



Residual Forestry Biomass Supply Chain: A Mapping Approach

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References

- [1] X. Zhang, H. Li, J. T. Harvey, A. A. Butt, M. Jia, and J. Liu, "A review of converting woody biomass waste into useful and eco-friendly road materials," *Transportation Safety and Environment*, vol. 4, no. 1, 2022, doi:10.1093/tse/tdab031.
- [2] M. Casau, M. F. Dias, J. C. Matias, and L. J. Nunes, "Residual biomass: A comprehensive review on the importance, uses and potential in a circular bioeconomy approach," *Resources*, vol. 11, no. 4, p. 35, 2022, doi:10.3390/resources11040035.
- [3] T. Karras, A. Brosowski, and D. Thrän, "A review on supply costs and prices of residual biomass in techno-economic models for Europe," *Sustainability*, vol. 14, no. 12, p. 7473, 2022, doi:10.3390/su14127473.
- [4] R. S. Schillo, D. A. Isabelle, and A. Shakiba, "Linking advanced biofuels policies with stakeholder interests: A method building on quality function deployment," *Energy Policy*, vol. 100, pp. 126–137, 2017, doi:10.1016/j.enpol.2016.09.056.
- [5] N. Zandi, Atashbar, N. Labadie, and C. Prins, "Modeling and optimization of biomass supply chains: A review and a critical look," *IFAC-PapersOnLine*, vol. 49, no. 12, pp. 604–615, 2016, doi:10.1016/j.ifacol.2016.07.742.
- [6] F. L. Braghioroli and L. Passarini, "Valorization of biomass residues from forest operations and wood manufacturing presents a wide range of sustainable and innovative possibilities," *Current Forestry Reports*, vol. 6, no. 2, pp. 172–183, 2020, doi:10.1007/s40725-020-00112-9.
- [7] G. Maraver, A. F. Ramos Ridaio, D. P. Ruiz, and M. Zamorano, "Quality of pellets from olive grove residual biomass," *Renewable Energy and Power Quality Journal*, vol. 1, no. 08, pp. 751–756, 2010, doi:10.24084/repqj08.463.
- [8] H. Carvalho, V. C. Machado, and J. G. Tavares, "A mapping framework for assessing supply chain resilience," *International Journal of Logistics Systems and Management*, vol. 12, no. 3, p. 354, 2012, doi:10.1504/ijlsm.2012.047606.
- [9] B. Mansoornejad, E. N. Pistikopoulos, and P. R. Stuart, "Scenario-based strategic supply chain design and analysis for the forest biorefinery using an Operational Supply Chain Model," *International Journal of Production Economics*, vol. 144, no. 2, pp. 618–634, 2013, doi:10.1016/j.ijpe.2013.04.029.
- [10] F. T. Couto, F. L. Santos, C. Campos, N. Andrade, C. Purificação, and R. Salgado, "Is Portugal starting to burn all year long? the transboundary fire in January 2022," *Atmosphere*, vol. 13, no. 10, p. 1677, 2022, doi:10.3390/atmos13101677.
- [11] S. Chopra and P. Meindl, *Supply Chain Management: Strategy, Planning, And Operation*, 7th ed. One Street Lake, New Jersey: Pearson, 2021.
- [12] D. Šafařík, P. Hlaváčková, and J. Michal, "Potential of forest biomass resources for renewable energy production in the Czech Republic," *Energies*, vol. 15, no. 1, p. 47, 2021, doi:10.3390/en15010047.
- [13] G. Berndes, B. Abt, A. Asikainen, A. Cowie, V. Dale, G. Egnell, M. Lindner, L. Marelli, D. Paré, K. Pingoud, and S. Yeh, "Forest biomass, carbon neutrality and climate change mitigation. From Science to Policy," *European Forest Institute*, 2016, doi:10.36333/fs03.

- [14] W. Deng, Y. Feng, J. Fu, H. Guo, Y. Guo, B. Han, Z. Jiang, L. Kong, C. Li, H. Liu, P. T. T. Nguyen, P. Ren, F. Wang, S. Wang, Y. Wang, Y. Wang, S. S. Wong, K. Yan, N. Yan, X. Yang, Y. Zhang, Z. Zhang, X. Zeng, and H. Zhou, "Catalytic conversion of lignocellulosic biomass into chemicals and fuels," *Green Energy & Environment*, vol. 8, no. 1, pp. 10–114, 2023, doi:10.1016/j.gee.2022.07.003.
