References

Åkre, T. (2008). *Electrowinning of Cobalt from Chloride Solutions: Anodic Deposition of Cobalt Oxide on DSA®—PhD Thesis*. NTNU. https://core.ac.uk/download/pdf/30885464.pdf

Aramendia, E., Brockway, P. E., Taylor, P. G., & Norman, J. (2023). Global energy consumption of the mineral mining industry: Exploring the historical perspective and future pathways to 2060. *Global Environmental Change*, *83*, 102745. https://doi.org/10.1016/j.gloenvcha.2023.102745

Arvidsson, R., Svanström, M., Sandén, B. A., Thonemann, N., Steubing, B., & Cucurachi, S. (2024). Terminology for future-oriented life cycle assessment: Review and recommendations. *The International Journal of Life Cycle Assessment*, *29*(4), 607–613. https://doi.org/10.1007/s11367-023-02265-8

Arvidsson, R., Tillman, A., 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

Azapagic, A. (1999). Life cycle assessment and its application to process selection, design and optimisation. *Chemical Engineering Journal*, *73*(1), 1–21. https://doi.org/10.1016/S1385-8947(99)00042-X

Bałdowska-Witos, P., Piotrowska, K., Kruszelnicka, W., Błaszczak, M., Tomporowski, A., Opielak, M., Kasner, R., & Flizikowski, J. (2020). Managing the Uncertainty and Accuracy of Life Cycle Assessment Results for the Process of Beverage Bottle Moulding. *Polymers*, *12*(6), Article 6. https://doi.org/10.3390/polym12061320

Battisti, R., & Corrado, A. (2005). Evaluation of technical improvements of photovoltaic systems through life cycle assessment methodology. *Energy*, *30*(7), 952–967. https://doi.org/10.1016/j.energy.2004.07.011

Baumstark, L., Bauer, N., Benke, F., Bertram, C., Bi, S., Gong, C. C., Dietrich, J. P., Dirnaichner, A., Giannousakis, A., Hilaire, J., Klein, D., Koch, J., Leimbach, M., Levesque, A., Madeddu, S., Malik, A., Merfort, A., Merfort, L., Odenweller, A., … Luderer, G. (2021). REMIND2.1: Transformation and innovation dynamics of the energy-economic system within climate and sustainability limits. *Geoscientific Model Development*, *14*(10), 6571–6603. https://doi.org/10.5194/gmd-14-6571-2021

British Geological Survey. (2019). *Cobalt commodity review*. British Geological Survey. https://www2.bgs.ac.uk/downloads/start.cfm?id=3565

Calvo, G., Mudd, G., Valero, Alicia, & Valero, Antonio. (2016). Decreasing Ore Grades in Global Metallic Mining: A Theoretical Issue or a Global Reality?

Resources, *5*(4), 36. https://doi.org/10.3390/resources5040036
Cao, Z., & Masanet, E. (2022). Material efficiency to tackle the sand crisis. *Nature Sustainability*, *5*(5), 370–371. https://doi.org/10.1038/s41893-022-00869-w
Chapman, P. F., & Roberts, F. (1983). *Metal Resources and Energy*. Butterworth. https://doi.org/10.1016/C2013-0-04151-5
Climate Watch. (2024). *Climate Watch data* [Dataset]. https://www.climatewatchdata.org
Cobalt Institute. (2015). *Cobalt facts—10 Supply & Demand 2014*. https://web.archive.org/web/20161220220950/http://www.thecdi.com/cdi/images/documents/facts/Cobalt%20Facts%20-%20Supply%20%20Demand%20-%2014.pdf
Cobalt Institute. (2016). *The Environmental Performance of Refined Cobalt—Life Cycle Inventory and Life Cycle Assessment of Refined Cobalt—Summary Report*. Cobalt Institute. https://www.cobaltinstitute.org/life-cycle-assessment.html
Colomb, V., Ait Amar, S., Mens, C. B., Gac, A., Gaillard, G., Koch, P., Mousset, J., Salou, T., Tailleur, A., & Van Der Werf, H. M. G. (2015). AGRIBALYSE® , the French LCI Database for agricultural products: High quality data for producers and environmental labelling. *OCL*, *22*(1), D104. https://doi.org/10.1051/ocl/20140047
Crundwell, Moats, Ramachandran, Robinson, & Davenport. (2011). *Extractive Metallurgy of Nickel, Cobalt and Platinum Group Metals*. Elsevier. https://doi.org/10.1016/C2009-0-63541-8
Cucurachi, S., Giesen van der, 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
de Bortoli, A., Chanel, A., Chabas, C., Greffe, T., & Louineau, E. (2025). More Rationality and Inclusivity are Imperative in Reference Transition Scenarios Based on Iams and Shared Socioeconomic Pathways—Recommendations for Prospective Lca. *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2025.115924
Deetman, S., Marinova, S., Van Der Voet, E., Van Vuuren, D. P., Edelenbosch, O., & Heijungs, R. (2020). Modelling global material stocks and flows for residential and service sector buildings towards 2050. *Journal of Cleaner Production*, *245*, 118658. https://doi.org/10.1016/j.jclepro.2019.118658
Deetman, S., Pauliuk, S., van Vuuren, D. P., van der Voet, E., & Tukker, A. (2018). Scenarios for Demand Growth of Metals in Electricity Generation Technologies, Cars, and Electronic Appliances. *Environmental Science & Technology*, *52*(8), 4950–4959. https://doi.org/10.1021/acs.est.7b05549
Dehaine, Q., Tijsseling, L. T., Glass, H. J., Törmänen, T., & Butcher, A. R. (2021). Geometallurgy of cobalt ores: A review. *Minerals Engineering*, *160*, 106656.

https://doi.org/10.1016/j.mineng.2020.106656

Dente, S. M. R., Aoki-Suzuki, C., Tanaka, D., & Hashimoto, S. (2018). Revealing the life cycle greenhouse gas emissions of materials: The Japanese case. *Resources, Conservation and Recycling*, *133*, 395–403. https://doi.org/10.1016/j.resconrec.2017.12.011

