



MANAGEMENT AND ECONOMICS OF  
RESOURCES AND THE ENVIRONMENT  
UNIVERSITY OF SOUTHERN DENMARK



# Integration of Electricity Storage Based Renewable Energy into the Danish Power System

- Ph.D. Project in Denmark

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# Experiences from my PhD Study in Denmark

- Course participation  
30 ECTS= 840 hours /1 semester/
  - Such as:
    - Advanced Energy System Analysis on the EnergyPLAN Model (Aalborg, Denmark)
    - Summer School in Economics and Finance, Economic and Quantitative Analysis of Energy Markets (Verona, Italy)
    - Conference Presentation at the 14<sup>th</sup> IAEE European Energy Conference (Rome, Italy)
    - Computational Methods in Economics and Econometrics (University of Victoria)
- Teaching activities and knowledge exchange  
840 hours (including 4 hours preparation + 1 hour teaching) /1 semester/
  - Such as:
    - Introductory Statistics (BA level, lecturer during 3 years)
    - Advanced Environmental and Research Economics (MSc level, exercise classes during 2 years)
- Participating in active research environment, including stay at other, mainly foreign, research institution  
/approx. 1 semester/
  - Department of Economics, University of Victoria, Canada (Supervisor: Prof. G. Cornelis van Kooten): August – December 2015
- PhD thesis
  - Principal supervisor: Professor Niels Vestergaard, Secondary supervisor: Associate Professor Lars Ravn-Jonsen
  - Four articles: Literature review + 3 empirical articles

**The PhD project is Co-financed by the SDU and by Syd Energi A/S.**

**Reporting to the PhD School but working at the Department/MERE research environment.**



# Integration of Renewable Energy Sources

Electricity Supply = Electricity Demand constantly

+



or



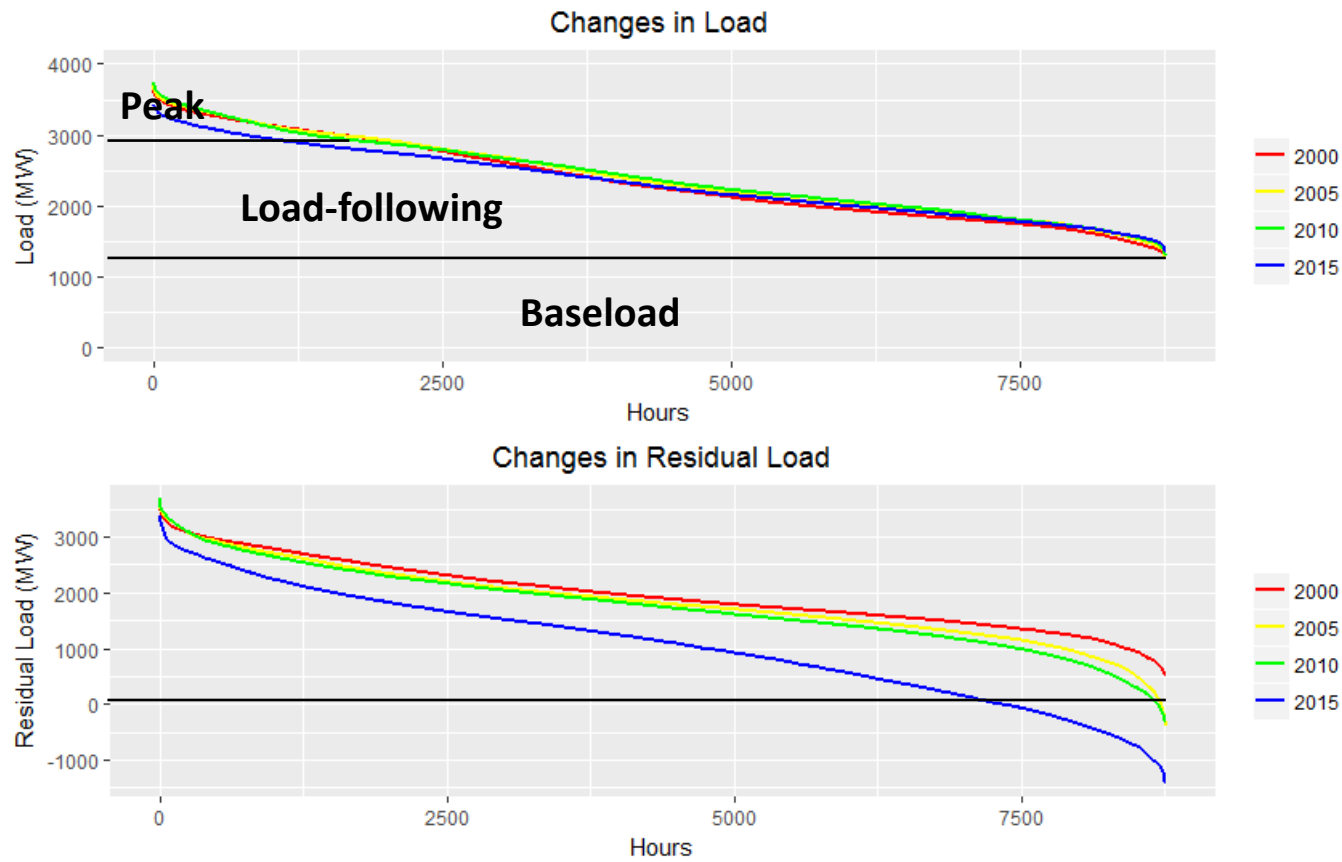
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Increasing pressure on system operator and conventional generators as they cannot adapt quickly





