Syllabus: Planning & Construction of Wind Farms


Instructors

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Pre-requisites

There are no pre-requisites for this course.

Course questions

All questions on understanding the material should be directed to your fellow students in the online forums first! At the beginning of each class session, we will discuss readings and have time to answer any questions which could not be answered already by your classmates.

Course goals and materials

The goal of the course is to teach participants what to expect when planning an onshore wind park with utility-scale turbines and how to deal with common challenges along the way. Unlike other technical courses, there is not an industry standard body of knowledge for wind farm planning, meaning that no comprehensive textbooks exist. Therefore, the content of this course is based on the instructors’ experience and other case studies, as well as readings which provide more in-depth information about the topics covered in class.

Grading policy

This class contains many graded assignments for several reasons: we want to encourage students to engage in the class and with the material over the entire duration of the class and we believe that is a fairer evaluation of students’ overall performance to consider, say, ten assignments rather than two.

The grading scale used in this course is the same as for all WES courses. For all single assignments, the following scale is used:

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<tr>
<th>Category</th>
<th>Grade range</th>
<th>Meaning</th>
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<tr>
<td>Very good</td>
<td>1,0</td>
<td>Excellent performance</td>
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<td>1,3</td>
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<td>1,7</td>
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<tr>
<td>Good</td>
<td>2,0</td>
<td>Performance significantly above average</td>
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<td>2,7</td>
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<tr>
<td>Satisfactory</td>
<td>3,0</td>
<td>Average performance</td>
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<td>Performance Level</td>
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<tr>
<td>Adequate</td>
<td>3.7</td>
<td>Performance which, despite some shortcomings, meets the minimum standards of the course</td>
</tr>
<tr>
<td>Fail</td>
<td>5.0</td>
<td>Does not meet minimum course requirements</td>
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The following assignments will be considered and weighted in your overall course grade:

1. **Short assignments: collectively 30%**
   Five short assignments, which should take about an hour to complete, will be assigned at regular intervals during the semester. Each assignment has equal grading weight. Details can be found later in this syllabus.

   There is one short assignment not listed in the syllabus: **reading presentations**. A schedule will be given out at the beginning of class, detailing who is to present which reading on which date. Your assignment is to review the contents of the previous week’s readings in a very short presentation at the beginning of class (about 3 slides, maximum of five minutes).

   If it is not possible for you to attend any seminars, you must give notice at the beginning of the course and you will be given an alternate assignment.

1. **Final exam: 70%**
   The final exam is a four-week project with multiple graded sections. Information about the exam itself is in this syllabus and more details about the grading will be given out closer to exam time.

**Participation requirements**

There will be nine, real-time class seminars, which students are required to attend. These seminars will take place in the first half of the course; the second half of the course will be devoted to the final project. The seminars will continue as Q&A sessions during the final project and attendance is no longer mandatory. However, there will be few chances to ask questions on the final project outside of these Q&A sessions.

**Weekly assignment: reading questions**

This class is not about memorizing information, but about collaborative problem solving. Each seminar will begin with a group discussion of the readings from last week, in order to review the important points and discuss further applications of the
readings. Students are required to keep up with these readings so that everyone can participate in the seminar.

One day before the start of each seminar, students are required to submit two questions over Moodle. The first question should be a question to your classmates which reviews some of the material from the readings (i.e. in what cases is scoping for an EIA usually not necessary?). The second question should be directed at the instructors and be either a transfer question (How would you apply the principles of x to y?) or pose a problem (How would deal with an issue that does not go according to plan?).

If you cannot attend the seminar, you must post your reading questions in the seminar’s forum, ideally a few days ahead of time. You must gather the responses to your questions and summarize them in a 300-400 word paper, in which you must also try to answer your transfer/problem question. This paper must be submitted over Moodle one day before the next seminar.

Seminar location and times

Seminars will be held on Tuesdays at 13:30 Central European time on the dates following in this syllabus. All seminars will be held over Adobe Connect and are 90 minutes long.

Texts, reading and other materials

Readings will either be scanned and posted on Moodle, or are available on the internet. All seminars will be recorded and made available on Moodle.

Hardware and software requirements

All students will need a computer for this course, ideally Windows. In addition to the usual Microsoft office programs (Word, PowerPoint), we will use industry software WindPRO (only runs on Windows) and DraftSight (Mac or Windows).
Because the planning of wind farms is a discipline for which few textbooks exist, this course is based heavily on our own experience as consultants, including many examples. Therefore, we have opted to structure the course around weekly online lectures and to use extensive reading material to support the topics covered in class. Readings for the respective week should be completed before class starts, as the class will begin with a discussion of the reading material.