Dietzenbacher, E., Van Burken, B., & Kondo, Y. (2019). Hypothetical extractions from a global perspective. *Economic Systems Research*, *31*(4), 505–519. https://doi.org/10.1080/09535314.2018.1564135

Duan, W., Li, P., Wu, Q., & Song, H. (2022). Life cycle assessment of a novel blast furnace slag utilization system. *Energy*, *251*, 123900. https://doi.org/10.1016/j.energy.2022.123900

EC. (2022). *Environmental Footprint (EF) 3.1* [Dataset]. https://eplca.jrc.ec.europa.eu/LCDN/developerEF.html

Eksi, G., & Karaosmanoglu, F. (2018). Life cycle assessment of combined bioheat and biopower production: An eco-design approach. *Journal of Cleaner Production*, *197*, 264–279. https://doi.org/10.1016/j.jclepro.2018.06.151

Elsherief, A. E. (2003). Effects of cobalt, temperature and certain impurities upon cobalt electrowinning from sulfate solutions. *Journal of Applied Electrochemistry*, *33*(1), 43–49. https://doi.org/10.1023/A:1022938824111

Elshkaki, A., Graedel, T. E., Ciacci, L., & Reck, B. K. (2018). Resource Demand Scenarios for the Major Metals. *Environmental Science & Technology*, *52*(5), 2491–2497. https://doi.org/10.1021/acs.est.7b05154

EN. (2019). *EN15804+A2: Sustainability of construction works—Environmental product declarations—Core rules for the product category of construction products.* https://eplca.jrc.ec.europa.eu/LCDN/EN15804.html

European Commission. (2013). *2013/179/EU: Commission Recommendation of 9 April 2013 on the use of common methods to measure and communicate the life cycle environmental performance of products and organisations.* https://eur-lex.europa.eu/eli/reco/2013/179/oj

Farjana, S. H., Huda, N., & Mahmud, M. A. P. (2019). Life cycle assessment of cobalt extraction process. *Journal of Sustainable Mining*, *18*(3), 150–161. https://doi.org/10.1016/j.jsm.2019.03.002

Frischknecht, R., Althaus, H.-J., Bauer, C., Doka, G., Heck, T., Jungbluth, N., Kellenberger, D., & Nemecek, T. (2007). The Environmental Relevance of Capital Goods in Life Cycle Assessments of Products and Services. *The International Journal of Life Cycle Assessment*, 11. https://doi.org/10.1065/lca2007.02.309

Gebremariam, A. T., Di Maio, F., Vahidi, A., & Rem, P. (2020). Innovative technologies for recycling End-of-Life concrete waste in the built environment. *Resources, Conservation and Recycling*, *163*, 104911. https://doi.org/10.1016/j.resconrec.2020.104911

GHG Protocol. (2004). *GHG Protocol—A Corporate Accounting and Reporting Standard*. https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf

Giljum, S., Hinterberger, F., Bruckner, M., Burger, E., Fruhmann, J., Lutter, S., Pirgmaier, E., Polzin, C., Waxwender, H., Kernegger, L., & Warhust, M. (2000). *Overconsumption? Our use of the world's natural resources*. SERI. https://dl.icdst.org/pdfs/files2/263d94705b1db13330192f3a57d693f7.pdf

Gorrée, M., Guinée, J., Huppes, G., & Oers, L. van. (2002). Environmental life cycle assessment of linoleum. *The International Journal of Life Cycle Assessment*, *7*(3), 158–166. https://doi.org/10.1007/BF02994050

Guinée, J., Huppes, G., de Koning, A., van Oers, L., Sleeswijk, A. W., & Suh, S. (2002). *Handbook On Life Cycle Assessment*. https://link.springer.com/book/10.1007/0-306-48055-7

Gütschow, J., & Pflüger, M. (2023). *The PRIMAP-hist national historical emissions time series 1750-2022* (Version 2.5) [Dataset]. https://doi.org/10.5281/zenodo.10006301

Haddad, E. A., Perobelli, F. S., Araújo, I. F., & Bugarin, K. S. S. (2021). Structural propagation of pandemic shocks: An input–output analysis of the economic costs of COVID-19. *Spatial Economic Analysis*, *16*(3), 252–270. https://doi.org/10.1080/17421772.2020.1844284

Harper, E. M., Kavlak, G., & Graedel, T. E. (2012). Tracking the Metal of the Goblins: Cobalt's Cycle of Use. *Environmental Science & Technology*, *46*(2), 1079–1086. https://doi.org/10.1021/es201874e

Harpprecht, C., Miranda Xicotencatl, B., van Nielen, S., van der Meide, M., Li, C., Li, Z., Tukker, A., & Steubing, B. (2024). Future environmental impacts of metals: A systematic review of impact trends, modelling approaches, and challenges. *Resources, Conservation and Recycling*, *205*, 107572. https://doi.org/10.1016/j.resconrec.2024.107572

Harpprecht, C., Sacchi, R., Naegler, T., Van Sluisveld, M., Daioglou, V., Tukker, A., & Steubing, B. (2025). Future environmental impacts of global iron and steel production. *Energy & Environmental Science*, *18*(16), 8009–8028. https://doi.org/10.1039/D5EE01356A

Harpprecht, C., Yang, Y., van Oers, L., & Steubing, B. (2021). Environmental impacts of key metals' supply and low-carbon technologies are likely to decrease in the future. *Journal of Industrial Ecology*. https://doi.org/10.1111/jiec.13181

Hauschild, M. Z., & Huijbregts, M. A. J. (Eds.). (2015). *Life Cycle Impact Assessment*. Springer Netherlands. https://doi.org/10.1007/978-94-017-9744-3

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

Heijungs, R. (2024). *Probability, Statistics and Life Cycle Assessment: Guidance for*

Dealing with Uncertainty and Sensitivity. Springer International Publishing. https://doi.org/10.1007/978-3-031-49317-1

