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Blockchain for Solid Waste Trading

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A green economy is an economy that aims to reduce environmental risks and ecological scarcities, and that lines up sustainable development without degrading the environment. Waste can be solid, liquid, or gas and each type has different methods of disposal and management. Since the common principles of management are efficiency and fairness, Blockchain as a peer-to-peer concept with a consensus mechanism is suitable for waste management. The paper presents the first stage of project “Blockchain in solid waste management”. From several points of view a review of solid waste management is performed, in which the blockchain has the major role: (1) problem definition and possible solutions; (2) Blockchain applications in solid waste management; (3) blockchain applications for different solid waste types; (4) blockchain elements for waste management; (5) blockchain in cooperation with other technologies. The author syntheses advanced sorting process, models of Blockchain in solid waste trading, and three use cases with selected granularity. The used design methodology is unified modelling language: activity diagrams and communication diagrams. The author applies the principles of supply and demand. The models are intended for business developers, university professors, and students.

Keywords: green economy, solid waste, waste management, blockchain, waste trading

Introduction

A circular economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products for as long as possible (News European Parliament, 2023). Very important element in it is waste management. It includes the processes and actions required to manage waste from its inception to its final disposal. This consists of collection, transport, treatment, and disposal of waste, together with monitoring and regulation of the waste management process and waste-related laws, technologies, economic and technological mechanisms. One of the technological mechanisms is Blockchain. Blockchain is a growing list of records, called *blocks*, that are securely linked together using cryptography. Literary sources for solid waste management and Blockchain in it could be merged in following basic topics with several subtopics.

Problem Definition and Possible Solutions

Taylor, Steenmans, and Steenmans (2020) focus on the waste management and suggests “problem-led” solving by definition of property rights of products and wastes, supporting law and policy goals, maintaining anonymity and privacy for institutions and individuals, and disregard “solution-led” problem solving by

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minimum landfill and automation technology. Franca, Amato Neto, Gonçalves, and Almeida (2020) describe the Blockchain public environment of Ethereum, and without any technical details for further waste processing: trading and recycling. Staub (2019) comments the early Blockchain adopters for cleaner and sustainable world, and without technical specifics. Joshi (2020) considers Blockchain as mechanism for whole life cycle of waste management. Dondjio and Themistocleous (2022) discuss the worsening living conditions in Land Conservation Districts due to increased trash generation. The Blockchain technology could be the solution as it make help waste management by increasing public knowledge, transparency, and stakeholder confidence. Furthermore, the study's findings will help addressing research gaps on using new technology to conserve the environment. Setiawan, Permana, and Rahman (2022) analyse criteria for introduction of Blockchain in waste management, using DEMATEL method (Decision-making Trial and Evaluation Laboratory). The method found active criteria and effected criteria. However, there is no detailed suggestion for Blockchain implementation model and development of unified system for a bigger region. Lenz Barkel, and Tsangaratos (2022) explain Blockchain technology as "state-based communication". But the task is moved to the next state in its life cycle by messages. So, the new paradigm could be "state-based with message-using communication". Caparros, Kleinheyer, Lenz, and Tsangaratos (2022) present curriculum where students develop specific competences about waste management and Blockchain, computer tools, win-win-situations in decentralized business environment and corporate communication. Steenmans and Taylor (2018) point out the Blockchain role in waste management: tracking and enforcing the rules, and without technical details.

Blockchain Applications in Waste Management

Sorting. Gopalakrishnan and Radhakrishnan (2019) illustrate the Blockchain platform Recereum which mainly addresses the waste sorting and related areas in waste management cycle. Detailed communications between sorted waste and recycle manufacturers miss. Malloy (2021) outlines sorting organised by QR-code scanning. Calaiaro (2022) analyses robots with Artificial Intellect (AI), which sort waste: recognition of shapes, colours, and even labels for material identification with ultrafast speed. However, organisation for waste trading missed.

Customer side. Blockchain expert (2019) focuses on waste management and not on the further processing to collect quantity and quality. Takyar (2023) emphasizes on waste management too and fixes the possible organisational problems and the Blockchain advantages by solving them. Shaik et al. (2021) also describe a waste management system. The platform is evaluated to check the performance efficiency. On the customer side it is observed that the weight of the bins is creating new transactions in the Blockchain network. However, the waste quality, a very important business feature, is not considered in detail. Fanjun et al. (2023) shows Trash Barrel Robots in the city to elicit natural interaction behaviours, and the further processing misses.