# The impact of the integration of Renewable Energy Sources (example from Denmark)





# Electricity Storage and other options to integrate large-scale renewable energy

- Electricity storage accepts energy generated by the power system, converts it into a form suitable for storage and returns as much of the electricity as possible back to the power system.
- Other options:
  - Increasing connectivity towards neighboring grid by raising transmission capacity
  - Implementing smart grid solutions
  - Demand-side management

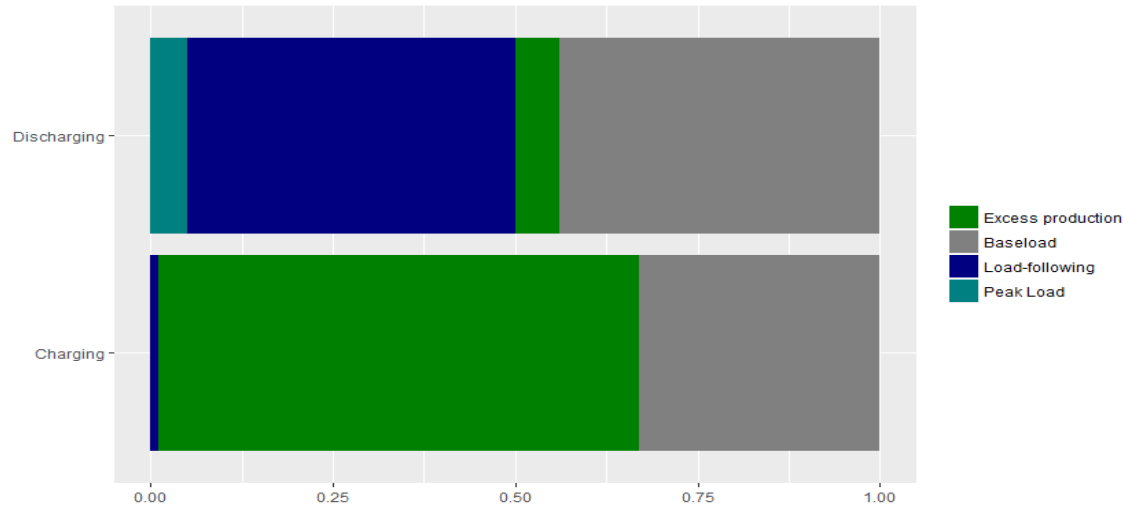




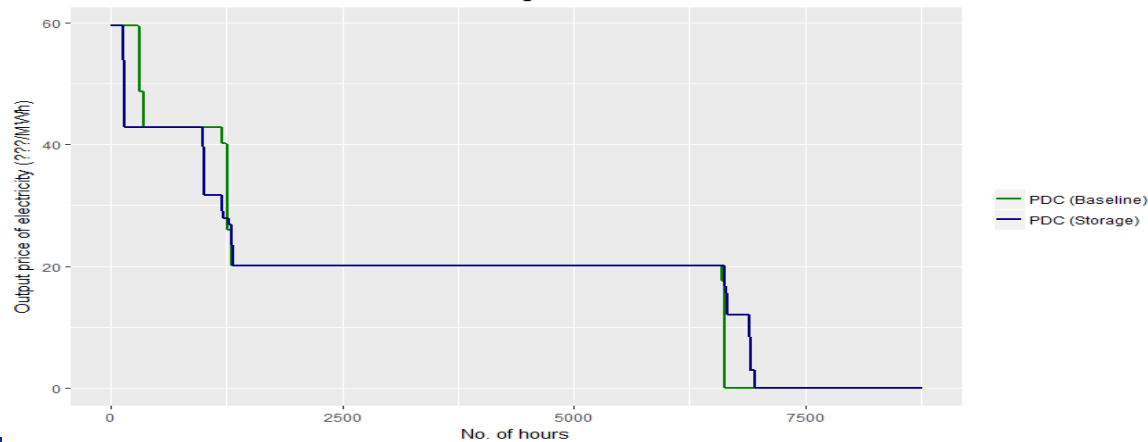
# How does the integration of electricity storage impact the operation of conventional generators and the associated CO2 emission?

The impact of Storage use in the current power grid

The distribution of charged and dispatched electricity by production type (in percentage)

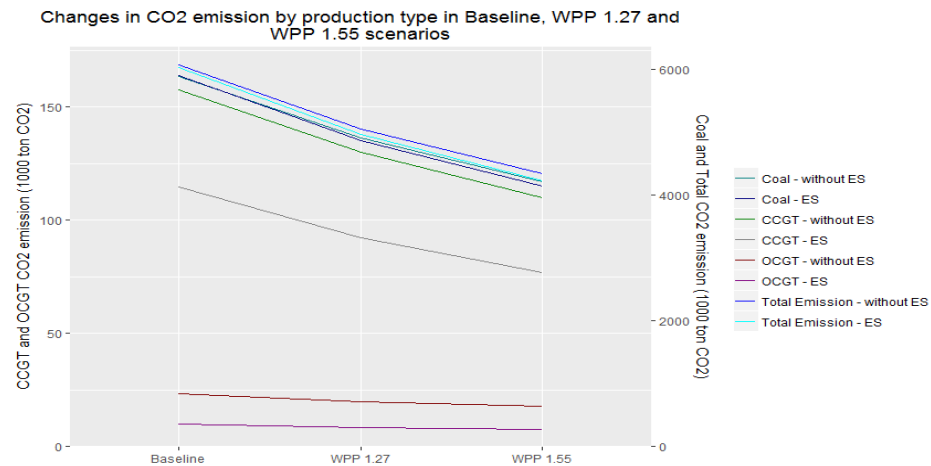
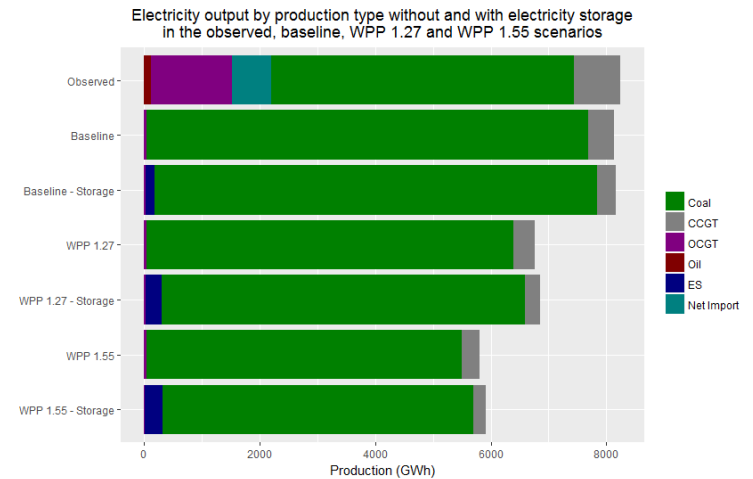
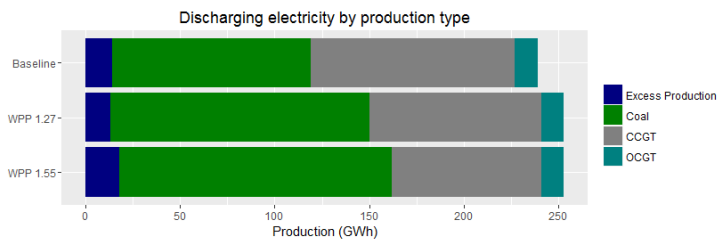
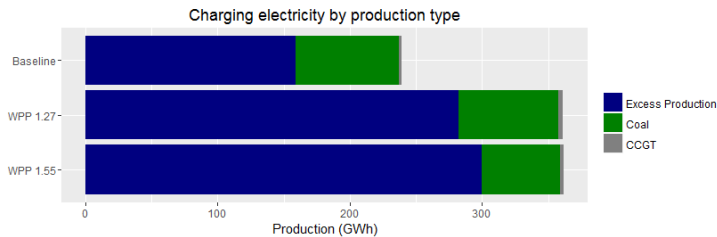


