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Chapter 16

Educating the wind energy engineers of the future

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DTU Wind Energy

A forecast by the Global Wind Energy Council states that large-scale onshore and offshore wind projects will generate 3.3 million sustainable jobs worldwide requiring a variety of skills across the full value chain of the sector over the coming five years [1]. Going back in time, the number of jobs in the global windenergy industry more than tripled from 2009 to 2019 (see Fig. 1), with 1.17 million jobs in the sector in 2019 [2]. This growth stagnated from 2016 onwards, but it will likely soon accelerate, given that global wind-power installations are expected to exceed 110 GW annually by 2025 [1].

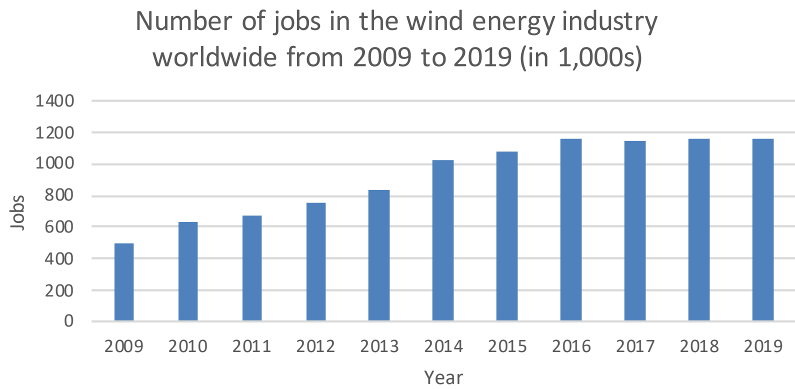
The wind energy engineers of the future will meet new challenges, and universities and other educational institutions must do all they can to prepare them to face them. Here we first take a closer look at the technological challenges that are currently emerging in the wind sector and the skill-sets that are needed to overcome them. We then consider the challenges and possibilities of a globalized windenergy sector and the need for the integration of sustainability across all disciplines in engineering education. We then consider the lifelong aspects of engineering education and the changing role of universities in this context. Lastly, we highlight the new possibilities for education all over the world with online tools and courses.

Technology leaps and the need for new skill-sets

The overall goal when designing wind turbines is to reduce the cost of producing one kWh of electrical energy measured as the Levelized Cost of Energy (LCOE). Today wind turbines are often situated in large wind farms, some of which can produce up to 1 GW. Due to lower turbulence, higher wind speeds and the cost of land, the very large projects are typically placed offshore. However, offshore foundations are also expensive, and to reduce the number of foundations, developers are demanding bigger and bigger turbines: currently wind turbines of up to 12 MW are commercially available. To reduce the cost of foundations and allow wind turbines to be installed at greater depths of water, floating foundations inspired by the oil and gas industry are under development. These floating foundations are more flexible than bottom-fixed supports, and their movement influences the stability of and loads on the rotor. Mastering the dynamics of a wind turbine mounted on a floating foundation exposed to wind and wave loads is one of the emerging technology leaps that will reduce the LCOE from wind energy.

A key past technology development was the advent of power electronic drives that allowed variable speed operation of generators and rotors so that wind turbines can operate near their optimum

Figure 1.
Number of jobs in the global wind-energy industry 2009-19 [2,3]



efficiency for a larger wind-speed range and reduce fatigue loads. The very big modern wind turbines are costly and therefore equipped with many more sensors to measure, for example, loads and constantly estimate the fatigue damage to various components. These sensors are actively used in the control in order to protect the wind turbine, their data constantly being monitored and analysed to optimize the turbine's operations and maintenance (O&M), thus reducing costs. This discipline is called 'condition monitoring' and is an important technology to protect these very large investments.

New data-analysis tools, such as machine-learning, are upcoming technologies that can be used to analyse the massive amounts of data continuously being sampled on a large wind farm to improve operations and the early detection of failures. Research is ongoing to measure the approaching wind speed using LiDAR in order to adjust pitch or possible flap settings in advance using a controller. This technology has not yet been commercialized, but it may well help in building larger and more competitive machines. It is clear that advanced remote sensing and data analysis are becoming more and more important to supplement the classical engineering disciplines such as structural mechanics, aerodynamics and electrical engineering.

