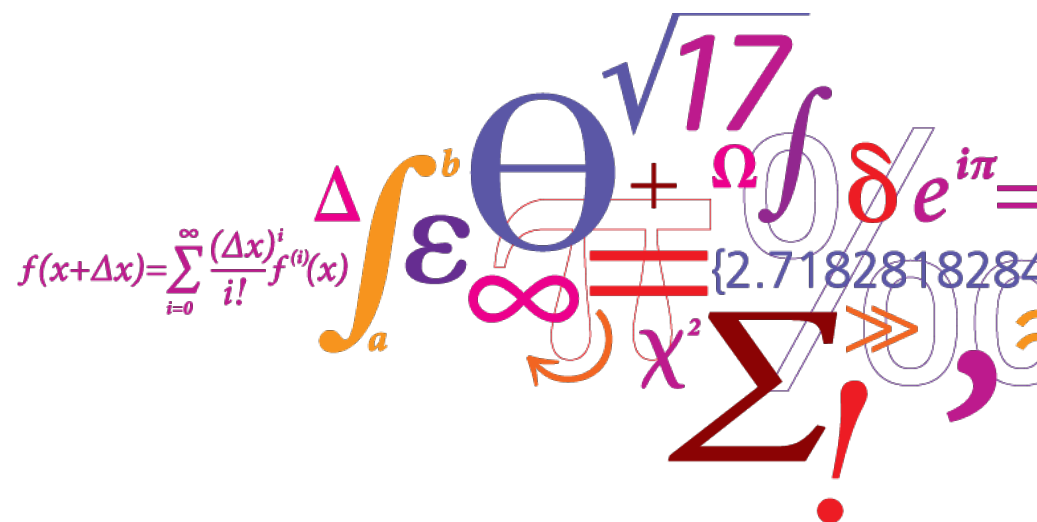


46755 – Renewables in Electricity Markets

Course introduction

Jalal Kazempour

February 3, 2025



This is a EuroTeQ course!



Link: <https://studyabroad.dtu.dk/english/dtu-study-abroad/international-course-offer-at-dtu>

Who are we?



Teacher



Jalal Kazempour

Professor, Head of Section

www.Jalalkazempour.com

jalal@dtu.dk

DTU Wind, Technical University of Denmark

TA



Asmus Winther Eriksen

MSc student in Sustainable Energy

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TA



Théodore Le Nalinec

MSc student in Sustainable Energy

s233235@student.dtu.dk

TA



Panagiotis Fekas

MSc student in Sustainable Energy

s230155@student.dtu.dk

TA



Yannick Heiser

PhD student at DTU Wind

yahei@dtu.dk

Who are we?



Asmus



Panagiotis



Théodore

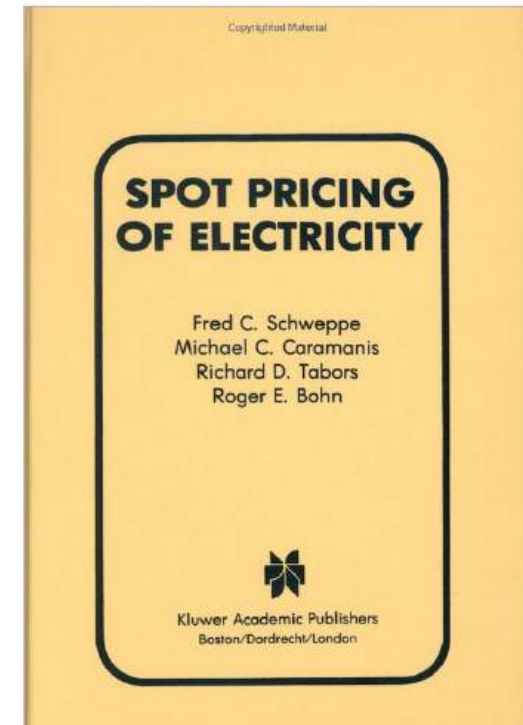
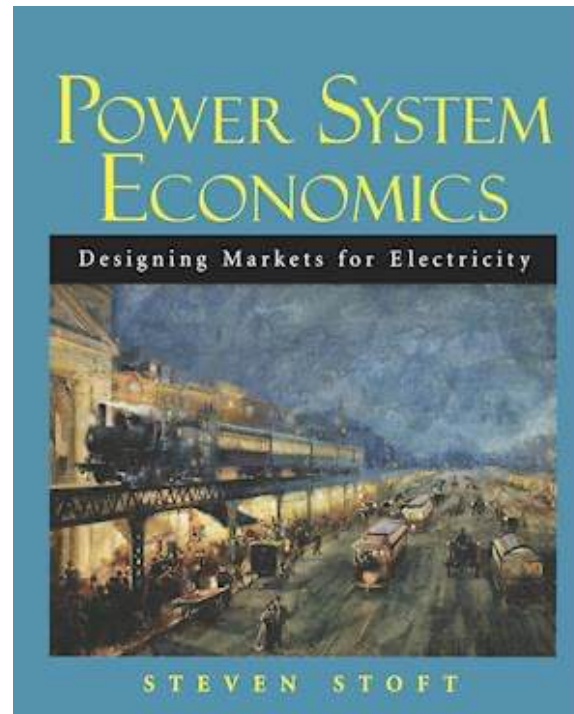
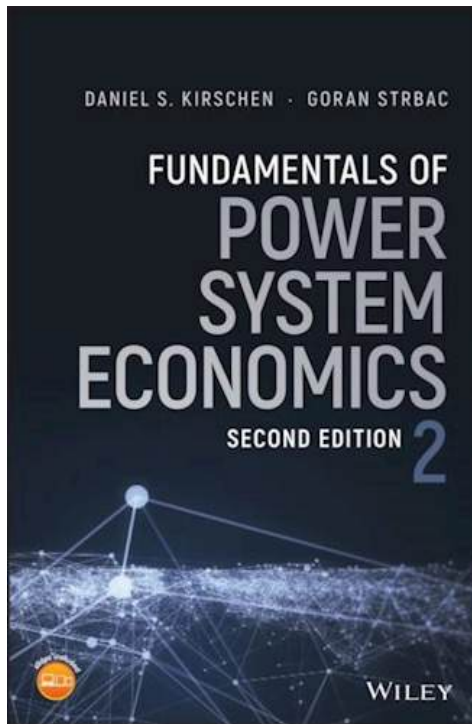
TA for DTU students
(attending in-person)



