

# **Synergies and trade-offs between storage, transmission, and sector coupling in high renewable energy systems**

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## **Abstract-**

**Energy storage, transmission, and sector coupling are some prominent flexibility solutions to support variable renewable energy (VRE) integration. However, investment cost uncertainties and public acceptance could hamper the deployment of these flexibility solutions. This raises questions about the development and cost-effectiveness of future energy systems, especially on how the dependence on local and cross-border solutions of flexibility would evolve if the uptake of these solutions is restricted. In this context, this paper identifies the synergies among flexibility options under restrictions on transmission expansion or increased costs of energy storage. It contributes to determining whether investments in energy storage and/or transmission expansion offer the least-cost transition and investigates the impact of sector coupling on these solutions. A long-term energy system planning and optimisation model towards 2050 is developed using the open-source energy system optimisation tool Balmorel, and a case study of the countries surrounding the Baltic Sea and the North Sea is established. Five cases with restrictions imposed on transmission expansion and higher energy storage technology costs are analysed at different levels of sector coupling. The results highlight the importance of transmission expansion at all levels of sector coupling. As the level of sector coupling increases, uncertainties around the cost of energy storage drive the least-cost pathways. Optimal investment solutions are found to have a mix of transmission and energy storage in capacity expansion at all levels of sector coupling.**

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**Graphical abstract**

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**Index Terms- Energy storage; Flexibility; Generation expansion; Integrated energy systems; Sector coupling; Transmission planning**

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