters graduates every year, at least 200 of whom are engaged in one or more of the technologies described. A total of between 50 - 100 PhDs in this field complete their training as researchers every year, with slightly fewer being trained at DTU.

In conjunction with the University of Copenhagen and DTU, CBS runs a Masters course in Business Administration and Bioentrepreneurship, with 13 graduating in 2015.

Unique research facilities

Over the past 10 years, considerable amounts have been invested in research infrastructure in departments involved in bioenergy at the University of Copenhagen and DTU. Overall, the Departments of Geosciences and Natural Resource Management, Chemistry and Biology have invested several hundred million DKK over the past five years in state-of-the-art equipment for spectroscopy, mass spectrometry and X-ray crystallography. DTU has also invested several hundred million DKK in new world-class research infrastructure.

Strong collaboration with leading international research environments

Researchers in Greater Copenhagen collaborate with leading biotech researchers worldwide. DTU thus works closely with researchers at Lund University (where they investigate recycling of organic waste), at Helsinki University (where they also research the use of wood and cellulose for energy purposes) and Stanford University (where they also study catalysis for energy purposes). Researchers at the University of Copenhagen have close relations with scientists in USA at Berkeley, MIT, University of Wisconsin, University of Illinois and Oakridge, Colorado.

Extensive corporate collaborations

Researchers in the field have a longstanding tradition for collaborating closely with the corporate sector. In the field of combustion, B&W Energy, (Burmeister & Wain Energy), BWSC (Burmeister and Wain Scandinavian Contractors) and B&W Vølund (Babcock & Wilcox Vølund) are among the most innovative in the sector worldwide. FL Smidth produces cement production facilities and use biomass and waste/residues extensively in their facilities.

Haldor Topsøe has developed efficient catalytic processes for converting biomass into petrol and natural gas. They are furthermore developing processes to produce biochemicals, including bio-based monomers for making bioplastic. In biofuel, Novozymes and DONG are key collaborative partners.

DONG owns the companies Renescience and Inbicon and has invested more than DKK 1bn in developing these companies and other bioenergy projects. Renescience produces biogas and fertiliser, etc., based on household waste, and has supplied waste treatment plants to Danish municipalities and customers in Europe and Asia. Inbicon also produces bioethanol from plant residues, in which cellulose is converted to sugars for processing into biofuel.

In 2017, DONG is delivering a significant system to Northwich in UK, to deal with the waste from 110,000 households. DONG delivered a number of plants on a licence basis but the Northwich plant is the first to be constructed, owned and operated by DONG.

Novozymes, too, has invested considerable amounts in developing enzymes and is an important supplier to Renescience and Inbicon as well as two other major bioenergy plants worldwide.

Research has also led to technologies using start-ups in this field and in collaboration with foreign companies. One example is Aikan, a subsidiary of the Solum Group, which was established more than 10 years ago. Aikan sells biogrowth systems which separate food waste for biogas and fertiliser.

In terms of innovation, patents and spin-outs, biotechnology and bioenergy are far ahead. At DTU, bioenergy is the largest of the 12 selected areas in this analysis in terms of numbers of innovations registered at DTU´s central innovation department. The same applies to the University of Copenhagen where the biosector accounts for about 15% of all innovations registered throughout the university over the past three years.

”We believe that Renescience and Inbicon will both be profitable and that green energy will be an important area of growth. These green companies employ many of the talented individuals trained at our universities that are far ahead in the field of bioenergy. We want to help ensure that at least half of the electricity and heating produced by our power stations in 2020 is based on sustainable biomass instead of coal and gas.”

Niels Henriksen, Senior Manager, DONG

“Biofuels constitute a small but rapidly growing part of the global energy supply. They are a renewable energy sources with the potential to reduce CO_2 emissions in the transport sector and to create economic opportunities for rural areas and developing countries. So, biofuels will be an important part of the energy mix in future. That´s why we are investing in this area.”

Johan Mogensen, Director, Novozymes

”As a small, R&D-based company, for us it is important to operate in an environment where there is good interaction between more theoretical research and our more practical realities. And there is lots of that in Denmark.”

Morten Brøgger, Head of Technology, Aikan

Cancer Research

Content and applications

Greater Copenhagen is home to a wide range of strong research environments within oncology (cancer research). The region has a leading international research environment focusing on fundamental understanding of disease, cancer diagnostics and environments focusing on testing and developing new therapeutic methods.

Cancer research is widely anchored at the University of Copenhagen, the Technical University of Denmark (DTU), Copenhagen University Hospital and various of the region's other hospitals.

Key environments and star researchers.

Basic cancer research is mainly done at the University of Copenhagen where BRIC and the new Stem Cell Center together provide the framework for a large number of leading international teams of researchers. Prof. Kristian Helin, who is the head of BRIC, is one of the leading researchers. DTU has world-class environments in immunotherapy and bioinformatics using advanced super computers to focus on cancer.

Copenhagen University Hospital has leading international teams in cancer diagnostics using PET scanning and advanced imaging diagnostics. Copenhagen University Hospital is also a Phase 1 Unit and is a leading international unit for early stage clinical testing for new types of cancer treatment.

Potential for attracting investment

- There are strong environments throughout the innovation-chain, from basic medical research, clinical research and cancer diagnostics to leading environments working with clinical testing of new forms of treatment.
- Globally speaking, oncology is one of the areas to attract most private corporate investment by biotech companies in R&D.
- There is a great deal of openness about commercial collaborations in many of the leading environments.
- There is a very large pool of talented young researchers that can help companies undertake the latest research and translate the results of research into new types of treatment.

Characteristics of the research area

Cancer research (oncology) in Greater Copenhagen is anchored at the health science departments at the University of Copenhagen and DTU as well as other clinical research environments in the region's hospitals.

Greater Copenhagen provides international research from basic understanding of disease ranging from the way cancer arises and spreads, to top research in advanced methods for effective diagnostics, and leading environments with expertise in testing and trial of new therapies.

International top quality niches

In the field of basic oncological research, Greater Copenhagen has leading research environments in epigenetics, cancer stem cells and research into cancer's signalling pathways and biomarkers. The research draws on research in bioinformatics and advanced methods for identifying patterns and identifying new biomarkers based on large volumes of biological data.

Greater Copenhagen also has leading environments in cancer diagnostics and testing. Copenhagen University Hospital's Department of Physiology and nuclear medicine is one of the largest in Europe and a leader when it comes to molecular imaging and researching new tracers for diagnostic purposes (PET-scanning). This department also works closely with researchers at the Department of Biomedical Sciences at the University of Copenhagen and DTU.

Another important stronghold in the whole area of cancer is Copenhagen University Hospital's Phase I unit which is one of the leading units in Europe for early stage clinical testing of new treatments for cancer. In recent years, there has been a significant increase in the number of foreign companies deciding to have new types of treatment tested by the Copenhagen University Hospital unit. 30 tests were expected to be done in 2016. Such rapid progress is due, among other things, to the Phase I Unit which is the only one in Europe to offer full gene sequencing for all patients. Just recently, they have established a broad collaboration with all the country's oncology departments on patient recruitment. This means that foreign companies can have more specially designed tests designed for their new drugs and therapeutic solutions.

Bibliometric key figures

The bibliometric indicators for research production and quality demonstrate that Greater Copenhagen is a clear leader in Europe when it comes to oncology and cancer-related research, cf. Table 1.

All in all, over the past 10 years, researchers at the University of Copenhagen and DTU have published almost 3700 scientific articles in internationally recognised journals. However, the total number of publications is lower than some of the regions of comparison, with Greater Copenhagen only taking a fifth place in terms of numbers of publications compared to the other European cities. Relatively speaking, cancer research accounts for a smaller proportion of all research in Greater Copenhagen than in the regions of comparison.

On the other hand, the quality of research is high. In terms of the proportion of scientific articles amongst the 10% most cited in the field, Greater Copenhagen comes second. And in terms of proportion of research jointly published with private companies, Greater Copenhagen is first amongst the regions of comparison.

Key bibliometric indicators

	Specialisation	Output ranking (No.)	Highly cited article ranking (%)	Co-publication ranking (%)
Oncology	0.83	5 (2080)	2 (19.4%)	1.5
Theoretical Computer Science	0.78	5 (1603)	2 (18%)	1.7

Period: 2005 -2015. Regions of comparison: Amsterdam, Berlin, Dublin, Geneva-Lausanne, Hamburg, Helsinki, Munich, Oslo and Stockholm/Uppsala.
Specialisation is an expression of the size of a field of research compared to all research production at University of Copenhagen, DTU and Copenhagen Business School compared with its size in the regions of comparison. A specialisation level 1 indicates that Greater Copenhagen is on level with the regions of comparison. Specialisation of >1 indicates that Greater Copenhagen is more specialised in the field of research than the regions of comparison.
Output ranking measures Greater Copenhagen's position in the field concerned among the regions of comparison in terms of article production (with the absolute numbers of articles in brackets).
Highly cited article ranking indicates Greater Copenhagen's placing in the regions of comparison for the proportion of articles in the field of research in Copenhagen that are among the 10% most cited worldwide (percentage in brackets).
Finally, co-publication ranking indicates Greater Copenhagen's rank among the regions of comparison for the proportion of articles in the field published jointly with the business sector (percentage of overall article production in Greater Copenhagen in brackets).

Key arguments for the research area's potential to attract investment

Every year, around 14 million people are diagnosed with cancer worldwide. The whole area of cancer is one of the areas of medical research to receive most investment in R&D.

A large number of global pharma companies make cross-border investments to gain access to new knowledge, access to talent and to develop and test new, more effective treatments for cancer.

Greater Copenhagen is strong on research throughout the entire value chain, from basic medical research, clinical research and diagnostics and has particularly good conditions for testing and trialling new cancer drugs and new ways of treating cancer.

Star researchers and major scientific breakthroughs

The region has a number of star researchers in a range of areas relating to cancer research. There are strong research teams at BRIC and the Stem Cell Centre at the University of Copenhagen and at DTU Bioinformatics. Prof. Kristian Helin, who heads BRIC is an example of one of the region's star researchers. He works together with his research group, the “Helin Group”, to understand the fundamental mechanisms underlying the development and growth of cancer cells. Kristian Helin also heads a Centre for Epigenetics, funded by the Danish National Research Foundation, and received an ERC Advanced Grant in 2012.

Recent years have seen a series of research breakthroughs that are important steps along the way to more targeted treatment of cancer and an actual cure.

Among other things, Prof. Ali Salanti of the Department of Immunology and Microbiology at the University of Copenhagen and an international team of researchers, developed a new method for targeting toxins at cancer cells.

Provisional trials show that the method can kill up to 95% of all types of cancer cell. The team is aiming to develop and test the technology in order to create an effective cure for cancer for testing in humans within a few years.

Prof. Henrik Clausen, at the Department of Cellular and Molecular Medicine, runs the Basic Research Centre for Glycomics. The centre has also developed "5E5", an antibody that has been shown to be extremely promising in experimental treatment of tumours and is expected to be used in immunotherapy in clinical trials within the next couple of years. Similarly, at the Department of Cellular and Molecular Medicine, Ian Hickson and his Center for Chromosome Stability have had very promising results in inhibition of DNA repairs in tumour cells.

Large talent pool

There is a large pool of talented postdocs and PhDs and Masters graduates specialising in a range of disciplines relating to cancer in this area. Greater Copenhagen provides access to highly qualified graduates with experience of collaborating with the many bright, internationally acclaimed researchers in the region.

At the University of Copenhagen alone, over the past five years more than 500 PhDs have been admitted to departments with a strong profile in cancer research, among other things at the Department of Biomedical Sciences, the Department of Drug Design and Pharmacology and the Department of Cellular and Molecular Medicine (CMM).

DTU also trains a significant number of PhDs and Masters graduates every year in important disciplines relating to the field of cancer, also in bioinformatics, etc. Many have become experts in 'big data' analysis of biological data using powerful supercomputers.

Unique research facilities

The hospitals, universities etc. in the region have access to advanced, state-of-the-art research infrastructure, including:

- The Phase 1 Unit at Copenhagen University Hospital which provides a state-of-the-art clinical testing service with effective patient recruitment and complete patient gene sequencing. The unit is a European leader in trials targeting new drugs to treat cancer. The Phase 1 Unit has established effective collaboration in recruiting cancer patients for clinical trials for the NEXT national alliance that involves oncological departments throughout Denmark.
- DTU Bioinformatics has one of the world's 100 most powerful supercomputers that can process enormous volumes of biological data as a precursor to developing new drugs. The supercomputer is part of the ELEXIR European research infrastructure.
- The Danish National Biobank has more than 16 million biological samples, making it possible to link biological samples to individually-based health data, etc.
- State-of-the-art equipment for diagnostics and medical imaging. Around DKK 250m has been invested in advanced equipment for PET/CT scanning at Copenhagen University Hospital. At the Cluster for Molecular Imaging, researchers operate a core facility for molecular imaging in animal testing.

Strong collaboration with leading international research environments

Globally speaking, the leading research environments in oncology and cancer research are mainly to be found in USA, at Harvard University, John Hopkins and also at Oxford University in England. The strong cancer research environments in Greater Copenhagen have collaborations with an extensive range of leading environments worldwide and the University of Copenhagen also ranks in the Top 50 of the strongest cancer research environments.

