How to assess the impact of blockchain on decarbonization in urban logistics?

Mehdi Jahangir Samet, Jonathan Köhler and Tomas Horak

Abstract— **The critical role of blockchain technology has been highlighted in decarbonization and logistics transitions in the literature. Blockchain technology combined with the Smart City paradigm is identified as one of the most important digital technology disruptions and trends of sustainable urban logistics in the future. Unfortunately, none of the current strategic assessment models can evaluate the impact of blockchain technology adoption on the decarbonization pathways in urban logistics. In this study, to assess the impact of blockchain technology adoption on decarbonization goals in urban logistics, we review the literature for the current strategic assessment tools/models, sustainable urban logistics, Smart City paradigm, and blockchain technology application in logistics and decarbonization. We propose a combination of different modelling approaches including the living lab, agent-based models, and specific decision-making algorithms of blockchain technology adoptions in urban logistics and Smart City paradigms to fill the identified gaps in the literature. The main contribution of this study is to identify the research gaps in the analysis of the impact of blockchain on decarbonization in urban logistics.**

Keywords — **Agent-Based Models, Blockchain Technology, Logistics Transitions, Strategic Assessment Models, Urban Logistics.**

I. Introduction

Decarbonization strategies in the logistics and freight transport sectors include energy efficiency improvement for vehicles, alternative powertrains and fuels and systemic change improvements [1]. The first three decarbonization strategies in logistics and freight transport can be represented by the current strategic assessment tools and freight transport modelling approaches. However, these models and tools are not able to assess the impact of digitalization on decarbonization goals in logistics transitions [2]. Digitalization and decarbonization are known as the main drivers of structural system changes in logistics transitions [2, 3]. Therefore, to develop models and tools in logistic transition, key aspects of digitalization and decarbonization should be appropriately modelled and assessed.

Smart City and Smart Mobility paradigms are highlighted as the most important digital trends in the transport sector in the latest version of the sixth assessment report of intergovernmental panel on climate change [3]. Smart City and Smart Mobility paradigms include a wide range of digital technology disruptions and transformations such as information and communication technologies (ICT), internet-of-things (IoT), mobility as a service, big data, big data analytics, and blockchain technology [3]. Blockchain technology plays enabler roles in the future of logistics and supply chain development, such as supply chain coordination and collaboration, circular economy, and shared economy [4-8].

The critical role of the blockchain was discussed over different research topics such as securities [9], smart contracts [6, 10], risk management [11], network architecture [12-14], etc. But unfortunately, no research study in the literature was found to assess the impact of blockchain technology adoption on the decarbonization pathways in the transport sector. In this study, we aim to discuss possible solution(s) to assess the impact of blockchain technology adoption on decarbonization goals in logistics and freight transport systems in the urban area.

II. Literature review

This section provides a brief review of the most related literature. Section II.A reviews sustainable urban logistics and the Smart City paradigm. Next, Section II.B reviews the blockchain technology application in logistics and decarbonization. Finally, Section II.C reviews the strategic assessment models/tools in the freight transport sector.

A. *Sustainable urban logistics and Smart City paradigm*

Urban logistics has a very complex ecosystem which includes the main components such as the marketing sectors, stakeholders, facilitators, and their impact assessments [15, 16]. The urban logistics ecosystem would be more challenging under the paradigm of sustainability. The objectives of sustainability in urban logistics are to minimize the negative externalities of logistic operations, to ensure service coverage, and to improve the quality of life of all inhabitants at the city level [17].

The negative externalities include environmental issues (e.g., CO_2 emissions, air prolusions), social issues (e.g., working

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conditions for human labor, quality of life), and economic issues (e.g., waste of resources, inefficiency) [15, 16]. Pan et al. [18] identified the five main new challenges in sustainable urban logistics based on the literature including fast-growing mega-cities and urban planning, ever-increasing on-demand deliveries, speed vs. flexibility in an omnichannel environment, strict regulations and policies, changing the consumer attitude towards sustainability.