Output price of electricity duration curve (PDC) for optimized-baseline and -storage cases



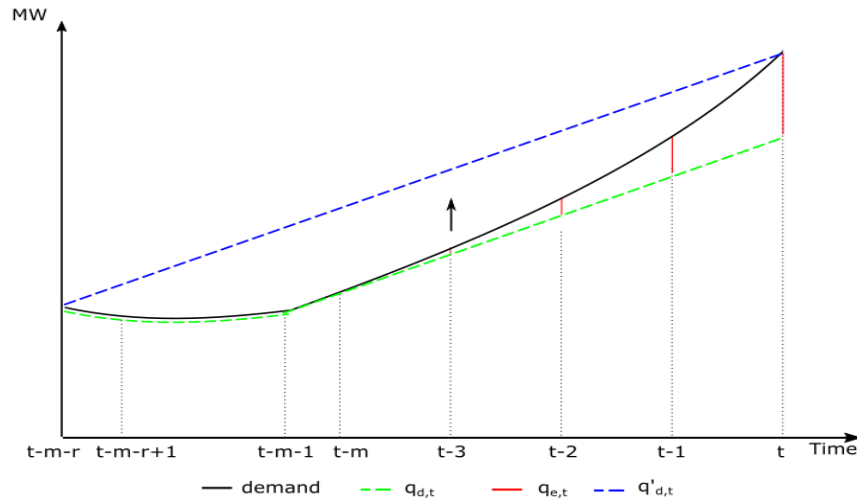


# Impact of ES with increasing wind power penetration

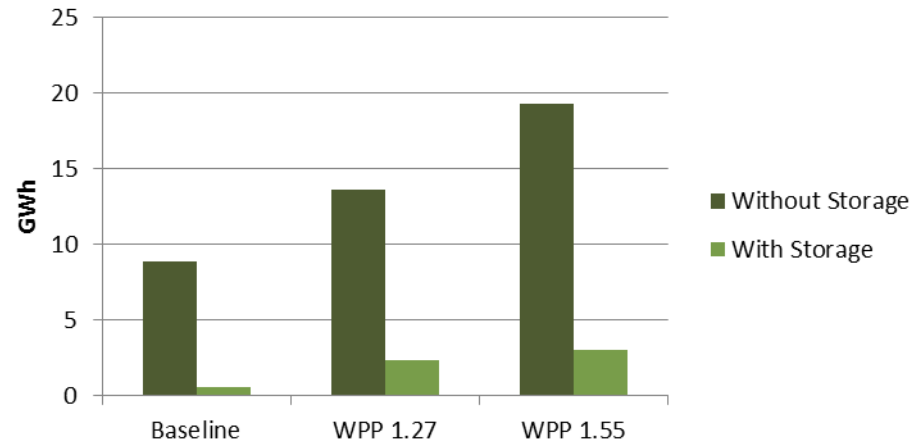




# Increasing efficiency by preventing excess production due to inflexible electricity output from conventional generators