Copenhagen University Hospital has well-developed ties to leading research centres abroad. Their Phase I Unit also works closely with the strongest phase I units in Europe, and is also responsible for a series of major clinical trials involving patients from the phase I units of other countries.

Extensive corporate collaborations

These strong cancer research environments interact closely with the business sector. Greater Copenhagen tops the ranking among the regions of comparison in terms of joint publication with the corporate sector, in both oncology and cancer research (see Table p. 2).

There are also several good examples of cancer research having formed the basis for new patents and spin-out companies. Over the past five years, DTU has announced seven new discoveries in cancer and at the University of Copenhagen, research has led to several successful spin-out companies.

One of the most successful examples is EpiTherapeutics, a company based on researching epigenetics from BRIC. EpiTherapeutics was sold in 2015 to a large American company for almost DKK 500m (see box).

Relations with internationally leading pharmaceutical companies in the field of cancer are also highly developed at the Phase 1 Unit at Copenhagen University Hospital. Over the past three years, the number of early stage clinical trials done for foreign pharmaceutical companies has risen sharply. In 2015, there were around 20 clinical trials on new cancer drugs. In 2016 around 30 companies were expected to trial new treatments for cancer via the Phase 1 Unit. It is the only Phase I Unit to offer complete gene sequencing for patients.

Spin out-company sold for almost DKK 500m.

EpiTherapeutics was established in 2008 by Kristian Helin in conjunction with several Danish venture capitalists - NOVO Seeds, SEED Capital.

The company was based on the groundbreaking research in epigenetics and cancer, led by Kristian Helin and his group at BRIC at the University of Copenhagen. Their research was patented and subsequently licensed to EpiTherapeutics on the basis of an agreement with the University of Copenhagen.

Epigenetics are about understanding the reasons underlying cellular change that is not due to heritable conditions associated with cellular DNA. BRIC's research led to the discovery of a new family of proteins which provided a new understanding of core mechanisms that can influence and restrict the development and growth of cancer cells.

EpiTherapeutics worked on developing and translating discoveries from research relating to the key role of specific proteins and enzymes for the development of different types of cancer cell for new forms of treatment and new cancer drugs.

EpiTherapeutics also worked on a series of development programmes aimed at taking innovative new ways of treating cancer up to the early stages of pre-clinical testing.

EpiTherapeutics was sold in 2015 for a total of USD 65m to an American pharma company, Gilead Sciences.

Food and fermentation

Content and applications

Copenhagen (and Denmark) has one of the strongest European environments for food research. These strengths derive in part from the historical importance of agriculture and the big food companies in Denmark. In recent decades research has especially been driven by the development of high value foods, enzymes and food safety.

Fermentation is due to chemical processes driven by micro-organisms such as lactic acid bacteria or yeast. Research is divided into fermentation for refining food products and the use of fermentation processes for making biofuels, chemicals and materials. The area has a great future potential.

Key environments and star researchers

Research is spread across a range of departments with many interfaces for example to health research, biotech and plant science. The two core environments in the food sector are University of Copenhagen FOOD and DTU Food (the National Food Institute) at the Technical University of Denmark (DTU).

Food fermentation is based at University of Copenhagen FOOD, while DTU works on fermentation with a focus on biotech with its DKK billion "Biosustain" investment. The centre also involves researchers at DTU Chemical Engineering and DTU Bioengineering in researching the use of yeast cells as 'cell factories' for use in the sustainable production of materials, chemicals and fuels.

Potential for attracting investment

There is considerable potential for attracting investment by virtue of increasing global demand for high value food products. In conjunction with Denmark's advanced industrial production, research has for many years been focusing on combining food production with high quality standards, shelf life and environmental sustainability, which carries a great global potential. Denmark has also specialised in investigating the health and nutritional aspects of food, including the influence of food chemistry on the human body.

Characteristics of the research area

Food research in Greater Copenhagen is a broad category of research covering a whole range of world-leading specialities. The areas share a focus on developing and producing high-value, high-quality food products. Research has grown out of a close interaction with Denmark's strong food sector. This applies to the hightech agricultural sector, the processing industry, including Arla, Dupont and Carlsberg, and the research-intensive biotech sector, e.g. Chr. Hansen and Novozymes.

This breadth has also resulted in the food sector being split into many different, relatively specialised sub-areas, which in many instances have close interaction with adjacent research areas such as protein research, nutrition and metabolism research and plant science.

One important outcome from food research is Greater Copenhagen's strength in fermentation technology. On the one hand, research is done into food fermentation related to conservation and spoilage of food products, including biocontrol, microbial food safety and hygiene, intestinal microflora and probiotics as well as food quality assurance. On the other hand, in particular DTU investigates the use of fermentation processes for biotechnological purposes including the development of yeast-based cell 'factories' that can be used to produce biofuels and new materials (such as plastic) from agricultural residue.

The two main actors in food research are the University of Copenhagen's Department of Food Science (FOOD) and National Food Institute (DTU Food). Food and food product related research are also done at the Department of Veterinary Disease Biology, the Department of Food and Resource Economics, the Department of Sport and Nutrition, Department of Veterinary Clinical and Animal Sciences at the Department of Large Animal Sciences. DTU Biosustain, DTU Vet (the National Veterinary Institute), DTU Chemical Engineering and DTU Bioengineering do research into the biotechnological opportunities for fermentation.

International top quality niches

Copenhagen has numerous research niches which are among the absolute global elite, including:

- Research into safety and quality control, with the application of spectroscopic, data-driven quality assurance methodologies to study industrial food production faster, cheaper and more efficient than using traditional random sampling.
- Research into food product design and food chemistry focusing on the molecular composition of food with respect to health and nutrition issues and the effect of food products on the body.
- Research into human sensory perception, acceptance and behaviour in selecting and rejecting food products. It also includes research into molecular gastronomy that have had a major impact in the development of the new Nordic cuisine.
- Research into sustainable food production, i.e. how to optimise the use of resources in food production while minimising waste and environmental impacts.
- Food microbiology, including advanced fermentation technology used in the food industry for processing food products but which also plays a part in research aimed at manipulating residue from agriculture in the production of biofuels and new materials.

All these areas feature Danish researchers, who are positioned in the Top 5 internationally.

Bibliometric key figures

The strong niches in the field of food and fermentation are not especially well captured by bibliometric categories, as they are divided between various categories comprising e.g. applied microbiology. This reflects the fact that the research to a high degree is practical and application-oriented, leading to the development of new methods and technologies for implementation in the commercial sector.

The bibliometric indicators for research production and quality do however show that Greater Copenhagen occupies a clear leading position in Europe when it comes to research into applied microbiology and bioengineering. Researchers at University of Copenhagen and DTU published more than 2000 scientific articles between 2005-2015 in internationally recognized journals.

Food and fermentation research is especially strong with respect to joint publication with the commercial sector which reflects close links between industry and research, and a strong application-oriented dimension.

Further, Greater Copenhagen is highly specialised in the field which means that research into food and fermentation accounts for a significantly larger proportion of research production in Greater Copenhagen than in the relevant European regions of comparison.

Copenhagen is also leading in joint publications in terms of the number of co-publications with authors from the private commercial sector.

Key bibliometric indicators

	Specialisation	Output ranking (No. articles)	Highly cited article ranking (%).	Co-publication ranking (%)
Applied microbiology and biotechnology	1.92	1 (1045)	3 (18.6%)	1 (12%)
Bioengineering	1.5	4 (1854)	2 (24.9%)	1 (12.4%)
Endocrinology, diabetes and metabolism	1.69	1 (2436)	2 (21.9%)	1 (26.1%)
Plant science	1.58	1 (1735)	3 (21.7%)	1.3

Period: 2005-2015. Regions of comparison: Amsterdam, Berlin, Dublin, Geneva-Lausanne, Hamburg, Helsinki, Munich, Oslo and Stockholm/Uppsala.

Specialisation is an expression of the size of a field of research compared to all research production at University of Copenhagen, DTU and Copenhagen Business School (CBS) compared with its size in the regions of comparison. A specialisation level 1 indicates that Greater Copenhagen is on level with the regions of comparison. Specialisation of >1 indicates that Greater Copenhagen is more specialised in the field of research than the regions of comparison.

Output ranking measures Greater Copenhagen's position in the field concerned among the regions of comparison in terms of article production (with the absolute numbers of articles in brackets).

Highly cited article ranking indicates Greater Copenhagen's placing in the regions of comparison for the proportion of articles in the field of research in Copenhagen that are among the 10% most cited worldwide (percentage in brackets).

Finally, co-publication ranking indicates Greater Copenhagen's rank among the regions of comparison for the proportion of articles in the field published jointly with the business sector (percentage of overall article production in Greater Copenhagen in brackets).

Key arguments for the research area's potential to attract investment

Food safety and food supplies are facing increasing challenges globally. This is partly because of a growing demand for high value food products, reflecting the rise of the middle classes in the major growth markets. Food scandals abroad have emphasized the need for effective, precise quality assurance systems. Another issue is that food production implies major climatic and environmental impacts, especially by way of waste water and greenhouse gases. Finally, there is an ever increasing focus on the nutritional and health aspects of food production.

Greater Copenhagen's food research directly addresses these global challenges. A significant part of food research heavily reflects the application and commercially-oriented issues arising from close interaction with major research-intensive companies such as Chr. Hansen, Arla, Carlsberg, Dupont and Novo Nordisk, and the processing industry and primary producers.

But high-tech food research has also given rise to new biotech openings, especially the use of fermentation technology that can be used to refine food products and protect them from micro-organisms to ensure their shelf life, and 'cell factories' to catalyse the production of biofuels and new materials.

Copenhagen's food research is interesting for e.g. foreign companies working on the development of high value foods and for the biotech sector as such, which may benefit from the more wide-ranging opportunities and applications deriving from the research. Furthermore, the strong position in data-driven methods for quality control of food products is interesting for industrial food producers. Finally, there are very considerable perspectives in fermentation technologies for improved preservation and refining of food products and for reducing dependence on fossil fuels.

Star researchers and major scientific breakthroughs

At University of Copenhagen FOOD, Prof. Søren Balling Engelsen's team carries out research into high-tech food production solutions, including foodomics and nutritional metabolomics. They investigate bioactive substances and biomarkers that indicate how the human body reacts when ingesting specific foods.

The team employs Process Analytical Technology (PAT), which uses spectroscopic instruments (NMR and NIR) to do continuous real-time readings (e.g. in food production) to control and optimise process parameters.

The research team has also specialized in chemometrics, which use advanced multivariate data analysis to process the increasing dataflows from quality assurance systems and the new 'omics' technology platforms. These methods have enormous potential for ensuring food quality, safety and uniformity in large production systems. This field is especially led by Prof. Rasmus Bro.

From an international point of view, food chemistry is another very strong area at University of Copenhagen FOOD. This area is headed up by Prof. Leif Horsted Skibsted, who is among the most frequently cited Danish food r esearchers. In his research, he investigates the interaction between the chemical composition of foods and the human body. This covers such things as butter going rancid, browning reactions (which can also have an effect on the development of cancer), the effect of minerals such as calcium on the body and how food can be chemically designed to be more nutritious.

In the field of ingredients, Prof. Wender Bredie, University of Copenhagen FOOD works on human sensory perception of food, including characterising the taste of food products and changes in acceptance of food throughout the course of life.

Fermentation technology and biorefining are some of Copenhagen's absolute core strengths. At University of Copenhagen FOOD, Prof. Susanne

Knøchel works with starter cultures and fermentation-based preservation technologies. Prof. Lene Jespersen investigates the use of micro-organisms to increase the quality and healthiness of our food. Amongst other things, she has investigated the development of starter cultures for optimising fermented food products such as bread, beer, wine, cheese and other dairy products and cultures for inhibiting micro-organisms that are harmful to health.

DTU Food hosts several star professors, featuring several interesting research breakthroughs. Prof. Tine Rask Licht heads up a research team, researching diet, applied micro-organisms and intestinal microbiology. The team investigates the effect of diet on the composition, activity and exchange of genes in the intestinal flora, and studies the effect of intestinal bacteria on health and resistance.

DTU Food also works on biorefining industrial food residue and waste, with a view to boosting sustainability and adding value in the food sector. Furthermore they work on bacterial 'cell factories' for producing chemicals, biofuels and food ingredients, including microbial production of high quality proteins that have many different applications. The team is headed up by Prof. Peter Ruhdal Jensen.

Prof. Krist Gernaey, DTU Chemical Engineering, also focuses on modelling and optimising industrial fermentation, biocatalysis and production processes in the food and pharma industries. His research employs PAT technology and process control /monitoring.

Finally, Prof. Jens Nielsen, DTU Biosustain, works on fermentation by manipulating the metabolism of micro-organisms to get them to produce chemicals so cost-effectively that the method can be used in industry as an alternative to the oil-based chemical industry.

Large talent pool

Greater Copenhagen has a large pool of talent engaged in the food industry. About 130 PhDs have been admitted within food research at the University of Copenhagen. DTU has a similar number of PhDs doing research on food at DTU Food, the National Veterinary Institute (DTU Vet) and the Department of Aquatic Resources (DTU Aqua). PhDs, which are in strong demand in the food and biotech industry. University of Copenhagen also runs two Masters courses in Food Science and Technology and in Food Innovation and Health, with a total of 60 students completing the two courses in 2015.