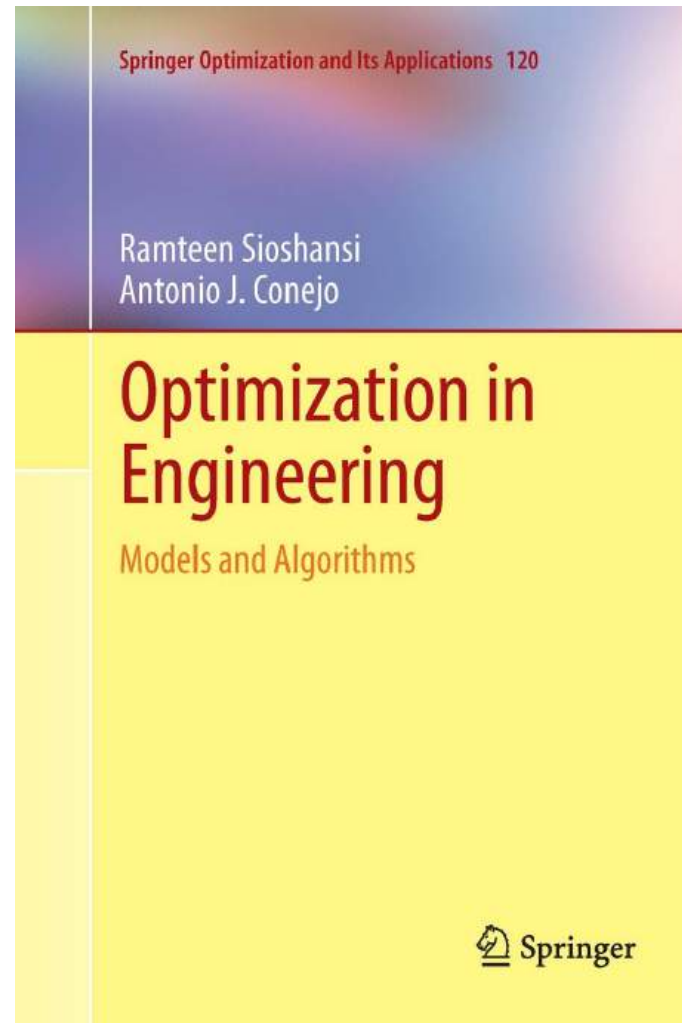
Yannick

Exclusive TA for EuroTeQ
students
(attending online)

