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OVERVIEW OF ENERGY FLEXIBILITY THROUGH DEMAND RESPONSE AND POWER-TO-X TECHNOLOGY

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Abstract – The increasing penetration of renewable energy sources and sector coupling significantly raises demand for and the potential of energy system flexibility. Technologies, including demand-side flexibility, Power-to-X solutions, energy storage, and electrified heating, are increasingly recognized as key enablers for achieving climate neutrality while maintaining system reliability and economic efficiency. However, despite significant technological progress, there remains a lack of empirical research that integrates real-time operational data, market signals, and user-related parameters to assess the practical flexibility potential of buildings and industrial systems. This study aims to provide a scoping review of demand-side flexibility and sector coupling technologies in supporting renewable energy integration and improving overall energy system efficiency. Attention is given to demand response harnessing technologies such as heat pumps and Power-to-X applications through hydrogen production with electrolysis and energy storage systems, which can absorb excess renewable electricity and provide balancing services to the power system. The methodological approach scoping review of energy flexible technology with the development of a conceptual framework for future energy flexibility evaluation. The proposed framework integrates real-time energy consumption data, indoor comfort parameters, and electricity market signals to identify opportunities for demand response and optimal system operation. In addition, the study examines the potential role of digital technologies, including data analytics and smart energy management systems, in enabling more responsive and efficient energy use. The results of the proposed research framework could highlight that sector coupling, and flexible demand can significantly enhance renewable energy utilization, reduce system costs, and decrease greenhouse gas emissions. Furthermore, the integration of market signals and digital monitoring tools can unlock additional flexibility from buildings and industrial processes.

Keywords – *Demand response technologies; demand-side flexibility; flexible technologies; renewable energy storage*

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