Heijungs, R., Guinée, J., Huppes, G., Lankreijer, R. M., de Haes, U., Sleeswijk, A. W., Eggels, P. G., Duin, R., & Goede, H. P. (1992). *Environmental life cycle assessment of products*. Centre of Environmental Science. https://hdl.handle.net/1887/8061

Heijungs, R., & Kleijn, R. (2001). Numerical approaches towards life cycle interpretation five examples. *The International Journal of Life Cycle Assessment*, *6*(3), 141. https://doi.org/10.1007/BF02978732

Heijungs, R., & Suh, S. (2002). *The computational structure of life cycle assessment*. Springer. https://link.springer.com/book/10.1007/978-94-015-9900-9

Heijungs, R., Yang, Y., & Park, H. (2022). **A** or **I** - **A** ? Unifying the computational structures of process- and IO-based LCA for clarity and consistency. *Journal of Industrial Ecology*, *26*(5), 1824–1836. https://doi.org/10.1111/jiec.13323

Hertwich, E. G. (2021). Increased carbon footprint of materials production driven by rise in investments. *Nature Geoscience*, *14*(3), 151–155. https://doi.org/10.1038/s41561-021-00690-8

Hertwich, E. G., Koslowski, M., & Rasul, K. (2024). Linking hypothetical extraction, the accumulation of production factors, and the addition of value. *Journal of Industrial Ecology*, *28*(4), 736–750. https://doi.org/10.1111/jiec.13522

Hesser, F., Mihalic, M., Paichl, B. J., & Wagner, M. (2017). Injection moulding unit process for LCA: Energy intensity of manufacturing different materials at different scales. *Journal of Reinforced Plastics and Composites*, *36*(5), 338–346. https://doi.org/10.1177/0731684416674565

Hirschberg, S., Bauer, C., Burgherr, P., Dones, R., Heck, T., Schenler, W., & Simons, A. (2009). *New Energy Externalities Developments for Sustainability (NEEDS)*. Paul Scherrer Institut. https://www.psi.ch/en/ta/projects/new-energy-externalities-developments-for-sustainability-needs

Huijbregts, M. (2016). *ReCiPe 2016 A harmonized life cycle impact assessment method at midpoint and endpoint level* (RIVM Report 2016-0104). National Institute for Public Healthand the Environment - The Netherlands. https://www.rivm.nl/bibliotheek/rapporten/2016-0104.pdf

Hummen, T., & Kästner, F. (2014). Evaluating Existing Methodological Approaches for Prospective LCA at Early Technology-Development Stages. *San Francisco Proceedings*. LCA XIV International Conference, American Center for Life Cycle Assessment, San Francisco. https://d1wqtxts1xzle7.cloudfront.net/43672956/Life_Cycle_Thinking_in_US_Biofuel_Polici20160312-12648-1xiaj10-libre.pdf?1457845625=&response-content-disposition=inline%3B+filename%3DLife_Cycle_Thinking_in_US_Biofuel_Polici.pdf&Expires=1752145775&Signature=b9alghCnhKRw-3KuevaifCqcucbA2794Y67Iu9fq

zmJAniVVzmaDlUOJzj5YHfCDfXXWgYY1kDkQjfO5Lh~WdLt8pwvlgwOYL~UpS~OH~kanE7i9c3UF~uQ5xMUwVJMqEE8uU~Dn2XzyNXxnTqZ~aaSHq-RtTufQJXFiLpHpdaUiA3-3EX0qLHMLZmw5vNTPd72h8EaPV7HtaRFgo8~4X81wuShMgXVcAjG4OoUg-wFkT1VHOzS4GDWi9Y7ROxs8z2klW7saqJLVwCB9FacoPAgOZ1betM1MQrmD6yYU--Xu8dz8AP4R0moxgZP~OR8PtvBQ3qTECEa9wTaTOYt1ng__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA#page=25

Ioannidou, D., Meylan, G., Sonnemann, G., & Habert, G. (2017). Is gravel becoming scarce? Evaluating the local criticality of construction aggregates. *Resources, Conservation and Recycling*, *126*, 25–33. https://doi.org/10.1016/j.resconrec.2017.07.016

IPCC. (2014). Climate Change 2013 – The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *Cambridge: Cambridge University Press*. https://doi.org/10.1017/CBO9781107415324

IPCC. (2022). *AR6 Synthesis Report: Climate Change 2022 — IPCC*. https://www.ipcc.ch/report/sixth-assessment-report-cycle/

ISO. (2006). *ISO 14044:2006 Environmental management—Life cycle assessment—Requirements and guidelines*. ISO. https://www.iso.org/standard/38498.html

ISO. (2018). *ISO 14064:2018 Greenhouse gases Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals*. https://www.iso.org/standard/66453.html

James, K., & Galatola, M. (2015). *Screening and hotspot analysis: Procedure to identify the hotspots and the most relevant contributions (in terms of, impact categories, life cycle stages, processes and flows)* (Version 4). European Commission. https://webgate.ec.europa.eu/fpfis/wikis/display/EUENVFP/Documents+of+common+interest?preview=%2F66618509%2F101648875%2FHotspot+Analysis+version+4.0.docx

JRC (with Schau, E. M., Castellani, V., Fazio, S., Diaconu, E., Sala, S., Zampori, L., & Secchi, M.). (2018). *Supporting information to the characterisation factors of recommended EF Life Cycle Impact Assessment methods: New methods and differences with ILCD*. Publications Office of the European Union. https://data.europa.eu/doi/10.2760/671368

Junne, T., Wulff, N., Breyer, C., & Naegler, T. (2020). Critical materials in global low-carbon energy scenarios: The case for neodymium, dysprosium, lithium, and cobalt. *Energy*, *211*, 118532. https://doi.org/10.1016/j.energy.2020.118532

Klöpffer, W., & Grahl, B. (2014). *Life Cycle Assessment (LCA): A Guide to Best Practice*. Wiley-VCH Verlag GmbH & Co. KGaA. https://onlinelibrary.wiley.com/doi/book/10.1002/9783527655625