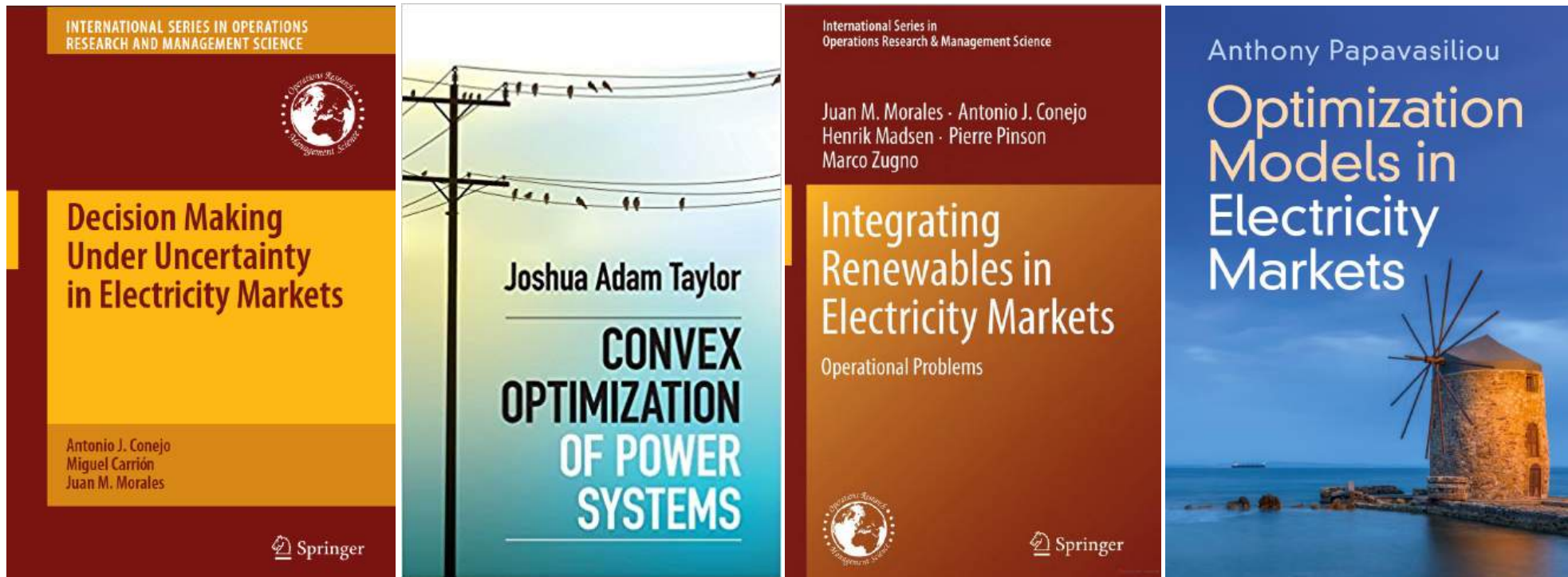
Recommended books on electricity markets



For the “optimization” part of the course



More top books in electricity markets, power system optimization, and beyond



and many others ...

Prerequisites



Recommended prerequisites 42101421124201546700 , Students without solid programming skills in Julia or Python or alike will not be able to pass this course, since programming is essential for the course assignments. Students must be familiar with the principles of optimization and linear programming, including duality and optimality Karush–Kuhn–Tucker (KKT) conditions (to be taught, e.g., in 42101 and 42112). It is recommended that students are familiar with the fundamentals of electric power systems and principles of energy economics.

Link: <https://kurser.dtu.dk/course/46755>

DTU Learn account is active!



46755 Renewables in electricity markets, S...



Seyyedjalal Kazempour



Course Admin My Course ▾ Activities ▾ Content Assignments Discussions Video & Streaming Help



Link: <https://learn.inside.dtu.dk/d2l/home/242310>

Two types of sessions

- **Lecture (1-3pm)**

- ✓ **1:00-1:15:** Recap of the previous lecture
- ✓ **1:15-1:45:** Lecture, part I
- ✓ **1:45-2:00:** Break
- ✓ **2:00-2:45:** Lecture, part II
- ✓ **2:45-3:00:** Break

- Up to you to join in-person or online!
- Zoom link is available on DTU Learn (the same link every lecture)
- If you join online, please use **“chat box” only** for asking questions or answering my questions!

- **Q&A + Working on group assignments (3-5pm)**

- ✓ Further details later (next slides)

Two types of sessions

- Lecture (1-3pm)

- ✓ 1:00-1:15: Recap of the previous lecture
- ✓ 1:15-1:45: Lecture, part I
- ✓ 1:45-2:00: Break
- ✓ 2:00-2:45: Lecture, part II
- ✓ 2:45-3:00: Break

- **Q&A + Working on group assignments (3-5pm)**

- ✓ Further details later (next slides)

- For DTU students: **Only in-person!** (TAs: Asmus, Théodore, and Panagiotis)
- For EuroTeQ students: **Online** (TA: Yannick). Yannick will share a Zoom link with EuroTeQ students.

General course objectives

- ✓ Electricity markets are today central in the way we exchange electricity.
- ✓ The increasing penetration of **renewable energy sources** with stochastic and variable supply in power systems has a substantial and complex impact on electricity markets.

Link: <https://kurser.dtu.dk/course/46755>

General course objectives

- ✓ Electricity markets are today central in the way we exchange electricity.
- ✓ The increasing penetration of renewable energy sources with stochastic and variable supply in power systems has a substantial and complex impact on electricity markets.
- ✓ The objective of this course is to introduce the students to the fundamental aspects of renewable energy in electricity markets, from the point of view of both **market operators** and **market participants**.

