Diversity of biomass usage pathways to achieve emissions targets in the European energy system

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Motivation

To meet climate targets, net-negative emissions in the energy system are likely necessary, with direct air capture and bioenergy with carbon capture and utilization or storage seen as important technology options. While bioenergy can be associated with both positive and negative environmental, social and economic effects, concerns about negative impacts have led the European Union to cap biofuels from food and feed crops and to increasingly emphasize the use of waste and residue resources. Further policy development needs to be informed about intersectoral competition and **effective use of biomass resources alongside emerging options** such as direct air capture, low-carbon electrolysis and e-fuels.

Method

The study investigates the use of biomass in the European energy system by exploring a wide range of technology mixes with similar costs, in scenarios that adhere to stringent emissions targets. We combine a rich portfolio of bioenergy technology options with a state-of-the-art sector-coupled energy system model employing a high spatial and temporal resolution. This allows us to show competition and synergies between biomass options on the one hand, and variable renewables, electrolytic hydrogen, e-fuels and direct air capture on the other. The **analysis of near-optimal solutions** avoids the common focus on least-cost results, and thus provides a more nuanced picture of the importance of individual biomass usage options. We also use metrics from feasibility studies to put the penetration of variable renewables and electrolysers into context and assess the role of biomass at lower growth rates for solar photovoltaics, wind power and electrolytic hydrogen.

Results

- Excluding biomass increases energy system costs by ~20% under stringent emissions targets, similar to excluding wind power or electrolytic hydrogen.
- The main value in the European energy system is the **provision of carbon** rather than energy.
- How biomass is used is less critical if carbon is captured to provide feedstock for fuels and chemicals and enable negative emissions.
- However, advanced biofuels and chemicals gain importance if the deployment of carbon capture, variable renewables or electrolytic hydrogen is slow.
- **E-biofuels** avoid carbon capture and dedicated e-fuel production by adding hydrogen to biofuel processes, and are cost-competitive.
- Biomass remains cost-effective even when associated with some upstream emissions, and the value of biomass and carbon capture and utilization increases significantly as fossil fuels are phased out.
- Policymakers need to **balance the risk-mitigating benefits of limiting the use of biomass for energy with its role in providing renewable carbon to meet emission targets**. This must be weighed against uncertainties about the possible scale-up pace of direct air capture, variable renewables, electrolytic hydrogen and carbon capture and storage.

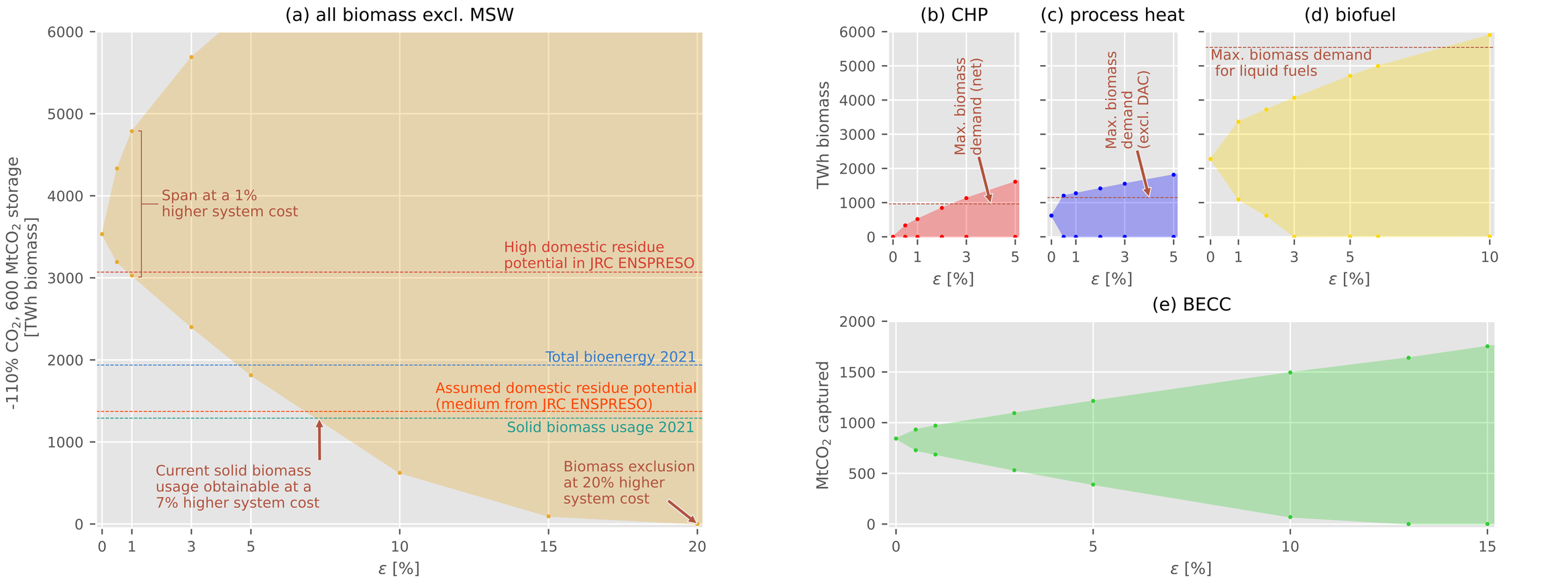

Figure 1. **Solution spaces for different biomass usages in a net-negative (−110%) emissions scenario** with an allowed carbon sequestration potential close to what is necessary to achieve the target, where the respective options are minimised and maximised to map out the space of feasible solutions (shaded area) for a given allowed system cost increase ε (percentual deviation from the total system cost).