Another challenge is the struggle against gravity, where the weight increases faster than the structures carrying the gravitational loads when upscaling wind turbines, a phenomenon known as the square-cube law. Here, the material sciences can help by, for example, switching from glassfibre to carbon fibre for some parts of the blades or improving computation of the material loads in order to get closer to the limit and thus save on materials and weight.

Globalization of engineering education

There is no doubt that globalization has greatly changed the present-day world and that this change is intimately related to education. The importance of global education is multiple: besides the actual academic and technical content of the different study programmes and courses, it also enables students to obtain skills from other cultures and learn how to work in multinational groups, as well as helping to develop a global perspective and language skills.

Based on interviews with 178 leaders in global thought, the Massachusetts Institute of Technology (MIT) has mapped the state of the art and future trends in global engineering education [4]. Currently, the Olin College of Engineering and MIT are recognized by many as the world-leading providers of engineering education. These and other institutions that receive high rankings are typically well-established universities located in the US or northern Europe and have large student cohorts. Other universities in different parts of the world are seen as emerging leaders in the field that represent a new generation of engineering programmes. These are characterized by being multidisciplinary and have a dual emphasis on engineering design and student self-reflection. Examples of emerging leaders in engineering education are the Singapore University of Technology and Design, University College London and the Pontifical Catholic University of Chile.

International wind energy education

In order to meet the growing demand for graduates with an understanding of cross-cultural issues, all wind-energy education at DTU is international in its aims and targets recruitment from all over the world. DTU Wind Energy takes care of training and education in most wind energy-related disciplines, comprising such different topics as aerodynamics, atmospheric physics and meteorology, aero-elasticity, aero-acoustics, composite materials, grid integration, offshore wind energy, the dynamics of machinery, measurement techniques, planning and energy economics. Combining these subjects with additional elective courses should enable students to address the cross-disciplinary challenges they might face later in connection with a job in the wind industry.

DTU Wind Energy is one of the very few institutions in the world to offer an international two-year MSc programme devoted uniquely to wind energy. This programme was established in 2002 at the Department of Mechanical Engineering, and from 2012 it became the responsibility of the Department of Wind Energy. Students following the programme acquire a thorough knowledge of the technologies required to analyse, design, develop and operate wind-based energy systems. The students may choose between an electrical and a mechanical track, with specializations in all relevant topics. The programme was open to international students from the beginning, and about 90% of its students come from outside Denmark. Typically, about half of the foreign students stay and work in Denmark after finishing their studies, ensuring an influx of highly skilled labour to the Danish wind industry.

Joint wind energy programmes

In 2012, together with the Delft University of Technology, Norwegian University of Science and Technology, and the Carl von Ossietzky University of Oldenburg, DTU launched a European wind-energy course, the Erasmus Mundus European Wind Energy Master's (EWEM), a two-year double degree programme. The idea behind this programme is to make it possible for students to study in more than one country in order to give them an understanding of the cultural differences between different European countries. All students start the first semester at DTU, after which, depending on their chosen specializations, they move to one or more of the partner universities. Besides being responsible for the first semester, DTU issues MSc in Wind Energy diplomas in the wind physics and rotor design tracks. DTU Wind Energy also contributes to two other international programmes: 1) the MSc in Sustainable Energy, which has a specialization in wind energy; and 2) the Nordic MSc programme in innovative and sustainable energy (ISEE), where the students study at two or more technical universities in the five Nordic countries. A complete overview of wind-energy study programmes is provided by the European Academy of Wind Energy (EAWE) [5]. In addition to education at university level, extensive training of technicians is carried out by the industry itself or specialized private companies.
To increase the recruitment of foreign students and to strengthen the international exchanges of DTU's own students, contacts and exchange programmes are being established with world-leading universities. Contacts with a number of American universities are already being established through the American Partnership for International Research and Education (PIRE) programme. These contacts include Johns Hopkins University, Cornell University, Texas Tech University, the University of Western Ontario and the University of Colorado. Similar agreements involve European partner universities in the EuroTech and Nordic Five Tech alliances.

