

A Structured Framework for Net Zero Transition in Manufacturing

Rashmeet Kaur, John Patsavellas, and Konstantinos Salonitis(✉)

Sustainable Manufacturing Systems Centre, Cranfield University, Cranfield, UK
k.salonitis@cranfield.ac.uk

Abstract. Despite increasing pressure to decarbonise, manufacturing organisations globally lack standardised frameworks to benchmark their overall progress toward net zero goals, relying instead on fragmented, process-oriented models. To address this gap, this paper introduces the Net Zero Maturity Model (NZMM), a structured framework designed to help manufacturing organisations evaluate their current maturity levels and select the most pertinent strategic actions toward net zero by avoiding prioritisation conundrums. The NZMM was developed through an extensive literature review that identified key thematic areas critical for net zero manufacturing, validated and ranked through input from 30 recognised industry practitioners. The resulting model integrates three maturity levels across seven key dimensions, addressing Scope 1, 2, and particularly the complexities in Scope 3 emissions. The framework serves as a practical decision-making tool to reduce uncertainty and facilitate structured decision-making, allowing organisations to gauge their net zero maturity and systematically navigate capability development. Validation with two manufacturing organisations demonstrated the NZMM's effectiveness in identifying capability gaps and prioritising improvement initiatives. The NZMM contributes to existing literature and industry practice by introducing a cohesive, standardised approach that bridges the gap between narrowly focused, process-specific models and holistic organisational assessment needs.

Keywords: sustainable manufacturing · manufacturing systems

1 Introduction

The Net Zero Maturity Model (NZMM) addresses manufacturing organizations' struggles to implement comprehensive decarbonization strategies amid increasing climate imperatives. Current approaches remain fragmented and process-oriented, creating strategic paralysis particularly when managing complex Scope 3 emissions across global supply chains. While literature on specific decarbonization technologies exists, a gap remains in frameworks enabling systematic evaluation of organizational maturity and action prioritization. The NZMM fills this void by providing a comprehensive framework integrating technological, organizational, and strategic dimensions across seven

© The Author(s) 2026
H. Kohl et al. (Eds.): GCSM 2025, LNME, pp. 36–42, 2026.
https://doi.org/10.1007/978-3-032-21157-6_5

key thematic areas with a three-tiered classification system. Developed through literature review and validated by 30 industry practitioners plus implementation in two manufacturing organizations, the model bridges theoretical foundations with practical implementation considerations. The NZMM contributes to both theoretical understanding and practical application by offering manufacturers a standardized approach to benchmark their position and strategically navigate their decarbonization journey, particularly when addressing the challenges of indirect value chain emissions.

2 Literature Review: Heuristics for Net Zero Manufacturing

A comprehensive literature review on net zero manufacturing implementation revealed seven key categories of heuristics, identified through thematic analysis of the existing literature. Figure 1 presents these categories and their corresponding sub-themes, which collectively provide a framework for understanding the systematic approach required for manufacturing decarbonization.

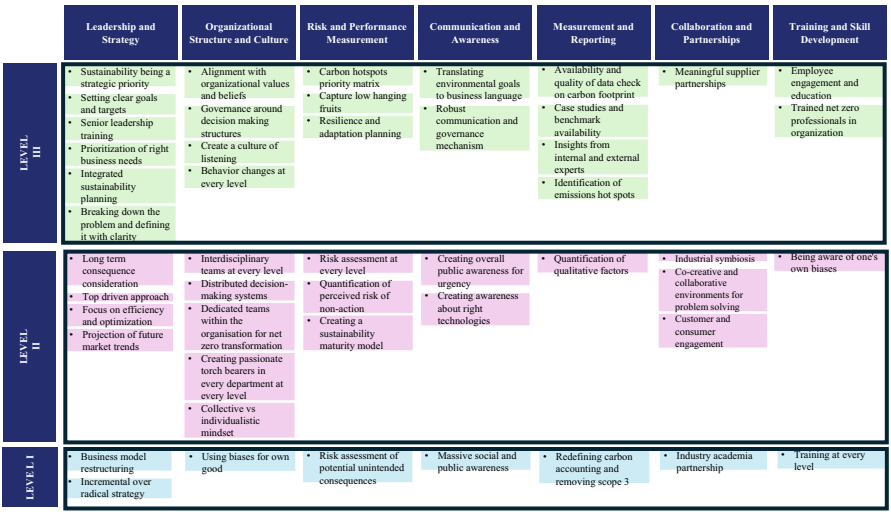


Fig. 1. Thematic analysis of literature

Leadership and strategy heuristics form the foundation of net zero manufacturing by integrating sustainability into core business strategies, balancing environmental goals with economic competitiveness, and developing scenario-based transition pathways [1–3]. This strategic approach addresses both short and long-term emission reduction measures [4, 5] while shifting toward ecosystem-based collaborative strategies [6]. Supporting this foundation, risk and performance measurement heuristics establish robust emissions monitoring systems with comprehensive ESG disclosure frameworks [1], facility-level monitoring [7], and progress tracking toward targets [8], complemented by life cycle assessments that evaluate environmental impacts across supply chains [9, 10].