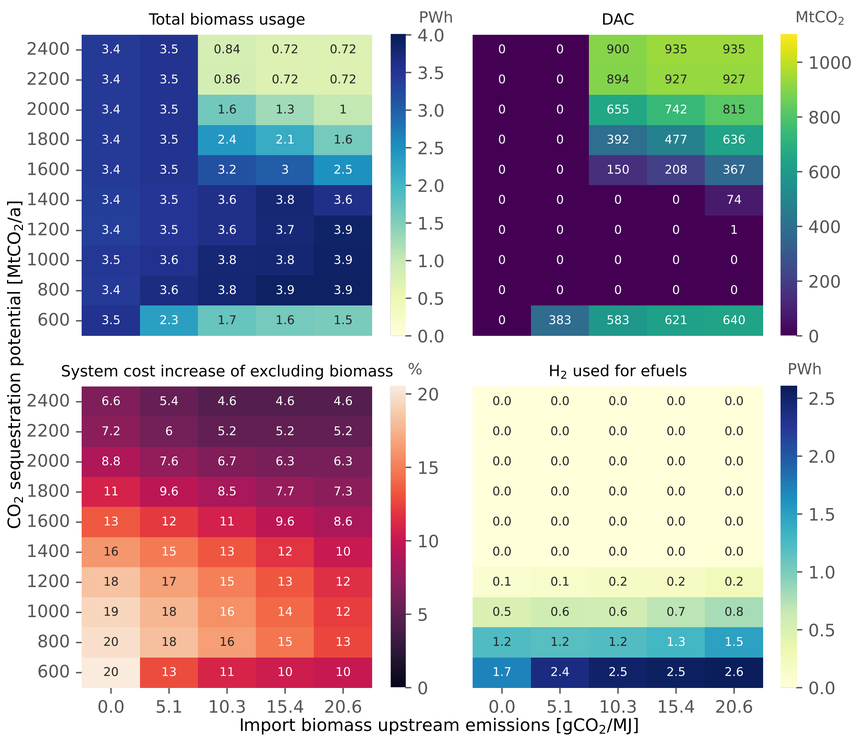

Figure 2. **Heat maps of cost-optimal configurations** for achieving a net-negative (−110%) emissions target when varying upstream emissions of biomass imports (x-axis) and allowed annual carbon sequestration potentials (y-axis). 10.3 gCO_2/MJ corresponds to upstream emissions equivalent to 10% of the biomass CO_2 emissions at full combustion.

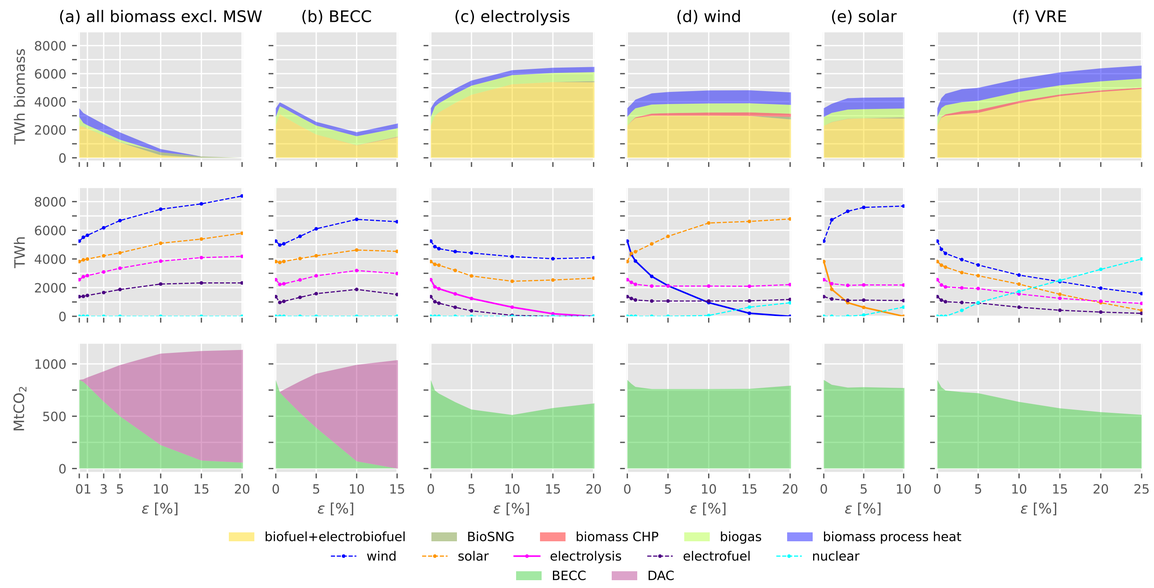

Figure 3. **Effect on the rest of the energy system when decreasing different options from cost-optimal levels** in the net-negative (−110%) emissions scenario with an allowed carbon sequestration potential close to what is necessary to achieve the target.

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