Today in class we will introduce ourselves as teachers, give an overview of the themes of the entire course and begin with our first topic: defining the planning phases of a wind farm project. The four phases of a wind farm are:

1. Development
2. Construction
3. Operation
4. Decommissioning

This course will cover three of these phases in chronological order; wind farm operation is offered as a separate course. We begin with the development phase of the project, which can be subdivided into 5 phases:

5. Development
   a. Scoping
   b. Feasibility study
   c. Economic calculation
   d. Preparation for permitting process
   e. Reception of building permit
6. Construction
7. Operation
8. Decommissioning

It is important to know about the phases listed above that they are solely for the purpose of this course. There is no internationally accepted naming of development phases, as wind farm projects and owners differ so wildly. The important thing is that the tasks contained in each phase can be recognized in almost all projects.

The first of these sub-phases, scoping, is a quick investigation of potential wind farm sites according to major positive or negative criteria. These criteria should be easy to check without time-consuming consultation with governmental authorities. For example, you could check which sites are within a 10 km radius of a high-voltage network, but would not consult with the grid operator about where the exact connection point could be for each site.
Often difficult locations for wind farms, which should be considered during the scoping process are:

- Protected areas – natural and cultural
- Grid congestion
- Existing wind farms
- Military areas
- Airports

On the other hand, the following aspects should be seen as positive in the scoping stage:

- Near to grid
- Available transportation infrastructure
- Far from houses
- High wind speeds
- Topography
- Legally designated areas for wind power

To evaluate potential sites according to these and other criteria, three main methods can be used: pro/con list, matrix comparison and GIS-based mapping. With the use of one of these methods, you can narrow down a list of potential sites to a set number of interesting sites. With these sites, you proceed to the feasibility study phase.

**Homework**

Project Management Body of Knowledge (PMBOK) Guide, Chapter 3: Project Management Processes (16 p.) and PMBOK Chapter 4: Project Integration Management (45 p.)

**Seminar 2  Dec 17**

**Development from site selection through building permit**

**Content**

After discussing the first development phase, scoping, last week, we will continue with the rest of the phases of wind farm development today (b-d):

a. Scoping
b. Feasibility study
c. Economic calculation
d. Preparation for permitting process
e. Reception of building permit

A **feasibility study** is, in our definition, a detailed investigation of and planning for a wind farm, including consultation with authorities and a preliminary wind farm layout. The goal of the feasibility study is to gather enough information
for a reasonable economic calculation.

The first task of the study, which often takes several months to complete, is to investigate the possibilities for land acquisition. In addition to the locations of the turbines themselves, it is important to remember to secure all areas of the wind park: access roads, crane pads, cable routes and temporary areas.

The next task is to construct a working layout for the wind farm, which is needed to determine how many turbines can be realistically erected on the site. To do this, a constraints map is made of the wind farm through consultation with authorities and the turbines are placed on the remaining land at at least 5 x 3 rotor diameter apart from each other.

Potential turbine types for the site are determined through the IEC class of the site and preliminary energy prognoses for fitting types. Finally, the anticipated location of all auxiliary areas (roads, crane pads, transformer station, cabling, temporary areas) are carefully drawn onto a technical plan.

With this information as a basis, the next step of project development: economic calculation.

Economic calculation models vary widely between project owners, but generally take into account expected revenue from the wind farm versus capital expenditures (CAPEX) and operational expenditures (OPEX) over a 15-20 year operational period. As one of the largest CAPEX costs, offers from turbine manufacturers should be carefully compared. Only after knowing the price of the turbine and all associated maintenance costs can a decision be made on which turbine is most economical for the site. Turbine offers should be compared with their predicted production and reduced to an investment cost per kWh, while the completeness and content of other submitted documents, such as the service contract, must also carefully be reviewed for risk and hidden costs.

If the economic calculation is positive, meaning that the expected return on investment is acceptable to the project owner, the project continues into the next development phase: preparation for the permitting process.

The tasks of this phase are very similar to those in the detailed feasibility study. The major difference in this phase is that all consultation with authorities and all offers should be binding. This is the phase where the studies and planning are done to fulfill all the legal requirements to submit a building permit. This often includes a full environmental impact statement.

After the building permit is received, there are typically several conditions in the permit (such as a monetary deposit
guaranteeing the decommissioning of the turbines), which must be fulfilled before construction. These are completed in this phase. Often parallel to this phase, the pre-construction activities are started.

