From Sustainable Innovation to Sustainable Impact: Scale-Up, Life-Cycle Assessment and Techno-Economic Evaluation

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Abstract

Technologies are increasingly described as green, bio-based, circular, low-carbon, resource-efficient, or sustainable before their system-level consequences are known. Such labels can be useful hypotheses, but they are not evidence. This editorial argues that sustainability claims require quantitative evaluation of environmental burdens, material and energy flows, scale-up behaviour, and economic feasibility relative to realistic alternatives. Life-cycle assessment, carbon accounting, material-flow analysis, techno-economic analysis, process simulation, water and energy balances, sensitivity analysis, and uncertainty analysis provide complementary tools, but their conclusions depend on system boundaries, functional units, allocation rules, data quality, geographic context, market assumptions, and scale. Emerging technologies are especially difficult because laboratory data must be extrapolated toward uncertain industrial configurations. Research priorities should therefore include prospective life-cycle assessment, scale-up-aware modelling, harmonized inventories, regionalized evaluation, transparent uncertainty analysis, integrated environmental-economic optimization, and validation against pilot or commercial evidence. Sustainable impact should be claimed only when results remain credible across plausible scenarios and when comparisons use realistic incumbent technologies rather than idealized baselines.

Keywords: life-cycle assessment; techno-economic analysis; scale-up; sustainability assessment; uncertainty; process systems engineering; circularity metrics

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1.0 Introduction

1.1 Context and Problem Framing

Sustainability language has become pervasive across engineering and biotechnology. Processes are routinely described as green because they use renewable electricity, bio-based because they use biomass, circular because they recover a secondary stream, or low-carbon because a particular operating step emits less carbon dioxide. These descriptions may identify promising design features, but they do not establish the environmental performance of a complete system. Life-cycle assessment (LCA) was developed precisely because interventions can shift burdens among lifecycle stages and impact categories. ISO 14040 and ISO 14044 formalized principles for defining goals and scope, inventory analysis, impact assessment, and interpretation, while later scholarship has expanded LCA toward broader decision support (ISO, 2006a, 2006b; Guinée et al., 2011).

Economic feasibility creates a parallel evidentiary requirement. A technology with low modeled greenhouse-gas emissions may depend on expensive equipment, rare feedstocks, large subsidies, or unrealistic product prices; conversely, a low-cost process may externalize environmental burdens. Techno-economic analysis (TEA) translates process designs into capital, operating, and product-cost estimates and can identify which technical variables determine commercial viability. Process simulation, mass and energy balances, equipment sizing, and market assumptions are therefore inseparable from sustainability evaluation. For emerging technologies, these assessments are particularly valuable because they reveal which laboratory improvements would materially change industrial performance.

1.2 Why the Issue Matters

The difficulty is that early-stage systems are evaluated with incomplete data. Laboratory reactors use different materials, energy intensities, and operating modes from industrial plants; future electricity systems may differ from present grids; production scales may change reaction yields, separation requirements, and equipment efficiency; and market prices can vary substantially over development timescales. Prospective LCA has emerged to address these problems by explicitly modelling future or scaled configurations rather than assuming current laboratory inventories represent industrial systems (Arvidsson et al., 2018; Erakca et al., 2024). The central position advanced here is that sustainability should be treated as a quantitative system claim. Renewable inputs or promising laboratory efficiency can motivate analysis, but only integrated environmental and economic evidence can establish whether a technology is likely to create sustainable impact. Early-stage assessment literature similarly emphasizes anticipatory and development-oriented LCA as a way to influence design before technology choices become locked in (Hetherington et al., 2014; Wender et al., 2014).

2.0 Current Landscape

2.1 Laboratory Innovation

LCA remains the dominant framework for comparing environmental burdens across product systems. Contemporary practice has moved beyond simple carbon footprints toward multiple impact categories that can include climate change, resource use, acidification, eutrophication, toxicity, water use, land occupation, and other effects. Hellweg and Milà i Canals (2014) described LCA as an increasingly important decision-support tool while also emphasizing challenges involving data, spatial differentiation, uncertainty, and interpretation. Life-cycle methods are now routinely applied to energy systems, chemicals, biomaterials, food, waste management, and industrial biotechnology. Comprehensive LCA texts provide the methodological basis for interpreting inventory, impact assessment, and lifecycle trade-offs across sectors (Hauschild et al., 2018).