In conjunction with the University of Copenhagen and DTU, CBS runs a Master's course in Business Administration and Bioentrepreneurship, with 13 graduating in 2015. 15 students graduated from the Masters course in food technology run by DTU in 2016. Various other Masters courses are relevant to the food industry, including Biochemistry, Public Health Science, Aquatic Food Production, Human Nutrition and Sustainable Agricultural Development.

DTU's Brewery is an incubator for innovation and innovative thinking focused on brewing beer, where students, researchers and companies can get together. The brewery is a collaboration between Novozymes, Nørrebro Brewery, Ingeniøren (The Engineer journal) and DTU, enabling food companies to get close to DTU's talented students, also by way of specific student projects. Similarly, DTU Skylab provides access to a broader group of entrepreneurial university students, and to innovative new student-run start-ups.

Unique research facilities

The Life Science & Bioengineering building is under construction at DTU. It will house around 800 personnel from three departments: DTU Aqua, DTU Food and the DTU Vet. Research will range widely from sustainable exploitation of the oceans, via nutrition, food safety and antibiotic resistance, to surveillance and combating disease in livestock, including vaccine development. The construction budget is DKK 13bn with completion scheduled for 2017.

DTU Biosustain investigates yeast-based cell factories, i.e. how to genetically modify yeast cells to produce materials, fuel, etc., and thereby reduce our dependence on fossil raw materials. DTU Biosustain is interdisciplinary and attracts a wide range of research niches such as synthesis biology, gene technology, biorefining and protein research. Its strength comes from the Danish expertise in fermentation deriving from close interaction with Carlsberg, Chr. Hansen and Novozymes, the University of Copenhagen and KTH, Stockholm (the Royal Institute of Technology in Sweden). The centre has approximately 300 employees and operates on the basis of a DKK 1.1bn grant from the Novo Nordisk Foundation.

Strong collaboration with leading international research environments

Food research in Copenhagen has strong international relations. DTU and University of Copenhagen collaborate with the highest ranking agricultural university in the world, Wageningen in the Netherlands, and elite universities such as TUM in Munich. DTU Biosustain has operations at the University of California, San Diego (UCSD), KTH and Chalmers University in Sweden. All these universities are generally among the 30 best in the world in the fields concerned, such as applied microbiology where the University of California and Chalmers are in the global Top 10.

Extensive corporate collaborations

Food and fermentation research has traditionally given greater priority to commercial applications than research excellence. This means in practice that researchers generally get more external funding from innovation-oriented bodies such as the former Strategic Research Council, Innovation Fund Denmark and Horizon2020 than for example the National Research Foundation or the European Research Council.

Commercialisation of food research in Copenhagen has especially been done by way of licensing. Food research at University of Copenhagen led to eight licences and two spin-outs between 2013-2015. The spinout company Biosyntia originated in this field of research. In addition research collaboration with companies such as Novozymes, Carlsberg and Chr. Hansen is extensive.

Biosyntia is a company spun out from DTU's fermentation research. The company employs biocatalysts to make complex chemical substances at high speed and efficiency. The method significantly reduces the costs of production and environmental impacts compared to other processes such as chemical synthesis. The company works with fine chemicals producers (flavours, fragrances, pigments, additives, etc.) with the focus on developing sustainable production processes. Biosyntia is located at Symbion in Copenhagen.

Humans and technology

Content and application

Greater Copenhagen has an international research strength on the interaction between people and new technology, which draws on the well-founded Danish design tradition and on an excellent research environment in business anthropology.

Research combines classic methods used in anthropology, sociology, cultural studies and linguistics science and how these perspectives can provide novel in-depth insights into how people perceive new technology and identify new, unrecognized needs among users.

Key environments and star researchers

Research on people and technology at the University of Copenhagen is anchored at the Departments of Sociology, Anthropology and parts of the Faculty of Humanities, including the Department of Media, Cognition and Communication and the Department of Linguistics.

Key research centres include the Centre for Communication and Computing as well as Anthropological Analysis - Center for Applied Anthropology, where researchers focus on the development corporate relations in the field of anthropology. At Copenhagen Business School (CBS), competencies in people and technology are present at the Department of IT Management where they work on IT-management and service design.

Potential for attracting investments

Technology is changing the way people live and work all over the world. Technology firms are increasingly using knowledge and insights into how people experience and employ new technology across different cultures, genders and age groups.

Greater Copenhagen hosts a research strength in developing and applying methods for interpreting user behaviours and identifying unrecognised needs amongst users.

Characteristics of the research area

Research on people and technology focuses on how new technology affects people's daily routines and working lives, as well as how people in different cultures experience and employ these new technologies.

In Greater Copenhagen, the research strength is especially based on methods and perspectives from sociology, anthropology and linguistics, which are used to achieve new insights into how people use new technological products and services, including new methods for decoding changing unacknowledged user needs.

Researchers at both CBS and the University of Copenhagen have been among the pioneers in Europe in the field of "business anthropology". Today, Greater Copenhagen has one of the strongest research environments in Europe within methods for understanding and analysing the interaction between technology and people in new ways that can add considerable value for companies.

International top quality niches

Research into technology and people in Greater Copenhagen is outstanding in the way it links a strong academic foundation in classic anthropological and sociological disciplines with an application-oriented focus on consumers, technology and companies.

The research field has developed close links to several of the region's world-leading companies and clusters, and has strong research competencies in understanding the interplay between technology and people within healthcare and medical technology.

A separate research centre has been established to focus on cultural understanding and the importance of culture in the use of technology, for example internet, smartphones, social media, etc.

Bibliometric key figures

There are no clear bibliometric indicators that clearly reflect Greater Copenhagen's research strengths within business-oriented applications for sociological and anthropological methods and approaches. But the area's comparative strength is reflected in the bibliometric performance of anthropological research,

The indicators are shown in the table below. They shows that just under 900 articles have been published in international journals. The specialisation rate for anthropology is less than 1, meaning that anthropology accounts for a slightly smaller share of total research in Greater Copenhagen relative to the regions of comparison. The region is only 5th for overall output.

On the other hand, the quality of research is high. In terms of the proportion of scientific articles among the 10% most cited in the field, Greater Copenhagen comes 2nd. Generally, co-publication with the corporate sector is limited within anthropology, which applies to all regions of comparison. Although Greater Copenhagen's figure is only 0.6%, this puts the region into 1st place.

Key bibliometric indicators

	Specialisation	Output ranking (No. articles)	Highly cited article ranking (%).	Co-publication ranking (%)
Antropology	0,90	5 (872)	2 (20,1%)	1 (0,6%)

Period: 2005 -2015. Regions of comparison: Amsterdam, Berlin, Dublin, Geneva-Lausanne, Hamburg, Helsinki, Munich, Oslo and Stockholm/Uppsala.

Specialisation is an expression of the size of a field of research compared to all research production at University of Copenhagen, the Technical University of Denmark (DTU) and CBS compared with its size in the regions of comparison. A specialisation level 1 indicates that Greater Copenhagen is on level with the regions of comparison. Specialisation of >1 indicates that Greater Copenhagen is more specialised in the field of research than the regions of comparison.

Output ranking measures Greater Copenhagen's position in the field concerned among the regions of comparison in terms of article production (with the absolute numbers of articles in brackets).

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Finally, co-publication ranking indicates Greater Copenhagen's rank among the regions of comparison for the proportion of articles in the field published jointly with the business sector (percentage of overall article production in Greater Copenhagen in brackets).

Key arguments for the research area's prospects for attracting investments

Tech-companies worldwide are increasingly investing in order to gain a greater understanding of end-users, and understand how different cultures influence the adaptation of new technologies

At the same time, the ability to decode new user needs, not yet acknowledged by the users, is increasingly being used to provide important input in the innovation processes adopted by many companies.

Generally, Denmark has a strong international profile in combining an understanding of users, technology and design. And the University of Copenhagen was among the first universities in Europe at the beginning of the 2000s to demonstrate an interest in developing Business Anthropology as a new field of research.

Today, Greater Copenhagen has a large pool of talented graduates in the research field, as well as a number of strong research environments within the humanities and social sciences at the University of Copenhagen as well as in the Department of IT Management at CBS.

Star researchers and major scientific breakthroughs

In 2016, the Carlsberg Foundation awarded a grant of DKK 11m for the major project - "The Peoples' Internet" (PIN). It focuses on how users in China, USA and Europe use the internet in the context of individual citizens' lives and daily routines. The PIN project employs in-depth fieldwork to reveal the details of how different cultures make use of the most important infrastructure in the 21st century. The project is based at the Department of Media, Cognition and Communication under the stewardship of Prof. Klaus Bruhn Jensen.

Also the Faculty of Humanities investigates the significance of digital media in day-to-day lives and society. At the Department of Media, Cognition and

Communication, Associate Professor Stine Lomborg is engaged in the project - Exercising with the Smartphone - which addresses how smartphones can support healthy lifestyles. She also studies the use of the social media such as Facebook. In the same department, Associate Professor Anne Mette Thorhauge investigates computer gaming, communication and cultural expression as well as digital communication in organisations.

The Department of Anthropology has a special team of researchers investigating Business and Organisation Anthropology. This team is coordinated by Karen Lisa Salamon, a leading researcher in business anthropology.

The Royal School of Library and Information Science (RSLIS) has a wide range of skills in developing information systems that can support learning. Their work on Information and Technology is led by Prof. Morten Hertzum, whose research focuses on the interaction between people and technologies, including the usability and user-friendliness of IT systems.

Significant talent pool

Greater Copenhagen has a large concentration of talent within the research field: graduates and PhDs taught and trained in business anthropology, design, technology and cultural understanding.

Every year, 50-60 students complete their Master's programmes in anthropology, around a third of whom will have completed courses in the business applications of anthropological and sociological methods. For example, the Department of Anthropology at the University of Copenhagen offers a specialisation in healthcare anthropology, which focuses on how people interact with medical technology, and a specialisation in business and organisational anthropology.

A similar number of students graduate from the related environments at CBS and the Faculty of Humanities at the University of Copenhagen.

Extensive corporate collaborations

Close corporate relations have been established over the past 15 years between the research environments and a whole range of leading Danish companies. Especially in the pharma industry, companies such as Novo and Coloplast have built up competencies in identifying how patients actually use their products in practice, and in identifying unacknowledged needs as part of their innovation processes.

A considerable number of graduates, with backgrounds in sociology and anthropology, have set up their own businesses. Currently, there are numerous small consultancies that advise corporate and public sector players in Denmark on new trends, user needs, design and modelling on the basis of anthropological and sociological methods.

ReD Associates is one of the largest companies in the field. The company advises companies on how to gain a better understanding of customer behaviours and their client list includes such companies as Adidas, Ford and Novo.

In the spring of 2016, a large US consultancy with 200,000 employees, Cognizant, acquired a 49% share of ReD Associates.

Metabolism and diabetes

Content and applications

Greater Copenhagen is home to one of the leading research clusters in the world in metabolism and metabolic/lifestyle disease such as diabetes and obesity.

Diabetes and obesity is growing rapidly worldwide and could have an income potential in the billions for companies that successfully translate research into improved, more effective therapies and prevention by way of healthy new foods, dietary regulation, etc.

Key environments and star researchers.

The region has a strong functional ecosystem covering medical and clinical top level research in cellular biology and molecular pharmacology. Copenhagen is also home to top level research relating to nutrition and exercise, including research into how physical activity and diet affects bodily function and helps prevent and alleviate lifestyle disease.

Researchers from the University of Copenhagen are responsible for the GLP-1 technology) that is one of the cornerstones for the treatment of diabetes and obesity. Research across several departments at the University of Copenhagen and DTU has been significantly helped along in recent years by a very large grant from the Novo Nordisk Foundation for establishing the Center for Basic Metabolic Research. Interaction between the research teams is good, and there is strong interaction between researchers working on the basic understanding of metabolic mechanisms and researchers specialising in nutrition, exercise and health.

Potential for attracting investment

- A tradition for strong relations between researchers and the corporate sector in metabolism, diabetes and obesity research.
- Significant production of PhDs, postdocs and attractive graduates that foreign companies can easily approach.
- World-leading ecosystem for diabetes research, with investments made throughout the chain from basic medical research to super modern centres for effective treatment of diabetes at hospitals in the region.

Characteristics of the research area

Strong research in metabolism and diabetes is anchored in the departments of the University of Copenhagen and the Technical University of Denmark (DTU) as well as in clinical research at the region's hospitals. Greater Copenhagen has top level research throughout the entire spectrum, right from basic medical research, via understanding the role of physical activity, hormones and enzymes, and clinical research into the treatment, diagnostics and prevention of diabetes and obesity.

Research is mainly concentrated at the centres around the University of Copenhagen's Nørre Campus, which is home to the majority of the Faculty of Health and Medical Sciences, including the Biotech Research and Innovation Center (BRIC) and the Center for Basic Metabolic Research funded by the Novo Nordisk Foundation. Department of Nutrition, Exercise and Sports, Faculty of Science is also located at North Campus.