Sustainability in engineering education

A good engineering practitioner must also be fully aware of what is happening in society, as well as have the necessary skills to face the social issues of technological development and include them in the design of next-generation technology to improve our quality of life. Among these holistic and systemic skills is ensuring sustainability, which has been included in engineering education. Given the type of work and role engineers have in society in, for example, developing new infrastructure and technological solutions to improve our quality of life, it is extremely important that they are familiar with sustainability. In the Barcelona Declaration of 2004 [6], sustainability is already mentioned along with a list of holistic competences supporting the integration of sustainability in engineering education. These are further elaborated in [7], which is based on a literature search. The result suggests that sustainability in engineering education contains elements of the following eight competences listed in Table 1.

The relevance of the eight competences listed in Table 1 were tested by Quelhas et.al. [7] by means of a questionnaire administered to thirty selected experts and teachers of sustainability in engineering in May to June 2018. All eight competences received an average grade of more than 4 on a scale of 1 (not important) to 5 (extremely important).

How to teach sustainability to engineering students?

Allen et al. [8] have carried out an analysis of accredited engineering programmes across the US that incorporate sustainability concepts. Based on

Competence	Relevance to sustainability
Systemic thinking	Understand interactions between systems and people in their social, cultural, environmental, commercial, legal and political contexts
Ability to solve problems	Apply engineering to complex problems of sustainability
Ability to work in interdisciplinary groups	Solving complex problems
Critical thinking	Question and expand existing standards and practices
Normative competence	Reflect on standards and underlying values
Self-knowledge	Reflect on one's own role in the community and society
Strategic competence	Collectively develop and implement innovative solutions to promote sustainability
Contextualization and future vision	Formulate scenarios, assess consequences

Table 1. Engineering competences and their relevance to sustainability. Based on [7].

Figure 2.
Students from the course 'Planning and development of wind farms' on site visit during January 2017. There were 84 students from 28 nationalities. Photo: Tom Cronin.

the results of the questionnaires and interviews conducted with representatives from 273 engineering departments (representing 20% of the contacted sample), the researchers concluded that there are four primary ways to incorporate sustainable engineering content and concepts into engineering curricula:

- To develop dedicated sustainable engineering courses (48%)
- To integrate sustainability concepts into traditional engineering courses (23%)
- To deliver classes on sustainable technologies (carbon capture, wind, solar power) (14%)
- To collaborate with a non-engineering department in interdisciplinary courses (15%).

Furthermore, in another literature review, Quelhas et al. [7] investigated teaching methods and pedagogical practices used in teaching sustainability and the underlying transdisciplinary competences. Education for sustainability is multifaceted and complex, broad and plural, fluid and amorphous. It is both global and local, social and individual [9]. This suggests that traditional lecture-based university teaching alone may not be the most effective. Quelhas et al. [7] found no examples of traditional lecture-based teaching in their study, rather they found student-centred teaching methods such as problem-based learning or case-based collaborative learning.

Sustainability at DTU

At DTU we have developed several dedicated courses in the topic, including even a full MSc in Sustainable Energy that, over a period of less than ten years, has grown to be among the five largest of DTU's 32 Master's programmes, with around a hundred students graduating annually.

An example of a course that does not have the word 'sustainability' in its title, but into which elements mentioned in Table 1 have been integrated is Course 46200, Planning and Development of Wind Farms, which since 2008 has been part of the MSc in Wind Energy at DTU (Fig. 2). The course is centred around a case of design in which a group of four students plan a new wind farm somewhere in the world, either on land or offshore. They have to find and argue for the site selection, layout, type of turbines, wind resource, environmental impacts and grid connection, as well as carry out a stakeholder analysis and an economic analysis. The course incorporates five to six of the eight core competences listed in Table 1.

