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Quantifying impacts of smart irrigation technology on long-term water-energy nexus challenges in the Indus River Basin

Ansir Ilyas (1), Adriano Vinca (2,3), Simon Parkinson (2,3), Edward Byers (2), Peter Burek (2), Yoshihide Wada (2), Volker Krey (2), Keywan Riahi (2), Ned Djilali (3), Asif Khan (1,4), Simon Langan (2), and Abubakr Muhammad (1)

(1) Lahore University of Management Sciences (LUMS), Lahore Pakistan, (2) International Institute for Applied Systems Analysis (IIASA), Austria, (3) University of Victoria, Canada, (4) University of Engineering and Technology, Pakistan

The Indus River Basin is home to an estimated 300 million people and ranks among the most water-dependent basins in the world in terms of reliance on irrigated farming. The basin also features a tight coupling between water and energy systems due to highly-distributed groundwater wells and large-scale hydropower schemes. Implementation of modern, so-called smart irrigation technologies such as digital soil moisture and canal sensors, real-time controls for irrigation and canal diversions, and laser-assisted field leveling demonstrate huge potential for reducing irrigation withdrawals. Yet, there is a lack of quantitative analysis providing insight into how transformation towards smart irrigation technologies would impact basin energy systems due to water-energy linkages. In this research, investment and operational decisions for smart irrigation technologies and approaches are incorporated into an integrated basin-scale resource planning framework that co-optimizes water, energy and land systems decision-making. The enhanced tool is used to quantify interactions between smart irrigation and energy transformations. Results indicate modern and smart irrigation technologies can play an important role in improving upstream water availability by reducing water application at the field-level and improving water distribution efficiency. Reduced irrigation withdrawals from rivers provide increased flexibility with hydropower potential to meet increasing energy demands while reducing greenhouse gas emissions and supporting the development of other variable renewable energy sources. The increased upstream water availability in the industrial and domestic sectors avoids expanded use of fossil groundwater and advanced water treatment, with co-benefits for energy demands and system capacity requirements. Associated investment costs for the new irrigation technologies and approaches could pose a barrier to implementation for low-income farmers and local governments. The current study can guide policy in sustainable resources use and investment costs and the applied analytical methods can be adapted to other regions of the world facing similar linked resource issues.