International top quality niches

Research in Greater Copenhagen also includes international top level research into the significance of hormones for regulating appetite. This has provided the basis for a range of new cancer treatment and drugs for treating type 2 diabetes. Regarding basic research into endocrinology and metabolism as well as research in the role played by nutrition and exercise in prevention and treatment of diabetes and obesity, Greater Copenhagen's researchers are clearly among the international elite (cf. section on bibliometric key figures).

One of Greater Copenhagen's key strengths lie in the good interaction between strong niches. Researchers in nutrition concurrently address how to translate the results of basic endocrinological research into new insights into dietary composition, exercise as well as methods for preventing and alleviating lifestyle diseases.

This research is also used by food companies to develop new products with special properties that reduce the risk of type 2 diabetes, obesity, etc. There is nowadays already considerable interaction between international food producers and nutritional and dietetics researchers.

Bibliometric key figures

The bibliometric indicators for research production and quality show that Greater Copenhagen is a clear leader in Europe when it comes to research into metabolism, endocrinology, physical activity and nutrition/dietetics, cf. Table 1.

All in all, over the past 10 years, researchers at the University of Copenhagen and DTU have published almost 3500 scientific articles in internationally recognised journals. This puts Greater Copenhagen into first place amongst the regions of comparison in terms of research output.

Further, Greater Copenhagen is highly specialised which means that metabolic and nutritional research accounts for a significantly larger proportion of research production in Greater Copenhagen than in the relevant European regions of comparison.

Finally, Greater Copenhagen also leads the regions of comparison with respect to quality of research, in terms of the numbers of publications amongst the most globally most cited 10% in this field of research.

Key bibliometric indicators

	Specialisation	Output ranking (No.)	Highly cited article ranking (%).	Co-publication ranking (%)
Endocrinology, metabolism, diabetes	1.7	1 (2436)	2 (21.9%)	1 (26%)
Nutritional and dietetics	1.7	1 (926)	1 (19.7%)	1 (8.5%)

Period: 2005 -2015. Regions of comparison: Amsterdam, Berlin, Dublin, Geneva-Lausanne, Hamburg, Helsinki, Munich, Oslo and Stockholm/Uppsala.

Specialisation is an expression of the size of a field of research compared to all research production at University of Copenhagen, DTU and Copenhagen Business School (CBS) compared with its size in the regions of comparison. A specialisation level 1 indicates that Greater Copenhagen is on level with the regions of comparison. Specialisation of >1 indicates that Greater Copenhagen is more specialised in the field of research than the regions of comparison.

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Finally, co-publication ranking indicates Greater Copenhagen's rank among the regions of comparison for the proportion of articles in the field published jointly with the business sector (percentage of overall article production in Greater Copenhagen in brackets).

Key arguments for the research area's potential to attract investment

Across the world, metabolic disease is on the rise, both in the west and in the major growth economies like India, China, Brazil and the Middle East.

Already now, around 390m people worldwide have type 2 diabetes and this figure is expected to be close to 600m by 2035. There is a very considerable, rapidly growing market for new pharmaceutical products, therapies and new healthy foods that can prevent and alleviate obesity, type 2 diabetes and other lifestyle diseases.

Greater Copenhagen has a clear research stronghold in the area, which is reflected in the parameters important for attracting investment. Research into lifestyle disease is interesting for a very broad range of foreign companies, such as those working to develop new drugs or diabetes and obesity, food producers that are developing healthy new products and companies working with treatment and prevention, such as those developing new personalised medical devices.

Star researchers and major scientific breakthroughs

Prof. J. J. Holst of the University of Copenhagen is internationally recognized as one of the top researchers behind the discovery of GLP-1 technology, which also forms the basis of Novo Nordisk's latest blockbuster product "Victoza" for treating type 2 diabetes and severe obesity. In the spring of 2016, J.J. Holst won a DKK 20m ERC grant. In 2013, he was awarded the "Mini Nobel Prize" in the form of the Anders Jahre Prize and the Fernström Prize. He is now Research Director of the Metabolism Center (funded by the Novo Nordisk Foundation) and Deputy Head of the Department of Biomedical Sciences.

Another star researcher in the field is Prof. Oluf Borbye Pedersen, who does research on intestinal bacteria and their significance for insulin resistance and obesity. Oluf Borbye Pedersen and his fellow researchers have analysed

large volumes of biological data to demonstrate that insulin resistance is especially closely associated with the spread of two types of intestinal bacteria. This discovery paves the way for entirely new ways of understanding and treating obesity and type 2 diabetes by influencing the intestinal flora, for example by targeting diet etc.

Various internationally recognized researchers also work at the Department of Nutrition, Exercise and Sports, including Prof. Arne Astrup, who has led several internationally acclaimed research projects on nutrition, exercise and obesity. He has also demonstrated how proteins, fats and carbohydrates have different effects on appetite, partly through GLP-1 and PYY, thus showing the way to more effective treatments for overweight patients and pre-diabetics.

Another profile in the same department is Prof. Erik A. Richter, who explores molecular physiology, focusing on the interaction between exercise, muscle-building and the importance of exercise for metabolic processes, including the significance of increased insulin sensitivity in healthily individuals and type 2 diabetics.

The work done by these researchers has resulted in a large number of highly cited scientific articles, while also forming the basis for stronger collaboration with Danish researchers and international companies in the food industry.

Large talent pool

Every year, scores of PhD students enter the field of metabolism and diabetes and get the opportunity to develop their talents under the guidance of the region's many star researchers. Since 2011, 43 PhD students have been admitted to the Center for Basic Metabolic Research at the University of Copenhagen.

Similar numbers of PhD students specializing in metabolic and lifestyle disease are also being admitted to the Department of Biomedical Sciences. About 115 PhD Students are employed at the Department of Nutrition, Exercise and Sports.

There is extensive, close interaction between universities and major companies in many PhD projects. Every year Novo Nordisk herself funds 30 PhD bursaries for young scientists, wishing to train as researchers in fields relating to Novo's areas of interest.

There is an annual intake of new Masters and PhD students specialising in biotechnology at CBS. In conjunction with the University of Copenhagen and DTU, CBS runs the Bio Business Innovation Platform (BBIP), which focuses on strengthening entrepreneurial skills in life science. The platform also provides specialized processes in Innovation and Strategy in Biobusiness, Finance, Accounting and Valuation in Bio Business, etc. CBS also offers the world's first Master's course in Business Administration and Innovation in Health Care, which addresses innovation and business development in the healthcare sector.

Unique research facilities

The region's universities, hospitals, etc., have advanced, state-of-the-art research infrastructure and the DKK 850m invested in the Metabolism Center has also helped create the best possible framework for research. Research infrastructure includes:

- Unique biobanks with biological material and the option of cross-batching data from electronic patient records, etc.
- Unique personal data registers and extensive expertise in undertaking large scale randomised studies.

Agreements have also been made with the Capital Region and the Novo Nordisk Foundation to establish regional supercentres for treating diabetes. There has also been an agreement to establish a world-leading centre for diabetes treatment at Herlev Hospital aimed at integrating leading treatment offerings and research. The Novo Nordisk Foundation has agreed to

invest DKK 2.8bn in the new centre which will be operational in 2020.

Strong collaboration with leading international research environments
There is close collaboration between research at the Metabolism Center and other relevant research environments, including the Department of Biomedical Sciences, the Department for Nutrition, Exercise and Sports and relevant environments at DTU in bioinformatics and drug delivery. There is also extensive collaboration with leading environments in USA (including the University of Massachusetts and Harvard), the Karolinska in Sweden and leading environments in China and Australia.

In the field of endocrinology research, the University of Copenhagen takes second place worldwide in terms of overall research output, and quality of research in terms of numbers of scientific articles among the 10% most cited. The University of Copenhagen is only surpassed by Harvard University in Boston, USA.

Extensive corporate collaborations
There is a long tradition of close collaboration between researchers and the corporate sector in the field of metabolic research with scientists employed by the university making the fundamental discoveries whilst the task of translating them into new drugs and therapies is done in close interaction between university researchers and scientists in companies such as Zealand Pharma, Novo Nordisk, etc.

Greater Copenhagen ranks as No 1 amongst the European regions of comparison in terms of the proportion of published scientific articles resulting from collaboration with private sector corporate researchers. Teams of researchers at the Metabolism Center, for example, all focus sharply on ensuring that their research has practical applications and leads to new effective treatments. There is close interaction with a whole range of international pharma companies such as Merck, Sanofi, etc.

Center for Basic Metabolic Research, University of Copenhagen
"We collaborate with a extensive range of the major global pharma companies. Novo is naturally a key collaborative partner but we also have many other collaborations, and for example we work closely with Merck Sharp & Dohme. We endeavour to reduce our research to practice in many ways. For example, we have two new spin-out companies going in this field and it all looks very promising."

Prof. Jens Juul Holst, Center for Basic Metabolic Research

Novo Nordisk
"I should remind you that the fundamental discoveries from which we have become amazingly rich were made at the universities. We translate and discover drugs on the basis of those discoveries.
I have bright inventors in my laboratories but we have never had anything to do with the original discovery. We often get masses of accolades and glory in the media but the real accolades and glory should usually go to the universities and collaborations between the universities and us."

Mads Krogsgaard Thomsen, Director of Research at Novo Nordisk in Berlingske Tidende 1 May 2016.

Zealand Pharma:
"Back in 1998, Zealand was a start-up company working in rented laboratories at the School of Agriculture in Copenhagen. It was here that ZP10, now called Lixisenatid, was discovered purely by chance. Today it is an approved drug produced and marketed globally by Zealand's partner Sanofi."

Source: Zealand Pharma, Annual Report 2012.

Nanoscience

Content and application

Greater Copenhagen hosts one of the world's leading nanoscience research clusters. This wide-ranging research field is generally focused on manipulating materials on the nano-scale, i.e. on the order of a hundred millionth of a millimeter. The entire inception of nanoscience is primarily driven by the electron microscope, which has revolutionised materials science and made it possible to develop materials with new properties, e.g. with respect to strength, surfaces and electrical conductivity.

Copenhagen is generally regarded as being among the 5-10 strongest research environments in the world in the nano-field, a position, which will be strengthened with the establishment of the ESS (European Spallation Source) in Lund and Copenhagen. ESS is expected to be applied in areas such as medicine, diagnostics, treatment of diseases, food processing and electronics.

Key environments and star researchers

Greater Copenhagen has a sizeable, wide-ranging research environment, covering many different disciplines and applications of nanotechnology. It hosts two centres that each collaborates widely with researchers in many departments. The Nano-Science Centre at the University of Copenhagen is headed by Bo Wegge Laursen with 150 researchers and PhDs. Well-known names include Jesper Nygård, Dimitrios Stamou and Morten Meldal. The other is DTU Nanotech at the Technical University of Denmark (DTU), with 200 researchers and PhDs. Renowned researchers include Marcel Somers, Anne Ladegaard Skov, Anja Boisen and Kristoffer Almdal.

Potential for attracting investments

The research area's prospects for attracting investment is strong. Nanotechnologies carry many potential applications that are already profitable today, and they have a promising long-term potential. A company wishing to be at the cutting edge of nano-technology can benefit strongly from being in close proximity to the strongest research environments. Nanoscience in Greater Copenhagen is evidently among the strongest environments, especially after researchers have successfully established a long-term collaboration with China in form of the Sino-Danish Center for Nano Electronics at the University of Copenhagen and a Sino-Danish Masters course in nanoscience at the Sino-Danish Center for Education and Research.

Characteristics of the research area

Nanoscience in Greater Copenhagen is characterised by being broadly anchored at a number of departments and by employing researchers, who are exploring applications for the many new technologies in the area. Research in Greater Copenhagen is based at two major centres, the Nano-Science Center at the University of Copenhagen and DTU Nanotech. Researchers from many different departments and units collaborate with both centres.

The Nano-Science Centre was established in 2001 as a joint venture between the Niels Bohr Institute and Department of Chemistry at the University of Copenhagen. Subsequently the Department of Biology has also joined the centre. Moreover, the centre collaborates with several departments of the Faculty of Health and Medical Sciences at the University of Copenhagen. Research is spread across 15 teams, broadly covering a wide array of areas in medicine, biology, nano/quantum electronics and surface physics/chemistry.

DTU Nanotech hosts 100 researchers and 100 PhDs, accompanied by close collaboration partners from several DTU departments (DTU Mechanical Engineering and DTU Chemical Engineering). The department covers four fields: Biomedical Engineering and Life Science, Sustainable Nanotechnology, Lab-on-a-chip and Materials and Fabrication.

International top quality niches

The two nanoscience environments at the University of Copenhagen and DTU work closely together. Research at the DTU focuses on bioengineering, metals and polymer, while the University of Copenhagen concentrates on medicine, electronics and chemistry. Both conduct research into many different global applications for nanotechnologies (see the section on relevance for companies and society).

Bibliometric key figures

Employing bibliometrics to measure production and quality of research within nanoscience carry limited validity because it is a relatively new research field that cuts across many different fields of research.

According to the researchers we have interviewed, Copenhagen is among the 5-10 strongest research environments in the world within nanoscience. This assessment should, however, be interpreted with some caution, as specific strengths can differ widely between the many different sub-fields involved in nanotechnology.

