Corporate Strategies for Recycling Decommissioned Wind Turbine Blades: Insights from an Evolutionary Game and System Dynamics Model

Abstract: The escalating global deployment of wind energy, while pivotal for a cleaner future, concurrently generates a growing volume of decommissioned wind turbine blades (WTBs). These blades, inherently challenging due to their substantial size and complex composite structures, present a critical waste management dilemma; their improper disposal not only burdens landfills and risks environmental pollution but also signifies a significant waste of valuable resources that could otherwise fuel a circular economy. Addressing this urgent imperative necessitates robust collaboration and strategic alignment among key stakeholders: governments, responsible for policy and oversight; large-scale recycling companies, tasked with collection, processing, and material recovery; and remanufacturers, crucial for integrating recovered materials into new product streams. This study employs an integrated analytical framework, combining evolutionary game theory and system dynamics (SD), to comprehensively analyze the dynamic interactions, strategic choices, and evolutionary trajectories of these critical actors. Through this dual-model approach, we aim to uncover how various factors influence their propensity to adopt sustainable recycling practices and foster effective collaborative mechanisms. Our key findings reveal that appropriate and well-targeted technical subsidies for recycling technologies, coupled with direct recycling subsidies, significantly enhance stakeholder participation, driving the system towards an efficient and highly collaborative operational model. Furthermore, while initial strategy probabilities among players transiently affect the speed of system stabilization, our simulations strikingly demonstrate that all parties ultimately converge to a fully cooperative stable state (1, 1, 1), underscoring the system’s inherent self-regulating capacity when robust incentives and deterrents are in place. We also find that remanufacturers’ willingness to embrace green production practices is robustly influenced by both responsive market demand for environmentally friendly products and supportive government policies, with sustained technological advancements proving instrumental in continuously improving the economic viability of recycling and remanufacturing, thereby enhancing overall environmental outcomes. This integrated study provides valuable quantitative evidence and strategic insights for policymakers and industry leaders, offering a clear roadmap for optimizing recycling

policies, designing new incentive structures, and fostering a collaborative environment that promotes the long-term sustainability of end-of-life WTB management, aligning corporate responsibility with broader environmental protection goals.

Keywords: Decommissioned wind turbine blades; Recycling; Evolutionary game theory; System dynamics; Policy recommendations; Corporate responsibility