2.2 Pilot Development

Techno-economic analysis complements LCA by connecting process performance with capital and operating costs. In emerging technologies, mass and energy balances are translated into equipment size, utility demand, labour, maintenance, financing, and product-cost estimates. Sensitivity analysis then identifies which variables most strongly affect economic outcomes. Integrated TEA–LCA is especially important for bio-based and circular processes because environmental benefit can depend on yields, feedstock prices, co-product allocation, energy sources, and separation intensity. NREL process-design studies such as Humbird et al. (2011) illustrate how detailed engineering assumptions expose cost drivers that cannot be inferred from laboratory conversion yields alone. Standard chemical-engineering design methods remain important for equipment sizing and cost estimation, while transparent TEA guidelines seek to improve comparability among emerging technologies (Peters et al., 2003; Towler & Sinnott, 2021; Zimmermann et al., 2020).

2.3 Life-Cycle Assessment

Prospective and ex-ante assessment methods are increasingly used when technologies are not yet mature. Piccinno et al. (2016) proposed a framework for scaling laboratory processes toward industrial inventories for LCA, while Arvidsson et al. (2018) developed recommendations for environmental assessment of emerging technologies. More recent systematic review confirms that scale-up remains methodologically heterogeneous and can be a dominant source of uncertainty in prospective LCA (Erakca et al., 2024). Scenario databases and future-background modelling seek to align emerging technologies with plausible future electricity, transport, and material systems rather than embedding them in present-day contexts. Ex-ante case studies likewise show that prospective analysis is most useful when it explicitly represents immature technology characteristics and future operating conditions (Cucurachi et al., 2018; Villares et al., 2017).

2.4 Techno-Economic Assessment

Material-flow analysis, circularity metrics, carbon accounting, and water footprints add other dimensions. Material-flow analysis can reveal where resources accumulate or leave systems, while circularity indicators attempt to quantify recirculation, lifetime extension, recycled content, or value retention. Saidani et al. (2019) demonstrate the wide diversity of circular-economy indicators, which reflects both methodological richness and a lack of convergence. Water-footprint methods similarly highlight geographic and scarcity dimensions that global-average inventories can obscure. The current landscape is therefore characterized not by a single sustainability metric but by a toolkit whose methods answer different questions.

3.0 Critical Challenges

3.1 System-Boundary Choices

System-boundary and functional-unit choices remain foundational challenges. A comparison between technologies can reverse when one assessment includes infrastructure, waste treatment, land use, or co-product displacement and another does not. Functional units can privilege particular forms of performance: one kilogram of product, one megajoule of energy, one treatment service, or one year of functional use may lead to different conclusions. Reap et al. (2008) identified these methodological choices among persistent unresolved issues in LCA, and they remain especially important for multifunctional bio-based and circular systems.

Allocation is similarly consequential. Biorefineries, recycling systems, and waste-valorisation processes often generate multiple products. Environmental burdens can be partitioned by mass, energy, economic value, system expansion, or substitution assumptions. These choices are not merely technical details because they determine how benefits and burdens are distributed among co-products. Gaffey et al. (2024) show that biorefinery studies continue to use heterogeneous approaches to allocation, boundaries, end-of-life, land effects, and uncertainty, limiting direct comparability. Inventory-generation methods can also alter results substantially when emerging processes lack measured industrial data (Parvatker & Eckelman, 2019).

3.2 Uncertainty

Data quality and scale-up create a third challenge. Laboratory measurements can exaggerate energy and solvent use because equipment is small and poorly integrated, but they can also underestimate industrial burdens by ignoring utilities, cleaning, compression, storage, recycle loops, or off-spec production. Piccinno et al. (2016) therefore emphasized systematic scale-up rather than direct multiplication of laboratory inventories. Erakca et al. (2024) likewise identified a limited set of explicit scaling methods across prospective LCA studies. Without scale-aware modelling, early sustainability claims can be dominated by artefacts of experimental setup.