Krausmann, F., Wiedenhofer, D., Lauk, C., Haas, W., Tanikawa, H., Fishman, T., Miatto, A., Schandl, H., & Haberl, H. (2017). Global socioeconomic material stocks rise 23-fold over the 20th century and require half of annual resource use. *Proceedings of the National Academy of Sciences*, *114*(8), 1880–1885. https://doi.org/10.1073/pnas.1613773114

Laurent, A., Weidema, B. P., Bare, J., Liao, X., Maia de Souza, D., Pizzol, M., Sala, S., Schreiber, H., Thonemann, N., & Verones, F. (2020). Methodological review and detailed guidance for the life cycle interpretation phase. *Journal of Industrial Ecology*, *24*(5), 986–1003. https://doi.org/10.1111/jiec.13012

Leccisi, E., & Fthenakis, V. (2021). Life cycle energy demand and carbon emissions of scalable single-junction and tandem perovskite PV. *Progress in Photovoltaics: Research and Applications*, *29*(10), 1078–1092. https://doi.org/10.1002/pip.3442

Lenzen, M., & Crawford, R. (2009). The Path Exchange Method for Hybrid LCA. *Environmental Science & Technology*, *43*(21), 8251–8256. https://doi.org/10.1021/es902090z

Lesage, P., & Mutel, C. (2019). *Presamples* (Version 0.2.3) [Python]. https://github.com/cmutel/presamples

Li, H., Gong, X. Z., Wang, Z. H., & Li, Y. (2017). Life Cycle Assessment of Cathode Copper Production. *Materials Science Forum*, *898*, 2422–2431. https://doi.org/10.4028/www.scientific.net/MSF.898.2422

Lotfi, S., Rem, P., Deja, J., & Mróz, R. (2017). An experimental study on the relation between input variables and output quality of a new concrete recycling process. *Construction and Building Materials*, *137*, 128–140. https://doi.org/10.1016/j.conbuildmat.2017.01.085

Majeau-Bettez, G., Wood, R., & Strømman, A. H. (2014). Unified Theory of Allocations and Constructs in Life Cycle Assessment and Input-Output Analysis. *Journal of Industrial Ecology*, *18*(5), 747–770. https://doi.org/10.1111/jiec.12142

Memary, R., Giurco, D., Mudd, G., & Mason, L. (2012). Life cycle assessment: A time-series analysis of copper. *Journal of Cleaner Production*, *33*, 97–108. https://doi.org/10.1016/j.jclepro.2012.04.025

Mendoza Beltran, A., Cox, B., Mutel, C., Vuuren, D. P., Font Vivanco, D., Deetman, S., Edelenbosch, O. Y., Guinée, J., & Tukker, A. (2018). When the Background Matters: Using Scenarios from Integrated Assessment Models in Prospective Life Cycle Assessment. *Journal of Industrial Ecology*, jiec.12825. https://doi.org/10.1111/jiec.12825

Miller, R. E., & Lahr, M. L. (2001). A Taxonomy of Extractions. *Regional Science Perspectives in Economic Analysis*, 407–441.

Miller, S. A., & Keoleian, G. A. (2015). Framework for Analyzing Transformative Technologies in Life Cycle Assessment. *Environmental Science & Technology*, 49(5), 3067–3075. https://doi.org/10.1021/es505217a

Mudd, G. M., Weng, Z., Jowitt, S. M., Turnbull, I. D., & Graedel, T. E. (2013).

Quantifying the recoverable resources of by-product metals: The case of cobalt. *Ore Geology Reviews*, *55*, 87–98. https://doi.org/10.1016/j.oregeorev.2013.04.010

Mulaudzi, N., & Kotze, M. H. (2013). *Direct cobalt electrowinning as an alternative to intermediate cobalt mixed hydroxide product*. 14. https://www.saimm.co.za/Conferences/BM2013/209-Mulaudzi.pdf

Müller, A., Diepers, T., Jakobs, A., Cardellini, G., Von Der Assen, N., Guinée, J., & Steubing, B. (2025). Time-explicit life cycle assessment: A flexible framework for coherent consideration of temporal dynamics. *The International Journal of Life Cycle Assessment*. https://doi.org/10.1007/s11367-025-02539-3

Müller, A., Harpprecht, C., Sacchi, R., Maes, B., Van Sluisveld, M., Daioglou, V., Šavija, B., & Steubing, B. (2024). Decarbonizing the cement industry: Findings from coupling prospective life cycle assessment of clinker with integrated assessment model scenarios. *Journal of Cleaner Production*, *450*, 141884. https://doi.org/10.1016/j.jclepro.2024.141884

Mutel, C. (2017a). Brightway: An open source framework for Life Cycle Assessment. *Journal of Open Source Software*, *2*(12), 236. https://doi.org/10.21105%2Fjoss.00236

Mutel, C. (2017b). *Wurst* [Computer software]. https://wurst.readthedocs.io/

Nansai, K., Nakajima, K., Kagawa, S., Kondo, Y., Suh, S., Shigetomi, Y., & Oshita, Y. (2014). Global Flows of Critical Metals Necessary for Low-Carbon Technologies: The Case of Neodymium, Cobalt, and Platinum. *Environmental Science & Technology*, *48*(3), 1391–1400. https://doi.org/10.1021/es4033452

Niero, M., Ingvordsen, C. H., Jørgensen, R. B., & Hauschild, M. Z. (2015). How to manage uncertainty in future Life Cycle Assessment (LCA) scenarios addressing the effect of climate change in crop production. *Journal of Cleaner Production*, *107*, 693–706. https://doi.org/10.1016/j.jclepro.2015.05.061

Noh, J., Suh, S. W., & Lee, K. M. (1998). *Methods for the Key Issue ldentifïcation in Life Cycle Assessment*. 59–62. https://www.gbv.de/dms/tib-ub-hannover/310222028.pdf

Norgate, & Rankin, W. (2000). *Life cycle assessment of copper and nickel production*. 133–138. https://www.ausimm.com/publications/conference-proceedings/minprex-2000/life-cycle-assessment-of-copper-and-nickel-production/