Key arguments for the research area's prospects for attracting investment

For both society and industry, nanoscience carry great potential and in several areas nanoscience has already had a considerable impact. Possible applications for research cover different areas such as materials research, communication and food.

Healthcare applications is expected to hold the greatest potential. Nanotechnologies make it possible to develop more precise and more personalised diagnostics of diseases such as cancer, as well as personalised treatments. Ultimately, the area carries prospects of each individual patient having their own medication-profile. A stronghold in nanoscience in this area lies in the use of fluorescing substances and optical methods.

Another application concerns the development of healthy foods. A third area is healthy/environmentally-friendly materials for packaging, clothing and dyeing. A fourth area is the development of enzymes and materials to reduce energy consumption in processing. A fifth area is new materials with strong structures and surface properties that can be used for example to make wind turbine blades capable of tolerating very strong winds.

Star researchers and major scientific breakthroughs

Considering the size of the nanoscience research environment of Copenhagen, it displays a considerable number of star researchers who enjoy international acclaim. At the University of Copenhagen, Prof. Bo Wegge Laursen is head of the Nano-Science Center as well as the Sino-Danish Center for Molecular Nanoelectronics.

Other leading names include Prof. Morten Meldal at the Department of Chemistry who explores so-called "click chemistry" (new methods for assembling large molecules) and Prof. Jesper Nygård from the Niels Bohr Institute at the University of Copenhagen, who researches solid state physics. The Department of Chemistry at the University of Copenhagen has also been apt in attracting top international scientists such as Dimitrios Stamou (who researches bio-nano technologies) and Karen Martinez (who investigates nano technology in neuroscience), both from EPFL in Switzerland.

Leading names at DTU feature Prof. Marcel Somers, among the leading metallurgists in the world, Prof. Anja Boisen, who does nanosensor research and Prof. Kristoffer Almdal, who works with polymer research. Moreover, Anne Ladegaard Skov is the head of the Danish Polymer Center, which is one of the leading centres in the world for developing new silicone polymers.

Nanoscience has experienced a number of breakthroughs in recent years. By and large these breakthroughs have revolved around what scientists refer to as 'enabling' technologies that when used with other technologies, provide new solutions to important challenges.

Some of the scientific breakthroughs relate to methods for diagnosing such diseases as cancer. Another type of breakthrough relates to catalysts, including enzymes that can dramatically improve the properties of other substances. A third type of breakthrough relates to materials with new surfaces that can for example reduce the risk of attack by fungus and mould. A fourth breakthrough is in new kinds of polymers (plastics) that can be made without using oil products and have novel properties.

Large talent pool

The University of Copenhagen and DTU both educate/train a considerable number of talented individuals. DTU educates/trains around 40 PhDs annually, while several hundred undergraduate and graduate students are taught at the department. The University of Copenhagen trains 20-25 PhDs annually in nanoscience, and a total of about 50 students attend MSc and BSc programmes with an emphasis on the nano field.

Unique research facilities

Nanoscience has attracted considerable funding from the Danish National Research Foundation, the EU and private foundations. The Danish National Research Foundation has for example provided funding for the Sino-Danish Center for Molecular Nanoelectronics at the University of Copenhagen and the Center for Synthetic Biology at the University of Copenhagen, which was initiated in 2009 with a DKK 120m grant from the Ministry of Higher Education and Science. DTU has received grants from the Danish National Advanced Technology Foundation which has boosted collaborations with industry considerably.

Over the past 10 years, a total of DKK 400m has been invested in research infrastructure at the University of Copenhagen and DTU. Much of the investment has funded state-of-the-art infrastructure, including equipment for X-ray spectroscopy, quartz crystals, ellipsometry, fluorescence, scanning probe microscopy and spectroscopy/microscopy.

In terms of research infrastructure, MAX IV, which opened in June 2016, and the coming European Spallation Source, ESS, scheduled for 2019, will have a major impact on nanoscience. MAX IV is the largest X-ray system in the world for investigating materials at a previously untested molecular level. ESS will be one of the strongest neutron accelerators in the world. Denmark is the second largest investor in ESS, following Sweden, and ESS´ Data

Management Center is in the process of being established at the University of Copenhagen's Nørre Campus.

Strong collaboration with leading international research environments
With considerable exchanges of visiting researchers and other visits and robust scientific production, there are close relations with other research environments worldwide, especially in China, Japan, Korea, USA, Germany and the UK. The Nano-Science Center at the University of Copenhagen and DTU Nano routinely have visiting scientists from these countries and both departments have active knowledge exchange programmes with these countries. Collaborations include researchers at Lund University, which hosts MAX IV and the coming ESS.

Extensive corporate collaborations
The nanoscience-environments in Greater Copenhagen have strong commercial links with a range of Danish and international corporations. Important partners for the University of Copenhagen and DTU include Novozymes, Dyrup, Maersk and Airbus. Another example of the significant potential is the successful spin-out from DTU, Scandinavian Micro Biodevices, which sells nano-diagnostic solutions for veterinary purposes. The company was sold in the spring of 2016 for DKK 500m. According to the company's management, this was due to the high level of knowledge at DTU (see citation).

This investment might be an indication that the field, which has so far been characterised by major research funding from the EU, the Danish State and private foundations, may now be moving into a new phase with private investment playing a greater role.

Nanoscience is not only promising for spin-outs. DTU informs that nanoscience is the field that has displayed the highest level of innovations announced in the past five years.

Nanoscience is characterised by a high complexity, which is why a local presence is essential for enabling companies to keep up with developments in the field. The two Danish centres are known for having a wide range of international and Danish corporate collaborative partners. One example of these is SBM Offshore, which investigates methods for developing new plastic materials that the company can use in offshore wave energy systems. The company is French, but has opted to collaborate with Greater Copenhagen rather than the University of Darmstadt because they felt Greater Copenhagen was a key knowledge platform due to its openness and strong research.

"I enjoy working with the Copenhagen researchers from DTU. The possibilities of polymers are unknown to many people but really fantastic. SBM is basically an oil company today – but we want to be part of the renewables revolution too. With DTU we are investigating the possibilities of using polymers in new equipment to make sea wave energy"
- Ambroise Wattez, SBM Offshore

"As a new, rapidly growing company providing new surface technologies and highly advanced data processing, we need to keep up to date. We have just been sold for DKK 500m and only have a headcount of 40. But a quarter of them were educated at DTU Nano. That probably says it all."
- Niels Kristian Bau Madsen, COO, Scandinavian Micro Biodevices

Protein research and bioinformatics

Content and application

Proteins are the fundamental building blocks of life. Research in Greater Copenhagen focuses on the significance of proteins and peptides for health, for example using proteins as biomarkers. Protein Research in Greater Copenhagen focuses on designing new proteins to treat neurodegenerative disease such as Alzheimer's and Parkinson's as well as for new personalised treatments. This research stronghold is underpinned by the region's strong competencies in bioinformatics, which employs biodata analysis and register-based health data to identify patterns in the interaction between types of patient, genetics, proteins and health conditions.

Key environments and star researchers

Denmark has fostered a range of world-leading research teams working with proteins and bioinformatics, especially at the interdisciplinary Center for Protein Research and the Department of Cellular and Molecular Medicine at the University of Copenhagen, combined as well as a whole range of other science and health science environments at the Technical University of Denmark (DTU) and the University of Copenhagen. Leading researchers include Niels Tommerup and Ian Hickson who research the stability of genes and chromosomes and its significance for health. Henrik Clausen and Hans Wandall investigate the significance of sugars for the functionality of cells and proteins, while Søren Brunak combine patient data with large volumes of biological data on protein interactions to discover patterns of importance for the personalised treatment of patients. Finally, Prof. Mathias Mann explores the importance of proteins as biomarkers.

Prospects for attracting investments

Protein research holds great potential, especially for the biotech sector and the pharmaceutical industry. Research and development form the basis of future diagnostic methods and the treatments of neurodegenerative conditions, cancer, fertility and allergy, for example. Protein research is furthermore an important precondition for developing better methods for drug delivery and personalised medicine. Protein research is closely connected to Greater Copenhagen's strengths in nanotechnology, cancer and diabetes research, and has led to a whole range of promising spin-outs.

Characteristics of the research area

Protein research is one of the most promising areas in life-science. Research in protein structures and the significance of proteins as well as their interaction with the cells of the human body could open up an entirely new paradigm in the development of new personalised diagnostic and therapeutic methods (personalised medicine).

Protein research in Greater Copenhagen is interdisciplinary and is carried out in a wide range of departments and centres at the University of Copenhagen and DTU. Researchers from many different disciplines collaborate on projects at the Center for Protein Research, which has been awarded funding of about DKK 850m from the Novo Nordisk Foundation.

At the Department of Cellular and Molecular Medicine researchers investigate glycomics and the stability of genes and chromosomes, which is highly significant in understanding and treating a whole range of diseases. At DTU, it is especially DTU Bioinformatics and DTU Bioengineering that are engaged in protein research. Moreover, DTU Bioengineering explores proteins in food and nutrition and the development of new enzymes.

Protein research draws on Greater Copenhagen's strength within bioinformatics, i.e. the use of computers to analyse large volumes of biological data. Bioinformatics can for example be used to identify enzymes and proteins that rapidly and efficiently can be used for identifying genetic patterns and show how new drugs affect patients in preclinical tests.

Bioinformatics benefit from Denmark's leading position in using big data from medical register data, electronic patient records and questionnaire surveys. Using these data and combining them with other forms of biological data enables scientists to mine and identify patterns among different types of patient.

Copenhagen Business School (CBS) also contributes to this research via the BioBusiness and Innovation Platform (BBIP), which is a collaboration between CBS, the University of Copenhagen and DTU. The platform aims to strengthen competencies and specific tools to support bio-based innovation.

International top quality niches

At the Center for Protein Research, scientists employ a broad, interdisciplinary approach in researching the role of proteins in health, diagnosis and treating disease.

The centre works with protein research from an integrative systems biology approach, i.e. they study the significance of how proteins interact with a whole range of other factors such as genes, sugars, circulation, etc. They investigate the structure of proteins, their interaction with internal cellular processes and how cells communicate with each other via proteins, e.g. when the immune system targets a disease.

The centre furthermore studies how proteins can be used therapeutically and how specially designed proteins can be produced quickly and efficiently. It uses bioinformatics to study proteins by developing algorithms that can recognise interrelationships and patterns in a combination of complex biodata, register data and electronic patient records. These big data studies could for example be crucial for treating cancer and in understanding the immune system and molecular evolution.

The protein research in Greater Copenhagen on the importance of sugars for protein functionality, glycomics, has major potential for supporting future therapies, gene technology and diagnosis. The University of Copenhagen's Center for Glycomics is especially prominent and is among the strongest environments in the world in the field. It is funded by the Danish National Research Foundation.

Bibliometric key figures

There is no category in the bibliometric database, which fully captures protein research and bioinformatics. The field is interdisciplinary and is reflected in categories such as structural biology, molecular biology and cell biology. With respect to corporate co-publication, Greater Copenhagen takes the lead in all categories.

With respect to the share of articles, which are among the most-cited in the global top 10%, protein research is 2nd among the regions of comparison for two of the categories and 1st in one of the categories (biochemistry). Finally, Greater Copenhagen is averagely specialized in this area, which reflects the fact that numerous international research environments are engaged in protein research.

Copenhagen is also in front among the regions of comparison in relation to joint publications measured as the number of co-publications with authors from the private commercial sector.

Key bibliometric indicators

	Specialisation	Output ranking (No. articles)	Highly cited article ranking (%).	Co-publication ranking (%)
Structural biology	0,98	6 (464)	2 (16,4)	1 (13,6%)
Molecular biology	0,68	8 (1122)	2 (18,4)	1 (10,1%)
Biochemistry	1,49	1 (337)	1 (28,1)	1 (12,9%)

Period: 2005 -2015. Regions of comparison: Amsterdam, Berlin, Dublin, Geneva-Lausanne, Hamburg, Helsinki, Munich, Oslo and Stockholm/Uppsala.

Specialisation is an expression of the size of a field of research compared to all research production at University of Copenhagen, DTU and CBS compared with its size in the regions of comparison. A specialisation level 1 indicates that Greater Copenhagen is on level with the regions of comparison. Specialisation of >1 indicates that Greater Copenhagen is more specialised in the field of research than the regions of comparison.

Output ranking measures Greater Copenhagen's position in the field concerned among the regions of comparison in terms of article production (with the absolute numbers of articles in brackets).

Highly cited article ranking indicates Greater Copenhagen's placing in the regions of comparison for the proportion of articles in the field of research in Copenhagen that are among the 10% most cited worldwide (percentage in brackets).

Finally, co-publication ranking indicates Greater Copenhagen's rank among the regions of comparison for the proportion of articles in the field published jointly with the business sector (percentage of overall article production in Greater Copenhagen in brackets).

Key arguments for the research area's potential to attract investment

There is global demand for new, more efficient ways of conducting early stage diagnostics of diseases.