Geography and future background systems add uncertainty. Electricity carbon intensity, water scarcity, feedstock availability, labour costs, transport distances, and waste-management practices vary by location. An emerging technology evaluated against a current fossil-intensive grid may appear very different under a future renewable system, and the incumbent technology may also improve over the same period. Mendoza Beltran et al. (2020) demonstrated the importance of integrating future scenarios into background inventories. Comparisons should therefore evolve both the new technology and its reference system through plausible futures rather than granting innovation a static incumbent. Electricity-generation comparisons illustrate how technology conclusions can depend on the assumed background energy system (Raugei & Leccisi, 2016).

3.3 Lack of Scale-Up Evidence

Economic uncertainty can be equally large. Capital estimates at early technology-readiness levels rely on scaling factors, analogous equipment, preliminary quotations, and uncertain contingencies. Feedstock and product prices fluctuate, while financing assumptions can dominate capital-intensive processes. Environmental and economic optima may also conflict. A low-energy separation may require expensive materials; a high-yield route may depend on costly catalysts; a circular process may recover material that has little market value. Sensitivity and uncertainty analyses should therefore test whether conclusions survive plausible variation rather than presenting single deterministic values.

3.4 Market and Implementation Barriers

Finally, sustainability metrics can encourage false precision. A single carbon footprint or circularity score may conceal trade-offs involving toxicity, land, water, resource depletion, or economic viability. Circularity indicators can reward internal material loops even when those loops consume high energy or preserve low-value materials. Environmental assessment should therefore avoid reducing sustainability to one number unless the decision context genuinely supports such aggregation. Earlier work on sustainability metrics likewise cautioned that indicators should guide decisions without obscuring the assumptions and trade-offs embedded in them (Schwarz et al., 2002).

4.0 Discussion and Priorities

4.1 Integrative Discussion

Environmental and economic assessments should be treated as complementary views of the same engineered system. LCA asks where environmental burdens occur and how they compare with alternatives; TEA asks whether the system can plausibly be built and operated under economic constraints. Both rely on the same physical foundation: material balances, energy flows, yields, equipment, lifetime, and scale. Divergence between the two assessments is therefore informative. If environmental benefit requires a configuration that is economically implausible, implementation barriers are material to sustainability. If the cheapest configuration externalizes severe environmental costs, economic optimization alone is insufficient. Integrated environmental and techno-economic frameworks have therefore been proposed specifically to align maturity, process assumptions, and decision criteria across emerging technologies (Thomassen et al., 2019).

Scale-up is the bridge between laboratory innovation and both types of assessment. A process concept cannot be evaluated credibly without assumptions about industrial equipment, recovery, recycle, utilities, and capacity. Process simulation offers a structured way to make those assumptions explicit and internally consistent. Prospective assessment then allows analysts to represent learning, efficiency improvement, and changing background systems. The objective is not to predict one exact future plant, but to identify whether favorable conclusions persist across defensible design and scenario ranges.

Transparency is therefore central. Inventories, equations, allocation choices, equipment assumptions, price years, discount rates, scale factors, system boundaries, and uncertainty ranges should be reported sufficiently for independent interpretation. Björklund (2002) showed that uncertainty arises from data, models, choices, and epistemic limitations; hiding this uncertainty behind point estimates weakens decision relevance. Sustainability assessment should make uncertainty visible and use it to guide research priorities.

Complementary scholarship informing this synthesis includes International Organization for Standardization. (2006a); and International Organization for Standardization. (2006b). These works broaden the evidentiary base considered across the field.

4.2 Research and Practice Priorities

A first priority is harmonized assessment practice. Studies should define functional units, system boundaries, allocation procedures, treatment of co-products, infrastructure, and end-of-life assumptions explicitly. Where sector-specific conventions exist, authors should use or justify departures from them. Comparative studies should align assumptions between emerging and incumbent systems rather than using detailed data for one and simplified data for the other. Detailed TEA–LCA guidance also demonstrates the value of aligned terminology, maturity assumptions, and transparent reporting when environmental and economic analyses are conducted together (Zimmermann et al., 2022).

Second, prospective LCA should be combined with explicit scale-up models. Laboratory and pilot data should be transformed using engineering relationships for heat and mass transfer, equipment utilization, recovery efficiency, and utility integration. The recent review by Erakca et al. (2024) shows the need for more systematic scaling approaches. Analysts should report which variables are expected to change with scale and quantify the uncertainty introduced by those assumptions.