**Homework**

Four full EIAs from various countries will be posted on Moodle. Choose two of these reports and skim them (including auxiliary documents). Pay attention to the scope of all topics and the mitigation measures taken; how are the reports different?

**Short assignment #1:** research and write a 400-word essay comparing the environmental impacts of wind farms with conventional energy sources (nuclear, coal, gas) on one of the following topics:

- Birds and bats
- Visual Impact
- Noise

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**Seminar 3**

**Jan 14**

**Development from site selection through building permit, part II + Permitting comparison of Germany and Scotland**

**Content**

Continuation of seminar 3, plus short comparison of permitting systems in Germany and Scotland.

**Homework:**

Introduction to Environmental Impact Assessment (Glasson, Therivel, Chadwick), Chapter 10: Comparative practice (25 pages)

National Wind Coordinating Collaborative: Bird and bat fact sheet (8 pages)

Scottish National Heritage Bird Survey Methods

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**Seminar 4**

**Jan 21**

**Environmental impact assessment of wind farms**

**Content**

According to the International Association for Environmental Impact Assessment (IAIA) environmental impact assessment (EIA) can be defined as "the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made."

EIA processes are governed by national legislation, international agreements or laws (i.e. EU directives) and partly through local
guidances, which results in a great variance in EIA in terms of process and quality. However, most EIA processes have the following steps in common:

1. Screening – in this step, it is determined if an EIA is necessary or not. Often, there is also the option of a partial EIA, for those projects where a full EIA is not required.

2. Scoping – often an optional, but important, step in which it is formally determined which topics to include in the EIA and in what depth. This is an opportunity to “scope out” topics which are usually of minimal impact for wind farm projects, such as air quality. The standards to which the EIA will be conducted are also determined here; this is particularly important in countries with weak EIA legislation. In this stage, stakeholder engagement is key to determining what important parties expect from the EIA and what their concerns are.

3. Conduct research and write report – During this step, the actual EIA is performed. For each topic, the baseline situation must be determined, which often involves measurements in the field. Surveys of birds and other fauna typically take one year to complete. After the baseline situations are determined, the impact of the wind farm on each topic is predicted and measures are suggested to mitigate any significant impacts. After this, the report is submitted to the appropriate authorities, where its approval is usually part of the permitting process for the project.

4. Follow-up – Usually, an EIA report will suggest mitigation measures during construction and operation of the wind farm. These plans must be carried out as follow-up to the EIA.

EIA reports consist of many chapters, and some are of more general concern for wind farms than others. Below is a list of the common chapters in a wind farm EIA, with the topics often seen as major issues in bold:

- Telecommunications and aviation
- Geology
- Hydrology
- Infrastructure and safety
- Air quality
- Flora
- Socio-economics
- Traffic
- Cultural Heritage (including archaeology)
- Landscape and visual impact
- Fauna, including birds and bats
- Noise
- Shadow flicker
Landscape and visual impact assessment is a topic that is regarded with varying importance. In Scotland, for example, many different types of visualizations of a planned wind farm are required for an EIA, such as zone of theoretical visibility, photomontages or even transparencies.

Impacts on fauna, primarily birds and in some cases bats, is almost always a major topic. The surveys required to determine the baseline populations and habitat usage normally last one year, but the specific methodology (transects, vantage points) depends heavily upon the species present and on their behavior. Site with migratory or breeding bird populations will require intense observation during those times. The flying behavior of each species, in large part the amount of time it spends flying within the swept rotor area, is a strong predictor of collision risk.

Assessing the impacts from noise and shadow flicker does not require extensive time in the field. Many countries have clearly defined requirements on allowable levels and proper calculation models for noise propagation. In countries where these regulations do not yet exist in adequate detail, it is essential to agree in the scoping stage which models and limits will be used in the EIA.

**Homework:**

* PMBOK Guide, Chapter 7: Project cost management

**Short assignment #2:** siting exercise.

Complete siting exercise, as done in class for Germany, on the two sites which will be emailed to students after class. Answers should roughly follow the format in the PowerPoint: a list of possible positives and negatives about the site, including screen shots of areas where these aspects were seen on the aerial photo or map.

