# 1.4 Methodology, Scope & Delimitations

This investigation adopts an explanatory, embedded multiple–case design centred on three large‑cap firms—one each from logistics, fast‑moving consumer goods, and automotive manufacturing. The design choice balances depth and generalisability: each firm provides a rich, longitudinal narrative, while cross‑case pattern matching surfaces sectoral commonalities and divergences.

Data strategy. The study relies exclusively on secondary, freely accessible sources released between 2015 and 2024. Quantitative inputs include annual and ESG reports, robot‑density tables, patent datasets, and open climate disclosures. Qualitative context is drawn from press releases, analyst call transcripts, and industry white papers, enabling triangulation of numeric findings. All documents are archived in a version‑controlled repository to support replication.

Analytical toolkit. Within‑case impact is tested through interrupted time‑series regressions that compare pre‑ and post‑Industry 4.0 trajectories for key supply‑chain and sustainability indicators. Associations between adoption proxies (for example, robot density or digital‑capex share) and performance outcomes are examined using ordinary least‑squares and autoregressive GLS models with robust standard errors. Efficiency movements are assessed via data‑envelopment and Malmquist indices, treating energy and capital as inputs and output units, revenue, and emissions reduction as desirable outputs. Finally, cross‑case synthesis employs z‑score normalisation, hierarchical clustering, and narrative pattern matching to surface transferable lessons.

Temporal and thematic scope. The analysis window spans ten fiscal years (2015–2024), capturing the most intense diffusion period of Industry 4.0 technologies to date and allowing for a minimum four‑year post‑intervention tail at each firm. The thematic lens covers (i) supply‑chain activities—planning, sourcing, production, and distribution; (ii) value‑chain extensions—product development and after‑sales; and (iii) environmental sustainability—energy, greenhouse‑gas emissions, and solid waste. Social‑sustainability metrics such as labour equity are acknowledged but not modelled quantitatively due to inconsistent public reporting.

Delimitations. The study is intentionally confined to publicly traded, data‑rich multinationals headquartered in the OECD. Small‑ and medium‑sized enterprises, emerging‑market contexts, and privately held firms lie outside scope, as do cyber‑security and finance‑only applications of Industry 4.0. The analysis halts at the firm boundary; upstream tier‑two suppliers and downstream retailers are incorporated only insofar as disclosures aggregate them. Finally, causality claims are limited by the observational nature of the data; where significant trends are detected, alternative explanations—macroeconomic shocks, regulatory changes, or sector cycles—are tested with controls but cannot be ruled out completely.

These methodological choices ensure that the research question is addressed with rigorous, reproducible evidence while acknowledging the contextual limits within which any conclusions must be interpreted.