

# **Biomass CHP combined with steam generating heat pumps: a multi-market strategy for industrial decarbonisation**

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## **Abstract-**

**Despite ongoing efforts to decarbonise industrial processes, energy-intensive industries still rely primarily on fossil fuels for high-temperature heat supply. This study addresses the need for competitive decarbonisation strategies by proposing the integration of a biomass-based combined heat and power (CHP) unit with steam generating heat pumps for electricity and process steam supply. A mixed-integer linear programming model is developed to optimise the operation of gas turbine-based CHP plants under dynamic multi-market conditions. The formulation accounts for fuel, start-up, shutdown, and emission costs, and enables participation in the day-ahead and frequency control markets, with an explicit distinction between balancing capacity and energy. The model is applied to a real Spanish industrial plant in which the biomass-based system is tested against conventional natural gas-fired CHP units. Results show that the proposed configuration reduces fossil fuel emissions by 76.9%. The integration of heat pumps enhances waste heat recovery, improves overall system efficiency, and decouples steam production from electricity market conditions. Accounting for emission costs allows the biomass-based system to exploit higher electricity price hours, maximising surplus electricity production without incurring emissions. Additional revenue from steam export leads to a 51.2% improvement in net profit compared with the fossil-based scenario. Participation in the balancing markets further increases total revenues by 3.5%, mainly through the provision of upward balancing energy. This comes at the expense of higher natural gas consumption during balancing activation, reducing emission savings to 74.3%. By maintaining compliance with EU sustainability criteria, this work offers a multi-market decarbonisation pathway for energy-intensive industries.**

**Index Terms-** Decarbonisation; Energy intensive industries; Biomass; Cogeneration plants; Heat pump systems; Mixed-integer linear programming; Balancing market

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