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Global climate impacts of bioenergy from forests: implications from biogenic CO_2 fluxes and surface albedo

Francesco Cherubini, Ryan Bright, and Anders Strømman

Department of Energy and Process Engineering, Norwegian University of Science and Technology (NTNU), Trondheim - Norway (francesco.cherubini@ntnu.no)

Production of biomass for bioenergy can alter biogeochemical and biogeophysical mechanisms, thus affecting local and global climate. Recent scientific developments mainly embraced impacts from land use changes resulting from area-expanded biomass production, with several extensive insights available. Comparably less attention, however, is given to the assessment of direct land surface-atmosphere climate impacts of bioenergy systems under rotation such as in plantations and forested ecosystems, whereby land use disturbances are only temporary.

In this work, we assess bioenergy systems representative of various biomass species (spruce, pine, aspen, etc.) and climatic regions (US, Canada, Norway, etc.), for both stationary and vehicle applications. In addition to conventional greenhouse gas (GHG) emissions through life cycle activities (harvest, transport, processing, etc.), we evaluate the contributions to global warming of temporary effects resulting from the perturbation in atmospheric carbon dioxide (CO_2) concentration caused by the timing of biogenic CO_2 fluxes and in surface reflectivity (albedo). Biogenic CO_2 fluxes on site after harvest are directly measured through Net Ecosystem Productivity (NEP) chronosequences from flux towers established at the interface between the forest canopy and the atmosphere and are inclusive of all CO_2 exchanges occurring in the forest (e.g., sequestration of CO_2 in growing trees, emissions from soil respiration and decomposition of dead organic materials). These primary data based on empirical measurements provide an accurate representation of the forest carbon sink behavior over time, and they are used in the elaboration of high-resolution IRFs for biogenic CO_2 emissions. Chronosequence of albedo values from clear-cut to pre-harvest levels are gathered from satellite data (MODIS black-sky shortwave broadband, Collection 5, MCD43A). Following the cause-effect chain from emissions to damages, through radiative forcing and changes in surface temperature, we quantify global climate impacts using different emission metrics, considering both absolute and normalized metrics for single pulses and sustained emissions.

Results show the importance of temporary climate agents (biogenic CO_2 and albedo), especially when biomass is sourced from forested areas affected by seasonal snow cover. The climate performance of bioenergy systems is highly dependent on biomass species, local climate, time horizons, and metrics considered. Bioenergy systems usually perform much better than fossil counterparts if assessed through instantaneous metrics, including global surface temperature changes. Metrics based on cumulative impacts show that bioenergy systems usually have higher net CO_2 emissions than fossil systems, but changes in albedo can in some cases more than offset these impacts. The analysis of sustained, i.e. continuous, emissions also shows that impacts from bioenergy systems are generally reversible, while those from fossils are permanent.

Bioenergy climate impact studies and accounting mechanisms should rapidly adapt to cover both biogeochemical and biogeophysical impacts, so that policy makers can rely on scientifically robust analyses and promote the most effective global climate mitigation options. Further, given the large influence that the metric choice can have and the variety of climate forcing agents to be combined, the dominant role traditionally assigned to cumulative impacts should be reconsidered as well, with the findings based on instantaneous metrics taken into proper consideration while interpreting final outcomes.