In these years, the global pharmaceutical industry is challenged by rapid advances within personalised therapies, designed and adapted to the biological characteristics of the individual (personalised medicine). This applies for example to treatment of HIV, cancer, blood disease and neurodegenerative conditions (which basically are caused by changes in proteins). Understanding proteins, peptides (chains of amino acids), glycomics (sugars) and gene stability are absolutely critical preconditions for developing such new diagnostics and treatments.

System biology research at the University of Copenhagen and DTU carries an enormous potential in this field. It has two aims: First, to understand how protein, peptide and glycome interacts with other biological factors in the body. Secondly how nanotechnology can be used to design new proteins. However, research is still relatively fundamental so in many instances returns on investment have very long timescales.

In the short-term, bioinformatics combined with Denmark's consistent register-based health data hold considerable potential with respect to investigating the link between biological characteristics and the effect of different therapies. The research aims to achieve better, more accurate segmentation of patient groups and to optimise drugs that are still at the preclinical stage of development.

Star researchers and major scientific breakthroughs

Protein research and bioinformatics in Greater Copenhagen have led to a number of breakthroughs. The Center for Glycomics under Prof. Henrik Clausen of the Department of Cellular and Molecular Medicine at the University of Copenhagen has developed a technique in which sugar structures attach to proteins. These structures stabilise proteins and can determine how long they persist in the human body. CHO cells from hamsters are used to produce human-compatible sugar structures that have been modified using advance genetic editing technologies. The technique can also be used to develop novel, more effective drugs for patients with cancer and other diseases.

The Center for Protein Research has several very promising teams headed by elite researchers, such as Prof. Jiri Lukas, who directs a programme focusing on protein signalling between cells, associated for example with DNA damage, and how these mechanisms can be disrupted. Similarly, Prof. Mathias Mann works with protein-based biomarkers for diabetes and other lifestyle diseases that are an important factor in developing personalised treatments.

Prof. Søren Brunak from the Center for Protein Research and DTU Bioinformatics is one of Denmark's leading protein researchers, working with bioinformatics and register data as the basis for developing more personalised medicine. His research focuses on how different kinds of medicine interact, especially in patients with complex conditions that require them to take many different types of medication.

At the Department of Cellular and Molecular Medicine, University of Copenhagen, Prof. Ian Hickson works on chromosomal instability, which leads to premature ageing in cells in the form of proteins that cannot be regenerated. This is significant for the development of cancer cells, joint disease and neurodegenerative conditions as well as numerous other health issues. He has also received an Advanced Grant from the European Research Council for his research (which indicates excellence at a very high level). Prof. Ian Hickson heads the Center for Chromosome Stability at the Basic Research Center.

Finally, Prof. Niels Tommerup works on designing new proteins for the development of new drugs, primarily focusing on diabetes and obesity. This

area could form the basis for new drugs in future

Large talent pool

Greater Copenhagen is one of the strongest life science regions in Europe, which is also reflected in the pool of talent related to protein research and bioinformatics. The Faculty of Science at the University of Copenhagen offers a Master's programme in bioinformatics in which around 12 students graduate every year. Biochemistry educate 58 graduates annually and Biology/Biotechnology has 57 graduates annually together with 44 in Molecular Biomedicine.

The Faculty of Health and Medical Sciences runs Master's programmes in pharmaceutical chemistry and pharmaceutical science. DTU offers Master's programmes in biotechnology, pharmaceutical technology, system biology, medicine and technology. CBS runs a Master's programme in bio-entrepreneurship, with 13 students completing the course every year. All in all, about 375 Masters students complete their training in this field every year.

In 2015, the Center for Protein Research had 34 postdocs, with 28 at the Department of Cellular and Molecular Medicine. Around 18 PhDs enrol at the Department of Cellular and Molecular Medicine annually, with about 10 at the Center for Protein Research. Every year, between 450-500 PhDs enrol at the Faculty of Health at the University of Copenhagen.

Unique research facilities

High level bioinformatics demands enormous computer power. DTU, the University of Copenhagen and DeiC have jointly invested DKK 40m in a new supercomputer. The computer will among other things be used for processing enormous volumes of patient data, such as DNA data, patient records, etc., in order to identify new patterns between disease, patients and factors such as genetics and lifestyle.

It is expected that in time, analytical results will make it possible to design drugs more cheaply and efficiently, and to target individual patients more effectively. Søren Brunak's research group is among the main users of the computer.

The research environments engaged in protein research all employ state-of-the-art mass spectroscopic equipment (e.g. Nuclear Magnetic Resonance), that can perform advanced structural analyses of proteins. The Center for Protein Research uses microscopic imaging for proteins. At the national level, the Research and Innovation Agency decided to provide DKK 40m in funding to support the establishment of the national PRO-MS Platform, the Danish National Mass Spectrometry Platform for Functional Proteomics.

Finally, we also expect great opportunities from using the super microscopes at ESS and MAX IV in Lund for protein research. This applies for example to studying enzymatic reaction mechanisms, the design of therapeutic proteins and research into new biomembranes.

Strong collaboration with leading international research environments

In Greater Copenhagen, protein research is characterized by close relations with leading international scientific environments. Among other things, Hans Wandall highlight a number of close relations with leading foreign research environments such as Harvard Medical, University of California, University of Pennsylvania and University College London. The Center for Protein Research also works with the German elite research environment at the Max Planck Institute of Biochemistry, where Prof. Mathias Mann also works.

Extensive corporate collaborations

Protein research is carried out in close interaction with the Danish life science sector, including Novozymes, Chr. Hansen and Novo Nordisk. There are also collaborations with international players such as Novartis and Roche. The Novo Nordisk Foundation provided funding for the Center for Protein Research and research on glycomics.

A total of eight licensing agreements were made with companies in this field in 2013-15. The Department of Cellular and Molecular Medicine and the Department of Biomedicine at the University have been responsible for four licensing agreements. Four spin-out companies were also incorporated during the same period (see examples in the box).

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FIDA-tech is a spin-out from the University of Copenhagen that employs innovative technology to analyse and characterise proteins, especially with a focus on diagnosing and monitoring autoimmune disease. The methods are characterised by being significantly faster than existing methods. They only require small samples and are easy to automate. The technology cuts the time needed to test samples by more than 75% and it is more accurate and flexible than existing methods.

Avilex Pharma is a spin-out from the University of Copenhagen that focuses on treatment for hemorrhagic strokes. This is one of the most frequent causes of death and is caused by a lack of blood flow to the brain. The company is developing new drugs using newly developed protein structures that 'dock' with the brains receptors and alleviate pain and protect against the cell death associated with stroke. Novo Seeds, Novo Nordisk Foundation and Copenhagen Spin-outs have invested in the company.

Quantum technology

Content and applications

Since Niels Bohr became a professor in theoretical physics 100 years ago, Copenhagen has been an important location for the understanding of quantum physics. Quantum technology is already now being used in such technologies as GPS, optical cables, superconducting magnets and in mobile phones. However, quantum technologies are on the verge of a new era in which their applications could revolutionise the world in several areas.

First and foremost, super computers based on quantum technology are expected to be able to set entirely new standards for processing big data. Quantum technology is expected to form the basis for a whole range of new devices that will make it possible to process and communicate data at a significantly higher level than today. The EU has named quantum technology as a major flagship initiative.

Key environments and star researchers

Greater Copenhagen has a very strong research environment within the area. At the Niels Bohr Institute at the University of Copenhagen, key researchers include Charles Marcus, Eugene Polzik and Peter Lodahl. At the Technical University of Denmark (DTU), leading names include Ulrik Lund Andersen at DTU Physics and Jesper Mørk at DTU Fotonik.

The quantum field is divided into two main areas, each of which contain several sub-disciplines. The area of solid state and quantum electronics is one of the main areas, while quantum optics and quantum photonics is the other.

Prospects for attracting investments

The area is highly relevant for attracting investment. Some of the technologies in the area are so novel that they will not be applicable for some years, while other applications, such as quantum-based cryptography, are already underway. Overall, however, the potential is considerable, indicated by the substantial investments made in the field by the EU, Innovation Fund Denmark, private foundations and companies. There is no doubt that the most important area of investment and applications will be the development of the supercomputers of the future.

Characteristics of the research area

Quantum research in Greater Copenhagen is especially anchored at the Niels Bohr Institute at the University of Copenhagen and at DTU Physics and DTU Fotonik, within each of which there are various specialized departments and centres. The Niels Bohr Institute and DTU each host about 70 researchers working in the quantum field. In all these environments, there are various postdocs and PhDs.

International top quality niches

Quantum research is divided into two main pillars. One is solid state research which contributes to the development of future electronics by researching the interaction between advanced materials and the quantum/ mechanical effects found in electronic nano components.

The second relates to quantum photonics and quantum optics, which especially aim to store and transmit digital information through optical beams, and the ability to store digital information in individual photons. Some projects aim to link the two areas of technology together. Research in Greater Copenhagen is well placed internationally within both pillars.

Bibliometric key figures

The bibliometric indicators for research production and quality confirm that Greater Copenhagen is at the international cutting edge. As shown in the table, the category of Condensed Matter Physics covers the solid state field of quantum technology. The Atomic and Molecular Physics and Optics category also covers the field of photonics and optics. Greater Copenhagen contributes with considerable research output, with a total of 6,700 articles in recognised journals over the past 10 years, amounting to a specialisation of around 1.

The quality of research is world-class. Greater Copenhagen takes a 2nd place when it comes to the proportion of research production in the top international 10% of most cited articles. This reflects the fact that quantum research in Greater Copenhagen is done in various smaller environments with international core competencies in a number of niche areas. With respect to the investment potential of the area, an equally important indicator is the proportion of co-publications with researchers from private companies which gives an indication of the commercial relevance of the research. On this indicator, Greater Copenhagen is placed 1st for both the above fields of research.

Key bibliometric indicators

	Specialisation	Output ranking (No. articles)	Highly cited article ranking (%).	Co-publication ranking (%)
Condensed matter physics	0.8	5 (3636)	2 (19.7%)	1 (6%)
Atomic and molecular physics and optics	1.17	3 (3038)	2 (13.8%)	1 (10.9%)

Period: 2005 -2015. Regions of comparison: Amsterdam, Berlin, Dublin, Geneva-Lausanne, Hamburg, Helsinki, Munich, Oslo and Stockholm/Uppsala.

Specialisation is an expression of the size of a field of research compared to all research production at University of Copenhagen, DTU and Copenhagen Business School (CBS) compared with its size in the regions of comparison. A specialisation level 1 indicates that Greater Copenhagen is on level with the regions of comparison. Specialisation of >1 indicates that Greater Copenhagen is more specialised in the field of research than the regions of comparison.

Output ranking measures Greater Copenhagen's position in the field concerned among the regions of comparison in terms of article production (with the absolute numbers of articles in brackets).

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Finally, co-publication ranking indicates Greater Copenhagen's ranking among the regions of comparison for the proportion of articles in the field of research published jointly with the business sector (percentage of overall article production in Greater Copenhagen in brackets).

Key arguments for the research area's potential to attract investment

The full perspectives for the potential of quantum technology is long-term and some uncertainty still remains. But quantum technology is among the areas expected to foster a number of crucial technological breakthroughs in coming decades.

However, there have already been many discoveries in the area. In 2014-15, Quantum at University of Copenhagen had a total of 13 out of 145 announced discoveries, i.e. about 9%. This should be viewed in relation to the fact that quantum research only employs about 2% of the permanent researchers at the University of Copenhagen.

Star researchers and major scientific breakthroughs

A number of outstanding researchers have secured Denmark's position on the world map of quantum research.

Key names include Prof. Charles Marcus, who heads the Center for Quantum Devices at the University of Copenhagen. He works on quantum electronics. Researchers are developing techniques and technologies that could form the basis for the supercomputers of the future by controlling and exploiting the fascinating, strange quantum properties of atoms, such as quantum entanglement.

Prof. Peter Lodahl from the Niels Bohr Institute at the University of Copenhagen is the Director of the Center for Quantum electronics and he works on controlling photons via nanophotonic structures, special crystals that can be used in future quantum communication. Prof. Eugene Polzik, who heads the Center for Quantop - Quantum teleportation, also works at the Niels Bohr Institute. The technology forms the basis for the superfast communication networks of the future as well as for quantum sensors for measuring electromagnetic fields and acceleration.

Jan Westenkær Thomsen, also working at the Niels Bohr Institute, is Director of the Center for Ultracold Atoms, where they conduct experimental research on super accurate measurements, such as quantum-based atomic clocks that only lose a second in 300m years.

At DTU Physics, Prof. Ulrik Lund Andersen heads a quantum information team and works on quantum sensing and on processing quantum information, including how data can be transferred with 100% security. Prof. Jesper Mørk at DTU Fotonik leads the research into ultra fast communication in conjunction with the VKR Center of Excellence Nanophotonic Components for Terabit Communications, and Prof. Leif Katsue Oxenløwe who is the head of the Silicon Photonics for Optical Communications basic research centre.

In Europe, Greater Copenhagen is one of only three regions to have made great headway in the selected technologies. The other strong research environments include Delft in the Netherlands and ETH in Zürich. The three strong research communities in USA are Yale, Harvard and Santa Barbara in California. The research communities in other countries such as UK, Germany, Korea and Japan also do high level research.