Different management aspects. Chapman (2021) considers the Blockchain as a technology which can track the quantity of produced waste, and it could also track the waste quality and the negotiations about the further processing. Distributed (2018) defines the zero-waste goal, discusses platforms that use Blockchain to reach this issue: Plastic Bank, Recereum, Swachhcoin, Agora Tech Lab, Dutch Ministry for Infrastructure, etc. But detailed models for improvement of recycling rates miss. Herrera (2022) explains Blockchain applications for waste management in different countries: Argentina, India, and USA (New York).

Blockchain Applications for Different Waste Types

Plastics. Flynn (2020) illustrates cross-organisation supply chain recycling tracking with accent on Blockchain solution for recycling companies. The solution is intended only for plastics recycling. Malloy (2021) outlines a concept only for plastic bottles, and details about the merchandise miss. Herrera (2022) focuses on the value of Blockchain: as a tool for recycled plastic trading as it can increase the traceability and transparency of these raw materials. However, a more uniform sorting, plastic recycling certification, and labelling system within the recycled plastic market is needed to properly scale its implementation.

Electronic waste. Gupta and Bedi (2018) analyse modules of smart contracts for e-waste management. In a research (Gupta & Bedi, 2020), they show forward supply chain for e-products and reverse supply chain for e-waste with tokenization, document storage, and payment interaction. However, business communications for recycling centres miss. IEEE explore digital library (2021) presents incentive-based management system for electronic waste.

Waste from specific industries. Shih and Palmer (2019) describe waste management for oil and gas extracting and transport. Anghelescu et al. (2022a; 2022b) and Petrova (2020) discuss the power plants and the mining industry as specific waste sources. Introducing these waste types in a unified management model will improve the recycling efficiency and will lessen the regulatory efforts.

Blockchain Elements for Waste Management

Editor's desk (2020) illustrates real-time waste tracking to disposal even to recycling with securing data transactions focus, and without further details. Njuguna (2020) outlines important feature of Blockchain *transactions:* publicly and chronologically storage. Basic for waste transport and regulatory compliance, the proof is with green fabrics company. However, without technological details. Gupta and Bedi (2018) point out modules of *smart contracts* for e-waste management. The interactions between the different modules need more details like communications messages. Saad et al. (2023) present *machine-to-machine (M2M) communications* by tracking waste vehicles. The authors suggest segregation and recycling of waste as research for a more comprehensive solution.

Blockchain in Cooperation with Other Technologies

Blockchain and IoT. Sharma (2020) shows how Blockchain brings transparency in waste management with IoT sensors and QR-codes to collect data. The author lists Blockchain advantages pointing some startups. Paturi et al. (2021) propose unique smart waste management system using Blockchain and IoT to simplify the waste segregation. The next step could be embedding IoT in AI-cameras.

Blockchain and cloud server. Shaik et al. (2021) trace a mechanism that integrates a cloud server and a Blockchain, and it is not considered in detail.

Blockchain and big data. Ivanova, Iliev, and Stoyanov (2020) analyse in detail Big Data Networks, which are very important for tracking the full life cycle of the products and implementation of producer responsibility.

The aim of this article is development of models for: (1) Sorting, which is tailored for waste trading, (2) Blockchain as suitable mechanism for waste trading, (3) Blockchain communications for selected use cases.