- [15] M. Dunky and A. Pizzi, "Chapter 23 - Wood adhesives," in *Adhesion Science and Engineering*, D. A. Dillard, A. V. Pocius, and M. Chaudhury, Eds., Amsterdam: Elsevier Science B.V., 2002, pp. 1039–1103. doi: 10.1016/B978-044451140-9/50023-8.
- [16] V.-H. Antolín-Cerón, F.-J. González-López, P. D. Astudillo-Sánchez, K.-A. Barrera-Rivera, and A. Martínez-Richa, "High-performance polyurethane nanocomposite membranes containing cellulose nanocrystals for protein separation," *Polymers*, vol. 14, no. 4, p. 831, 2022, doi:10.3390/polym14040831.
- [17] L. Hamelin, M. Borzęcka, M. Kozak, and R. Pudełko, "A spatial approach to bioeconomy: Quantifying the residual biomass potential in the EU-27," *Renewable and Sustainable Energy Reviews*, vol. 100, pp. 127–142, 2019, doi:10.1016/j.rser.2018.10.017.
- [18] Y. Torreiro, L. Pérez, G. Piñeiro, F. Pedras, and A. Rodríguez-Abalde, "The role of energy valuation of agroforestry biomass on the circular economy," *Energies*, vol. 13, no. 10, p. 2516, 2020, doi:10.3390/en13102516.
- [19] M. Costa, D. Piazzullo, D. Di Battista, and A. De Vita, "Sustainability assessment of the whole biomass-to-energy chain of a combined heat and power plant based on biomass gasification: Biomass Supply Chain Management and life cycle assessment," *Journal of Environmental Management*, vol. 317, p. 115434, 2022, doi:10.1016/j.jenvman.2022.115434.
- [20] S. Wu, S. Zhang, C. Wang, C. Mu, and X. Huang, "High-strength charcoal briquette preparation from hydrothermal pretreated biomass wastes," *Fuel Processing Technology*, vol. 171, pp. 293–300, 2018, doi:10.1016/j.fuproc.2017.11.025.
- [21] J. Karthäuser, V. Biziks, C. Mai, and H. Miltz, "Lignin and lignin-derived compounds for wood applications—a review," *Molecules*, vol. 26, no. 9, p. 2533, 2021, doi:10.3390/molecules26092533.
- [22] Z. Chen and C. Wan, "Biological valorization strategies for converting lignin into fuels and chemicals," *Renewable and Sustainable Energy Reviews*, vol. 73, pp. 610–621, 2017, doi:10.1016/j.rser.2017.01.166.
- [23] J. Becker and C. Wittmann, "A field of dreams: Lignin valorization into chemicals, materials, fuels, and health-care products," *Biotechnology Advances*, vol. 37, no. 6, p. 107360, 2019, doi:10.1016/j.biotechadv.2019.02.016.
- [24] M. Dashtpeyma and R. Ghodsi, "Forest biomass and Bioenergy Supply Chain Resilience: A systematic literature review on the barriers and Enablers," *Sustainability*, vol. 13, no. 12, p. 6964, 2021, doi:10.3390/su13126964.
- [25] H. Stadler, *Supply Chain Management and advanced planning: Concepts, models, software and case studies*, 4th ed. Berlin, Germany: Springer, 2008.
- [26] P. L. King and J. S. King, *Value stream mapping for the process industries: Creating a roadmap for Lean Transformation*, 1st ed. New York, USA: CRC Press, 2017.
- [27] L. J. R. Nunes, M. Casau, M. F. Dias, J. C. O. Matias, and L. C. Teixeira, "Agroforest woody residual biomass-to-energy supply chain analysis: Feasible and sustainable renewable resource exploitation for an alternative to fossil fuels," *Results in Engineering*, vol. 17, p. 101010, 2023. doi:10.1016/j.rineng.2023.101010.
- [28] C. Cambero, T. Sowlati, M. Marinescu, and D. Röser, "Strategic optimization of forest residues to bioenergy and Biofuel Supply Chain," *International Journal of Energy Research*, vol. 39, no. 4, pp. 439–452, 2014. doi:10.1002/er.3233.