So far, breakthrough research has been made on the development of new atomic clocks, satellite controls systems, cryptography and sensors. Future big research breakthroughs are expected to be within supercomputing, communication and ultra accurate sensing, areas in which Greater Copenhagen is in a global leading position.

Large talent pool

The University of Copenhagen and DTU both educate/train a considerable number of talented individuals. The Niels Bohr Institute has 700 physics students with about 150 Master's graduating every year, practically all of whom will have done studies in the quantum field. 40-45 PhDs graduate at the Institute every year. DTU also has 500 engineering students of whom 75% attend courses in the quantum field, with many continuing as PhDs. DTU has a Master's programme within quantum technology and a hands-on

QuantumLab for students.

These highly specialised talented researchers work closely on a day-to-day basis with some of the world's most skilled researchers in quantum science. This enables them to gain knowledge, which gives their collaborative partners entirely unique opportunities to be at the forefront internationally with respect to access to knowledge in this field, if they make use of opportunities for recruitment.

Unique research facilities

Over the past 10 years, a total of about DKK 200m has been invested in state-of-the-art research infrastructure at University of Copenhagen and DTU. This process has also been assisted by donations from the Villum Foundation, the Carlsberg Foundation, the Lundbeck Foundation, the Novo Nordisk Foundation, the Danish National Research Foundation and the Danish Council for Independent Research.

The list of infrastructure includes various instruments for making and characterising photonic and electronic quantum components. Among these an electron-beam writer dedicated to making ultra-high-definition quantum nano-structures. DTU Danchip is a national clean room for making quantum components, featuring international top class facilities and research infrastructure.

The quantum field has been highly prioritized, and has received considerable funding from the EU, the Danish National Advanced Technology Foundation and Innovation Fund Denmark. Researchers from the Niels Bohr Institute at the University of Copenhagen have thus been awarded a series of prestigious ERC Grants: Eugene Polzik (2011), Peter Lodahl (2010 and 2014), Anders Søndberg Sørensen (2012) and Albert Schliesser (2014). Three awards have been awarded in this field from the Danish National Research Foundation for the Center for Quantum Optics, the Center for Quantum Devices and the Center for Silicon Photonics for Optical Communication.

This field will probably have even greater priority in future. In the spring of 2016, Innovation Fund Denmark disbursed a grant of DKK 80m (the largest ever single award from the Fund), which will be used for developing new encryption methods and topological quantum computers.

The essential future investment might come from the EU. In the spring, a working group including EU Commissioner Oettinger, the Dutch Minister of Business Affairs and Charles Marcus and Eugene Polzik from the University of Copenhagen, released a Quantum Manifesto with guidelines for how the quantum field should develop in the future, new areas of application as well as an ambition to put Europe at the forefront of global developments in the quantum field. A vision, which will entail that the EU and EU member states invest a total of EUR 1bn in the field.

Eugene Polzik also has a seat on the steering group for quantum research set up by the EU as part of its process for so-called flagship technologies.

Strong collaboration with leading international research environments

There is great international interest in visiting the Niels Bohr Institute, which therefore gets visiting researchers from the whole world. The institute is itself active in collaborating with knowledge centres worldwide. One close partner is the University of Delft in the Netherlands, but the institute also works with quantum researchers at ETH Zürich, Yale and Stanford. Similarly, DTU has an extensive range of internationally recognised collaborative partners in the quantum field, such as Queensland University, University of California Santa Barbara and University of Delft.

Extensive corporate collaboration

The Niels Bohr Institute at the University of Copenhagen, DTU and Aarhus University have jointly established the Quantum Innovation Centre (Qubiz) in close collaboration with a range of Danish and international companies, all leaders in the commercial exploitation of quantum technology. Their ambition is to create a world leading innovation centre for commercial exploitation of quantum technology research.

Qubiz already collaborates with companies such as Accelink Denmark, Attocube Systems, Cryptomatic, Elionix, Foss, ID Quantique, Microsoft, Montana Instruments, M Squared Lasers, NIL Technology, NKT Photonics, Quantumwise, Scontel and Toptica.

Most recently, in the spring of 2016, Seier Capital invested millions of Danish kroner in a newly started quantum business, Sparrow Quantum, which supplies chip solutions to companies requiring sophisticated algorithms for simulating the properties of materials, for example. Sparrow Quantum is a spin-out from the quantum photonics environment at the Niels Bohr Institute at the University of Copenhagen and makes photonic chips designed to meet companies needs for advanced simulation algorithms. The investment was Seier Capital's largest and most surprising until now.

"If everything goes as planned, there is enormous potential. SPARROW QUANTUM is taking the first steps towards a future with super fast quantum computers, unbreakable encryption and possibly also quantum-based internet. "

- Lars Seier Christensen

Half of Qubiz´ collaborative partners are international. We interviewed Montana Instruments in Montana, USA.

"We are in the Wild West – both literally and figuratively speaking. We produce optical cryogen systems. With our now single photon developed with our Copenhagen partners, we can help our costumers all over the world produce new materials. We think the guys in Copenhagen are world class."

- Luke Moritsen, Director, Montana Instruments, US

"We have been strongly inspired by the new Quantum Manifesto which has the backing of the EU Commission. We believe in a strongly growing market for quantum simulations, an area in which we do not so far have many competitors."

- Troels Marcussen, Civil Engineer, Quantumwise Denmark

Social Big Data

Content and applications

Greater Copenhagen displays a special strength in Social Big Data and data science. This area employs methods from data science, social sciences and humanities to identify patterns in structured and unstructured data, such as texts from social media. Social Big Data provides entirely new opportunities for understanding how behaviours and preferences are shaped and for understanding new market trends among groups of consumers, etc.

Key environments and star researchers

Social Big Data involves several different areas of research. Copenhagen Business School (CBS), the University of Copenhagen and the Technical University of Denmark (DTU) are all heavily involved in the field. At the University of Copenhagen, departments at the Faculty of Social Sciences, some departments at the Faculty of Humanities and the Department of Computer Science host researchers who are active in this field. At CBS, various individuals and areas of research work on Social Big Data, including Ravi Vatrapu at the Department of IT Management, and Thomas Ritter, who heads the CBS Competitiveness Platform. At DTU, various researchers from DTU Compute are heavily engaged in this field. From University of Copenhagen the key star researcher in the area is Prof. David Dreyer Lassen, who received the prestigious Elite Research Award in 2016. He leads a major new research centre focusing on Social Big Data.

Potential for attracting investment

Social Big Data is still in its infancy but it has very considerable potential, both as a new field of research and as an area with great commercial potential. For companies, the perspectives entail better predictions of new trends, deeper understanding of consumer preferences and in gaining new insights into their consumers. Greater Copenhagen is the only region in the Nordic countries to have made a major research effort in this field. Particularly interesting from an international point of view is that the new insights are often discovered by combining unstructured data from social media for example with register-based data on income, education, age, etc.

Denmark is one of the countries in the world with the best register data.

Characteristics of the research area

Social Big Data is a new field of research which combines a broad range of research disciplines in the humanities, data science and social sciences. It involves developing methods to analyse unstructured data such as Tweets, Facebook updates, data from apps and sensors, etc. Furthermore, the research is about developing algorithms for pattern recognition and interpreting and understanding the patterns and relationships that are revealed. The research also holds significant prospects for developing new data-driven corporate business models and patient procedures in hospitals.

This demands a high level of interdisciplinarity with linguists, data scientists, social scientists, anthropologists and economists working closely together to develop new approaches and methods that can translate Social Big Data into new insights for research, the business sector and society in general.

International top quality niches

Researchers in Greater Copenhagen have previously had an interest in Social Big Data, which has already secured a solid basis. Greater Copenhagen's strength lies in a combination of several features, including excellent, close collaboration between researchers in the social sciences and bright researchers in computer science who have extensive experience of Big Data science and in developing specific algorithms, etc.

The University of Copenhagen and DTU Compute have jointly established the Copenhagen Center for Social Big Data Science, which is a unique environment in the world, working on combining unstructured behavioural data with more than 40 years of register data for the entire population.

At the Center for Communication and Computing, researchers from the humanities and natural sciences also work on digital cultures and the interaction between societal phenomena, ICT technology and big data. Among many other things, the centre investigates interactive visualisation of social data and the use of Big Data in healthcare and welfare solutions.

There is also good collaboration between researchers at the Department of Computer Science and Nordic Philology at the Centre for Natural Language Processing, which researches ways to comprehend for example tweets and search patterns on the internet.

CBS has various activities relating to Big Data, such as a three year project on Big Social Data Analytics, which has received DKK 6.2m in funding from the Danish Industry Foundation. Researchers and businesses are collaborating on developing new methods and approaches to the use of Social Big Data Analyses as part of companies' business development processes, enabling them to make better decisions on product development, marketing, sales, strategy and to gain greater insights into user behaviours.

The Danish Industry Foundation has also supported the CBS research project - Big Data, Big Business - anchored at the CBS Competitiveness Platform. The project focuses on transforming Big Data into profitable business models by way of taking novel approaches to existing business models. The Center for Business Data Analytics at the Department of IT Management is participating in these projects and working on Social Big Data as well as an extensive range of other areas, such as health services.

An interdisciplinary centre - DABAI - has been established with funding from Innovation Fund Denmark. It focuses among other things on using Social Big Data to create new innovative solutions to support better forms of teaching, better prediction of flooding, better food traceability and a better overview of patients in the healthcare sector

Bibliometric key figures

The bibliometric key figures do not reveal the strength of Greater Copenhagen's Social Big Data research. This can be ascribed to the fact that this research cuts across various different disciplines. It is especially difficult to identify strengths in the humanities and social sciences in the bibliometry.

The table below displays the bibliometric key indicators for the more “hard”

research areas - General Mathematics and Theoretical Computer Science, which play an important role in Social Big Data in general. Output in Greater Copenhagen is generally somewhat lower than in the regions of comparison. But in terms of quality research as the proportion of articles among the 10% most cited in the field, Greater Copenhagen takes 2nd place among the European regions of comparison.

Key bibliometric indicators

	Specialisation	Output ranking (No. articles)	Highly cited article ranking (%).	Co-publication ranking (%)
General mathematics	0.7	6 (464)	2 (21.1%)	5 (1.7%)
Theoretical Computer Science	0.68	8 (1122)	2 (18.0%)	5 (6.3%)

Period: 2005 -2015. Regions of comparison: Amsterdam, Berlin, Dublin, Geneva-Lausanne, Hamburg, Helsinki, Munich, Oslo and Stockholm/Uppsala. Specialisation is an expression of the size of a field of research compared to all research production at University of Copenhagen, DTU and CBS compared with its size in the regions of comparison. A specialisation level 1 indicates that Greater Copenhagen is on a par with the regions of comparison. Specialisation of >1 indicates that Greater Copenhagen is more specialised in the field of research than the regions of comparison. Output ranking measures Greater Copenhagen's position in the field concerned among the regions of comparison in terms of article production (with the absolute numbers of articles in brackets). Highly cited article ranking indicates Greater Copenhagen's placing in the regions of comparison for the proportion of articles in the field of research in Copenhagen that are among the 10% most cited worldwide (percentage in brackets). Finally, co-publication ranking indicates Greater Copenhagen's rank among the regions of comparison for the proportion of articles in the field published jointly with the business sector (percentage of overall article production in Greater Copenhagen in brackets).

Key arguments for the research area's potential to attract investment

The increasing use and spread of social media, apps and digital devices leaves extensive digital traces and data behind us that can be analysed and provide valuable insights into modern preferences and attitudes and how these change over time. At the same time, the widespread digitalization of the business sector (transition to Industry 4.0) provides entirely new opportunities for developing digital services and new digital business model.

Many companies are already in the process of harvesting social data and identifying patterns as well as interpreting the different types of data. The aim is to be better at decoding new trends in the market and to use Big Data as the basis for developing better products, efficient processes and new types of digital service.

Denmark has a special strength in this area due to its highly technologically literate population and unique opportunities for combining unstructured data and register data. Greater Copenhagen has, as the only region in the Nordic countries, already undertaken a range of major projects to research the use of Social Big Data.

Star researchers and major scientific breakthroughs

Recent years have seen several interesting research projects focusing on Social Big Data.

At the Department of Computer Science at the University of Copenhagen, Prof. Ingemar Cox works on gathering and analysing data from the internet that can be used to predict epidemics and reveal other social phenomena. Prof. Cox, who is the most cited computer scientist in Denmark, collaborates with Google. Prof. Anders Søgaard, also at the Department of Computer Science (and with a past at the School of Authors and in linguistics), does research into artificial intelligence, language technology and machine learn-

ing. His research has been crucial for developing and improving machine translation systems such as Google Translate.

The Carlsberg Foundation provides funding for "The Peoples' Internet" project headed by Prof. Klaus Bruhn Jensen, which combines ethnographic and Big Data-based methods to study how the internet's potential is exploited differently in the EU, China and the US.

The Centre for Information and Bubble Studies under Prof. Vincent Hendricks of the Department of Media, Cognition and Communication at the University of Copenhagen is also supported by the Carlsberg Foundation. The centre uses interdisciplinary perspectives to investigate social bubbles, for example bubbles in financial systems, political opinion forming in the social media or appropriate/inappropriate 'group thinking' in corporate boardrooms. The centre also studies how companies and investors for example navigate their way through Big Data, including the risks to which companies may be exposed when they try to extract value from digital data.