Büyüközkan and Ilıcak [19] reviewed the literature on smart urban logistics (SUL) and Smart City. They highlighted the role of SUL in achieving sustainability goals in urban logistics (e.g., emission reduction, cost reduction). According to different definitions and terminologies provided for SUL and Smart City [18, 19], "interconnected" infrastructures (e.g., physical, IT, social, business) would be required for making "smart" or "intelligent" decisions to achieve sustainability goals in urban logistics.

The role of digital transformation and information and ICT technologies has been emphasized for SUL and Smart City paradigm in the literature [20, 21]. Bin et al. [21] discussed the role of different digital technologies such as blockchain and cyber-physical systems (CPSs) in the achievement of decarbonization targets with intelligent mobility.

Singha et al. [12] identified the challenges of applying a blockchain and artificial intelligence (AI) enabled framework for Smart City network architecture. They also discussed the solutions and future direction in the development of the Smart City concept.

Bagloee et al. [13] highlighted the role of blockchain in Smart City paradigm. The blockchain-driven digital platform in this study covers sensor networks, smart devices, communication platforms, data analytics, control systems, and cloud services. They proposed a decision support framework for blockchain adoption based on the concept of benefit-cost ratio. Tian et al. [22] designed and examined a blockchain-based platform to evaluate customer delivery satisfaction in sustainable urban logistics.

B. *Blockchain technology, logistics, and decarbonization*

Decentralized and distributed ledger technologies such as blockchain can help to establish a trust system amongst users in a shared network. This technology is a real-time, distributed, immutable ledger and works on a peer-to-peer basis. Blockchain technology applications in logistics and supply chain management can save cost and time by removing the central intermediary control system [23]. The other advantages of blockchain technology adoption are transparency and security. Depending on the blockchain applications (with different transparency and security requirements) different consensus mechanisms are required [24].

Public or permissionless consensus mechanisms such as proof of work lead to higher operational costs compared to the private or permissioned consensus mechanisms such as proof of identity and proof of authority. The difference in the operational costs depends on the intensity of the energy consumption and computational powers required for providing higher security levels in the networks [25]. Moreover, the scalability of blockchain technology has a major impact on energy consumption levels. The energy consumption in the consensus mechanisms depends on the network size (node number) of a blockchain-based platform/system for conducting different types of transactions [24].

Different terminologies and classifications might be found for the blockchain technology in the literature. The most complete picture of blockchain technology evolutions in logistics is described by Choi and Siqin [26]. They described 5 levels of blockchain evolution from blockchain 1.0 to blockchain 5.0. Blockchain 1.0 refers to the basic blockchain application as the currency (e.g., in finance) and blockchain 5.0 refers to the advance blockchain applications combined with AI and industry 4.0's technologies (e.g., IoT, smart sensors).

Two main themes of blockchain applications in carbon footprint monitoring and decarbonization were identified by Pu and Lam [27]. These two themes are 1) carbon trading or carbon emission management and 2) operational carbon emission resulting from computational procedures in a blockchain-based platform/system. The former theme refers to the enabler role of blockchain technology to achieve decarbonization goals. The latter refers to the operational carbon emission of running a blockchain-based platform/system.

A third theme of blockchain technology applications for achieving decarbonization targets is neglected in the literature. As it is concluded by Sedlmeir et al. [24], blockchain technology combined with industry 4.0 [28] and Smart City paradigms [29] might result in a greater reduction potential of emissions and costs. According to Bagloee et al. [13], transport and supply chain management are known as the most important area of blockchain technology applications in Smart City paradigm.

The critical role of blockchain technology in the Smart City paradigm and sustainable logistics was discussed over different topics such as securities [9], smart contracts [6, 10], risk management [11], network architecture [12-14], and customer relationship management [22]. It was claimed that blockchain technology can bring around 30% extra reduction of emissions and costs in the energy and manufacturing systems for the next decade [21]. Unfortunately, no research study in the literature was found to quantify the impact of blockchain technology adoption on the decarbonization pathways in the transport sector.