Third, environmental and techno-economic models should share a common process representation. Mass and energy balances should feed both assessments so that changes in yield, recycle, solvent recovery, equipment choice, or energy source propagate consistently. Integrated optimization can then identify designs that improve environmental performance without simply transferring cost, or reduce cost without creating disproportionate environmental burden.

Fourth, uncertainty and sensitivity analysis should become mandatory for strong sustainability claims. Monte Carlo analysis, scenario analysis, global sensitivity methods, or other appropriate techniques should show which uncertain inputs control conclusions. Heijungs and Huijbregts (2004) demonstrated the value of formal uncertainty propagation in LCA; similar discipline should extend to integrated TEA–LCA. Claims should distinguish robust conclusions from outcomes that depend on narrow parameter assumptions. Reviews of LCA practice show that uncertainty analysis is still underused despite substantial parameter, scenario, and model uncertainty; global and sparse-representation methods can help identify the inputs that actually drive conclusions (Bamber et al., 2020; Bisinella et al., 2016; Huijbregts, 1998).

Fifth, regionalization and future scenarios should be expanded. Electricity, water, land, transport, waste treatment, and feedstock systems vary geographically and will change over the lifetime of emerging technologies. Prospective databases and scenario tools can help align background systems with realistic deployment dates (Mendoza Beltran et al., 2020). Regional assessment is particularly important for biomass, water-intensive processes, and technologies whose value depends on local waste streams.

Sixth, transparent inventories and open models should be encouraged where commercial and legal constraints permit. Reproducible spreadsheets, process models, inventory tables, and code improve scrutiny and allow future studies to update assumptions rather than rebuild analyses. Confidential industrial data can be aggregated or parameterized, but the structure of the model should remain interpretable.

Finally, assessment should be validated against pilot and commercial evidence whenever possible. Retrospective comparison between projected and observed performance can reveal systematic bias in scale-up, cost factors, utilization, and utility estimates. Sustainability assessment should become an iterative engineering discipline in which predictions are updated as technology maturity increases.

4.3 Implications for the Journal's Scope

The journal should require sustainability claims to be proportionate to the evidence presented. Laboratory use of a renewable feedstock or lower temperature is not sufficient basis for describing a technology as sustainable when major lifecycle stages, utilities, or economic constraints remain unexamined. Strong manuscripts will state clearly whether they demonstrate process performance, estimate future sustainability, or validate environmental and economic outcomes at pilot or industrial scale. Green-chemistry LCA research has made the same point: qualitative claims of environmental improvement should be tested quantitatively against complete process alternatives (Tufvesson et al., 2013).

Particularly valuable contributions include prospective LCA, integrated TEA–LCA, scale-up methodology, process-systems modelling, uncertainty analysis, regionalized assessment, circularity metrics, material-flow analysis, water and energy accounting, and comparative evaluations against realistic incumbents. Studies that reveal unfavorable

trade-offs should be welcomed because they prevent premature claims and identify where engineering improvements are actually needed. Quantitative transparency should be the foundation for sustainability language.

4.4 Conclusion

Sustainable innovation is not established by terminology. Renewable, biological, circular, low-carbon, and resource-efficient technologies can all create substantial environmental or economic burdens when assessed across complete systems. The purpose of lifecycle and techno-economic methods is therefore not to decorate promising technologies with additional metrics, but to test whether their underlying claims survive scale-up, comparison, and uncertainty.

The strongest evaluations will connect material and energy balances with environmental impacts, capital and operating costs, realistic incumbent technologies, geographic conditions, and future scenarios. They will state clearly where data are measured, where they are modelled, and which assumptions determine outcomes. As technologies mature, assessments should be updated against pilot and commercial evidence. Sustainable impact begins when environmental and economic performance is demonstrated quantitatively at the system level—not when a technology first acquires a sustainable label.

5.0 Declarations

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Dr. Priya Menon and Dr. Lucas Ferreira contributed to the conceptual development, literature synthesis, critical interpretation, drafting, and revision of the editorial.