Norgate, T., Jahanshahi, S., & Rankin, W. (2007). Assessing the environmental impact of metal production processes. *Journal of Cleaner Production*, *15*(8–9), 838–848. https://doi.org/10.1016/j.jclepro.2006.06.018

Norgate, T., & Rankin, W. (2002). The Role of Metals in Sustainable

Development. *Current Biology*, 49–55. https://www.researchgate.net/publication/237816400_The_Role_of_Metals_in_Sustainable_Development

Northey, S., Mohr, S., Mudd, G., Weng, Z., & Giurco, D. (2014). Modelling future copper ore grade decline based on a detailed assessment of copper resources and mining. *Resources, Conservation and Recycling*, *83*, 190–201. https://doi.org/10.1016/j.resconrec.2013.10.005

Northey, S., Mudd, G., & Werner, T. (2018). Unresolved Complexity in Assessments of Mineral Resource Depletion and Availability. *Natural Resources Research*, *27*(2), 241–255. https://doi.org/10.1007/s11053-017-9352-5

Nuss, P., & Eckelman, M. (2014). Life Cycle Assessment of Metals: A Scientific Synthesis. *PLoS ONE*, *9*(7), e101298. https://doi.org/10.1371/journal.pone.0101298

O'Neill, B. C., Kriegler, E., Riahi, K., Ebi, K. L., Hallegatte, S., Carter, T. R., Mathur, R., & van Vuuren, D. P. (2014). A new scenario framework for climate change research: The concept of shared socioeconomic pathways. *Climatic Change*, *122*(3), 387–400. https://doi.org/10.1007/s10584-013-0905-2

Panepinto, D., Blengini, G. A., & Genon, G. (2015). Economic and environmental comparison between two scenarios of waste management: MBT vs thermal treatment. *Resources, Conservation and Recycling*, *97*, 16–23. https://doi.org/10.1016/j.resconrec.2015.02.002

Paris, A., van der Meide, M., Müller, A., Steubing, B., Guinée, J., Cucurachi, S., & Thonemann, N. (2026). Recommendations for an Informed and Responsible Use of Integrated Assessment Models in Prospective LCA. *International Journal of Life Cycle Assessment*. https://doi.org/10.1007/s11367-026-02659-4

Pauliuk, S., Arvesen, A., Stadler, K., & Hertwich, E. G. (2017). Industrial ecology in integrated assessment models. *Nature Climate Change*, *7*(1), 13–20. https://doi.org/10.1038/nclimate3148

Peduzi, P. (2014). Sand, rarer than one thinks. *Environmental Development*, *11*, 208–218. https://doi.org/10.1016/j.envdev.2014.04.001

Pierobon, F., Eastin, I. L., & Ganguly, I. (2018). Life cycle assessment of residual lignocellulosic biomass-based jet fuel with activated carbon and lignosulfonate as co-products. *Biotechnology for Biofuels*, *11*(1), 139. https://doi.org/10.1186/s13068-018-1141-9

Pradeleix, L., Roux, P., Bouarfa, S., Jaouani, B., Lili-Chabaane, Z., & Bellon-Maurel, V. (2015). Environmental Impacts of Contrasted Groundwater Pumping Systems Assessed by Life Cycle Assessment Methodology: Contribution to the Water–Energy Nexus Study. *Irrigation and Drainage*, *64*(1), 124–138. https://doi.org/10.1002/ird.1865

Rasul, K., & Hertwich, E. G. (2023). Decomposition Analysis of the Carbon Footprint of Primary Metals. *Environmental Science & Technology*, *57*(19), 7391–7400.

https://doi.org/10.1021/acs.est.2c05857

Reinhard, J., Mutel, C., Wernet, G., Zah, R., & Hilty, L. M. (2016). Contribution-based prioritization of LCI database improvements: Method design, demonstration, and evaluation. *Environmental Modelling & Software*, *86*, 204–218. https://doi.org/10.1016/j.envsoft.2016.09.018

Reinhard, J., Wernet, G., Zah, R., Heijungs, R., & Hilty, L. M. (2019). Contribution-based prioritization of LCI database improvements: The most important unit processes in ecoinvent. *The International Journal of Life Cycle Assessment*, *24*(10), 1778–1792. https://doi.org/10.1007/s11367-019-01602-0

Ren, P., Ling, T.-C., & Mo, K. H. (2021). Recent advances in artificial aggregate production. *Journal of Cleaner Production*, *291*, 125215. https://doi.org/10.1016/j.jclepro.2020.125215

Rørbech, J. T., Vadenbo, C., Hellweg, S., & Astrup, T. F. (2014). Impact Assessment of Abiotic Resources in LCA: Quantitative Comparison of Selected Characterization Models. *Environmental Science & Technology*, *48*(19), 11072–11081. https://doi.org/10.1021/es5023976

Roux, C., Schalbart, P., Assoumou, E., & Peuportier, B. (2016). Integrating climate change and energy mix scenarios in LCA of buildings and districts. *Applied Energy*, *184*, 619–629. https://doi.org/10.1016/j.apenergy.2016.10.043

Sacchi, R. (2025a). *Personal communication*.

Sacchi, R. (2025b). *Premise Documentation*. https://premise.readthedocs.io/en/v.2.2.9/

Sacchi, R., Terlouw, T., Siala, K., Dirnaichner, A., Bauer, C., Cox, B., Mutel, C., Daioglou, V., & Luderer, G. (2022). PRospective EnvironMental Impact asSEment (premise): A streamlined approach to producing databases for prospective life cycle assessment using integrated assessment models. *Renewable and Sustainable Energy Reviews*, *160*, 112311. https://doi.org/10.1016/j.rser.2022.112311

Sankey, H. R. (1898). Introductory note on the thermal efficiency of steam-engines. Report of the committee appointed on the 31st March, 1896, to consider and report to the council upon the subject of the definition of a standard or standards of thermal efficiency for steam engines: With an introductory note. *Minutes of Proceedings of the Institution of Civil Engineers*, *134*, 278–283. https://doi.org/10.1680/imotp.1898.19100