C. *Strategic assessment models/tools*

Three types of models have been used to show the decarbonization pathways in the transport sector: 1) integrated assessment models (IAMs), 2) global transport energy sectoral models (GTEMs), and 3) national transport/energy models (NTEMs). These models differ from each other based on sectoral scopes, geographical scopes, technological details, and behavioral details. They have common assumptions for the trajectories of socioeconomic development, technological development, resource availability, policy, and behavioral change. [3, 30]

IAMs represent a simplified version of a complex physical and social system by focusing on the endogenous interaction between the economy, society, and environment. The G- /NTEMs benefit more from the detailed transport demand, technology, behavior, and policy at national/regional resolutions with an exogenous linkage to the other sectors [3]. We identified the six most important G- /NTEMs which have been used widely in Europe. In the following paragraphs, we briefly describe these models.

- PRIMES [31] was developed by energy economy environment modelling lab (E3M). The model has been used for European climate policy for over 20 years focusing on long-term transitions and policy impact assessment for market and emissions.
- ASTRA (ASsessment of TRAnsport Strategies) [32] has been used for over 20 years for strategic policy assessment in transport and energy fields. The policy assessment potential of ASTRA covers a wide range of policies with flexible timing and different levels of policy implementation such as standard setting, fuel taxation, infrastructure pricing, speed limits, carbon taxes, etc.
- HIGH-TOOL [33, 34] was developed to assess the economic, environmental, and social impacts of transport policies. This model has been used for the strategic assessment of 30 different transport policy measures such as efficiency standards, internal market measures, and pricing measures.
- TransTools 3 [35] was developed to improve the main shortcoming of its older version. The model has been improved by adding a linkage to an intermodal network-based transport model.
- TRIMODE [36] was developed for European Commission (DG RTD) between 2016 and 2020. It was claimed that the model was the first example of a large-scale integrated model developed with a freshly designed structure for each model component [36-38].
- The international energy agency's (IEA) mobility model (MoMo) is a techno-economic simulation model for estimating and calibrating the energy use and emissions of motorised transport vehicle activity [39]. The model is primarily built based on the "what-if" scenario creations and back-casting to match transport sectoral and modal sub-sectoral greenhouse gas (GHG) emission targets.

III. Discussion

The literature review of strategic assessment models shows that they do not consider the new blockchain technologies. In this section, we discuss the possible ways to estimate the impact of blockchain technology adoption on the decarbonization pathways in the freight transport sector by using the Smart City paradigm. We identify the research gaps in strategic assessment tools/models, urban logistics, and blockchain technology in the literature in Section III.A. Then we discuss the possible ways to assess the impact of blockchain technology in strategic assessment models/tools in Section III.B.

A. The identified research gaps in the current strategic assessment tools/models, urban logistics, and blockchain technology in the literature

The following research gaps were identified in the current strategic assessment models/tools to assess the blockchain technology adoption on decarbonization goals in logistics and freight transport systems in the urban area.

1) First research gap (RG1)

None of the current strategic assessment models/tools can explicitly describe and evaluate the future systemic change regarding decarbonization and digitalization. The possible changes in data handling, data exchange, vertical coordination, and horizontal collaboration in the logistics system and industrial organization are neglected in the current strategic assessment tools/models.

2) Second research gap (RG2)

The current strategic assessment models/tools neglect the intermediate and dynamic impact of digital technology disruption and transformation as well as the decarbonization for the short-term and mid-term horizons. Some of the current strategic assessment models/tools such as HIGH-TOOL and IEA MoMo consider some levels of operational efficiency in logistics due to, for example, the implementation of the physical internet (PI), co-loading, and urban consolidation in long-term future scenarios. However, these models only present approximate estimates of the operational efficiencies in logistics in aggregated regional/national measures (e.g., vehicle kilometers) based on a few case studies.

3) Third research gap (RG3)

Spatial and analytical resolutions in the current strategic assessment models are not appropriate to assess the impact of technology disruptions and transformations. The spatial and analytical resolutions in the current assessment models/tools are designed based on the aggregated input-output structure at regional and national levels. While the systemic changes due to technology disruptions and transformations (e.g., blockchain technology, PI) require more detailed analysis of individual or group of actors (e.g., customers, shippers, logistics service providers (LSPs), terminal operators) behaviors in logistics and supply chain at an urban scope.