Link: <https://kurser.dtu.dk/course/46755>

Learning objectives

Eight learning objectives:

A student who has met the objectives of the course will be able to:

Link: <https://kurser.dtu.dk/course/46755>

Learning objectives

Eight learning objectives:

A student who has met the objectives of the course will be able to:

- 1) Explain the **fundamentals of electricity markets**

Link: <https://kurser.dtu.dk/course/46755>

Learning objectives

Eight learning objectives:

A student who has met the objectives of the course will be able to:

- 1) Explain the fundamentals of electricity markets
- 2) Explain various **markets**, **actors**, and **pricing mechanisms**

Link: <https://kurser.dtu.dk/course/46755>

Learning objectives

Eight learning objectives:

A student who has met the objectives of the course will be able to:

- 1) Explain the fundamentals of electricity markets
- 2) Explain various markets, actors, and pricing mechanisms
- 3) Explain the **market-clearing process** from both **optimization** and **equilibrium** perspectives

Link: <https://kurser.dtu.dk/course/46755>

Learning objectives

Eight learning objectives:

A student who has met the objectives of the course will be able to:

- 1) Explain the fundamentals of electricity markets
- 2) Explain various markets, actors, and pricing mechanisms
- 3) Explain the market-clearing process from both optimization and equilibrium perspectives
- 4) Describe the impact of **renewables** on electricity markets

Link: <https://kurser.dtu.dk/course/46755>

Learning objectives

Eight learning objectives:

A student who has met the objectives of the course will be able to:

- 1) Explain the fundamentals of electricity markets
- 2) Explain various markets, actors, and pricing mechanisms
- 3) Explain the market-clearing process from both optimization and equilibrium perspectives
- 4) Describe the impact of renewables on electricity markets
- 5) Develop **mathematical models** including optimization and equilibrium problems for clearing various electricity markets

Link: <https://kurser.dtu.dk/course/46755>

Learning objectives

Eight learning objectives:

A student who has met the objectives of the course will be able to:

- 1) Explain the fundamentals of electricity markets
- 2) Explain various markets, actors, and pricing mechanisms
- 3) Explain the market-clearing process from both optimization and equilibrium perspectives
- 4) Describe the impact of renewables on electricity markets
- 5) Develop mathematical models including optimization and equilibrium problems for clearing various electricity markets
- 6) Design mathematical models for **market participants** enabling them to make **optimal offering strategy** decisions under **uncertainty**

Link: <https://kurser.dtu.dk/course/46755>

Learning objectives

Eight learning objectives:

A student who has met the objectives of the course will be able to:

- 1) Explain the fundamentals of electricity markets
- 2) Explain various markets, actors, and pricing mechanisms
- 3) Explain the market-clearing process from both optimization and equilibrium perspectives
- 4) Describe the impact of renewables on electricity markets
- 5) Develop mathematical models including optimization and equilibrium problems for clearing various electricity markets
- 6) Design mathematical models for market participants enabling them to make optimal offering strategy decisions under uncertainty
- 7) Implement some of these mathematical models in **Julia** or **Python**

Link: <https://kurser.dtu.dk/course/46755>

Learning objectives

Eight learning objectives:

A student who has met the objectives of the course will be able to:

- 1) Explain the fundamentals of electricity markets
- 2) Explain various markets, actors, and pricing mechanisms
- 3) Explain the market-clearing process from both optimization and equilibrium perspectives
- 4) Describe the impact of renewables on electricity markets
- 5) Develop mathematical models including optimization and equilibrium problems for clearing various electricity markets
- 6) Design mathematical models for market participants enabling them to make optimal offering strategy decisions under uncertainty
- 7) Implement some of these mathematical models in Julia or Python
- 8) Present, analyze, and interpret the **numerical results**