Methodology

Methodology for describing use cases for Blockchain in waste trading includes Unified Modelling Language—UML (Fowler, 2004; StarUML, 2022). UML is a general-purpose, developmental, modelling language in the field of software engineering that is intended to provide a standard way to visualise the design of a system. The diagrams are organized into two distinct groups: structural diagrams and behavioural (interaction) diagrams. Structural UML diagrams are Class Diagram, Package Diagram, Object Diagram, Component Diagram, Composite Structure Diagram, and Deployment Diagram. Behavioural UML Diagrams are Activity Diagram, Sequence Diagram, Use Case Diagram, State Diagram, Communication Diagram, Interaction Overview Diagram, and Timing Diagram. The author has experience with Use Case Diagram, Communication Diagram (Ilieva-Obretenova & Chaudhary 2020), and Class Diagram (Ilieva-Obretenova, 2022). This research will use Behavioural Diagrams: Activity Diagram and Communication Diagram. The used indications in Activity Diagram are start point (filled point), fork node, and final point (filled point with a circle around it). Communication Diagrams are preferred over Sequence Diagrams because they focus on the links in the process. Sequence Diagrams demonstrate the sequence of the process steps. Communication Diagram consists of system links and communication types in dynamical relationships between actors. Components of Communication Diagram are Lifeline (participant), Connector, Forward Message and Reverse Message. The Lifeline is represented as a rectangle. It relates to a Class in Class Diagram. The connector is represented as a line. It relates to both classes it connects. The Forward Message is represented as a line with arrow to the right. It has number and text. The Reverse Message is represented as a line with arrow to the left. It has number and text. However, in Communication Diagram the messages follow the layout of Lifelines.

Results

The results for modelling Blockchain for waste trading comprise Activity Diagram for sorting centre and Communication Diagrams for waste trading.

Figure 1 illustrates the processes in sorting centre: sorting adapted for waste trading. All stages are depicted after the trucks unload on the tip floor and the front-end loader dumps the material onto the conveyor belt at a rate of 30 to 60 tonnes per hour.

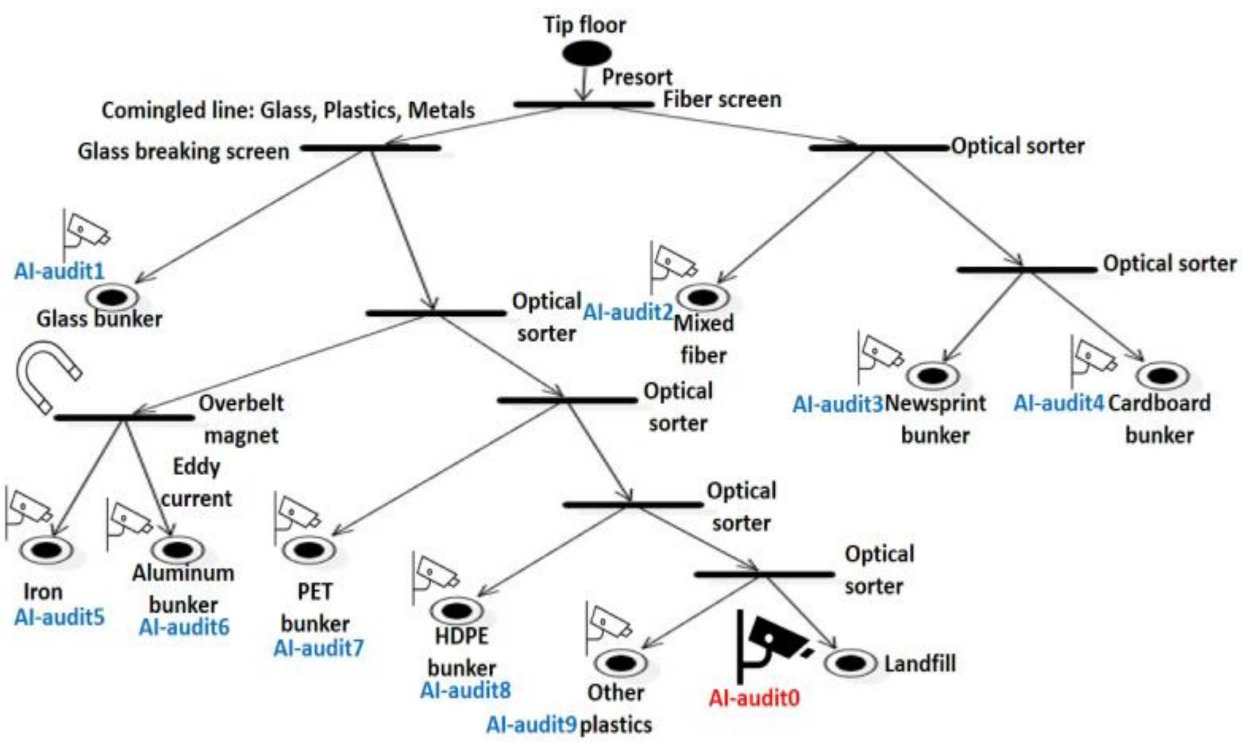

Figure 1. Processes in sorting centre: sorting, adapted for waste trading.