In summary, including sustainability in engineering education means much more than just referring to the UN Sustainable Development Goals [10]. To be labelled a *sustainable university*, Jones et al. [11] suggested what they call the '4C model', stipulating that the university needs to implement sustainability in its curriculum, campus, community and culture.

Lifelong learning

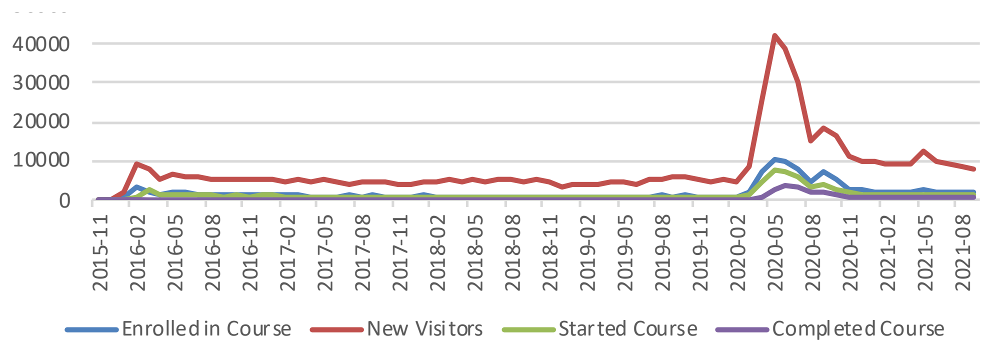
As a result of the rapid changes in the labour market in recent years and the demand for new skill-sets, learning is becoming a lifelong journey. In this new and global labour market, employees will need to build on their university degrees and acquire new skills throughout their careers [12]. Universities are beginning to see this as an opportunity to broaden their portfolios of courses and degrees and to generate an income from continuing education activities, in addition to the more traditional graduate and undergraduate programmes. To support lifelong learning activities, DTU has recently established a centre called 'DTU Learn for Life'.

In its efforts to couple manufacturing with research, development and innovation, the Manufacturing Academy of Denmark (MADE) has launched a new initiative called MADE Learning Factories. Its purpose is to explore and develop new possibilities for lifelong learning targeted at engineers, technicians and production staff. The intention is to create new and strong partnerships between researchers and production environments in Denmark. For instance, DTU's Department of Mechanical Engineering (DTU MEK) is involved in a partnership around 3-D printing and digital modelling.

Online training offers new possibilities

In order to remove the physical barriers to an engineering education, many top-ranked technical universities offer courses or fully accredited degree programmes online. Platforms such as Coursera, EdX and the Khan Academy have developed business models for offering free access to course materials developed by member universities. Learners only pay for a certificate of completion, if desired. Because of the free and easy access, such courses can attract participants by the thousands [13]. Education on this scale places limits on person-to-person interaction, and the learning experience becomes more automated. The great advantage is the high degree of flexibility that facilitates learning anytime and anywhere.

For universities, Massive Open Online Courses (MOOC) generate exposure and valuable analytics about the target group. Fig. 3 gives examples from DTU's course on 'Wind Energy', which is hosted by Coursera and has attracted more than 100,000 learners since 2015. Interestingly, the COVID-19 outbreak in early 2020 has boosted the number of new enrolments dramatically from the order of 700 learners per month to up to 10,000 learners per month during the summer of 2020. Today, the number of enrol-



