Englsh abstract- Modelling use of biomass and waste in future energy systems

The world has launched an urgent call for immediate and decisive action towards mitigation of greenhouse gas emissions. Climate change, pollution, dependence on fossil fuels and volatile fuel prices are setting the world at a cross road concerning the future of energy. Furthermore, global demand for resources is increasing, driven by population growth and improving standards of living, and a transition towards a circular economy is needed, where the use of resources should be optimized throughout their life cycle. The magnitude of the challenges ahead calls for prompt action that must encourage a complete transformation of the existing energy and waste sectors into a system that integrates a range of renewable alternatives and clean technologies, where the use of biomass and waste resources is optimized. This transition must be socially-fair and cost efficient, thus decision-makers deal with difficult choices in the face of large uncertainties, and energy systems analysis might support them. Biomass and waste-to-energy have often been modelled in the contest of either biomass value chains and waste management, or energy systems, but without integrating them in a holistic approach. The research focus of this PhD thesis is to develop decision support tools that can help in using the resources in the overall best possible way, and hence stimulate future sustainable usage of biomass and waste management, integrating economic and environmental considerations.

The model OptiFlow has been developed and integrated within the energy systems model Balmorel, in order to represent multiple inflows and outflows. Optiflow is a data-driven network model that can handle any commodity (arcs) and processes (nodes), optimizing the topological network design at each time slice and geographical entity, including movements across the spatiotemporal dimensions. OptiFlow is a general model that can be used for a wide variety of applications, such as modelling of waste-to-energy and biomass conversion pathways, among others. Further development of Balmorel and use of global sensitivity analysis has also been undertaken to facilitate analysis of future integrated energy systems with high uncertainties.

This PhD thesis assesses the role of waste-to-energy by combining long-term co-optimization of waste management and energy systems, using the Balmorel-OptiFlow model, with life cycle assessments, to identify the economic and climate impact consequences of waste incineration in the present and future Danish energy system. From an economic perspective, the use of combustible waste for incineration in a cogeneration plant would provide benefits, which increase with economy of scale. Nevertheless, plastic burning emits fossil greenhouse gas emissions while Denmark is aiming for climate-neutrality, and the electricity and district heating are becoming decarbonized. Thus, the carbon footprint is worsened when diverting residual combustible waste towards incineration for electricity and heat production, if technologies that have less associated emissions are displaced. Therefore, other pathways for handling residual combustible waste should be evaluated, such as gasification or pyrolysis, which might provide higher value-added products, in terms of economy and the environment, e.g. transport fuels or chemical compounds.

Availability of sustainable biomass is limited, and large demand of biomass resources or imperfect land governance might increase the direct and indirect-land use change emissions. On this basis, biomass is a scarce resource whose use must be optimized among competing technologies in order to maximize the value they provide to the society. Results from the linked use of the models Balmorel-OptiFlow and TIMES-DK, in a Danish context, highlight that solid biomass should preferentially be used in those sectors that cannot be easily electrified, such as heavy transport, including shipping and aviation, through thermal gasification and Fischer-Tropsch synthesis. Biomethane from anaerobic digestion after upgrading is mostly used in some industrial applications and the heavy segments of the transport sector. Nevertheless, it is still challenging to achieve carbon neutrality in the energy system while attaining for national self-sufficiency with regards to biomass resources. Therefore, due to the fact that the sustainability of biomass resources is limited, a higher integration of electrofuels or a more aggressive electrification of the energy demand is required.