Sustainable System Design for Science Park Development in Taiwan

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Background and Objective

The explosive global demand for artificial intelligence and advanced semiconductor manufacturing has driven unprecedented economic expansion in Taiwan's high-tech industrial clusters. In 2025, Taiwan's three major science parks generated a record-breaking NT$5.8 trillion in revenue, reflecting a 21.83% year-on-year growth. The Southern Taiwan Science Park (STSP) alone experienced a 34% surge, precipitating a 600-hectare Phase 4 territorial expansion into agricultural zones like Shalun Farm.

While these science parks occupy merely 0.1% of Taiwan's total land area, they account for approximately 16% of the nation's manufacturing revenue. This intense spatial and economic concentration creates a severe "Sustainability Gap." The uninterrupted, energy-intensive nature of semiconductor fabrication demands massive volumes of ultra-pure water and gigawatts of electricity, placing immense stress on regional power grids, accelerating Scope 2 carbon emissions, and driving local habitat fragmentation. The primary objective of this study is to utilize systems thinking to evaluate how policy interventions can balance immediate economic performance with long-term ecological resilience as Taiwan pushes toward its 2050 Net Zero target.

Methodology

This research applies System Dynamics (SD) methodology, utilizing Causal Loop Diagrams (CLDs) and stock-and-flow computer simulation models to capture the delayed feedback mechanisms between industrial expansion and ecological degradation.

The core dynamic hypothesis identifies a reinforcing "Economic Growth Loop" wherein high global demand drives profitability, triggering government-backed infrastructure and territorial expansion. However, this triggers a balancing "Environmental Loop." Unchecked physical expansion increases absolute resource depletion and carbon emissions, leading to grid instability, stricter regulatory penalties, and environmental conflicts. If left unmanaged, these ecological frictions drive up production costs and restrict future technological innovation.

Key Findings: The Efficiency Paradox

Historical data analysis from 2016 to 2025 reveals a critical "Efficiency Paradox." Through corporate sustainability efforts, the resource intensity per unit of revenue (water, energy, and carbon per NT$) has steadily declined. However, the sheer exponential scale of industrial expansion has completely overpowered these per-unit efficiency gains. Consequently, absolute resource consumption and total emissions continue to rise, demonstrating that efficiency improvements alone cannot resolve scale-induced ecological overshoot.

Simulated Policy Interventions

To counter this trajectory, the simulation evaluated the systemic impact of four overlapping policy interventions designed to decouple economic growth from resource consumption.

Policy Domain	Regulatory Mechanism	Systemic Outcome
Carbon Taxation	NT$300 per tonne CO2 fee under the Climate Change Response Act	Internalizes carbon externalities, introducing financial friction that disincentivizes carbon-intensive operations.
Renewable Energy	Mandatory 25% green power for semiconductor fabs by 2030 (100% by 2050)	Decarbonizes the energy supply stock, preventing Scope 2 emissions from scaling linearly with production volume.
Water Circularity	Mandatory 85% process water recycling rate for high-tech firms	Buffers industrial output against seasonal droughts; targets reclaimed water capacity of 319,100 tonnes per day by 2030.
Spatial Compensation	175 hectares on-site preservation; 18-hectare off-site Erren River reserve	Mitigates habitat fragmentation caused by Phase 4 expansion and stabilizes local biodiversity stocks.

Conclusions and Strategic Implications

The traditional paradigm of treating resource supply as an infinite variable to fuel high-tech expansion is fundamentally unsustainable. The simulation demonstrates that without aggressive structural decoupling, environmental constraints will inevitably limit future economic growth.

To achieve the 2050 Net Zero target while maintaining global supply chain dominance, policymakers must integrate ecological boundaries directly into macroeconomic blueprints and spatial planning approvals. Science parks must transition from volume-based expansion to value-based innovation, mandating closed-loop infrastructure (reclaimed water and localized green grids) and proactive spatial budgeting prior to any future territorial development.