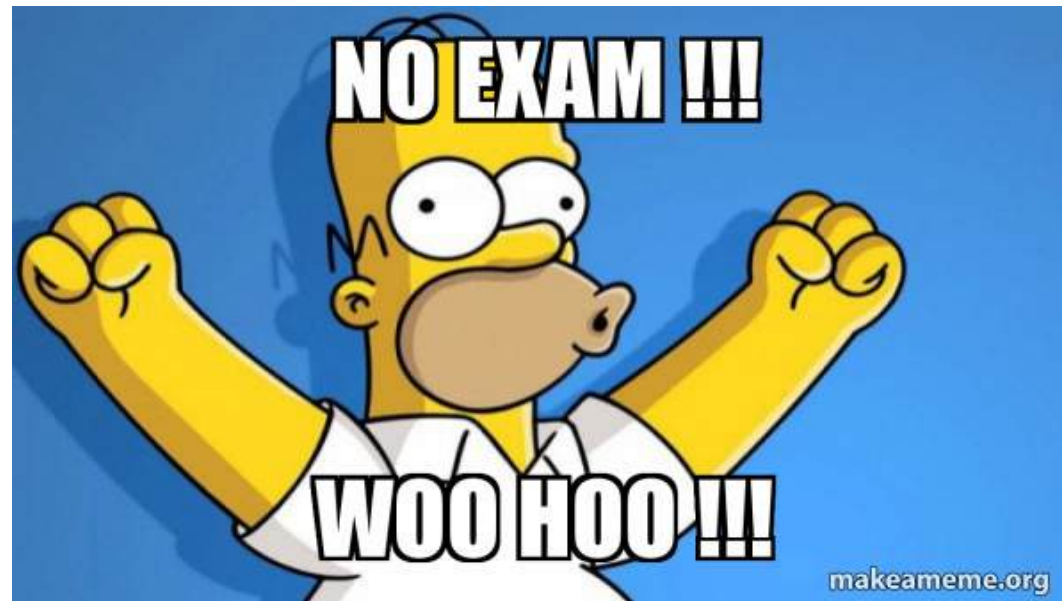
Link: <https://kurser.dtu.dk/course/46755>

Course schedule in Spring 2025



Lecture (date)	Content (1-3pm)	Lecturer	Update on the assignments	3-5pm
#1 (Feb 3)	○ Course introduction ○ Introduction to electricity markets	Jalal Kazempour		None
#2 (Feb 10)	Fundamentals of electricity markets	Jalal Kazempour	Assignment 1 to be released	Q&A
#3 (Feb 17)	Electricity market clearing: Optimization vs. equilibrium	Jalal Kazempour		Q&A
#4 (Feb 24)	Day-ahead markets	Jalal Kazempour		Q&A
#5 (Mar 3)	Intraday and balancing markets	Jalal Kazempour		Q&A
#6 (Mar 10)	Ancillary service markets	Jalal Kazempour		Q&A
#7 (Mar 17)	Impact of renewables on electricity markets	Jalal Kazempour		Q&A
#8 (Mar 24)	Working on Assignment 1 (no lecture)	Jalal Kazempour	Deadline for the submission of the report for Assignment 2	Q&A
#9 (Mar 31)	Offering strategy of wind power producers	Jalal Kazempour	Assignment 2 to be released	Q&A
#10 (Apr 7)	Invited lecture	Marco Saretta		Q&A
Easter				
#11 (Apr 28)	Risk-constrained offering strategy	Jalal Kazempour		Q&A
#12 (May 5)	Offering strategy in ancillary service markets	Jalal Kazempour		Q&A
#13 (May 12)	Working on Assignment 2 (no lecture)	-	Deadline for the submission of the report for Assignment 2	Q&A

No Final Written Exam!



Two group assignments



Two group assignments



Assignment 1

(focus on the **market operator** perspective)

To be released on February 10

Deadline: March 24, 11:59 pm

Assignment 2

(focus on the **market participant** perspective)

To be released on March 24

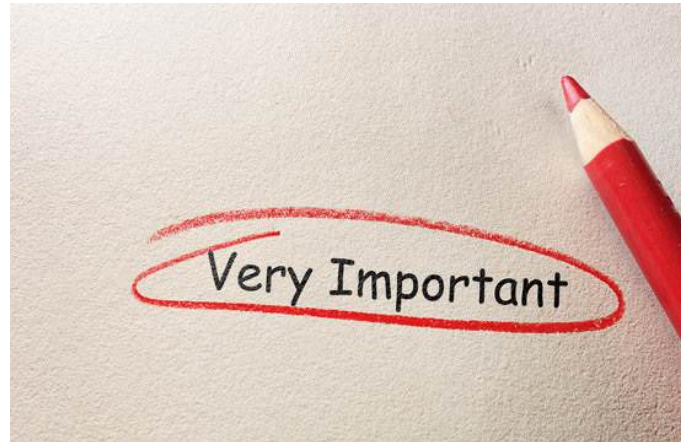
Deadline: May 12, 11:59 pm

Both projects are quite time and effort demanding!

Please make sure you have good planning for projects!

Both projects are heavily programming demanding!

You can use any programming language (Julia, Python, etc)



This course is NOT meant to support your programming skills

- If your programming skills are not strong today, you are not taking this course in the right semester!
- Please improve your programming skills and take this course next year!

Two group assignments

- ✓ Both assignments include optimization tasks which require programming.
- ✓ Both assignments to be completed in groups of four
 - less than 4 is not fine due to the large number of students in the course!

Where to form groups?