4) Fourth research gap (RG4)

Assessment of the urban logistics ecosystem is neglected in the current strategic assessment tools/models. The Smart City paradigm includes subdivisions of ICT infrastructure and intelligent control systems. To evaluate the Smart City paradigm, a model should consider multi-dimensional (e.g., environmental, economic, social behavior) linkage between the level of disruptive technology adoption and existing city infrastructure. The current assessment models cannot evaluate such interactions between sectoral subdivisions at a city level.

5) Fifth research gap (RG5)

Blockchain technology disruption and transformation are not evaluated in the current assessment models. There is a lack of decision-making algorithms and multi-dimensional assessment models to evaluate blockchain technology adoptions in urban logistics. Regarding the literature review in Section II.C, the impact assessment of blockchain technology for achieving decarbonization targets should cover the following themes:

1) Carbon trading or carbon emission management,
2) Operational GHG emissions resulting from operating a blockchain-based system, and
3) The potential operational cost saving and emission reduction in logistics and supply chain (because of the blockchain technology adoption).

B. The model requirements to assess the blockchain impact on decarbonizations, urban logistics, and the Smart City paradigm

This section aims to discuss the research gaps in literature and seek possible solutions to fill them. Following sub-sections discuss the role of Living labs, agent-based models (ABMs), and specific decision-making algorithms for blockchain technology as the main modelling approaches to fill the gaps in the literature.

1) Living lab

Living lab is suggested for modelling the technology disruptions and transformations in a complex sociotechnical system such as city logistics [40, 41]. The living lab in the city logistics aimed at continuously revising and improving the logistics performance via modelling 1) collaborative participation, 2) government processes, and 3) technology disruptions. The living lab in the city logistics has the following characteristics: 1) it includes all relevant stakeholders and business models in the city logistics, 2) it predicts the effects by using simulation, gaming, and other analysis tools, 3) it has a responsive/adaptive approach for evaluating the impacts and policy measures to ultimately implement the solution.

However, applying the living lab concept in the city logistics might have the following challenges [40]: 1) it is difficult to record and evaluate the perspectives and preferences of large numbers of stakeholders, 2) there is a lack of monitoring system to evaluate the impacts of disruptive technologies, 3) it is difficult to reflect the decision making of all the individual stakeholders and the emergent impacts of them at the system level.

2) ABMs

ABMs are bottom-up microsimulation tools which can be used for different contexts such as passenger and freight transport models, technology adoption, socio-technical behavioral models, and coordination and collaboration in supply chain and logistics systems [42, 43]. The ABM has three main elements of agent(s) (e.g., customers, shippers, LSPs, terminal operators), environment (e.g., geographic information systems), interactions between agents in the environment. The application of the ABMs in the logistics and freight transport models has the following advantages compared to the traditional ones: 1) it can evaluate each carrier based on mode choice variables, 2) it can explicitly model the behaviors and interactions among agents, 3) it is a dynamic modelling method which can investigate time-dependent variables such as building trust over time between agents and in the whole system.

However, the application of ABMs in logistics and freight transport models might have the following challenges: 1) the methodology for applying ABMs on a large-scale, aggregated, or macro level is unclear. Data collection and detailed behavioral modelling for individual agents or groups of agents are challenging in terms of computational power; 2) modelling and validation of the result is challenging because the empirical datasets at strategic, technical, and operational levels are not available. The main reasons for not sharing such data might be that companies considered them as confidential information and business secrets.

3) Specific decision-making algorithms for blockchain adoptions

The decision-making algorithms for blockchain adoption in the Smart City paradigm should be able to assess the costs and benefits of blockchain adoption in sub-systems and subdivisions in the Smart City paradigm. The costs and benefits of the blockchain implementation can be assessed, tested and revised continuously to reach optimum solutions based on the living lab concept. The decision-making algorithms for blockchain adoption in the Smart City paradigm should include the following components:

- Blockchain maturity model and adoption scenarios: Different scenarios of blockchain applications should be specified based on the adoption and maturity of blockchain technology in relationship with other digital technologies and modelling concepts (e.g., CPS, IoT, PI, digital twin) in the Smart City paradigm. Five levels of blockchain evolutions from blockchain 1.0 to blockchain 5.0 [26] can specify the levels of involvement for different key elements in the Smart City paradigm (e.g., citizens, vehicles, systems and utilities, and infrastructure and governance) [13].
- System performance analysis: The system performance of the blockchain-based platform can be evaluated by simulation tools and "virtual operation" modelling such as Simul8 [44]. These models need very detailed information about smart contract designs, network size, and consensus mechanisms.
- Operational cost analysis: The operational cost can be estimated by using simulation tools such as Ethereum virtual machine. These models need detailed information about smart contract designs, network size, and consensus mechanisms [25].
- Operational energy (electricity) consumption analysis: The operational energy consumption can be estimated based on the system performance analysis [24].
- GHG emission analysis: The GHG emission can be estimated by knowing the local GHG intensity of electricity and the operational energy (electricity) consumption [24].

C. *The research gaps vs. the modelling approaches for impact assessment of blockchain application*

Table I shows a summary of the modelling approaches discussed for blockchain application in urban logistics and the Smart City paradigm in this study. Table I presents the potential share of each model to fill the five research gaps (RG1-RG5) in Section III.A.

TABLE I
THE RESEARCH GAPS VS. THE MODELLING APPROACHES FOR IMPACT ASSESSMENT OF BLOCKCHAIN APPLICATION IN URBAN LOGISTICS AND SMART CITY PARADIGM TO ACHIEVE DECARBONIZATION GOALS.

Modelling approaches	**The research gaps in the literature**[1]				
	RG1	RG2	RG3	RG4	RG5
Living lab in urban logistics and Smart City paradigm	◐	◐	○	◐	◔
+ABMs in urban logistics and Smart City paradigm	◔	◔	◐	◔	◔
+Specific decision-making algorithms for blockchain adoptions in urban logistics and Smart City paradigm	◔	◔	◐	◔	◐
Cumulative impacts of the above models to fill the research gaps	●	●	●	●	●

1- The circle symbols show the approximate share of each model (○ for 0%, ◔ for 25%, ◐ for 50%, ◕ for 75%, and ● for 100%) to fill the research gaps in blockchain adoption in urban logistics and Smart City paradigm to achieve the decarbonization goals based on the literature review and the authors' assessment.

Taking a closer look at the items in Table I reveals that the combination of all three modelling approaches including living lab, ABMs, and a specific decision-making algorithm for blockchain technology are required to fill the identified research gaps (RG1-RG5) in the current strategic assessment models. However, the application of these models is associated with multiple challenges. The challenges are discussed in detail in the previous sections. The main challenges are the difficulties in data collection, lack of infrastructure, monitoring system, modelling, and validation.

IV. CONCLUSION

In this study, to assess the impact of blockchain technology adoption on decarbonization goals in urban logistics, we reviewed the literature for the current strategic assessment tools/models, sustainable urban logistics, Smart City paradigm, and blockchain technology application in logistics and decarbonization. We identified five research gaps in the current strategic assessment models to evaluate the blockchain impact on the decarbonization of urban logistics.

The research gaps in the current strategic assessment tools/models are 1) lack of presenting the overall systemic changes of decarbonization and digitalization in the future logistics systems, 2) lack of intermediate and dynamic impact assessment of the digital technology disruptions and transformations, 3) lack of appropriate spatial and analytical resolutions for impact assessment of the digital technology disruptions and transformation at the urban level, 4) lack of impact assessment of the urban logistics ecosystem, and 5) lack of decision-making algorithm and multi-dimensional assessment models to evaluate the blockchain technology adoptions in urban logistics.

We proposed a combination of different modelling approaches including the living lab, ABMs, and specific decision-making algorithms of blockchain technology adoptions in urban logistics and Smart City paradigms to fill the identified research gaps in the literature. Our proposal is a simplified and strategic approach to assess the impact of blockchain technology adoption on decarbonization goals in urban logistics. We also identified possible challenges such as difficulties in data collection and lack of infrastructure, monitoring system, modelling, and validation.

The main contribution of this study is to identify the research gaps in the analysis of the impact of blockchain on decarbonization in urban logistics. The next step in the research is to develop a demonstration ABM to model scenarios of digitalization in European logistics. This will address new logistics structures including logistics control towers, synchromobility and automated logistics systems applying blockchain technologies.