1. Presort. Human-workers remove large items.
2. Separating fibre (paper) from glass, plastics, and metals.
3. Sorting paper mixed fibre and others.
4. Sorting other fibre—magazines and cardboard.
5. Sorting glass. Smash glass and fall to the bunker.
6. Sorting metals—by overbelt magnets, which collect ferrous metals in a bunker and by eddy-current-inducing machine, which jolts nonferrous metals to another bunker.
7. Sorting plastics: (a) Separating PET for water bottles, (b) Separating HDPE for detergent bottles, (c) Separating other plastics.
8. Separating waste for landfill—between 10% and 30% of what came in on the trucks.

Figure 2 shows a scheme, on which landfills and recycle centres for paper, for plastics for metal, and for glass are depicted. Each actor has a Full node and a Light node. The Full node consists of Blockchain copy and its basic functions include confirmation of transactions and consensus support with other Full nodes. Full nodes (AI-audit0) are installed on distribution points of all participants. Full node could offer, seek, and reject requests. Light nodes (departments of landfill or recycling factory) are used for requests to Full node. They apply Simple Payment Verification (SPV) for transaction validation. They don't consist of the fully copy of Blockchain, but only of a copy of its own transactions. They depend on Full node. Light nodes are connected to AI-audit_n of the respective Full node.

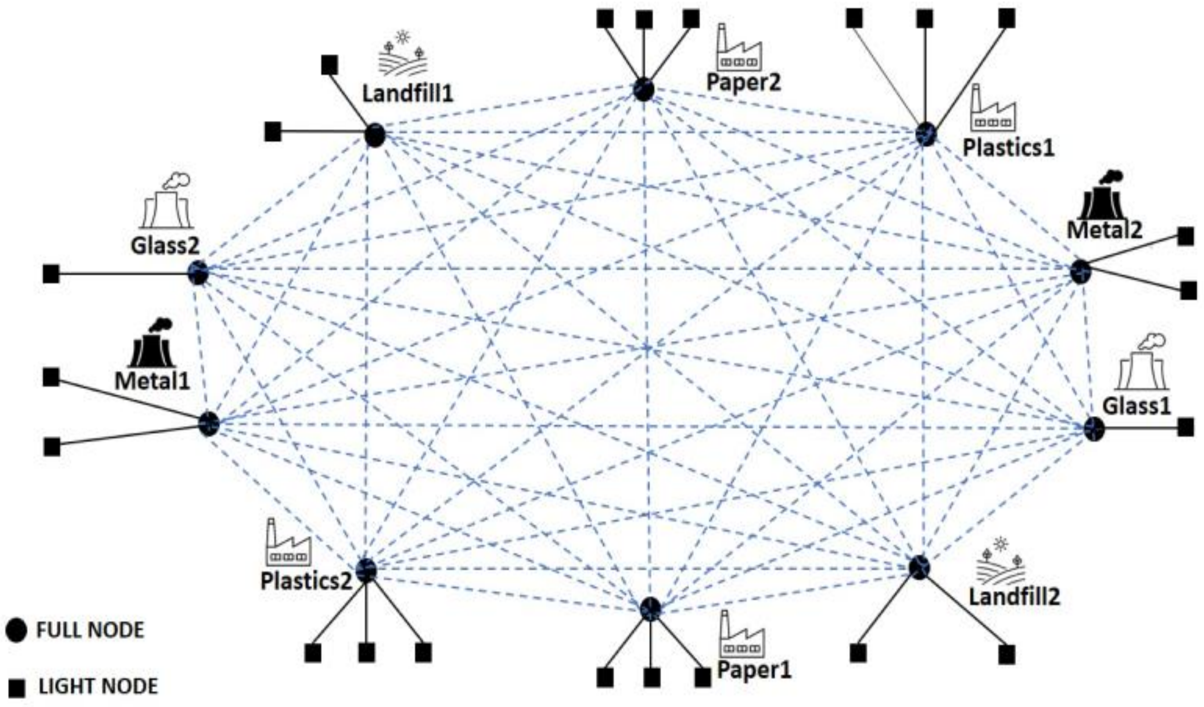

Figure 2. Blockchain for waste trading—common representation.