At CBS, Prof. Ravi Vatrapu and Prof. Thomas Ritter are both responsible for the two Big Data projects being funded by the Danish Industry Foundation. Their research involves companies and researchers investigating the challenges and potentials in the use of social media data in business development and actual data-driven business models. Another exciting research project is Social Fabric, which focuses on young people's friendships and their use of mobile phones.

Researchers at the University of Copenhagen and DTU gathered data over a three year period on how 1000 young students use their mobile phones. Their ambition is to use this data to identify friendships and networks amongst young people and to illuminate what friendships mean for students' chances of completing or dropping out of their education.

The research project is headed by Prof. David Dreyer Lassen, one of the leading researchers in Social Big Data, who is also the Director of the Copenhagen Centre for Social Data Science.'

Large talent pool

Exploiting Social Big Data requires close interaction between skilled sociologists, economists and linguists, etc. on the one hand and smart data processors and computer scientists with skills in statistics, algorithms and data science on the other.

Greater Copenhagen already has many bright researchers, PhDs and graduates who have built up considerable knowledge and experience in the field as a result of the many projects implemented in recent years such as Social Fabric, DABAI and the Center for Business Data Analytics and the Big Data - Big Business project at Copenhagen Business School.

One of Greater Copenhagen's major strengths is its strong tradition of data scientists being trained in algorithm design and machine learning. They typically have long experience in interdisciplinary collaborations with researchers from other fields of research.

In addition to the Department of Computer Science, talented PhDs, postdocs and Master's students specializing in the field also come from DTU Compute, CBS and environments at the Faculty of Humanities and Social Science at the University of Copenhagen The overall numbers of talented individuals in Big Data Science will get a major boost in the coming years when the data centre for ESS is anchored at the Niels Bohr Institute.

Unique research facilities

Greater Copenhagen has several strong cards when it comes to attracting foreign investment to the region in the field of Social Big Data.

One of the strongest cards is the unique opportunity for combining data from social media with register data, an area in which Denmark is among the world leaders. This makes it possible to do analyses in which behaviour is correlated with differences in financial circumstances, geography, etc. Danes

are also some of the most digitally literate people with the most widespread use of computers, internet, etc. This means that there are good opportunities in Denmark to undertake natural experiments from which interesting new data can emerge.

One specific example of how unique new data sets can be built up comes for example from data from the Social Fabric project that includes data on 1000 young people's use of mobile phones over a period of three years. This type of data constitutes an important foundation for an entirely new type of research and insights based on analysis of Social Big Data.

Extensive corporate collaborations

Commercial exploitation of Social Big Data is still at an early stage and interaction with the corporate sector in this field is still relatively limited.

However, there are some specific examples of enhanced commercial interaction within the framework of the Danish Center for Data Analytic Driven Innovation, a major project supported by Innovation Fund Denmark and with the participation of the University of Copenhagen and DTU. This allows companies to get a "Big Data" consultation, in which two experts in the field work with the company to exploit Big Data Analytics in the company's innovation processes.

Another example is at CBS, where they have set up a major project entitled Big Data – Big Business. With funding from the Danish Industry Foundation, the project aims to provide advisory services for companies on opportunities for using Big Data in their business development and business model innovation.

Wind and energy storage

Content and applications

Greater Copenhagen is strongly positioned within research in wind energy and energy storage. The two areas are closely interdependent since energy storage increases the value of fluctuating supplies of wind (and solar) energy. Energy can be stored using chemical processes in materials, especially in batteries, and by electrolysis. The most important form of electrolysis separates water into oxygen and hydrogen, which can then be used to upgrade biofuel or to generate power in a fuel cell.

Key environments and star researchers

For some years, Denmark has been implementing an active energy policy and has supported considerable research efforts. In Greater Copenhagen, this is especially reflected at the Technical University of Copenhagen (DTU), where six departments contribute to a very strong, extensive research environment in this field. These are DTU Wind Energy, DTU Energy, DTU Electrical Engineering, DTU Mechanical Engineering, DTU Compute and DTU Physics. Two key people in these environments are the Head of Department at DTU Wind Energy, Peter Hauge Madsen, and Søren Linderoth, who heads DTU Energy.

Potential for attracting investment

There is very considerable potential for attracting investment in both a long and short-term perspective. Denmark is a world leader in wind power, both in terms of the proportion of electrical power derived from wind, and the size and international competitiveness of the wind industry.

However, there is also great potential in the field of energy storage and conversion and smart grids. This field includes electrolysis and fuel cells, flow batteries and electrical systems for controlling smart grids. We have major research strengths as well as competitive companies in this field that can provide the basis for new ‘green growth’ when the EU´s climate targets get more demanding.

Characteristics of the research area

Energy research is characterised by major research efforts in all areas that are conducive for Denmark's green transition process, including wind energy, energy conversion (from chemical energy and fuel cells to electricity) and energy storage.

In Greater Copenhagen, five DTU departments contribute to a very strong and extensive energy research environment. DTU Wind Energy (with a headcount of 250, including 100 permanent research staff) studies a range of different fields of technology. DTU Energy (also with a headcount of 250 and around 100 permanent researchers) does research in energy conversion and storage. DTU Electrical Engineering host a section called Center for Electric Power and Energy. DTU Mechanical Engineering has a section for thermal energy, while DTU Compute does research on software to support smart grids.

International top quality niches

Wind energy research in Greater Copenhagen consists of a number of different sub-fields. First, wind energy, including the design, improvement and testing of wind turbines and components, with a clear focus on optimisation of performance and costs, siting and integration in order to achieve the best possible effect of wind energy.

Second, high voltage equipment, systems and software for power systems. A third main track is electrolysis and fuel cells. Fourth, the development of batteries using fewer rare or environmentally damaging materials, which could consequently contribute to a significant spread of battery technologies. Then there are special issues such as different ways of storing energy, e.g. using wax or salts that change state from solid to fluid and solar cells in plastics.

All these areas have Danish researchers that are in the Top 5 internationally, and in most cases, among the global Top 5.

Bibliometric key figures

Researchers in Greater Copenhagen are strongly ranked internationally, which is confirmed by the bibliometric key figures. They should be interpreted with caution, however, because of the fact that all areas of energy in Scopus include non-sustainable energy sources such as combustion technologies, nuclear power, etc., which does not correspond with the Danish research stronghold. Measured in terms of the proportion of highly cited articles, Greater Copenhagen is highly placed. The high co-publication rate reflects the high level of corporate involvement in research at the Departments at DTU noted above.

Key bibliometric indicators

	Specialisation	Output ranking (No. articles)	Highly cited article ranking (%).	Co-publication ranking (%)
General energy	1.13	3 (502)	1 (28.1%)	1 (9.7%)
Mechanical engineering	1.15	2 (1853)	2 (24.1%)	3 (6.4%)
Fuel technology	2.1	2 (531)	2 (30.7%)	3 (11%)

Period: 2005-2015. Regions of comparison: Amsterdam, Berlin, Dublin, Geneva-Lausanne, Hamburg, Helsinki, Munich, Oslo and Stockholm/Uppsala. Specialisation is an expression of the size of a field of research compared to all research production at University of Copenhagen, DTU and Copenhagen Business School (CBS) compared with its size in the regions of comparison. A specialisation level 1 indicates that Greater Copenhagen is on level with the regions of comparison. Specialisation of >1 indicates that Greater Copenhagen is more specialised in the field of research than the regions of comparison.

Output ranking measures Greater Copenhagen's position in the field concerned among the regions of comparison in terms of article production (with the absolute numbers of articles in brackets). Highly cited article ranking indicates Greater Copenhagen's placing in the regions of comparison for the proportion of articles in the field of research in Copenhagen that are among the 10% most cited worldwide (percentage in brackets). Finally, co-publication ranking indicates Greater Copenhagen's rank among the regions of comparison for the proportion of articles in the field published jointly with the business sector (percentage of overall article production in Greater Copenhagen in brackets).

Key arguments for the research area's potential to attract investment

Renewable energy research is highly relevant for solving societal challenges such as pollution, climate-change and energy supply. The green transition to a non-fossil society requires the development of cleaner and cheaper sources of energy. Denmark is already a pioneer in the green transition and will continue to have the opportunity to benefit from significant gains in this area, also in coming years. As the EU sets green targets e.g. for cutbacks in CO_2 more strict, other countries will also have to cope with fluctuating electricity supply. In this context, the Danish experience, both in electrical systems, energy conversion and energy storage can play an important role.

Star researchers and major scientific breakthroughs

DTU has a large, strong research community. Key figures include Peter Hauge Madsen, head of department at DTU Wind Energy, Søren Linderoth, who heads DTU Energy and Kristian Stubkjær, Director of DTU Electrical Engineering. There are numerous internationally recognised top researchers in these departments that have contributed to important improvements within wind, grid-system and energy storage.

Prof. Jens Nørkær Sørensen heads the Fluid Dynamics Section, which conducts research in aerodynamics and fluid dynamics, Prof. Mathias Stolpe leads research in Wind Turbine structures and Component Design, which contributes to the development of turbines. Prof. Bent F. Sørensen leads the Composites & Material Mechanics section, who researches materials for aerofoils. Prof. Jacob Østergård heads a section at DTU Electrical Engineering conducting research in electrical systems. Professors Jakob Mann, Anke Hagen, Peter Vagn Hendriksen, Teis Vegge and Frederik Krebs have made outstanding contributions to new science on wind energy, fuel cells, electrolysis, batteries and plastic solar cells.

In the field of energy, DTU has introduced a range of improvements in wind turbine technologies as well as energy conversion and storage. An area where Denmark is a world leader (thanks to research in Greater Copenhagen), is systems for managing fluctuating electricity generation – an area in which many companies are interested in following the development.

The Villum Foundation has awarded DKK 150m for an eight-year project - "Science of the Sustainable Fuels and Chemicals", which includes the participation of Stanford University. The project mainly researches methods for energy storage and is headed up by Prof. Ib Chorkendorff from DTU Physics.

Large talent pool

The production of talent in the field of energy is large. Approximately a third of the 1900 engineers who complete their Master's annually have attended an energy-related course. The same applies to the approximately 400 PhDs who complete their education/training at DTU. The PhDs are widely recruited, e.g. in relation to the wind sector, grid-systems, thermal energy, energy conversion, energy storage, etc.

Unique research facilities

DTU has world class research facilities in the fields of wind and energy. On the West Coast of Jutland two very large facilities for testing large wind turbines is located in Høvsøre and near Østerild. At Risø in Roskilde and in Lyngby researchers have state-of-the-art laboratories and measuring equipment, including the National Wind Tunnel, which is being constructed for wind energy purposes. In the smart grid field, DTU works on real-time data on current power generation and consumption on Bornholm, which as an isolated island provides a range of unique opportunities to test equipment and systems for managing fluctuating production and demand. Finally, DTU has excellent test facilities in the fuel, electrolysis and chemical fields.

Strong collaboration with leading international research environments

Researchers in Greater Copenhagen are popular collaboration partners for researchers worldwide. The energy sector is so broad that just who has the

strongest environments varies from area to area. There are strong environments in wind energy in USA, Germany, Spain and UK which have been supporting green technology programmes over the past 5-10 years. USA, Switzerland and UK have strong environments for electrical systems, and in the field of energy conversion and storage, the strong environments are in China, Korea, Germany, France, Switzerland and UK. So the picture is fragmented but making progress in the field of energy predicates collaboration across technological borders and so having a wide-scale research environment in the field of energy is a strength in itself.

Extensive corporate collaborations

Danish energy researchers have a tradition for collaborating closely with industry. Within wind energy, DTU collaborates with the major players in the industry, i.e. Vestas and Siemens Windpower, but also with smaller companies such as Envision (a Chinese wind turbine company with a development department in Silkeborg) and power companies such as DONG and Vattenfall and their sub-contractors. In the grid-systems area, DTU works with many Danish and foreign companies, such as IBM and Siemens and various smaller companies. In the field of energy storage and conversion, there is collaboration with a whole range of companies such as Haldor Topsøe and Varta and some smaller companies.

In terms of innovations and discoveries, patents and spin-outs, the field of energy is highly placed with a total of 15% of all the innovations in the past five years registered by DTU (in the 12 research strengths identified in this analysis).

The scientists at DTU are pretty much on the ball. We make methanol fuel cells, with DTU´s know-how providing important input. And DTU´s researchers have a fundamental understanding of how long-term basic research interacts with our needs, which naturally have a shorter timeline. The research projects are definitely well-run"

Mads Friis Jensen, Commercial Manager, Serenergy, Aalborg

"Batteries will become an increasingly important business area for us and an important part of future energy systems. And compared to universities and the rest the world, DTU´s researchers are at the cutting edge. So naturally, being located as close to DTU as we do is really valuable for us."

Søren Dahl, Program Manager, Haldor Topsøe

"For a wind turbine business such as ours (Envision), it is important to absorb all the knowledge we can. We collaborate with DTU Wind, DTU Energy and DTU Electrical Engineering especially in grid systems. DTU manages to establish fundamental knowledge that is directly applicable for a company such as ours."

Anders Rebsdorf, Country Manager, Envision