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Now and into the future: modelling and analysis of Danish urban energy systems

The global population is growing and so is the urbanisation share - currently over half of the world population lives in urban areas. Urban energy and transport systems are responsible for up to 70% of worldwide greenhouse gas (GHG) emissions, therefore the climate action on the local level is crucial if the goals of the Paris Agreement are to be fulfilled.

In Denmark, many municipalities implement ambitious climate and energy policy aiming to reach carbon neutrality within next decades. Planners and decision-makers need decision support tools for devising their strategic energy plans and energy system models can help assess the feasibility of renewable energy and energy savings projects on a system level and identify scenarios for cost-efficient reduction of CO_2 emissions.

The PhD thesis employs mathematical modelling of energy scenarios for three Danish cases: the Greater Copenhagen area and two middle-sized municipalities: Helsingør in eastern Denmark and Sønderborg in western Denmark. The dissertation also examines relations between the technical changes in the energy systems caused by increased share of renewables and energy efficiency and selected economic characteristics, such as system costs. Moreover, it explores the role of energy system modelling in municipal planning with qualitative research consisting of interviews and content analysis.

This PhD thesis finds that it is possible to significantly reduce CO_2 emissions from urban energy systems in a cost-effective way by implementing a mix of different energy conversion pathways and storage, and a balance between district heating expansion and heat savings. Whereas the detailed findings are applicable mainly for Copenhagen, Helsingør and Sønderborg, on a more general level they are indicative for other areas with similar climatic conditions, population and natural resources. Out of the models used, Sifre and Balmorel are found suitable to analyse integrated energy systems and energyPRO and the spreadsheet tool LCT - heating and heat savings. Among the weaknesses of quantitative energy scenario modelling is the inability to depict complex and non-linear stakeholder interactions. Therefore, to better portray sustainability transitions, energy system modelling should be supplemented by other analyses. The qualitative analysis shows the modelling process can be improved by more efforts to share the data, assumptions and models, inter- and cross-municipal collaboration and constant dialogue on how to make tools useful for planning and implementing measures towards sustainability.

Overall, the findings of this PhD thesis can support planners and decision-makers in the transition towards a more sustainably planned energy system of a city, allowing achieving technical, environmental, social and economic benefits.