Please form your groups on DTU Learn, ideally, by the beginning of the 2nd lecture (**February 10, 1am**), but no later than the the 3rd lecture (**February 17**)



Course Admin My Course ▾ Activities ▾ Content Assignments Discussions Video & Streaming Help

 **Manage Groups** Settings Help

[New Category](#)

View Categories

Assignments ▾

Assignments (45) ▾

 Email  Delete

☐	Groups	Members	Assignment	Discussions	Locker
☐	Group 1	0	2		
☐	Group 2	0	2		
☐	Group 3	0	2		

Suggestion (1/3): How to form groups?

There should be **a good balance of various skills** in your group, such as

- Management and communications
- Mathematical model development (e.g., good optimization skills)
- Programming (coding)
- Analysis of numerical results and thorough discussions
- Plotting and writing

Before finalizing your group, make sure you have checked the diversity of skills!

Suggestion (2/3): How to form groups?

Align your expectations in terms of grade and workload:

- Recall a 5-ECTS course requires a workload of around 140 hours.

Examples:

- If one student aims for a grade of 12 while another is ok with a 7 or 4, they may not be ideal group partners since their expectations are not well aligned.
- Aside from the 4 hours of class, if one student is willing to dedicate 8-10 hours per week to the project while the other is considering a half workload, they may not be well-matched to work together in the same group.

Suggestion (3/3): How to form groups?

Use the “group formation” forum on DTU Learn:



[Course Admin](#)
[My Course ▾](#)
[Activities ▾](#)
[Content](#)
[Assignments](#)
[Discussions](#)
[Video & Streaming](#)
[Help](#)

Discussions

[Settings](#)
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[Subscriptions](#)
[Group and Section Restrictions](#)
[Statistics](#)

New ▾

More Actions ▾

Filter by: [Unread](#) [Unapproved](#)

Collapse All Forums ▾

Group formation ▾

Are you looking for a group or group members? Please feel free to post here! Share your skills or specify the expertise you need in your group. Relevant skills may include **mathematical modeling**, **energy economics**, **coding**, **data analysis**, **visualization**, **report writing**, and **project management**.

Since you are responsible for forming your own groups, please take the time to ensure a good fit. **Keep in mind that any future disagreements within the group will be your responsibility to resolve.**

Topic	Threads	Posts	Last Post
Group formation ▾	0	0	



Group for EuroTeQ students



- It is most straightforward for you to form your own “fully online” group, but you are also welcome to join groups with DTU students who are joining in person (not online).
- Use the Forum on DTU Learn to find group members.
- Yannick will assist with group formations for EuroTeQ students, so please don't hesitate to contact him if you need any help.

Disagreement in the group?

You are responsible for forming your own groups and resolving any potential disagreements within the group. Please take the time to ensure you create a well-functioning group.



- The teacher is NOT responsible for resolving any internal conflicts within the group.
- ONLY ONE report per group assignment should be submitted.

Where to submit group assignment reports?



On DTU Learn (one report per group per assignment):

DTU 46755 Renewables in electricity markets, Sprin... Seyyedjalal Kazempour

Course Admin My Course ▾ Activities ▾ Content Assignments Discussions Video & Streaming Help

→ Assignments [? Help](#)

[New Assignment](#) [Edit Categories](#) [More Actions ▾](#)

Bulk Edit

☐	Assignment	New Submissions	Completed	Evaluated	Feedback Published
	No Category				
☐	Assignment 1 ▾ Due on 24 March, 2025 11:59 PM Deadline		0/43	0/43	0/43
☐	Assignment 2 ▾ Due on 12 May, 2025 11:59 PM Deadline		0/43	0/43	0/43

Forums on DTU Learn



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→ Discussions

Settings Help

Discussions List Subscriptions Group and Section Restrictions Statistics

New ▾

More Actions ▾

Filter by: Unread Unapproved

▼ Collapse All Forums

Group formation ▾

Topic	Threads	Posts	Last Post
Group formation ▾ Are you looking for a group (or group members)? Please write here! You can write about your skills (or additional skills you need in your group). In terms of skills, you can think of competence in mathematical modelling, energy economics, coding, analyzing results, plotting, writing reports, and project management.	0	0	

Forums on DTU Learn



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→ Discussions

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New ▾

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Filter by: Unread Unapproved

Group formation ▾

Available forums:

- Group formation
- Assignments
- Lectures

Topic	Threads	Posts	Last Post
Group formation ▾ Are you looking for a group (or group members)? Please write here! You can write about your skills (or additional skills you need in your group). In terms of skills, you can think of competence in mathematical modelling, energy economics, coding, analyzing results, plotting, writing reports, and project management.	0	0	

Forums on DTU Learn



Course Admin My Course ▾ Activities ▾ Content Assignments Discussions Video & Streaming Help

Discussions

Settings Help

Discussions List Subscriptions Group and Section Restrictions Statistics

New ▾

More Actions ▾

Filter by: Unread Unapproved

Group formation ▾

Topic

Threads

Group formation ▾

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0

Available forums:

- Group formation
- Assignments
- Lectures

Please consider these forums as a communication platform **among students to ask questions, brainstorm, exchange ideas, etc.** Please feel free to actively use them. In the case of relevant discussions, the lecturer will also be involved.