REFERENCES

[1] V. Ghisolfi, L. A. Tavasszy, G. H. d. A. Correia, G. d. L. D. Chaves, and G. M. Ribeiro, "Freight Transport Decarbonization: A Systematic Literature Review of System Dynamics Models," *Sustainability*, vol. 14, no. 6, p. 3625, 2022. [Online]. Available: https://www.mdpi.com/2071-1050/14/6/3625.

[2] J. Köhler and C. Brauer, "Assessment of new needs and knowledge analysis gaps, defining requirements for analysis methods and data, STORM project D2.1 Grant no. 101006700, Fraunhofer ISI, Karlsruhe.," VTT, 2022.

[3] P. Jaramillo *et al.*, "Transport. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)].", Cambridge, UK and New York, NY, USA, 2022. [Online]. Available: https://www.ipcc.ch/report/sixth-assessment-report-working-group-3/

[4] S. Pfoser, H. Kotzab, and I. Bäumler, "Antecedents, mechanisms and effects of synchromodal freight transport: a conceptual framework from a systematic literature review," *The International Journal of Logistics Management*, 2021.

[5] L. Tavasszy, B. Behdani, and R. Konings, "Intermodality and synchromodality," in *Ports and Networks*: Routledge, 2017, pp. 251-266.

[6] A. Dolgui, D. Ivanov, S. Potryasaev, B. Sokolov, M. Ivanova, and F. Werner, "Blockchain-oriented dynamic modelling of smart contract design and execution in the supply chain," *International Journal of Production Research*, vol. 58, no. 7, pp. 2184-2199, 2020.

[7] Z. Li, H. Guo, A. V. Barenji, W. M. Wang, Y. Guan, and G. Q. Huang, "A sustainable production capability evaluation mechanism based on blockchain, LSTM, analytic hierarchy process for supply chain network," *International Journal of Production Research*, vol. 58, no. 24, pp. 7399-7419, 2020.

[8] C. Antônio Rufino Júnior, E. R. Sanseverino, P. Gallo, D. Koch, H.-G. Schweiger, and H. Zanin, "Blockchain review for battery supply chain monitoring and battery trading," *Renewable and Sustainable Energy Reviews*, vol. 157, p. 112078, 2022/04/01/ 2022, doi: https://doi.org/10.1016/j.rser.2022.112078.

[9] K. Biswas and V. Muthukkumarasamy, "Securing Smart Cities Using Blockchain Technology," in *2016 IEEE 18th International Conference on High Performance Computing and Communications; IEEE 14th International Conference on Smart*

City; IEEE 2nd International Conference on Data Science and Systems (HPCC/SmartCity/DSS)*, 12-14 Dec. 2016 2016, pp. 1392-1393, doi: 10.1109/HPCC-SmartCity-DSS.2016.0198.

[10] P. De Giovanni, "Blockchain and smart contracts in supply chain management: A game theoretic model," *International Journal of Production Economics*, vol. 228, p. 107855, 2020/10/01/ 2020, doi: https://doi.org/10.1016/j.ijpe.2020.107855.

[11] J. Lohmer, N. Bugert, and R. Lasch, "Analysis of resilience strategies and ripple effect in blockchain-coordinated supply chains: An agent-based simulation study," *International Journal of Production Economics*, vol. 228, p. 107882, 2020/10/01/ 2020, doi: https://doi.org/10.1016/j.ijpe.2020.107882.

[12] S. Singh, P. K. Sharma, B. Yoon, M. Shojafar, G. H. Cho, and I.-H. Ra, "Convergence of blockchain and artificial intelligence in IoT network for the sustainable smart city," *Sustainable Cities and Society*, vol. 63, p. 102364, 2020/12/01/ 2020, doi: https://doi.org/10.1016/j.scs.2020.102364.

[13] S. A. Bagloee, M. Heshmati, H. Dia, H. Ghaderi, C. Pettit, and M. Asadi, "Blockchain: The operating system of smart cities," *Cities*, vol. 112, p. 103104, 2021/05/01/ 2021, doi: https://doi.org/10.1016/j.cities.2021.103104.