Scipioni, A., Niero, M., Mazzi, A., Manzardo, A., & Piubello, S. (2013). Significance of the use of non-renewable fossil CED as proxy indicator for screening LCA in the beverage packaging sector. *The International Journal of Life Cycle Assessment*, *18*(3), 673–682. https://doi.org/10.1007/s11367-012-0484-x

Srocka, M., & Montiel, F. (2021). Chapter 7: Algorithms of Life Cycle Inventory Analysis. In A. Ciroth & R. Arvidsson (Eds.), *Life Cycle Inventory Analysis: Methods and Data*. Springer, Cham. https://doi.org/10.1007/978-3-030-

62270-1

Stehfest, E., van Vuuren, D. P., Kram, T., Bouwman, L., Alkemade, R., Bakkenes, M., Biemans, H., Bouwman, A., Elzen, M., Janse, J., Lucas, P., van Minnen, J., Muller, C., & Prins, A. G. (2014). *Integrated Assessment of Global Environmental Change with IMAGE 3.0. Model description and policy applications*. PBL Netherlands Environmental Assessment Agency. https://www.pbl.nl/en/publications/integrated-assessment-of-global-environmental-change-with-IMAGE-3.0

Steubing, B., & Koning, D. (2021). Making the use of scenarios in LCA easier: The superstructure approach. *The International Journal of Life Cycle Assessment*. https://doi.org/10.1007/s11367-021-01974-2

Steubing, B., Koning, Haas, & Mutel, C. (2019). The Activity Browser – An open source LCA software building on top of the brightway framework. *Software Impacts*, 100012. https://doi.org/10.1016/j.simpa.2019.100012

Steubing, B., Mendoza Beltran, A., & Sacchi, R. (2023). Conditions for the broad application of prospective life cycle inventory databases. *The International Journal of Life Cycle Assessment*, 28(9), 1092–1103. https://doi.org/10.1007/s11367-023-02192-8

Steubing, B., Mutel, C., Suter, F., & Hellweg, S. (2016). Streamlining scenario analysis and optimization of key choices in value chains using a modular LCA approach. *The International Journal of Life Cycle Assessment*, *21*(4), 510–522. https://doi.org/10.1007/s11367-015-1015-3

Suh, S. (2004). *CEDA 3.0 User's Guide: A Comprehensive Environmental Data Archive for Economic and Environmental Systems Analysis* (CEDA/3001/01/2004). Leiden University Institute of Environmental Science (CML). https://openlibrary.org/works/OL36525740W/CEDA_3.0_User%27s_Guide?edition=key%3A/books/OL49372015M

Suh, S., & Heijungs, R. (2007). Power series expansion and structural analysis for life cycle assessment. *The International Journal of Life Cycle Assessment*, *12*(6), 381. https://doi.org/10.1065/lca2007.08.360

Sun, X., Hao, H., Liu, Z., Zhao, F., & Song, J. (2019). Tracing global cobalt flow: 1995–2015. *Resources, Conservation and Recycling*, *149*, 45–55. https://doi.org/10.1016/j.resconrec.2019.05.009

Sverdrup, Harald U., Koca, D., & Schlyter, P. (2017). A Simple System Dynamics Model for the Global Production Rate of Sand, Gravel, Crushed Rock and Stone, Market Prices and Long-Term Supply Embedded into the WORLD6 Model. *BioPhysical Economics and Resource Quality*, *2*(2), 8. https://doi.org/10.1007/s41247-017-0023-2

Sverdrup, Harald Ulrik, Ragnarsdottir, K. V., & Koca, D. (2017). Integrated Modelling of the Global Cobalt Extraction, Supply, Price and Depletion of Extractable Resources Using the WORLD6 Model. *BioPhysical Economics and Resource*

Quality, *2*(1), 4. https://doi.org/10.1007/s41247-017-0017-0

Thonemann, N., Schulte, A., & Maga, D. (2020). How to Conduct Prospective Life Cycle Assessment for Emerging Technologies? A Systematic Review and Methodological Guidance. *Sustainability*, *12*(3), 1192. https://doi.org/10.3390/su12031192

Tisserant, A., & Pauliuk, S. (2016). Matching global cobalt demand under different scenarios for co-production and mining attractiveness. *Journal of Economic Structures*, *5*(1), 4. https://doi.org/10.1186/s40008-016-0035-x

Torres, A., Brandt, J., Lear, K., & Liu, J. (2017). A looming tragedy of the sand commons. *Science*, *357*(6355), 970–971. https://doi.org/10.1126/science.aao0503

Tukker, A., Behrens, P., Deetman, S., Hu, M., Alejandre, E. M., van der Meide, M., Zhong, X., & Zhang, C. (2023). Circular construction: Six key recommendations. *One Earth*, *6*(11), 1425–1429. https://doi.org/10.1016/j.oneear.2023.10.021

UN. (2015). *Central Product Classification (CPC) Version 2.1*. https://unstats.un.org/unsd/classifications/unsdclassifications/cpcv21.pdf

UNEP. (2023). *Building Materials and the Climate: Constructing a New Future*. https://wedocs.unep.org/handle/20.500.11822/43293

UNFCCC. (2022). *Greenhouse Gas Inventory Data* [Dataset]. http://di.unfccc.int/

United States Geological Survey. (2011). *Estimates of Electricity Requirements for the Recovery of Mineral Commodities, with Examples Applied to Sub-Saharan Africa*. https://pubs.usgs.gov/of/2011/1253/

United States Geological Survey. (2014). *Historical Statistics for Mineral and Material Commodities in the United States—Data Series 140* [Dataset]. https://www.usgs.gov/centers/nmic/historical-statistics-mineral-and-material-commodities-united-states

United States Geological Survey. (2017a). *2015 Minerals Yearbook Cobalt [Advance Release]*. https://www.usgs.gov/centers/nmic/cobalt-statistics-and-information

United States Geological Survey. (2017b). *2015 Minerals Yearbook Copper [Advance Release]*. https://www.usgs.gov/centers/nmic/copper-statistics-and-information

