Environmental assessment of energy production from waste and biomass

Optimal utilization of biomass and waste for energy purposes offers great potentials for reducing fossil fuel dependency and resource consumption. The common understanding is that bioenergy decreases greenhouse gas (GHG) emissions as the carbon released during energy conversion has previously been captured during growth of the plants. However, neglects that using the land for energy crops implies that the same land cannot be used for other purposes, including food cropland, forestry, grassland, etc. This may induce cascading effects converting natural biomes into arable land with associated impacts. However, existing and emerging waste treatment technologies offer different environmental benefits and drawbacks which should be evaluated in order to recommend appropriate technologies in selected scenarios. To evaluate the environmental and energy performance of bioenergy and waste-to-energy systems life cycle assessment was used in this thesis. This was supported by other tools such as material, substance, energy flow analysis and energy system analysis. The primary objective of this research was to provide a consistent framework for the environmental assessment of innovative bioenergy and waste-to-energy systems including the integration of LCA with other tools (mentioned earlier). The focus was on the following aspects:

- Evaluation of potential future energy scenarios for Denmark. This was done by integrating the results of energy system analysis into life cycle assessment scenarios.
- Identification of the criticalities of bioenergy systems, particularly in relation to land use changes.
- Identification of potentials and criticalities associated with innovative waste refinery technologies. This was done by assessing a specific pilot-plant operated in Copenhagen, Denmark. The waste refining treatment was compared with a number of different state-of-the-art technologies such as incineration, mechanical-biological treatment and landfilling in bioreactor.

The results highlighted that production of liquid and solid biofuels from energy crops should be limited when inducing indirect land use changes (iLUC). Solid biofuels for use in combined heat and power plants may perform better than liquid biofuels due to higher energy conversion efficiencies. The iLUC impacts stood out as the most important contributor to the induced GHG emissions within bioenergy systems. Although quantification of these impacts is associated with high uncertainty, an increasing number of studies are documenting the significance of the iLUC impacts in the bioenergy life cycle. With respect to municipal solid waste, state of the art incineration, MBT and waste refining (with associated energy and material recovery processes) may all provide important and comparable GHG emission savings. The waste composition (e.g. amount of organic and paper) and properties (e.g. LHV, water content) play a crucial role in affecting the final ranking. When assessing the environmental performance of the waste refinery, a detailed knowledge of the waste composition is recommendable as this determines the energy outputs and thereby the assessment results. The benefits offered by the waste refinery compared with incinerators and MBT plants are primarily related to the optimized electricity and phosphorous recovery. However, recovery of nutrients and phosphorous might come at the expenses of increased N-eutrophication and emissions of hazardous substances to soil. The first could be significantly mitigated by post-treating the digestate left from bioliquid digestion (e.g. composting). Compared with waste refining treatment, efficient source-segregation of the organic waste with subsequent biological processing may decrease digestate/compost contamination and recover phosphorous similarly to the waste refinery process. However, recent studies highlighted how this strategy often fails leading to high mass/energy/nutrients losses as well as to contamination of the segregated organic waste with unwanted impurities. All in all, more insight should be gained into the magnitude of iLUC impacts associated with energy crops. Their quantification is the key factor determining a beneficial or detrimental GHG performance of bioenergy systems based on energy crops. If energy crops are introduced, combined heat and power production should be prioritized based on the results of this research. Production of liquid biofuels for transport should be limited as the overall energy conversion efficiency is significantly lower thereby leading to decreased GHG performances. On this basis, recovery of energy, materials and resources from waste such as residual agricultural/forestry biomass and municipal/commercial/industrial waste should be seen as the way ahead. Highly-efficient combustion and incineration offer robust energy and environmental performances. Innovative waste refineries may achieve similar performances from a GHG perspective and, in addition, may recover nutrients. In the perspective of future energy systems with increased shares of fluctuating energy sources (e.g. wind energy) the flexibility of the energy conversion process should also be considered in the environmental assessment. The storability of the produced energy carrier along with the regulation ability and the capacity of switching among outputs may offer substantial benefits to the surrounding energy system. In this perspective, waste refineries producing storable biogas and solid fuel may offer increased flexibility compared with base load incinerators.