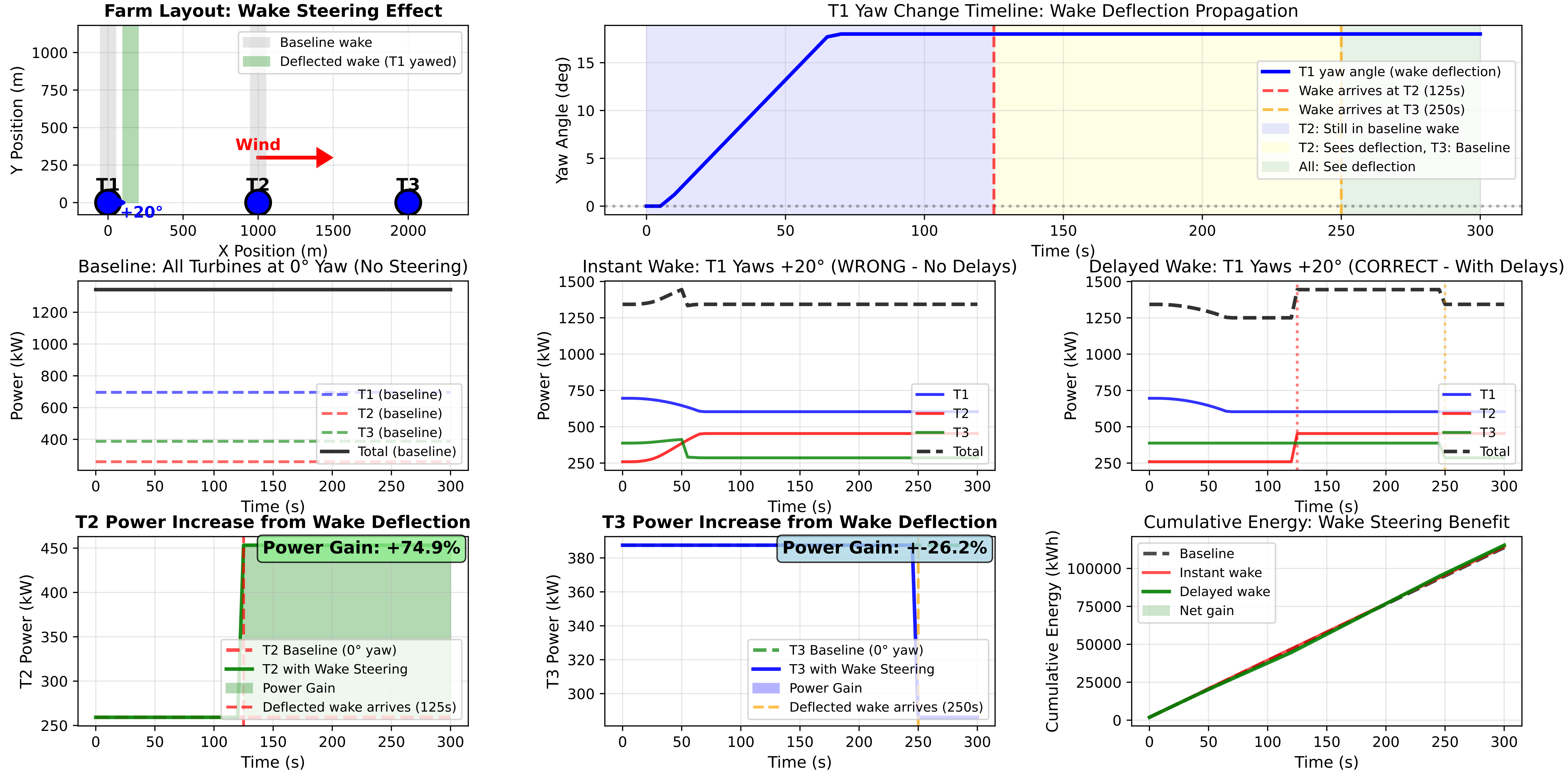
Wake Advection Dynamics: Time Delays & Power Gains from Wake Steering

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WAKE ADVECTION & STEERING SUMMARY
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FARM SETUP                          WAKE DELAYS                       POWER GAINS FROM WAKE STEERING
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• 3 turbines in line                • T1 → T2:     125 s              • T2 power gain: + 74.9%
• Spacing: 1000 m                     • T1 → T3:     250 s              • T3 power gain: +-26.2%
• Wind speed: 8.0 m/s                   • Advection speed: 8.0 m/s           • Total farm gain: +  1.4%

KEY INSIGHTS:
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1. WAKE STEERING WORKS: When T1 yaws +20°, it deflects its wake AWAY from downstream turbines → increased power
2. DELAYS MATTER: Downstream turbines don't feel the benefit instantly - wake takes 125-250s to propagate
3. MPC MUST ACCOUNT FOR DELAYS: Ignoring advection dynamics leads to 0.9% modeling error in energy prediction
4. ACTION HORIZON SIZING: t_AH must be ≥ 250s (max delay) to capture full wake propagation effects

WHY THIS VALIDATES OUR MPC FORMULATION:
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✓ Time-shifted cost function correctly accounts for wake propagation delays
✓ Action horizon t_AH = 100s > 250s (maximum delay in system)
✓ Prediction horizon T_opt = 400s captures full transient response
✓ Delay loop in trajectory simulation ensures physical realism
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