United States Geological Survey. (2017c). Chapter F - Cobalt. In *Critical mineral resources of the United States—Economic and environmental geology and prospects for future supply*. U.S. Geological Survey. https://pubs.er.usgs.gov/publication/pp1802F

United States Geological Survey (with McRae, M.). (2018). *2015 Minerals Yearbook Nickel [Advance Release]*. U.S. Geological Survey. https://www.usgs.gov/centers/nmic/nickel-statistics-and-information

Van Den Oever, A. E. M., Puricelli, S., Costa, D., Thonemann, N., Lavigne Philippot, M., & Messagie, M. (2024). Revisiting the challenges of ozone depletion in life cycle assessment. *Cleaner Environmental Systems*, *13*, 100196. https://doi.org/10.1016/j.cesys.2024.100196

van der Giesen, C., Cucurachi, S., Guinée, J., Kramer, G. J., & Tukker, A. (2020). A critical view on the current application of LCA for new technologies and recommendations for improved practice. *Journal of Cleaner Production*, *259*, 120904. https://doi.org/10.1016/j.jclepro.2020.120904

van der Meide, M. (2025a). *Data for: Recovering sand and gravel from End-of-Life concrete: The global potential* [Dataset]. https://doi.org/10.5281/zenodo.15304338

van der Meide, M. (2025b). *HEM-in-LCA* (Version 0.0.1) [Computer software]. https://doi.org/10.5281/zenodo.16417963

van der Meide, M. (2025c). *Hypothetical Extraction Method in Life Cycle Assessment: Method and uses*. https://doi.org/10.5281/zenodo.18165029

van der Meide, M. (2025d). *Premise Analysis Tool* (Version 0.0.1) [Computer software]. https://doi.org/10.5281/zenodo.17733339

van der Meide, M., Harpprecht, C., Northey, S., Yongxiang, Y., & Steubing, B. (2021). *Scenario data for article: Effects of the energy transition on environmental impacts of cobalt supply: A prospective Life Cycle Assessment study on future supply of cobalt*. https://doi.org/10.5281/zenodo.5730097

van der Meide, M., Harpprecht, C., Northey, S., Yongxiang, Y., & Steubing, B. (2022). Effects of the energy transition on environmental impacts of cobalt supply: A prospective life cycle assessment study on future supply of cobalt. *Journal of Industrial Ecology*. https://doi.org/10.1111/jiec.13258

van der Meide, M., Heijungs, R., Guinée, J., Hu, M., & Steubing, B. (2025). Contribution Analysis in LCA: an overview of approaches and when to apply them. *International Journal of Life Cycle Assessment*. https://doi.org/10.1007/s11367-025-02487-y

van der Voet, E., van Oers, L., Verboon, M., & Kuipers, K. (2018). Environmental Implications of Future Demand Scenarios for Metals: Methodology and Application to the Case of Seven Major Metals: Environmental Impacts of Metal Scenarios. *Journal of Industrial Ecology*, *23*(1), 141–155. https://doi.org/10.1111/jiec.12722

Van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., Hurtt, G. C., Kram, T., Krey, V., Lamarque, J.-F., Masui, T., Meinshausen, M., Nakicenovic, N., Smith, S. J., & Rose, S. K. (2011). The representative concentration pathways: An overview. *Climatic Change*, *109*(1–2), 5–31. https://doi.org/10.1007/s10584-011-0148-z

Villares, M., Işıldar, A., Giesen van der, 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. *The International Journal of*

Life Cycle Assessment, *22*(10), 1618–1633. https://doi.org/10.1007/s11367-017-1270-6

Volkart, K., Mutel, C. L., & Panos, E. (2018). Integrating life cycle assessment and energy system modelling: Methodology and application to the world energy scenarios. *Sustainable Production and Consumption*, *16*, 121–133. https://doi.org/10.1016/j.spc.2018.07.001

Watari, T., Cao, Z., Serrenho, A. C., & Cullen, J. (2023). Growing role of concrete in sand and climate crises. *iScience*, *26*(5), 106782. https://doi.org/10.1016/j.isci.2023.106782

Watari, T., Northey, S., Giurco, D., Hata, S., Yokoi, R., Nansai, K., & Nakajima, K. (2022). Global copper cycles and greenhouse gas emissions in a 1.5 °C world. *Resources, Conservation and Recycling*, 179, 106118. https://doi.org/10.1016/j.resconrec.2021.106118

Waugh, F. (1950). Inversion of the Leontief Matrix by Power Series—The Econometric Society. *Econometrica*, *18*(2), 142–154. https://doi.org/10.2307/1907265

Werner, T. T., Mudd, G. M., & Jowitt, S. M. (2017). The world's by-product and critical metal resources part II: A method for quantifying the resources of rarely reported metals. *Ore Geology Reviews*, *80*, 658–675. https://doi.org/10.1016/j.oregeorev.2016.08.008

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., & Weidema, B. (2016). The ecoinvent database version 3 (part I): Overview and methodology. *The International Journal of Life Cycle Assessment*, *21*(9), 1218–1230. https://doi.org/10.1007/s11367-016-1087-8

Xu, C., Dai, Q., Gaines, L., Hu, M., Tukker, A., & Steubing, B. (2020). Future material demand for automotive lithium-based batteries. *Communications Materials*, *1*(1), 99. https://doi.org/10.1038/s43246-020-00095-x

Xu, C., Steubing, B., Hu, M., Harpprecht, C., van der Meide, M., & Tukker, A. (2022). Future greenhouse gas emissions of automotive lithium-ion battery cell production. *Resources, Conservation and Recycling*, *187*, 106606. https://doi.org/10.1016/j.resconrec.2022.106606

Yang, X., Hao, X., Li, H., & Sun, S. (2014). The Life Cycle Assessment of Copper Metallurgical Process. In J. Yurko, L. Zhang, A. Allanore, C. Wang, J. S. Spangenberger, R. E. Kirchain, J. P. Downey, & L. D. May (Eds.), *EPD Congress 2014* (pp. 579–586). John Wiley & Sons, Inc. https://doi.org/10.1002/9781118889664.ch70