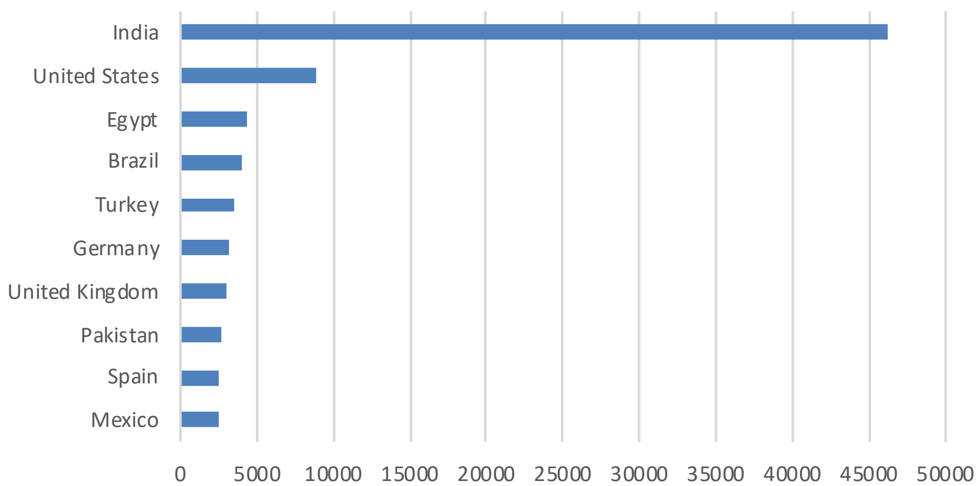


Figure 3.
Analytics from coursera.org showing (left) the number of participants in DTU's online course 'Wind Energy' and (right) the top ten countries from which the participants come.

ments has stabilized at around 2,000 new learners per month. The MOOC analytics show that learners from India are very well represented, with more than 40,000 enrolled individuals, whereas the US takes second place and accounts for around 8,000 individual learners. MOOC analytics can give an indication of the emerging markets for education in wind energy engineering, but they should be interpreted with some caution, since other factors such as pricing also play a role in the enrolment of learners.

Given that wind energy is expanding on a global scale, universities and other institutions also see a benefit in offering online short courses and degree programs with full accreditation. This requires a much more supervised learning environment, with frequent interactions between the students and lecturers. These interactions can take place through personal feedback on assignments and live or asynchronous discussions online [14]. The teacher becomes a moderator of such discussions and assumes a different role compared to teaching in a physical classroom setting [15]. Ultimately, the best of both worlds can be achieved by blending physical and online teaching elements whenever possible.

Achieving high-quality online training

The COVID-19 outbreak and the global lock-downs of university campuses has pushed the uptake of digital learning methods forward. Teachers all over the world have been forced to switch to online teaching at extremely short notice. The situation today is that digital tools are widely being used by universities, including in connection with physical courses. There is, however, a need to upgrade the didactic qualifications of teaching staff in order to benefit fully from the new digital opportunities, and this will take years to achieve.

In their report from 2019, Damvad Analytics formulates eight statements on how digitalization can support learning processes at different levels of the Danish educational system [16]. The report is based on work by a group of didactic experts and practitioners from different Danish institutions, including DTU. Its key message is that digitalization alone will not lead to high-quality education. It really matters how digital tools are implemented and used in teaching and learning situations. In connection with the MADE Learning Factory, an experiment has been carried out with e-learning on a global scale. This has led to a set of recommendations for effective e-learning [17]. Another set of recommendations has been published by the Danish evaluation institution (EVA) in the context of continuing education [18,19].

Outlook

Recent technological leaps in wind energy have created new requirements for the skills and specializations of future wind energy engineers. Wind energy is undergoing a rapid expansion to new markets in different parts of the world, a process of globalization that calls for a massive upscaling of the education of engineers who are qualified to build future wind farms and energy systems. Companies with a long record in the exploitation of oil and gas are currently going through a transition to deliver green and sustainable energy solutions. To succeed in this, a skilled and specialized work force is essential. Universities in northern Europe have a long history of expertise in educating engineers for the wind-energy industry. Their strategy for meeting the new requirements has been to collaborate through the establishment of joint degree programmes and PhD networks, typically supported by European funding bodies. Sustainability and the UN's Sustainable Development Goals are increasingly being integrated into these educational programmes. As windenergy projects are also planned and established in Asia, the US and South America, new players are currently entering the game of engineering education. Local universities are building up capacity to meet the shortage of engineers and to secure the establishment of a local work force. In parallel with this, online teaching makes it possible for top-ranking universities to reach and educate individuals all over the world. Thanks to these new possibilities and the increasing mobility of the global work force, engineering education is becoming a life-long activity for many.

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