Research strengths of Greater Copenhagen with investment prospects

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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



Potential for attracting investment

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.

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

	Specialisa- tion	Output rank- ing (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