Artificial Intelligence and the Internet of Things in Microgrids and Smart Grids: An Economic Analysis of Productivity, Efficiency, and Demand Response to Dynamic Pricing

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ABSTRACT

This dissertation investigates the economic impacts of Internet of Things (IoT) and Artificial Intelligence (AI) technologies in the electricity sector, in the context of smart grids and microgrids. It examines the transition from centralized, monopolistic market models to more competitive markets due to the integration of distributed energy sources. The research further examines whether AI and IoT enhance productive efficiency and investment returns in the broader microgrid market connected to smart grids.

The theoretical frameworks applied are neoclassical production theory, Total Factor Productivity (TFP), investment efficiency metrics (LCOE, IRR, NPV), and principles of welfare economics and demand elasticity. A multi-case study methodology is employed to test three core hypotheses: (1) that AI/IoT integration enhances operational efficiency and reduces costs; (2) that these technologies are pivotal for integrating variable renewable energy sources and fostering a shift toward competitive market structures; and (3) that AI/IoT adoption improves investment efficiency in microgrids.

The analysis of four case studies—the Blue Lake Rancheria microgrid, Airtel Madagascar's remote telecom power systems, the Olympic Peninsula Demonstration Project, and the California Statewide Time-of-Use (TOU) Pricing Pilots—provides strong empirical support for these hypotheses. Key findings demonstrate significant improvements in operational efficiency, such as a TFP of 4.02 at Blue Lake Rancheria and a 40% reduction in the Levelized Cost of Energy (LCOE) for Airtel Madagascar. The studies also reveal that dynamic pricing mechanisms, enabled by smart grid technologies, that shift consumer demand, confirm the role of AI and IoT in enabling more competitive and efficient market structures.

The dissertation concludes that the integration of AI and IoT in the energy sector yields economic benefits, driving productivity, improving investment viability, and enhancing market efficiency. These findings have suggested a need for accelerated investment in smart grid infrastructure, updated regulatory frameworks, and the promotion of interoperability standards to realize the full potential of a digitized, resilient, and sustainable energy future.