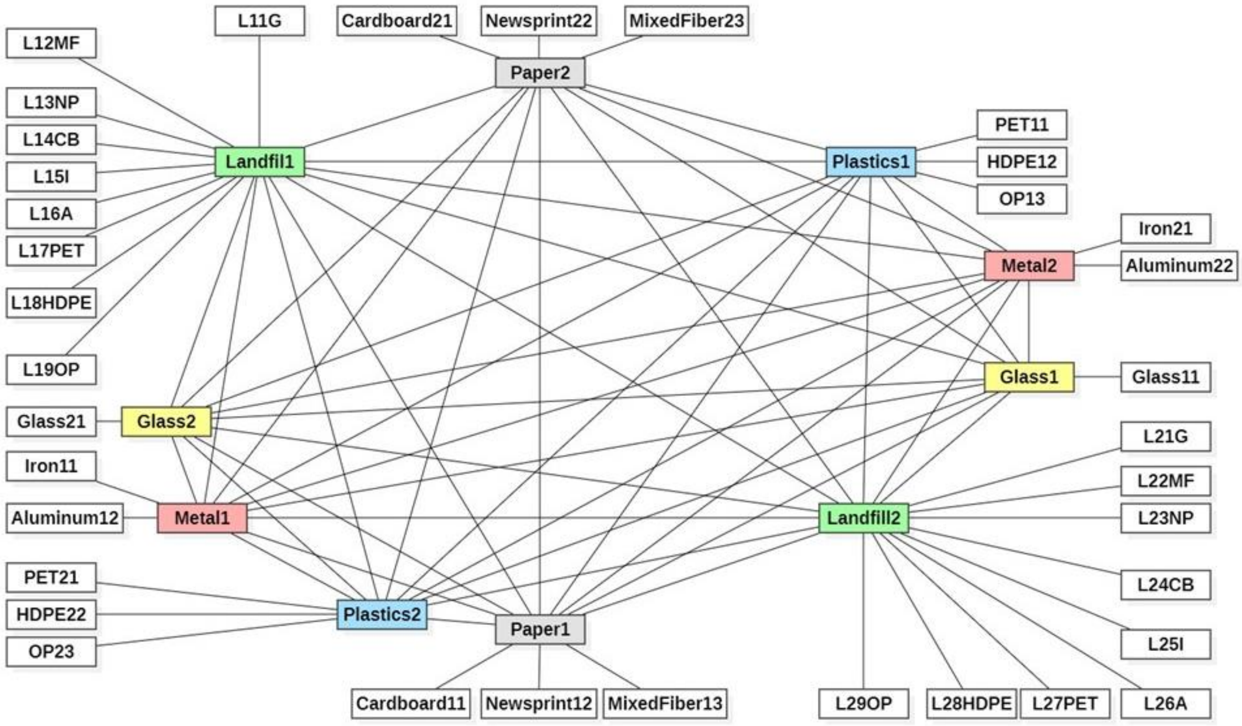

Figure 3. Blockchain in waste trading—detailed representation.

Figure 3 studies scheme with Full nodes and Light nodes of landfills, paper recycling, plastics recycling, metal recycling, and glass recycling. Light nodes consider the bunkers of Figure 1.

- Full node Landfill1 has the following Light nodes:
  - L11G—Lanfill1-1-Glass,
  - L12MF—Landfill1-2-Mixed Fibre,
  - L13NP—Landfill1-3-Newsprint,
  - L14CB—Landfill1-4-Cardboard,
  - L15I—Landfill1-5-Iron,
  - L16A—Landfill1-6-Alumin,
  - L17PET—Landfill1-7-PET (Polyethylene Terephthalate),
  - L18HDPE—Landfill1-8-HDPE (High-density polyethylene),
  - L19OP—Landfill1-9-OP (Other plastics).
- Full node Landfill2 has the same Light nodes:
  - L21G—Lanfill2-1-Glass,
  - L22MF—Landfill2-2-Mixed Fibre,
  - L23NP—Landfill2-3-Newsprint,
  - L24CB—Landfill2-4-Cardboard,
  - L25I—Landfill2-5-Iron,
  - L26A—Landfill2-6-Alumin,
  - L27PET—Landfill2-7-PET (Polyethylene Terephthalate),

- L28HDPE—Landfill2-8-HDPE (High-density polyethylene),
- L29OP—Landfill2-9-OP (Other plastics).