Forums on DTU Learn



Course Admin My Course ▾ Activities ▾ Content Assignments Discussions Video & Streaming Help

Discussions

Settings Help

Discussions List Subscriptions Group and Section Restrictions Statistics

New ▾

More Actions ▾

Filter by: Unread Unapproved

Available forums:

- Group formation
- Assignments
- Lectures

If you have a question:

- Please ask it on Monday 1-5pm (especially 3-5)
- Write in the relevant forum
- **Please don't send direct emails to the lecturer or TAs. Your question might be a question to others as well. So, please write in the forum!**

Please consider these forums as a communication platform **among students to ask questions, brainstorm, exchange ideas, etc.** Please feel free to actively use them. In the case of relevant discussions, the lecturer will also be involved.

What will we do every Monday 3-5pm?

➤ **February 3:** none

➤ **February 10 and onwards:**

- Every group works on the assignment
- TAs (and the lecturer) will be available for the Q&A
 - Asmus, Théodore, and Panagiotis in person
 - Yannick online (ONLY for EuroTeQ students)

Assessment

Based on group assignment reports only

- Assignment 1: 50%
- Assignment 2: 50%

About two assignments:

- One report per group per assignment
- Deadlines: already mentioned
- You can expect to receive feedback on your reports within 2 weeks after the deadline
- Assessment criteria: Next slide
- Report template and content: Next slides

Assessment criteria (same for both reports)

- Mathematical model development: 35%
- Code(s): 25%
- Report: efficient writing, rigorous results, and rigorous discussions: 40%

A **sample report** will be available on DTU Learn on February 10 (together with Assignment 1).

A **rubric table** will be shared along with each assignment, so you will have an idea how your report will be graded.

Grading



Conversion of the final grade in percentage to the 7-scale Danish grading system (based on DTU instruction):

- [92% - 100%] ---> Grade 12 (pass)
- [84% - 92%) ---> Grade 10 (pass)
- [68% - 84%) ---> Grade 7 (pass)
- [60% - 68%) ---> Grade 4 (pass)
- [50% - 60%) ---> Grade 2 (pass)
- [20% - 50%) ---> Grade 0 (fail)
- [0% - 20%) ---> Grade -3 (fail)

Contribution table **(necessary to be included in the report)**

Please fill in this table and include it in the first page of each report:

	Name (group member 1)	Name (group member 2)	Name (group member 3)	Name (group member 4)
Contribution to model development	? %	? %	? %	? %
Contribution to programming	? %	? %	? %	? %
Contribution to the analysis of numerical results	? %	? %	? %	? %
Contribution to writing the report	? %	? %	? %	? %
Overall	? %	? %	? %	? %

Any other point:

Contribution table **(necessary to be included in the report)**

Please fill in this table and include it in the first page of each report:

	Name (group member 1)	Name (group member 2)	Name (group member 3)	Name (group member 4)
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Contribution to programming	? %	? %	? %	? %
Contribution to the analysis of numerical results	? %	? %	? %	? %
Contribution to writing the report	? %	? %	? %	? %
Overall	? %	? %	? %	? %

Any other point:

Note: Your contribution will directly affect your final grade!

Contribution table **(necessary to be included in the report)**

Please fill in this table and include it in the first page of each report:

	Name (group member 1)	Name (group member 2)	Name (group member 3)	Name (group member 4)
Contribution to model development	? %	? %	? %	? %
Contribution to programming	? %	? %	? %	? %
Contribution to the analysis of numerical results	? %	? %	? %	? %
Contribution to writing the report	? %	? %	? %	? %
Overall	? %	? %	? %	? %

Any other point:



Expected to be at least **25%**. Any value lower than 25% will lower the grade (see next slides).
This is how grades of two students from the same group might be different.

Contribution table **(necessary to be included in the report)**

Please fill in this table and include it in the first page of each report:

	Name (group member 1)	Name (group member 2)	Name (group member 3)	Name (group member 4)
Contribution to model development	? %	? %	? %	? %
Contribution to programming	? %	? %	? %	? %
Contribution to the analysis of numerical results	? %	? %	? %	? %
Contribution to writing the report	? %	? %	? %	? %
Overall	? %	? %	? %	? %

Any other point:

Ideally, each student will have enough contribution to every task, but this will not be part of grading. We highly encourage students to have at least 15% contribution to every task.