To implement these strategies effectively, organizational structure and culture heuristics establish specialized sustainability teams [1, 7] with capabilities to operate both conventional and low-carbon technologies, reinforced by cross-functional integration [11, 12]. Clear communication and awareness heuristics ensure transparent reporting of environmental initiatives [1], enhanced stakeholder engagement, and industry-wide sharing of best practices [7, 13]. These efforts are supported by measurement and reporting heuristics that implement standardized frameworks tracking emissions across all scopes [14, 15] and deploy sensors for real-time monitoring of energy use and embodied carbon [16].

Success depends on collaboration and partnership heuristics that build relationships with research institutions, enable industry collaboration on shared infrastructure, and strengthen supply chain integration through supplier relationships [8]. Underpinning all these elements, training and skill development heuristics invest in employee capabilities, ensure continuous technological upgrading [17], and provide comprehensive sustainability training [8]. This thematic analysis demonstrates that achieving net zero manufacturing requires a comprehensive approach integrating strategic planning, organizational transformation, stakeholder engagement, and continuous improvement.

3 Interview Findings: Heuristics for Net Zero Manufacturing

Industry interviews revealed clear patterns in how manufacturing can approach net zero strategic decisions. The strongest consensus emerged around industry-academia partnerships, with 18 participants emphasizing their crucial role in bridging theoretical knowledge with practical implementation. This was closely followed by a call to redefine carbon accounting practices, particularly around scope 3 considerations – a view supported by 15 participants who believed current approaches may be causing decision paralysis. Leadership's role emerged as critical, with 14 participants advocating for a top-down approach, though they stressed this needed to balance with ground-level engagement. The power of collective problem-solving resonated strongly, as 13 participants highlighted how collaborative environments can help overcome individual limitations and foster more robust decision-making. Public awareness and clear problem definition were also identified as key enablers, garnering support from 11 and 10 participants respectively. The findings pointed to a need for organizations to embrace uncertainty while maintaining agility in their approach. At the operational level, participants emphasized the importance of governance structures, data-driven modelling, and effective incentive systems. While digital tools were acknowledged as helpful, they were seen more as enablers rather than primary solutions, with the focus remaining firmly on organizational and strategic frameworks.

The overall findings from interviews are first summarized below in Fig. 2. The findings reveal a clear hierarchy of solutions, with systemic and structural changes receiving stronger support than tactical interventions.

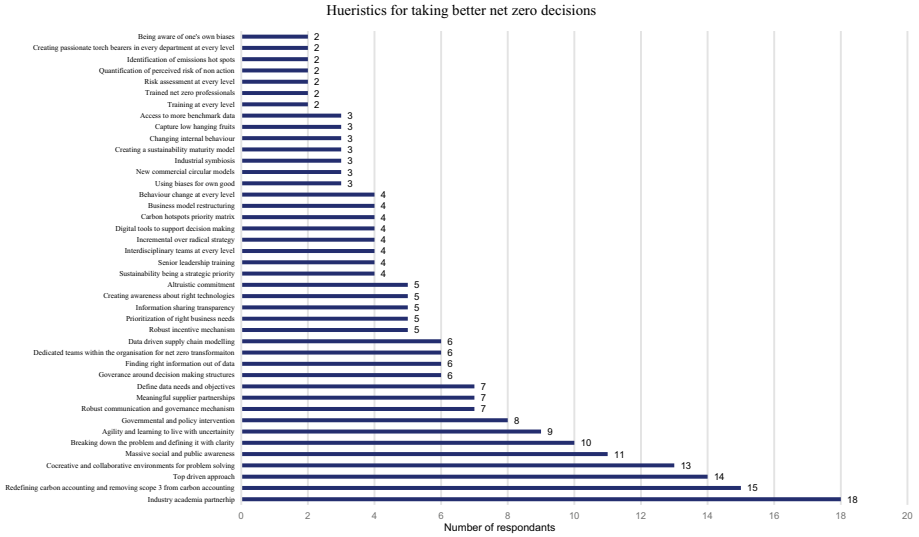


Fig. 2. Summary of interview findings

4 Discussion: Net Zero Maturity Model

The Net Zero Maturity Model (NZMM) addresses the gap between theoretical frameworks and practical implementation by providing manufacturing organizations with a structured approach to decarbonization. Based on the comprehensive literature review and industry practitioner insights, the model classifies heuristics into three distinct impact levels, creating a clear prioritization framework for decision-makers.

