**System flexibility through bioenergy – Themenbereich 5**

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**Overview and research question**

Variable renewable energy (VRE) production based on photovoltaic and wind energy is on the rise to phase out the consumption of fossil fuels on the one hand and to provide electricity for growing multi-sectoral demand on the other. Continuing and increasing growth rates in different world regions are more and more contributing to the emission reduction goals. They will inevitably lead to temporal imbalances in production and consumption patterns. Curtailment, electricity and heat storage, improved transmission and demand response will play an essential role in system flexibilization. The integration into existing energy models of most of these short- to medium term options is built upon a growing literature base. However, the role of bioenergy, including the potential contribution for longer-term (seasonal storage) flexibility and even providing flexibility regarding different bioeconomy services, is less discussed in the energy economics community. The presented paper will address the current status, technological prospects and barriers for flexible bioenergy in energy systems with expanding VRE-shares.

**Methods**

The methodology for this research is based on a literature review extended collected input from expert and country questionnaires and several workshops held within the consortium and work of the International Energy Agency (IEA) Bioenergy Technology Collaboration Programme (TCP) Task44 on system integration and flexibilization. During the Task44 triennium 2018-2021, the consortium collected techno-economic parameters on flexible bioenergy technologies and categorized them into (1) short term flexibility to balance and stabilize the electricity grid by both positive and negative ancillary services and (2) long term flexibility by biomass-based energy carriers that can be (seasonally) stored and transported within existing infrastructure. Based on this techno-economic catalogue, an expert questionnaire collected the current status of these technologies and overall flexibilization needs and respective policy landscapes from Australia, Austria, Denmark, Finland, Germany, Ireland, Italy, Netherlands, Sweden, Switzerland and The United States. A specific knowledge gap, namely the need for a broader definition of flexibility and a clearer understanding of how to valorize flexibility, has been identified and was followed up by a comprehensive but targeted literature review and discussion.

**Results**

Flexibility is provided from bioenergy throughout the entire biomass-to-end-use chain. Various technologies and various combinations of pre-treatment and final conversion and combinations concerning feedstocks and end-uses exhibit relatively high Technological Readiness Levels (TRLs) (see Figure 1).



Figure 1: Bioenergy flexibility throughout the biomass-to-end-use chain. Green arrows indicate technologies that are already applied; yellow arrows indicate technologies that have been demonstrated technically but do not yet have a working business case; red arrows indicate technologies under development Source: own illustration

Based on the detailed techno-economic catalogue, the country experts evaluated the current status of the technology implementation in their specific countries. The share of biomass and biomass CHP in power demand ranges from 3-4% (US & NL) to 17% (DK). Targets and incentives for flexible bioenergy in the power sector are only found in Germany. In contrast, more flexibilization targets are set in the other countries for the transport and the heating sector. Further opportunities are identified for the gas sector, especially in Italy and Switzerland, and agriculture and industry. Overall, the main barriers to implementing flexible bioenergy are primarily economic reasons and market mechanism and regulations and political framework, which are often interlinked. In the discussions on these barriers, we find that even though flexibility of the bioenergy concepts goes beyond the power sector, expectations regarding economic viability mainly focus on short-term grid services.

**Conclusions**

Bioenergy flexibilization potentials address different dimensions throughout their supply chains, from feedstock flexibility to seasonal storage options for intermediary bioenergy carriers to short-term flexible electricity production and negative auxiliary services (when combined with hydrogen production) and finally, the opportunity to shift the whole supply chain to provide a completely different service, such as, e.g. biochemicals, when suddenly the need arises. Further integration of these options face significant barriers when it comes to valorizing flexibility; (1) longer-term flexibility contribution to the power sector (2) the contribution to the overall energy system beyond electricity (3) as well as to the broader bioeconomy and its goals have to be taken into account. Including next to economic- furthermore environmental and socio-economic parameters and designing mechanisms how the contribution of the flexibility service on a system level can be monetized on a component/firm-level could have considerable impacts on how the transformation will be shaped in the upcoming decades.