- [29] H. Woo, M. Acuna, S. Cho, and J. Park, "Assessment techniques in forest biomass along the timber supply chain," *Forests*, vol. 10, no. 11, p. 1018, 2019. doi:10.3390/f10111018.
- [30] B. Rijal, S. H. Gautam, and L. LeBel, "The impact of forest disturbances on residual biomass supply: A long-term forest level analysis," *Journal of Cleaner Production*, vol. 248, p. 119278, 2020. doi:10.1016/j.jclepro.2019.119278.
- [31] A. J. A. Urquiaga, N. S. Cossío, J. A. Acevedo-Suárez, and A. J. Urquiaga-Rodríguez, "A model with a collaborative approach for the operational management of the supply chain," *International Journal of Industrial Engineering and Management*, vol. 12, no. 1, pp. 49–62, 2021, doi: 10.24867/IJIEM-2021-1-276.
- [32] A. Jankovic-Zugic, N. Medic, M. Pavlovic, T. Todorovic, and S. Rakic, "Servitization 4.0 as a trigger for sustainable business: Evidence from Automotive Digital Supply Chain," *Sustainability*, vol. 15, no. 3, p. 2217, 2023. doi:10.3390/su15032217.
- [33] O. Anichkina et al., "A novel mathematical model to design an agile supply chain for perishable products," *International Journal of Industrial Engineering and Management*, vol. 13, no. 2, pp. 88–98, 2022. doi: 10.24867/IJIEM-2022-2-303.
- [34] A. Kumar, S. Adamopoulos, D. Jones, and S. O. Amiamdamhen, "Forest biomass availability and utilization potential in Sweden: A Review," *Waste and Biomass Valorization*, vol. 12, no. 1, pp. 65–80, 2020, doi: 10.1007/s12649-020-00947-0.
- [35] A. A. Rentizelas, "Biomass storage," in *Biomass Supply Chains for Bioenergy and Biorefining*, J. B. Holm-Nielsen and E. A. Ehimen, Eds., Woodhead Publishing, 2016, pp. 127–146. doi: 10.1016/B978-1-78242-366-9.00006-X.
- [36] M. S. Roni, S. D. Eksioğlu, E. Searcy, and J. J. Jacobson, "Estimating the variable cost for high-volume and long-haul transportation of densified biomass and biofuel," *Transportation Research Part D: Transport and Environment*, vol. 29, pp. 40–55, 2014, doi: 10.1016/j.trd.2014.04.003.
- [37] A. Ilari, E. Foppa Pedretti, C. De Francesco, and D. Duca, "Pellet production from residual biomass of greenery maintenance in a small-scale company to improve sustainability," *Resources*, vol. 10, no. 12, p. 122, 2021, doi: 10.3390/resources10120122.
- [38] L. R. A. Ferreira, R. B. Otto, F. P. Silva, S. N. M. De Souza, S. S. De Souza, and O. H. Ando Junior, "Review of the energy potential of the residual biomass for the distributed generation in Brazil," *Renewable and Sustainable Energy Reviews*, vol. 94, pp. 440–455, 2018, doi: 10.1016/j.rser.2018.06.034.
- [39] K. Rimienė and D. Grundey, "Logistics Centre concept through evolution and definition," *Engineering Economics*, vol. 54, no. 4, 2007.
- [40] N. Shabani, S. Akhtari, and T. Sowlati, "Value chain optimization of forest biomass for Bioenergy Production: A Review," *Renewable and Sustainable Energy Reviews*, vol. 23, pp. 299–311, 2013, doi: 10.1016/j.rser.2013.03.005.
- [41] B. L. MacCarthy, W. A. H. Ahmed, and G. Demirel, "Mapping the supply chain: Why, what and how?," *International Journal of Production Economics*, vol. 250, p. 108688, 2022, doi:10.1016/j.ijpe.2022.108688.
- [42] J. T. Gardner and M. C. Cooper, "Strategic Supply Chain Mapping Approaches," *Journal of Business Logistics*, vol. 24, no. 2, pp. 37–64, 2003, doi: 10.1002/j.2158-1592.2003.tb00045.x.