Example

Consider a group with the following report grades:

Assignment 1: 88%

Assignment 2: 82%

Consider student A has an overall contribution of 25% to Assignment 1, and similarly 25% to Assignment 2. The grade:

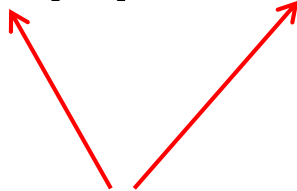
Example

Consider a group with the following report grades:

Assignment 1: 88%

Assignment 2: 82%

Consider student A has an overall contribution of 25% to Assignment 1, and similarly 25% to Assignment 2. The grade:

$$\{ [0.88 * 1.0] + [0.82 * 1.0] \} / 2 = 85\%$$


A coefficient between zero and one

- 1 is max. It will not be more than 1 if the contribution is more than 25%.

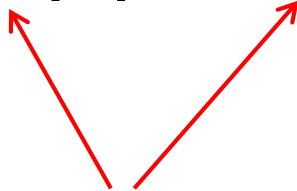
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A coefficient between zero and one

➤ 1 is max. It will not be more than 1 if the contribution is more than 25%.

- [92% - 100%] ---> Grade 12 (pass)
- [84% - 92%) ---> Grade 10 (pass)
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- [60% - 68%) ---> Grade 4 (pass)
- [50% - 60%) ---> Grade 2 (pass)
- [20% - 50%) ---> Grade 0 (fail)
- [0% - 20%) ---> Grade -3 (fail)

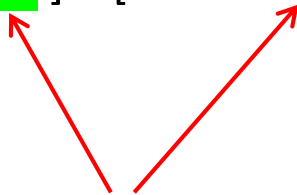
Example

Consider a group with the following report grades:

Assignment 1: 88%

Assignment 2: 82%

Consider student B has an overall contribution of **20%** to Assignment 1, and **35%** to Assignment 2. The grade:

$$\{ [0.88 * \mathbf{0.8}] + [0.82 * \mathbf{1.0}] \} / 2 = \mathbf{76.2\%}$$


A coefficient between zero and one

- 1 is max. It will not be more than 1 if the contribution is more than 25%.

- [92% - 100%] ---> Grade 12 (pass)
- [84% - 92%) ---> Grade 10 (pass)
- **[68% - 84%) ---> Grade 7 (pass)**
- [60% - 68%) ---> Grade 4 (pass)
- [50% - 60%) ---> Grade 2 (pass)
- [20% - 50%) ---> Grade 0 (fail)
- [0% - 20%) ---> Grade -3 (fail)

Report template and content

- ❑ Each report includes the pdf file of your project report, programming code(s), and other files, if necessary. We will check your codes, so please make sure we will be able to run them.

Report template and content

- ❑ Each report includes the pdf file of your project report, programming code(s), and other files, if necessary. We will check your codes, so please make sure we will be able to run them.

- ❑ Single column

Report template and content

- ☐ Each report includes the pdf file of your project report, programming code(s), and other files, if necessary. We will check your codes, so please make sure we will be able to run them.
- ☐ Single column
- ☐ Length: as short and efficient as possible, **15 pages** maximum (each report), but we encourage you to not go beyond **12 pages**. Please recall that efficient writing is part of the assessment criteria! An **appendix** can be included (outside the page limit) for less important information, e.g., input data, etc.

Report template and content

- ☐ Each report includes the pdf file of your project report, programming code(s), and other files, if necessary. We will check your codes, so please make sure we will be able to run them.
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- ☐ A short **introduction** can be included.

Report template and content

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- ☐ Single column
- ☐ Length: as short and efficient as possible, **15 pages** maximum (each report), but we encourage you to not go beyond **12 pages**. Please recall that efficient writing is part of the assessment criteria! An appendix can be included (outside the page limit) for less important information, e.g., input data, etc.
- ☐ A short introduction can be included.
- ☐ **Formulation** should be included in a complete way. If relevant, you can use a compact representation of your formulation. The **notation** needs to be defined precisely.

Report template and content

- ☐ Each report includes the pdf file of your project report, programming code(s), and other files, if necessary. We will check your codes, so please make sure we will be able to run them.
- ☐ Single column
- ☐ Length: as short and efficient as possible, **15 pages** maximum (each report), but we encourage you to not go beyond **12 pages**. Please recall that efficient writing is part of the assessment criteria! An appendix can be included (outside the page limit) for less important information, e.g., input data, etc.
- ☐ A short introduction can be included.
- ☐ Formulation should be included in a complete way. If relevant, you can use a compact representation of your formulation. The notation needs to be defined precisely.
- ☐ There will be a case study. It is recommended to provide the most important **numerical results** in the form of **figures** or **tables**. Please avoid reporting trivial results. It is highly important to interpret and **analyze** the results obtained.

Report template and content

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- ☐ Please include additional relevant information such as number of variables and constraints in the optimization problem, computation aspects (machinery used, time, etc).

Thanks for your attention!

Email: jalal@dtu.dk