- Full node Paper1 has the following Light nodes:
  - Cardboard11,
  - Newsprint12,
  - MixedFiber13.
- Full node Paper2 has the following Light nodes:
  - Cardboard21,
  - Newsprint22,
  - MixedFiber23.
- Full node Glass1 has the following Light node (possible building of other shops too):
  - Glass11.
- Full node Glass2 has the following Light node (possible building of other shops too):
  - Glass21.
- Full node Metal1 has the following Light nodes:
  - Iron11,
  - Aluminum12.
- Full node Metal2 has the following Light nodes:
  - Iron21,
  - Aluminum22.
- Full node Plastics1 has the following Light Nodes:
  - PET11,
  - HDPE12,
  - OP13—Other plastics.
- Full node Plastics2 has the following Light Nodes:
  - PET21,
  - HDPE22,
  - OP23—Other plastics.

Figure 4 summarises Communication Diagram for glass request from shop of Recycling factory. The following messages are exchanged between Light nodes and Full nodes in Blockchain infrastructure.

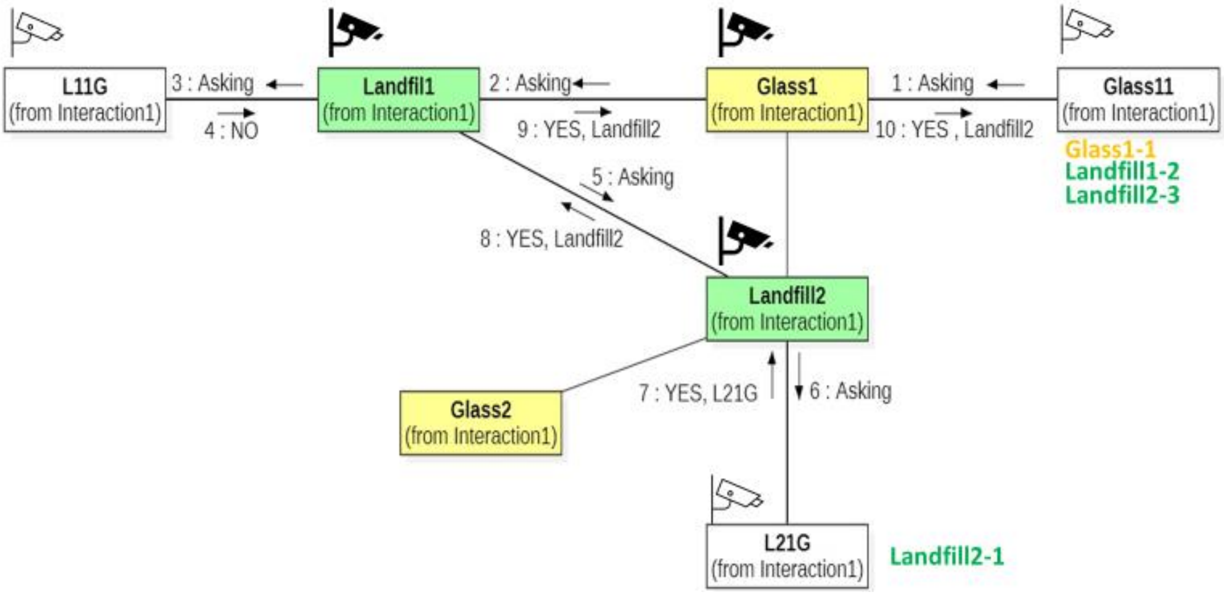

Figure 4. Communication diagram of glass request.