[14] N. V. Thanh, "Blockchain Development Services Provider Assessment Model for a Logistics Organizations," *Processes*, vol. 10, no. 6, doi: 10.3390/pr10061209.

[15] U. Logistic, "How to unlock value from last mile delivery for cities, transporters and retailers, Arthur D," *Little FUM, May*, 2015.

[16] V. Sharma, R. D. Raut, U. H. Govindarajan, and B. E. Narkhede, "Advancements in urban logistics toward smart, sustainable reforms in developing enabling technologies and markets," *Kybernetes*, vol. 51, no. 3, pp. 1038-1061, 2022, doi: 10.1108/K-01-2021-0026.

[17] S. Anderson, J. Allen, and M. Browne, "Urban logistics––how can it meet policy makers' sustainability objectives?," *Journal of Transport Geography*, vol. 13, no. 1, pp. 71-81, 2005/03/01/ 2005, doi: https://doi.org/10.1016/j.jtrangeo.2004.11.002.

[18] S. Pan, W. Zhou, S. Piramuthu, V. Giannikas, and C. Chen, "Smart city for sustainable urban freight logistics," *International Journal of Production Research*, vol. 59, no. 7, pp. 2079-2089, 2021/04/03 2021, doi: 10.1080/00207543.2021.1893970.

[19] G. Büyüközkan and Ö. Ilıcak, "Smart urban logistics: Literature review and future directions," *Socio-Economic Planning Sciences*, vol. 81, p. 101197, 2022/06/01/ 2022, doi: https://doi.org/10.1016/j.seps.2021.101197.

[20] T. Fraske and B. Bienzeisler, "Toward smart and sustainable traffic solutions: a case study of the geography of transitions in urban logistics," *Sustainability: Science, Practice and Policy*, vol. 16, no. 1, pp. 353-366, 2020/12/10 2020, doi: 10.1080/15487733.2020.1840804.

[21] C. Y. Bin, W. Yang, and X. Wang, "Blockchain for Decarbonization," in *Intelligent Decarbonisation: Can Artificial Intelligence and Cyber-Physical Systems Help Achieve Climate Mitigation Targets?*, O. Inderwildi and M. Kraft Eds. Cham: Springer International Publishing, 2022, pp. 61-72.

[22] Z. Tian, R. Y. Zhong, A. Vatankhah Barenji, Y. T. Wang, Z. Li, and Y. Rong, "A blockchain-based evaluation approach for customer delivery satisfaction in sustainable urban logistics," *International Journal of Production Research*, vol. 59, no. 7, pp. 2229-2249, 2021/04/03 2021, doi: 10.1080/00207543.2020.1809733.

[23] C. Y. Bin, W. Yang, and X. Wang, "Blockchain for Decarbonization," in *Intelligent Decarbonisation*: Springer, 2022, pp. 61-72.

[24] J. Sedlmeir, H. U. Buhl, G. Fridgen, and R. Keller, "The Energy Consumption of Blockchain Technology: Beyond Myth," *Business & Information Systems Engineering*, vol. 62, no. 6, pp. 599-608, 2020/12/01 2020, doi: 10.1007/s12599-020-00656-x.

[25] A. Jabbar and S. Dani, "Investigating the link between transaction and computational costs in a blockchain environment," *International Journal of Production Research*, vol. 58, no. 11, pp. 3423-3436, 2020/06/02 2020, doi: 10.1080/00207543.2020.1754487.

[26] T.-M. Choi and T. Siqin, "Blockchain in logistics and production from Blockchain 1.0 to Blockchain 5.0: An intra-inter-organizational framework," *Transportation Research Part E: Logistics and Transportation Review*, vol. 160, p. 102653, 2022.

[27] S. Pu and J. S. L. Lam, "Greenhouse gas impact of digitalizing shipping documents: Blockchain vs. centralized systems," *Transportation Research Part D: Transport and Environment*, vol. 97, p. 102942, 2021/08/01/ 2021, doi: https://doi.org/10.1016/j.trd.2021.102942.

[28] B. Esmaeilian, J. Sarkis, K. Lewis, and S. Behdad, "Blockchain for the future of sustainable supply chain management in Industry 4.0," *Resources, Conservation and Recycling*, vol. 163, p. 105064, 2020/12/01/ 2020, doi: https://doi.org/10.1016/j.resconrec.2020.105064.

