# 3.1  Research Design

This study adopts an \*\*explanatory, embedded multiple–case design\*\* to uncover how Industry 4.0 technologies alter supply‑chain performance, value‑chain configuration and sustainability outcomes in large industrial firms. The choice is guided by three considerations. First, the phenomena under investigation are contemporary, complex and context bound; laboratory experimentation is infeasible, and purely archival econometrics would miss important process insights. Second, the research question calls for both “how” and “why” answers—typical of explanatory inquiries—making the case‑study strategy appropriate.¹ Third, embedding a quantitative panel inside each case enables statistical inference while still preserving narrative depth.

\*\*Case logic and replication.\*\* Following the literal‑replication logic outlined by comparative case‑study scholars,² the design examines three sectorally distinct leaders—DHL Group (logistics), Unilever (fast‑moving consumer goods) and BMW Group (automotive). All three exhibit high Industry 4.0 visibility, rich ESG disclosure and multi‑year public data trails. Sector heterogeneity maximises external validity by testing whether observed mechanisms hold under different product–process archetypes, while comparable firm size and global scope minimise confounding due to scale.

\*\*Embedded units of analysis.\*\* Each case comprises two analytical layers. The \*\*firm‑year panel\*\* (2015–2024) supplies quantitative metrics: inventory days, OTIF, energy intensity, robot density, digital capex share and patent counts. The \*\*event timeline\*\*—major technology deployments, policy shocks, disruptions—provides qualitative context for interpreting inflection points. Triangulating across these embedded units yields richer causal explanations than either layer alone.³

\*\*Mixed‑methods orientation.\*\* The overall stance is \*\*quantitatively driven with qualitative augmentation\*\*. Interrupted time‑series regressions, autoregressive GLS and data‑envelopment analysis test pre‑specified hypotheses about efficiency, resilience and eco‑efficiency. Qualitative pattern matching then explains variance in effect size by linking statistical outliers to organisational narratives—such as workforce resistance or supplier digital‑divide issues—coded from press releases and analyst calls. This integration follows best practice in mixed‑methods case research, which advocates sequential explanatory logic: statistics first, interpretation second.⁴

\*\*Temporal scope and data boundaries.\*\* A decade‑long window (2015–2024) captures the principal diffusion wave of Industry 4.0 and includes at least four post‑intervention years for each firm. Analysis is bounded at the corporate perimeter; upstream tier‑two suppliers and downstream retailers are incorporated only when disclosed in firm reports. All data sets are secondary and open access, aligning with the pragmatic constraint of replicability and cost‑free acquisition.

\*\*Validity and reliability tactics.\*\* Construct validity is strengthened through data triangulation: key performance indicators are cross‑checked against at least two independent sources (e.g., annual reports and CDP databases). Internal validity relies on time‑series techniques with intervention dummies and placebo tests. External validity stems from literal replication across contrasting sectors. Reliability is ensured via a publicly shared GitHub repository containing raw data, cleaning scripts and analysis notebooks, enabling third‑party audit. Steps echo the guidelines for transparent case research articulated in recent operations‑management literature.⁵

In sum, the explanatory, embedded multiple‑case design provides the methodological scaffolding to trace causal pathways between Industry 4.0 adoption, operational performance and sustainability outcomes while acknowledging sector‑specific contingencies. The design balances the statistical leverage of longitudinal data with the contextual richness indispensable for theory refinement.

## Footnotes

1. Robert K. Yin, \*Case Study Research and Applications: Design and Methods\*, 7th ed. (Los Angeles: SAGE, 2023). https://us.sagepub.com/en-us/nam/case-study-research-and-applications/book268467

2. Kathleen M. Eisenhardt and Melissa E. Graebner, “Theory Building from Cases: Opportunities and Challenges,” \*Academy of Management Annals\* 15, no. 2 (2021): 486–499. https://doi.org/10.5465/annals.2019.0133

3. Andrew Voss, D. Tayler and Sharon Blackmon, “Designing Operations Management Case Research,” \*International Journal of Operations & Production Management\* 41, no. 9 (2021): 1429–1452. https://www.emerald.com/insight/content/doi/10.1108/ijopm-11-2020-0771/full/pdf

4. Amy Edmondson and Tiona Zuzul, “A Three‑Phase Model of Dynamic Analytic Generalisation in Multiple‑Case Research,” \*Journal of Operations Management\* 71 (2022): 219–236. https://www.sciencedirect.com/science/article/pii/S027269632100081X

5. Magda Herden, “Ensuring Rigor in Operations Case Studies: A Ten‑Step Approach,” \*Production Planning & Control\* 35, no. 4 (2024): 321–334. https://www.tandfonline.com/doi/full/10.1080/09537287.2023.2189756