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Low-carbon municipalities: modelling of Sønderborg, Denmark*

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* This brochure is based on the paper published in June 2017, entitled:"Energy supply modelling of a low-CO2 emitting energy system: Case study of a Danish municipality": https://doi.org/10.1016/j.apenergy.2017.03.086

Introduction

Energy policy and CO_2 reduction targets on the municipal level play a significant role in the national and global CO_2 reduction efforts. In 2009 Sønderborg, a municipality located in southern Denmark, set the target of becoming CO_2-neutral by 2029 and developed a plan to achieve the target. This study aims at comparing alternative pathways for achieving a low-carbon energy system in Sønderborg, where novel energy conversion technologies such as large-scale heat pumps, biogas production, thermal gasification, electrolysis, biogas methanation and transport fuel synthesis are investigated.

Scenario name	Scenario description
Municipal plan (A)	Scenario according to the strategic energy plan of Sønderborg municipality
Biomass (B)	Low fossil-fuel scenario: biomass replaces fossil fuels, no significant electrification (e.g. no utility-scale heat pumps)
Electrification (C)	Low fossil-fuel scenario: focus on electrification, biomass consumption kept close to the locally available limits
Electrolysis (D)	Same as C, with the addition of gasification and solid oxide electrolysis for a more energy-efficient biomass utilization. Biogas upgrade conducted through biogas methanation instead of CO_2 removal
Reversible electrolysis (E)	Same as D, with the addition of reversible solid oxide cells for electrolysis and fuel cell operation

Energy scenarios investigated in this study

Methods

The main method is modelling of energy supply, using Sifre, a mixed-integer linear optimization tool, which optimizes energy flows and energy prices in all sectors of the specified energy system in discrete time steps.

The results for the five different model scenarios for 2029 are evaluated and compared using the following four indicators: the total system socio-economic costs, the energy system's net CO_2 emissions, the total biomass consumption (relative to the locally available resources) and the total energy conversion efficiency of the system.

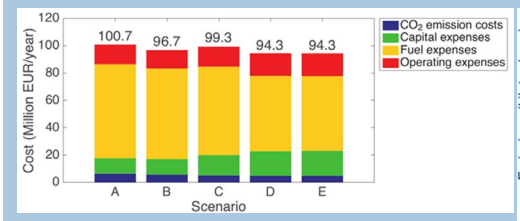
Results

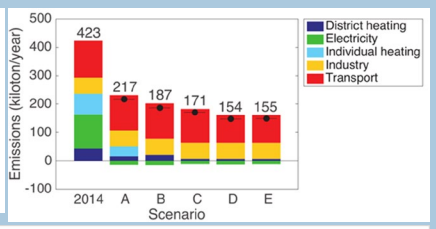
The **Electrification scenario** has the highest total system energy conversion efficiency and least dependence on biomass.

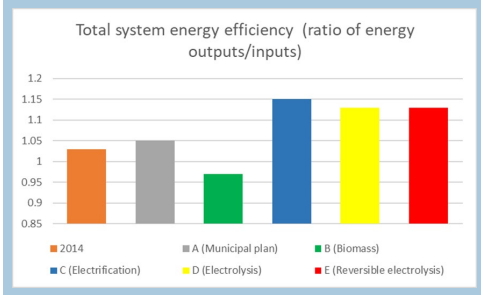
The **Electrolysis and Reversible electrolysis scenarios** are most feasible from a system cost and CO_2 emission perspective, while providing substantial biomass consumption savings.

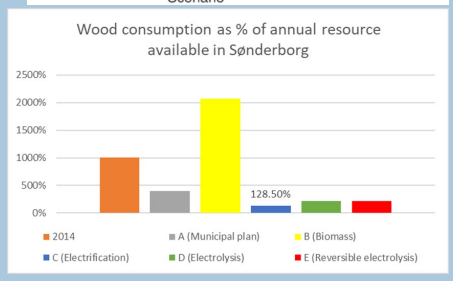
The **sensitivity analysis shows** that the Electrolysis and Reversible electrolysis scenarios perform best on the emissions and cost even if electricity and fossil fuel prices change. Only a drop in biomass prices would make the Biomass scenario the least costly.

Main results for each scenario



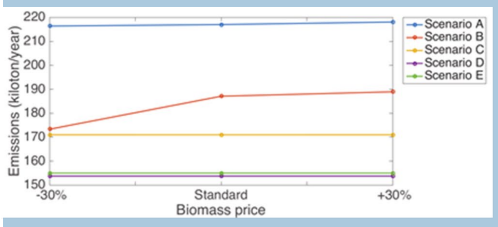


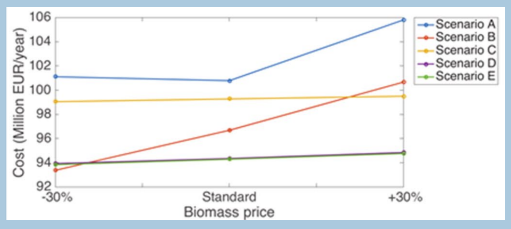


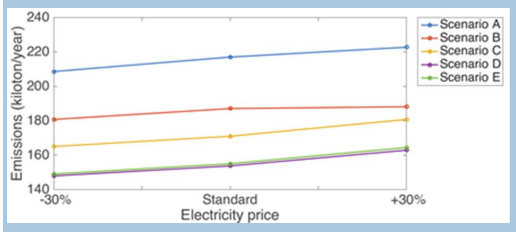


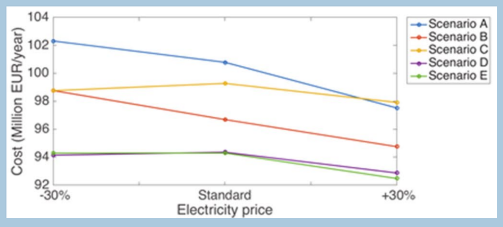
Symbol	Scenario name
A	Municipal plan
B	Biomass
C	Electrification
D	Electrolysis
E	Reversible electrolysis

Sensitivity analysis









Conclusions

- Scenarios with a high degree of electrification perform better on the selected indicators than scenarios with a high degree of biomass utilization.
- Electrolysis and reversible electrolysis are promising conversion technologies to be used on a municipal scale.
- Achieving the CO_2 emission goals in the most energy-efficient, cost-effective and sustainable way requires comparing a wide range of energy system configurations.
- These findings can be transferable to other middle-sized northern European cities with limited biomass resources.

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Acknowledgment: Innovation Fund Denmark. Grant 1305-00027B