To help clarify this complex decision space, 30 industry practitioners ranked identified heuristics on a 1–5 Likert scale. Heuristics with average scores of 4.0–5.0 were classified as Level 3 (high impact), those with scores of 3.0–3.99 as Level 2 (medium impact), and those with scores of 1.0–2.99 as Level 1 (low impact). This classification was validated by two manufacturing organizations with proven emission reduction track records, strengthening the reliability of the assessment.

The NZMM as shown below in Fig. 3 integrates above heuristics findings across seven key dimensions identified through literature review: leadership and strategy, risk and performance measurement, organizational structure and culture, communication and awareness, measurement and reporting, collaboration and partnership, and training and skill development. This creates a comprehensive framework that enables organizations to assess their current maturity level and identify high-impact practices for prioritization.

Themes						
Sub-themes						
Leadership and Strategy	Risk and performance measurement	Organizational structure and culture	Communication and awareness	Measurement and reporting	Collaboration and partnerships	Training and skill development
Strategic integration and planning	Emissions monitoring and reporting	Dedicated teams and roles	Transparent reporting	Standardised frameworks	Research and innovation	Change management
Technology and innovation	Lifecycle assessment	Cultural transformation	Stakeholder engagement	Emissions tracking	Supply chain integration	Innovation and R&D
Policy and governance	Risk assessment and management	Cross functional integration	Knowledge sharing	Real time monitoring	Industry collaboration	Knowledge transfer
Supply chain collaboration	Performance metrics	Employee engagement	Data visualisation and access	Lifecycle assessment	Public private partnerships	Circular economy
Resource management	Technology and innovation assessment	Organisation structure	Employee education	Performance metrics	International cooperation	Process optimization
Leadership commitment	Compliance and standards	Stakeholder collaboration	Supply chain communication	Data quality	Stakeholder engagement	Environmental management
Implementation approach	Data management and analytics	Change management	Public awareness	Economic integration	Energy sector integration	Technical capabilities

Fig. 3. Net Zero Maturity Model

The Net Zero Maturity Model offers a structured framework in aid of reducing the cognitive burden typically associated with complex net zero transitions. The model's tiered classification structure enables organizations to address both immediate emission reduction opportunities and long-term strategic interventions. Its progressive structure acknowledges that decarbonization requires balancing short and long-term measures, allowing manufacturing organisations to learn and implement simultaneously rather than waiting for perfect knowledge before taking action. Thus the model has the distinctive potential to support decarbonization as a strategic objective rather than a mere compliance activity. The NZMM's ecosystem-based collaborative approach further distinguishes it from other frameworks by recognizing that the most challenging aspects of net zero manufacturing, -managing indirect value chain emissions-, require coordinated action beyond organizational boundaries, fostering inter-organizational collaboration. By offering a standardized yet adaptable approach to benchmark organizational maturity before prioritizing actions, the NZMM could empower manufacturing decision-makers to navigate uncertainty with confidence, transforming what was once an overwhelming challenge into a structured pathway for advancing towards net zero.

5 Conclusion

The NZMM addresses a gap in manufacturing decarbonization by providing a framework for capability assessment and action prioritization across seven key dimensions with hierarchically organized heuristics. Validation with two manufacturing organizations confirmed its practical utility as a strategic decision-making tool. However, at the same time this means that its generalizability across diverse industrial contexts may be limited. Additionally, the assessment relied primarily on practitioner perceptions rather than quantitative performance metrics, which may introduce subjective bias. Future research should expand validation across different manufacturing sectors, organizational sizes, and geographical regions to enhance generalizability. Longitudinal studies tracking organizations' progression through maturity levels may provide additional valuable

insights into the model's effectiveness as a transformation roadmap. Further work could also explore the correlation between NZMM implementation and quantifiable emission reductions, developing more objective assessment methodologies. Finally, research examining the interplay between regulatory frameworks and maturity progression would enhance the model's practical application in varying policy environments.