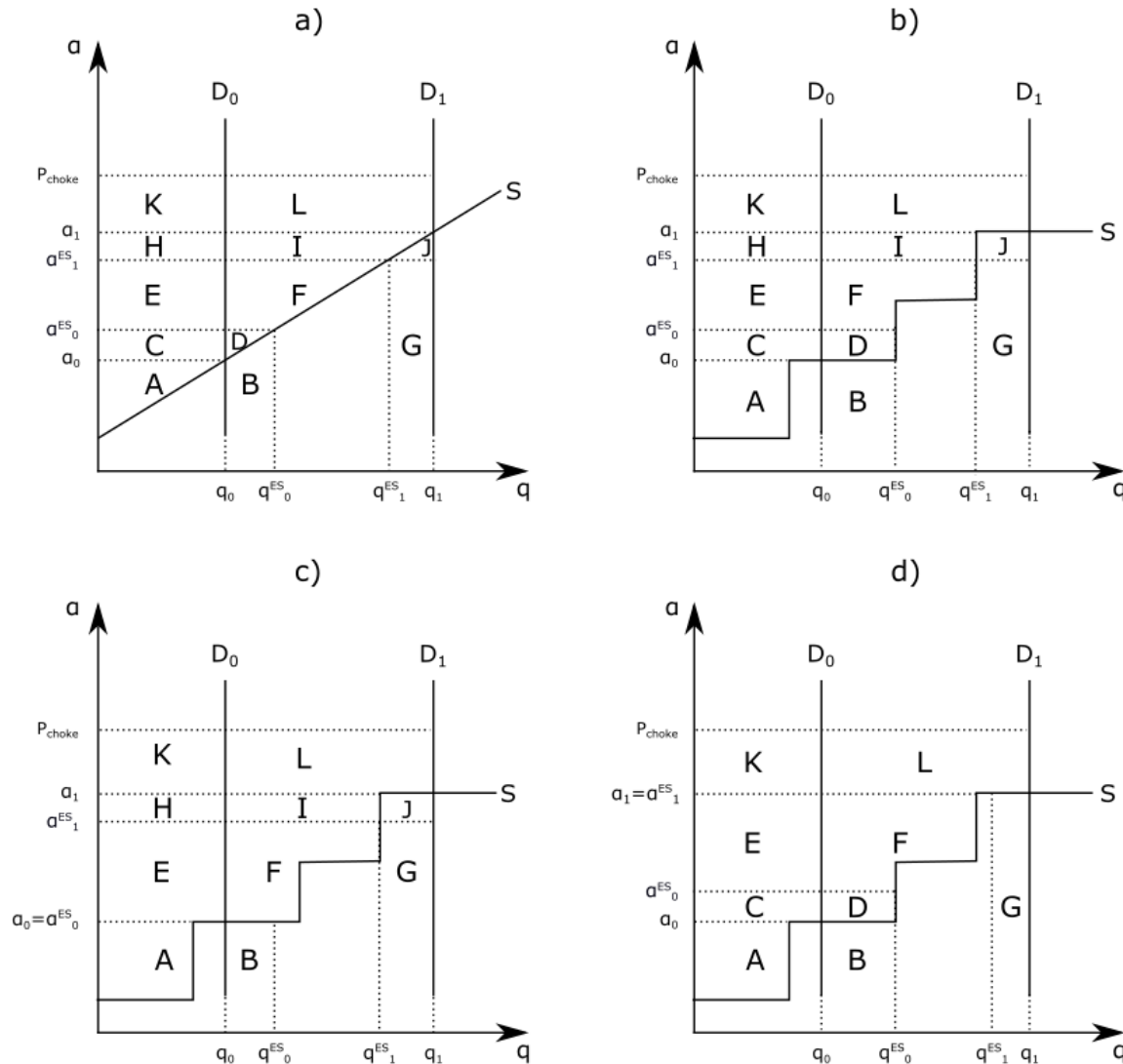
Excess electricity production due to binding ramping constraint







# The welfare impact of storage use in a non-convex approach





Thank you for your attention! 😊