5.2 Funding

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5.3 Competing Interests

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5.4 Data Availability

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5.5 AI Use Disclosure

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6.0 References

Arvidsson, R., Tillman, A.-M., Sandén, B. A., Janssen, M., Nordelöf, A., Kushnir, D., & Molander, S. (2018). Environmental assessment of emerging technologies: Recommendations for prospective LCA. Journal of Industrial Ecology, 22(6), 1286–1294. https://doi.org/10.1111/jiec.12690

Bamber, N., Turner, I., Arulnathan, V., Li, Y., Zargar Ershadi, S., Smart, A., & Pelletier, N. (2020). Comparing sources and analysis of uncertainty in consequential and attributional life cycle assessment: Review of current practice and recommendations. International Journal of Life Cycle Assessment, 25, 168–180. https://doi.org/10.1007/s11367-019-01663-1

Bisinella, V., Conradsen, K., Christensen, T. H., & Astrup, T. F. (2016). A global approach for sparse representation of uncertainty in life cycle assessments of waste management systems. International Journal of Life Cycle Assessment, 21(3), 378–394. https://doi.org/10.1007/s11367-015-1014-4

Björklund, A. E. (2002). Survey of approaches to improve reliability in LCA. International Journal of Life Cycle Assessment, 7, 64–72. https://doi.org/10.1007/BF02978849

Cucurachi, S., van der Giesen, C., & Guinée, J. (2018). Ex-ante LCA of emerging technologies. Procedia CIRP, 69, 463–468. https://doi.org/10.1016/j.procir.2017.11.005

Erakca, M., Baumann, M., Helbig, C., & Weil, M. (2024). Systematic review of scale-up methods for prospective life cycle assessment of emerging technologies. Journal of Cleaner Production, 451, 142161. https://doi.org/10.1016/j.jclepro.2024.142161

Gaffey, J., Collins, M. N., & Styles, D. (2024). Review of methodological decisions in life cycle assessment (LCA) of biorefinery systems across feedstock categories. Journal of Environmental Management, 358, 120813. https://doi.org/10.1016/j.jenvman.2024.120813

Guinée, J. B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., Ekvall, T., & Rydberg, T. (2011). Life cycle assessment: Past, present, and future. Environmental Science & Technology, 45(1), 90–96. https://doi.org/10.1021/es101316v

Hauschild, M. Z., Rosenbaum, R. K., & Olsen, S. I. (Eds.). (2018). Life Cycle Assessment: Theory and Practice. Springer. https://doi.org/10.1007/978-3-319-56475-3

Heijungs, R., & Huijbregts, M. A. J. (2004). A review of approaches to treat uncertainty in LCA. In Proceedings of the 2nd International Congress on Environmental Modelling and Software (iEMSs), Osnabrück, Germany. https://scholarsarchive.byu.edu/iemssconference/2004/all/197/

Hellweg, S., & Milà i Canals, L. (2014). Emerging approaches, challenges and opportunities in life cycle assessment. Science, 344(6188), 1109–1113. https://doi.org/10.1126/science.1248361

Hetherington, A. C., Borrion, A. L., Griffiths, O. G., & McManus, M. C. (2014). Use of LCA as a development tool within early research: Challenges and issues across different sectors. International Journal of Life Cycle Assessment, 19, 130–143. https://doi.org/10.1007/s11367-013-0627-8

Huijbregts, M. A. J. (1998). Application of uncertainty and variability in LCA. Part I: A general framework for the analysis of uncertainty and variability in life cycle assessment. International Journal of Life Cycle Assessment, 3(5), 273–280. https://doi.org/10.1007/BF02979835

Humbird, D., Davis, R., Tao, L., Kinchin, C., Hsu, D., Aden, A., Schoen, P., Lukas, J., Olthof, B., Worley, M., Sexton, D., & Dudgeon, D. (2011). Process design and economics for biochemical conversion of lignocellulosic biomass to ethanol. National Renewable Energy Laboratory. https://doi.org/10.2172/1013269

International Organization for Standardization. (2006a). ISO 14040:2006 Environmental management—Life cycle assessment—Principles and framework. ISO.

International Organization for Standardization. (2006b). ISO 14044:2006 Environmental management—Life cycle assessment—Requirements and guidelines. ISO.