References

1. Crocco, E., Broccardo, L., Alofaysan, H., Agarwal, R.: Sustainability reporting in carbon-intensive industries: Insights from a cross-sector machine learning approach. Bus. Strategy Environ. (2024). https://doi.org/10.1002/bse.3850
2. Dohale, V., Ambilkar, P., Mangla, S.K., Narkhede, B.E.: Critical factors to sustaileanant innovations for net-zero achievement in the manufacturing supply chains. J. Clean. Prod. **455** (2024). https://doi.org/10.1016/j.jclepro.2024.142295
3. Rinaldi, L., Ghezzi, D., Colombo, E., Rocco, M.V.: Assessing environmental and market implications of steel decarbonisation strategies: a hybrid input-output model for the European union. Environ. Res. Lett. **19**(7) (2024). https://doi.org/10.1088/1748-9326/ad5bf1
4. Karlsson, I., et al.: Roadmap for decarbonization of the building and construction industry—a supply chain analysis including primary production of steel and cement. Energies (Basel) **13**(6) (2020). https://doi.org/10.3390/en13164136
5. Ghosh, D., Dutta, A., Dutta, M.: Impact of financial performance on environmental sustainability in the presence of credit constraints: evidence from Indian manufacturing firms. J. Sustain. Finan. Investment (2022). https://doi.org/10.1080/20430795.2022.2122688
6. Xie, Y., Chen, R., Yan, S.: Configuration effect of resource and capability factors on the business ecological advantage of electric vehicle enterprises. Renew. Sustain. Energy Rev. **210** (2025). https://doi.org/10.1016/j.rser.2024.115180
7. Okeke, I.J., Kamath, D., Nimbalkar, S.U., Cresko, J.: The role of low-carbon fuels and carbon capture in decarbonizing the U.S. clinker manufacturing for cement production: CO2 emissions reduction potentials. Energies (Basel) **17**(20) (2024). https://doi.org/10.3390/en17205233
8. Yadav, A., et al.: Unlocking net-zero supply chain performance system through life cycle assessment: empirical evidence from rubber industry. Heliyon (2024). https://www.cell.com/heliyon/fulltext/S2405-8440(24)15975-0
9. Yadav, A., et al.: Achieving net-zero in the manufacturing supply chain through carbon capture and LCA: a comprehensive framework with BWM-Fuzzy DEMATEL. Sustainability (Switz.) **16**(16) (2024). https://doi.org/10.3390/su16166972
10. Nodehi, M., Aguayo, F., Madey, N., Zhou, L.: A Comparative Review of Polymer, Bacterial-based, and Alkali-Activated (also Geopolymer) Binders: Production, Mechanical, Durability, and Environmental impacts (life cycle assessment (LCA)). Elsevier Ltd. (2024). https://doi.org/10.1016/j.conbuildmat.2024.135816
11. Qian, F., et al.: Deep decarbonization strategy for synergistic reduction of CO2 and air pollutant emissions in metropolises: a case study of Suzhou, China. Energy Sustain. Dev. **83** (2024). https://doi.org/10.1016/j.esd.2024.101575
12. Wen, C.M., Foster, C., van Winden, W., Ierapetritou, M.: Toward net-zero greenhouse gas emission: techno-economic and life cycle analyses of routes for Triacetic Acid Lactone (TAL) bioproduction. ACS Sustain. Chem. Eng. **12**(33), 12430–12445 (2024). https://doi.org/10.1021/acssuschemeng.4c03349
13. Gourvenec, S.: Offshore geotechnical challenges of the energy transition. Geomechanics for Energy and the Environment 39 (2024). https://doi.org/10.1016/j.gete.2024.100584

14. Buettner, S.M., Schneider, C., König, W., Mac Nulty, H., Piccolroaz, C., Sauer, A.: How do german manufacturers react to the increasing societal pressure for decarbonisation? Appl. Sci. (Switz.) **12**(2) (2022). https://doi.org/10.3390/app12020543
15. Monroy-Osorio, J.C.: Charting the digital route to net-zero: a framework for sustainable industry practices. Cleaner Logistics Supply Chain **13** (2024). https://doi.org/10.1016/j.clscn.2024.100191
16. Cox, R., Pagone, E., Jolly, M., Salonitis, K., Birch, T.: A bespoke carbon footprint framework to set the path towards Net Zero in foundries. In: IFAC-PapersOnLine, pp. 1084–1089. Elsevier B.V. (2024). https://doi.org/10.1016/j.procir.2024.10.210
17. Aris, N.M., Auzair, S.M.: Carbon management systems and environmental performance: the role of technological capability as a mediator. Jurnal Pengurusan **72** (2024). https://doi.org/10.17576/pengurusan-2024-72-1

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License (http://creativecommons.org/licenses/by-nc-nd/4.0/), which permits any noncommercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if you modified the licensed material. You do not have permission under this license to share adapted material derived from this chapter or parts of it.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.





https://dspace.org/

A structured framework for net zero transition in manufacturing

Kaur, Rashmeet; Patsavellas, John; Salonitis, Konstantinos

2025-09-10
Springer
https://doi.org/10.1007/978-3-032-21157-6_5
Kaur R, Patsavellas J, Salonitis K. (2026) A structured framework for net zero transition in manufacturing. In: Proceedings of the 21st Global Conference on Sustainable Manufacturing (GCSM 2025), 10-12 September 2025, Bologna, Italy, Volume 1, Lecture Notes in Mechanical Engineering, pp. 36-42

Downloaded from a DSpace repository. https://dspace.org/