Zampori, L., & Pant, R. (2019). *Suggestions for updating the Product Environmental Footprint (PEF), EUR 29682 EN* (ISBN 978-92-76-00654-1). doi.org/10.2760/424613

Zhang, C., Hu, M., Di Maio, F., Sprecher, B., Yang, X., & Tukker, A. (2022). An overview of the waste hierarchy framework for analyzing the circularity in construction and demolition waste management in Europe. *Science of The Total Environment*, *803*, 149892. https://doi.org/10.1016/j.scitotenv.2021.149892

Zhang, C., Hu, M., van der Meide, M., Di Maio, F., Yang, X., Gao, X., Li, K., Zhao, H., & Li, C. (2023). Life cycle assessment of material footprint in recycling: A case of concrete recycling. *Waste Management*, *155*, 311–319. https://doi.org/10.1016/j.wasman.2022.10.035

Zhang, Y., Luo, W., Wang, J., Wang, Y., Xu, Y., & Xiao, J. (2019). A review of life cycle assessment of recycled aggregate concrete. *Construction and Building Materials*, *209*, 115–125. https://doi.org/10.1016/j.conbuildmat.2019.03.078

Zhong, X., Deetman, S., Tukker, A., & Behrens, P. (2022). Increasing material efficiencies of buildings to address the global sand crisis. *Nature Sustainability*, *5*(5), 389–392. https://doi.org/10.1038/s41893-022-00857-0

Zink, T., Maker, F., Geyer, R., Amirtharajah, R., & Akella, V. (2014). Comparative life cycle assessment of smartphone reuse: Repurposing vs. refurbishment. *The International Journal of Life Cycle Assessment*, *19*(5), 1099–1109. https://doi.org/10.1007/s11367-014-0720-7

Curriculum Vitae

Marc was born in Vlissingen, the Netherlands in 1992. Marc became interested in sustainability in his late teens. Somewhere during this time he saw a 'VPRO Tegenlicht' episode where one of the interviewees had studied 'Industrial Ecology', which sparked his interest.

During his studies for Bacherlor of Science in Mechanical Engineering at the Hogeschool Rotterdam (2013-2017) he did a minor in 'Sustainable Development' at Leiden University. There he learned about the Master of Science programme 'Industrial Ecology' at Leiden University that was also hosted there and decided to enroll (2017-2020). While the programme was intense, the sense of community and deep interests in sustainability of his peers made the effort worth it.

At the end of his masters programme, the Covid-19 epidemic happened, and he was forced to do most of his master thesis from home. Despite the added challenges everyone faced during this time, his thesis supervisor, Bernhard Steubing saw an opportunity to keep working together and Marc started a PhD with Bernhard, Mingming Hu and Arnold Tukker.

During his masters and PhD, Marc also worked on the development of the LCA software 'activity browser', which was quite rewarding in its own right.

After completing his PhD thesis, Marc will continue his academic work as a PostDoc working with Mara Hauck and working on prospective LCA of re-useable solar panels at the Technische Universiteit Eindhoven.

List of publications

First Author

van der Meide, M., Harpprecht, C., Northey, S., Yongxiang, Y., & Steubing, B. (2022). Effects of the energy transition on environmental impacts of cobalt supply: A prospective life cycle assessment study on future supply of cobalt. *Journal of Industrial Ecology*.
https://doi.org/10.1111/jiec.13258

van der Meide, M., Heijungs, R., Guinée, J., Hu, M., & Steubing, B. (2025). Contribution Analysis in LCA: an overview of approaches and when to apply them. *International Journal of Life Cycle Assessment*.
https://doi.org/10.1007/s11367-025-02487-y

van der Meide, M. (2025). Hypothetical Extraction Method in Life Cycle Assessment: Method and uses.
https://doi.org/10.5281/zenodo.18165029 **Preprint**

van der Meide, M., Hu, M., Steubing, B., Tukker, A. (2025) Recovering sand and gravel from End-of-Life concrete: The global potential.
https://doi.org/10.5281/zenodo.17192667 **Preprint**

van der Meide, M., Hu, M., Steubing, B., Tukker, A. (2026) An analysis of the effects of changes in *Premise* databases on the environmental impacts of key products. *International Journal of Life Cycle Assessment*.
https://doi.org/10.1007/s11367-026-02712-2

Other contributions

Xu, C., Steubing, B., Hu, M., Harpprecht, C., **van der Meide, M.**, Tukker, A. (2022) Future greenhouse gas emissions of automotive lithium-ion battery cell production *Resources, Conservation and Recycling.*
https://doi.org/10.1016/j.resconrec.2022.106606

Zhang, C., Hu, M., **van der Meide, M.**, Di Maio, F., Yang, X., Gao, X., Li, K., Zhao, H., Li, C. (2023) Life cycle assessment of material footprint in recycling: A case of concrete recycling. *Waste management*.
https://doi.org/10.1016/j.wasman.2022.10.035

Tukker, A., Behrens, P., Deetman, S., Hu, M., Alejandre, E., **van der Meide, M.**, Zhong, X., Zhang, C. (2023) Circular construction: Six key recommendations. *One Earth*
https://doi.org/10.1016/j.oneear.2023.10.021

Harpprecht, C., Xicotencatl, B., van Nielen, S., **van der Meide, M.**, Li, C., Li, Z., Tukker, A, Steubing, B. (2024). Future environmental impacts of metals: A systematic review of impact trends, modelling approaches, and challenges. *Resources, Conservation and Recycling*.
https://doi.org/10.1016/j.resconrec.2024.107572

Ozcelikci, E., Hu, M., **van der Meide, M.**, Sahmaran, M. (2025). Life cycle assessment of SCM substitution in various CDW-based geopolymer concretes and sensitivity analyses on allocation methods. *Waste management*.
https://doi.org/10.1016/j.wasman.2025.115034

Paris, A., **van der Meide, M.**, Müller, A., Steubing, B., Guinée, J., Cucurachi, S., Thonemann, N. (2026). Recommendations for an Informed and Responsible Use of Integrated Assessment Models in Prospective LCA *International Journal of Life Cycle Assessment*.
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