**Seminar 5**

**Jan 28**

**Project management in wind farm planning and development**

**Content**

TBR

**Homework:**

* Identifying and Managing Project Risk: Chapter 3 -Scope Risk

* Identifying and Managing Project Risk: Chapter 4-Scheduling Risk
Today we will cover the preparations necessary for wind farm construction. At this stage, it is important to remember the full scope of components which need to be built:

Components standard to all wind farms:
- Roads
- Crane pads
- Foundations
- Turbines
- Cabling
- Transfer or transformer station
- Temporary areas (parts of roads, crane pads, construction compound and storage area)

Optional, typically for large wind farms:
- Permanent wind measuring masts
- Control center

During preparation for the construction phase, the final technical designs for all of these components are prepared and finalized in consultation with the project owner and, often, other contractors involved in the project.

The design requirements (dimensions, bearing capacity, etc.) of the roads and crane pads are determined by the turbine manufacturer, as they are the party which delivers the turbines to the site and is responsible for their erection. The purpose of these requirements is to give the minimum characteristics which make the roads and crane pads usable in all weather. When the specifications are not followed (i.e. wrong materials used, roads too narrow), it can lead to construction delays and increased costs if vehicles become stuck on the roads or cannot drive on them at all.

Road designs are quite similar for major manufacturers (width of 4-5m, increased width in curves), but dimensions of crane pads vary widely according to the kind of crane used and the kind of tower used (hybrid towers require extra assembly space). Manufacturers are also increasingly providing designs for site in the forest or in hilly areas with minimal space requirements or special adaptations to steep slopes.

The design requirements for the electrical system are determined by the national grid code of the country where the
project is located. Given the electrical capabilities of the turbine, the electrical design team finalizes a plan for the internal and external (if necessary) cabling which meets the necessary grid requirements. The trenches for internal cabling are often located next to the access roads.

Whether the wind farm should be connected to the medium of high voltage network is a decision that must be made in cooperation with the grid operator. In order to connect to a high voltage grid, the electricity produced by the wind farm must be stepped up to a higher voltage through a transformer station. Such a station is often an economically viable alternative if the wind farm has at least 20-30 MW.

The **foundations** are the last critical element for which a technical design must be prepared. The purpose of a foundation is to absorb the loads from the turbine tower, nacelle and blades, while holding the turbine in the correct position. Foundations are generally constructed out of steel-reinforced concrete and constructed on-site, as they are too large and heavy to transport.

The exact dimensions and characteristics of the foundation depend on the bearing capacity of the soil below it. In soils with a good bearing capacity, a round foundation (known as a flat foundation) is a common solution. For weaker soils, there are a number of common techniques used to increase the bearing capacity of the soil below the foundation, such as pile reinforcement or exchange of earth for gravel.

For the entire design process, it is important to keep the **local and national regulations in mind**, especially when working with an international team. Even if international design standards exist, they may not be accepted by all governments!

**Homework:**  
*Project Construction Management*, Chapter 7: Bidding & Evaluation


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<th>Seminar 7</th>
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**Content:** TBR

**Homework:**  
*Project Construction Management*, Chapter 4: Delivery Methods and Contracts
**Seminar 8  Feb 18**

**Tendering**

**Content**

**TBR**

**Homework:** Decide if you want to use DraftSight for the layout of the final project, or if you want to do the layout by hand. DraftSight is a free 2D technical drafting software, which can be used to complete the construction planning of wind farms. Download DraftSight ([http://www.3ds.com/de/products-services/draftsight/download-draftsight/](http://www.3ds.com/de/products-services/draftsight/download-draftsight/)) and watch the tutorial posted on the functions you will need to complete the layout. Complete the exercise at the end of the tutorial and decide if you will use DraftSight for the final project. Using this software has the advantage that you can measure dimensions in order to calculate investment costs for the wind farm. If you choose to draw the wind farm by hand, you will need to physically measure the dimensions.

**Short assignment #3:** production calculations and using buffers in WindPRO.

In preparation for the final project, watch the tutorial posted on Moodle about wind farm production and using buffers. Complete the assignment at the end of the tutorial and submit your buffer zones and production calculation via Moodle.

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**Seminar 9  Feb 25**

**Technical Design & Construction, Part 2**

**Content**

During the design process for the wind farm (and even further back in the development of the project), transportation considerations must be taken into account. Usually, the turbine manufacturer is responsible for delivering the turbine to the wind farm site. This includes all expenses, permits and organization required to transport the turbines. Using the “just-in-time” delivery method, turbine components are delivered directly before erection, which is a benefit for areas with space constraints (forested sites, for example), as there it is not necessary to build a large storage area. However, the logistic and transport costs are often higher for this method.
During development, a transport study must be done, which takes into account the any obstacles or needed road improvements from the point of delivery (usually a port) to the site. Common issues which are addressed in a transport study include:

- Road width (including obstacles on sides such as trees and fences) and slope
- Curves: roundabouts and obstacles to turning
- Underpasses: bridges and electrical wiring
- Bearing capacity of bridges
- Transport and availability of cranes
- Storage and delivery possibilities: harbor, on-site

A transport plan must be based on the individual turbine model, as the transport dimensions vary and the number of transports for hybrid concrete towers are much higher than for steel towers. Cranes can be transported with normal tractor trailers, but require many trailers to transport the pieces.