- [43] M. S. Mubarik, N. Naghavi, M. Mubarik, S. Kusi-Sarpong, S. A. Khan, S. I. Zaman, and S. H. Kazmi, "Resilience and cleaner production in industry 4.0: Role of supply chain mapping and visibility," *Journal of Cleaner Production*, vol. 292, p. 126058, 2021, doi: 10.1016/j.jclepro.2021.126058.

- [44] S. Y. Cha, "The art of cyber security in the age of the digital supply chain: detecting and defending against vulnerabilities in your supply chain," in *The Digital Supply Chain*, B. L. MacCarthy and D. Ivanov, Eds., Elsevier, 2022, pp. 215–233. doi: <https://doi.org/10.1016/B978-0-323-91614-1.00013-7>.
- [45] Ghadge, M. Er Kara, H. Moradlou, and M. Goswami, "The impact of industry 4.0 implementation on supply chains," *Journal of Manufacturing Technology Management*, vol. 31, no. 4, pp. 669–686, 2020, doi: 10.1108/JMTM-10-2019-0368.
- [46] M. Theodore Farris, "Solutions to strategic supply chain mapping issues," *International Journal of Physical Distribution and Logistics Management*, vol. 40, no. 3, pp. 164–180, 2010, doi:10.1108/09600031011035074.
- [47] P. Childerhouse and D. R. Towill, "Simplified material flow holds the key to supply chain integration," *Omega*, vol. 31, no. 1, pp. 17–27, 2003, doi:10.1016/s0305-0483(02)00062-2.
- [48] D. I. Miyake, A. S. Torres Junior, and C. Favaro, "Supply chain mapping initiatives in the Brazilian automotive industry: challenges and opportunities," *Journal of Operations and Supply Chain Management*, vol. 3, no. 1, p. 78, 2010, doi: 10.12660/joscmv3n1p78-97.
- [49] P. S. Thirumurugan, "Social Network Analysis of Team Communication And Supply chain Interactions in Manufacturing Industry," M.S. thesis, Pennsylvania State University, Pennsylvania, USA, 2018.
- [50] R. K. Yin, *Case study research and applications: Design and methods*. Los Angeles, CA, USA: SAGE, 2018.
- [51] S. Crowe, K. Cresswell, A. Robertson, G. Huby, A. Avery, and A. Sheikh, "The case study approach," *BMC Medical Research Methodology*, vol. 11, no. 1, 2011, doi: 10.1186/1471-2288-11-100.
- [52] A. Priya, "Case study methodology of qualitative research: Key attributes and navigating the conundrums in its Application," *Sociological Bulletin*, vol. 70, no. 1, pp. 94–110, 2020. doi:10.1177/0038022920970318.
- [53] C. Makri and A. Neely, "Grounded theory: A guide for exploratory studies in management research," *International Journal of Qualitative Methods*, vol. 20, p. 160940692110136, 2021. doi:10.1177/16094069211013654.
- [54] M. Rodrigues, À. Cunill Camprubi, R. Balaguer-Romano, J. Ruffault, P. M. Fernandes, and V. R. de Dios, "Drivers and implications of the extreme 2022 wildfire season in Southwest Europe," 2022, doi:10.1101/2022.09.29.510113.
- [55] S. Khan and R. VanWynsberghe, "Cultivating the Under-Mined: Cross-Case Analysis as Knowledge Mobilization", *FQS*, vol. 9, no. 1, Jan. 2008. doi:10.17169/fqs-9.1.334.
- [56] P. Rijal, H. Carvalho, J. Matias, S. Garrido, and C. Pimentel, "Towards a conceptual framework for agroforestry residual biomass sustainable business models," *Quality Innovation and Sustainability*, pp. 211–221, 2023. doi:10.1007/978-3-031-12914-8_17.
- [57] L. Yu et al., "Policy analysis of biomass recycling supply chain considering carbon and pollution emission reduction—taking China's straw subsidy policy for example," *Systems*, vol. 11, no. 7, p. 343, 2023. doi:10.3390/systems11070343.
- [58] B. C. Chidozie, A. L. Ramos, J. V. Ferreira, and L. P. Ferreira, "Residual agroforestry biomass supply chain simulation insights and directions: A systematic literature review," *Sustainability*, vol. 15, no. 13, p. 9992, 2023. doi:10.3390/su15139992.