[29] A. Rejeb, K. Rejeb, S. J. Simske, and J. G. Keogh, "Blockchain technology in the smart city: a bibliometric review," *Quality & Quantity*, vol. 56, no. 5, pp. 2875-2906, 2022/10/01 2022, doi: 10.1007/s11135-021-01251-2.

[30] IPCC, "Annex III: Scenarios and modelling methods [Guivarch, C., E. Kriegler, J. Portugal-Pereira, V. Bosetti, J. Edmonds, M. Fischedick, P. Havlík, P. Jaramillo, V. Krey, F. Lecocq, A. Lucena, M. Meinshausen, S. Mirasgedis, B. O'Neill, G.P. Peters, J. Rogelj, S. Rose, Y. Saheb, G. Strbac, A. Hammer Strømman, D.P. van Vuuren, N. Zhou (eds)]. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. ," Cambridge, UK and New York, NY, USA, 2022. [Online]. Available: https://www.ipcc.ch/report/sixth-assessment-report-working-group-3/

[31] E3Modelling, *PRIMES MODEL VERSION 2018 Detailed model description*, 2018. [Online]. Available: https://e3modelling.com/wp-content/uploads/2018/10/The-PRIMES-MODEL-2018.pdf.

[32] ASTRA. "ASTRA model." http://www.astra-model.eu/ (accessed 24-10-2022, 2022).

[33] E. Szimba *et al.*, "HIGH-TOOL–a strategic assessment tool for evaluating EU transport policies," *Journal of Shipping and Trade*, vol. 3, no. 1, pp. 1-30, 2018.

[34] HIGH-TOOL. https://www.high-tool.eu/ (accessed 04-11-2022.

[35] O. A. Nielsen and A. Burgess, "The European TRANS-TOOLS transport model," *Transportation*, pp. 1-18, 2008.

[36] TRIMODE. http://www.trt.it/en/PROGETTI/trimode_project/ (accessed 10-11-2022.

[37] P. Siskos, P. Capros, G. Zazias, D. Fiorello, and K. Noekel, "Energy and fleet modelling within the TRIMODE integrated transport model framework for Europe," *Transportation Research Procedia*, vol. 37, pp. 369-376, 2019/01/01/ 2019, doi: https://doi.org/10.1016/j.trpro.2018.12.205.

[38] A. Martino *et al.*, "TRIMODE: integrated transport model for Europe," *Proceedings of 7th Transport Research Arena TRA 2018, April 16-19, 2018, Vienna, Austria*, 2018.

[39] MoMo. "Mobility Model IEA." https://www.iea.org/areas-of-work/programmes-and-partnerships/the-iea-mobility-model (accessed 09-11-2022.

[40] H. Quak, M. Lindholm, L. Tavasszy, and M. Browne, "From Freight Partnerships to City Logistics Living Labs – Giving Meaning to the Elusive Concept of Living Labs," *Transportation Research Procedia*, vol. 12, pp. 461-473, 2016/01/01/ 2016, doi: https://doi.org/10.1016/j.trpro.2016.02.080.

[41] V. Gatta, E. Marcucci, and M. Le Pira, "Smart urban freight planning process: integrating desk, living lab and modelling approaches in decision-making," *European Transport Research Review*, vol. 9, no. 3, p. 32, 2017/06/06 2017, doi: 10.1007/s12544-017-0245-9.

[42] V. Reis, "Analysis of mode choice variables in short-distance intermodal freight transport using an agent-based model," *Transportation Research Part A: Policy and Practice*, vol. 61, pp. 100-120, 2014/03/01/ 2014, doi: https://doi.org/10.1016/j.tra.2014.01.002.

[43] M. Jahangir Samet, J. Köhler, T. Horak, and P. Vařacha, "Proposals for integrated strategic assessment methods and models. STORM project D4.2 Grant no. 101006700," VTT, 2023.

[44] V. Martinez, M. Zhao, C. Blujdea, X. Han, A. Neely, and P. Albores, "Blockchain-driven customer order management," *International Journal of Operations & Production Management*, 2019.