When construction begins, the roads and crane pads are always the first to be built. After this, it is common to have two parallel construction processes: electrotechnical and turbine. On the electrotechnical side, the internal wind farm cabling is laid and commissioned, the external cabling laid and commissioned and the transfer or transformer station built and commissioned. Parallel to this, turbine foundations are framed and poured on site and left to harden, turbine components are delivered and erected and commissioned. After both sides are commissioned, the trial runs and grid tests begin, to ensure that the wind park functions as designed and that all delivered components are performing adequately. The grid tests are generally overseen by the grid operator and the turbine trial run by the wind farm owner, though the turbine manufacturer is responsible for carrying out the tests.

Once all tests are successfully passed, the owner officially accepts the works. However, even after successful tests there are usually small to medium defects which must be repaired by the manufacturers. To ensure that these items are repaired, a “punch list” of defects is created and is part of the owner’s acceptance; the owner accepts the works as delivered on the condition that all defects are remedied as agreed in the punch list.

Common causes for construction delays include windy weather (turbines cannot be erected), extreme cold or hot weather (pouring and hardening of concrete requires special measures), delay of component or crane delivery or unexpectedly weak ground conditions.

After construction is completed, work on the site continues for a short time to remove and restore temporary areas (including part
of crane hardstandings) and to complete any environmental restoration necessary.

**Homework:**  
**Short assignment #4:** Noise and shadow flicker calculations in WindPRO.

In preparation for the final project, watch the tutorial posted on Moodle about calculating noise and shadow flicker. Complete the assignment at the end of the tutorial and submit your resulting noise and shadow flicker calculations via Moodle.

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**Final Exam - Seminars 11-15**

The final exam will be a mock project development, a several-week project in four sections. Each section will be graded individually. You may work on this project with a partner of your choice, or alone.

There will be extensive support provided for this project in the form of ongoing weekly meetings at normal lecture time where we discuss progress and inputs.

**Q&A session** dates for final project:
- Feb 27
- March 6
- March 13
- March 20

The project sections are as follows:

**Section 1: Scoping (due March 4th)**

Task: You will be given maps and site boundaries of two potential wind farm sites. Your task is to use the internet to go through the scoping criteria we learned in class and compare the sites. Choose one site with which to proceed in the rest of the project. Research and suggest three possible turbine models for the site.

Graded assignment: 3-page report comparing the two sites and explaining which site you chose to proceed with and why and which turbine models you suggest and why. (15% of exam grade).

**Section 2: Layout (due March 11th)**

Task: Using the software WindPRO and some given constraints of the site and the given turbine types, investigate the different possibilities for placing turbines on the site. This should include a prediction of energy production, noise impact and shadow
flicker impact. Decide on a turbine model for the site out of the models given.

After the turbine model and layout are determined, make a construction layout including roads, crane pads, electrical systems and all other necessary components. You can do this using the Draftsight software or by hand.

**Graded Assignment:** The layout itself and WindPRO results for production, noise and shadow flicker will be graded. Write a 3-5 page paper describing your steps in creating the layout, including a list of all constraints which you considered (30% of exam grade).

**Section 3: Calculation of investment costs (due March 18th)**

Task: A large part of a wind farm financial model is calculating the investment costs, which you will do in this section. You will be given a comprehensive list of unit inputs (i.e. cost of road with bearing capacity x per square meter), from which you must select the inputs that are relevant for your own planning and organize these inputs in Microsoft Excel to come up with a cost of investment (€/kWh) for the 15-year life of the wind farm.

Graded assignment: Excel calculation and a 3-5 page paper, explaining the structure of your financial model (30% of exam grade).

**Section 4: Update of layout, calculation of investment costs and final turbine choice (due March 25th)**

Task: During project development, new information often changes the current planning. In this section, you will receive some new information about each of the two sites. You must update your layout and economic calculation to reflect this information. You are free to change the turbine model or any other aspect of the layout.

Graded assignment: Final layout and economic calculation, plus 10 minute oral exam on results (25% of exam grade).

**Oral exams will be held on March 27-29.**