Mendoza Beltran, A., Cox, B., Mutel, C., van Vuuren, D. P., Vivanco, D. F., Deetman, S., Edelenbosch, O. Y., Guinée, J., & Tukker, A. (2020). When the background matters: Using scenarios from integrated assessment models in prospective life cycle assessment. Journal of Industrial Ecology, 24(1), 64–79. https://doi.org/10.1111/jiec.12825

Parvatker, A. G., & Eckelman, M. J. (2019). Comparative evaluation of chemical life cycle inventory generation methods and implications for life cycle assessment results. ACS Sustainable Chemistry & Engineering, 7(1), 350–367. https://doi.org/10.1021/acssuschemeng.8b03656

Peters, M. S., Timmerhaus, K. D., & West, R. E. (2003). Plant Design and Economics for Chemical Engineers (5th ed.). McGraw-Hill.

Piccinno, F., Hischier, R., Seeger, S., & Som, C. (2016). From laboratory to industrial scale: A scale-up framework for chemical processes in life cycle assessment studies. Journal of Cleaner Production, 135, 1085–1097. https://doi.org/10.1016/j.jclepro.2016.06.164

Raugei, M., & Leccisi, E. (2016). A comprehensive assessment of the energy performance of the full range of electricity generation technologies deployed in the United Kingdom. Energy Policy, 90, 46–59. https://doi.org/10.1016/j.enpol.2015.12.011

Reap, J., Roman, F., Duncan, S., & Bras, B. (2008). A survey of unresolved problems in life cycle assessment. Part 1: Goal and scope and inventory analysis. International Journal of Life Cycle Assessment, 13, 290–300. https://doi.org/10.1007/s11367-008-0008-x

Saidani, M., Yannou, B., Leroy, Y., Cluzel, F., & Kendall, A. (2019). A taxonomy of circular economy indicators. Journal of Cleaner Production, 207, 542–559. https://doi.org/10.1016/j.jclepro.2018.10.014

Schwarz, J., Beloff, B., & Beaver, E. (2002). Use sustainability metrics to guide decision-making. Chemical Engineering Progress, 98(7), 58–63.

Thomassen, G., Van Dael, M., Van Passel, S., & You, F. (2019). How to assess the potential of emerging green technologies? Towards a prospective environmental and techno-economic assessment framework. Green Chemistry, 21, 4868–4886. https://doi.org/10.1039/C9GC02223F

Towler, G., & Sinnott, R. (2021). Chemical Engineering Design: Principles, Practice and Economics of Plant and Process Design (3rd ed.). Elsevier.

Tufvesson, L. M., Tufvesson, P., Woodley, J. M., & Börjesson, P. (2013). Life cycle assessment in green chemistry: Overview of key parameters and methodological concerns. International Journal of Life Cycle Assessment, 18, 431–444. https://doi.org/10.1007/s11367-012-0500-1

Villares, M., Işildar, A., van der Giesen, C., & Guinée, J. (2017). Does ex ante application enhance the usefulness of LCA? A case study on an emerging technology for metal recovery from e-waste. International Journal of Life Cycle Assessment, 22, 1618–1633. https://doi.org/10.1007/s11367-017-1270-6

Wender, B. A., Foley, R. W., Hottle, T. A., Sadowski, J., Prado-Lopez, V., Eisenberg, D. A., Laurin, L., & Seager, T. P. (2014). Anticipatory life-cycle assessment for responsible research and innovation. Journal of Responsible Innovation, 1(2), 200–207. https://doi.org/10.1080/23299460.2014.920121

Zimmermann, A. W., Wunderlich, J., Müller, L., Buchner, G. A., Marxen, A., Michailos, S., Armstrong, K., Naims, H., McCord, S., Styring, P., Sick, V., & Schomäcker, R. (2020). Techno-economic assessment guidelines for CO_2 utilization. Frontiers in Energy Research, 8, 5. https://doi.org/10.3389/fenrg.2020.00005

Zimmermann, A., Müller, L., Wang, Y., Langhorst, T., Wunderlich, J., Marxen, A., & Armstrong, K. (2022). Techno-economic assessment and life cycle assessment guidelines for CO_2 utilization. Global CO_2 Initiative, University of Michigan.