1. Light node Glass11 issues a request to Full node Glass1. *Glass1 initializes a Blockchain and writes "Glass1-1" in the memory of Glass11.*

2. Full node Glass1 sends a request to Full node Landfill1. It could send a message to another glass recycling factory (Glass2), but Landfills have a priority. *Glass1 writes "Landfill1-2" in the memory of Glass11 as the second counterparty.*

3. Full node Landfill1 asks its Light node L11G (glass bunker) for the requested quality and quantity of glass.

4. Light node L11G answers: NO.

5. The Blockchain with the asking is directed to Landfill2. *Glass1 writes "Landfill2-3" in the memory of Glass11 as the third counterparty.*

6. Full node Landfill2 asks its Light Node L21G (glass bunker) for the requested quality and quantity of glass. *Landfill2 writes "Landfill2-1" in the memory of L21G (as the first transaction for the day).*

7. Light node L21G answers: YES.

8. Full node Landfill2 answers YES to Full node Landfill1.

9. Full node Landfill1 answers YES (It's Landfill2).

10. Full node Glass1 answers YES to Light node Glass11.

The payment could be cleared. The glass transport could be started. In the requesting Light node a list of Full nodes is stored, participating in the demand. In the answering Light node a list of requests from its Full node on the recent day is stored. All nodes are equipped with the corresponding AI-audit camera for dispatching and receiving a quantity and quality.

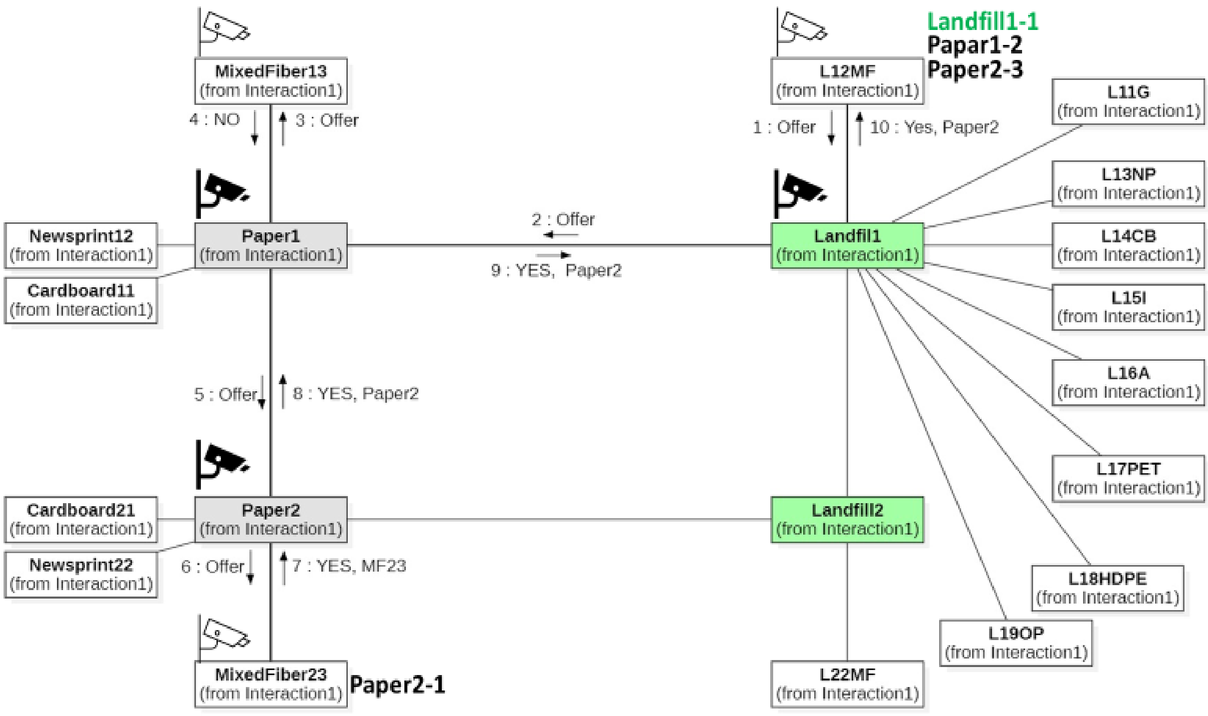

Figure 5. Communication diagram of paper offer.

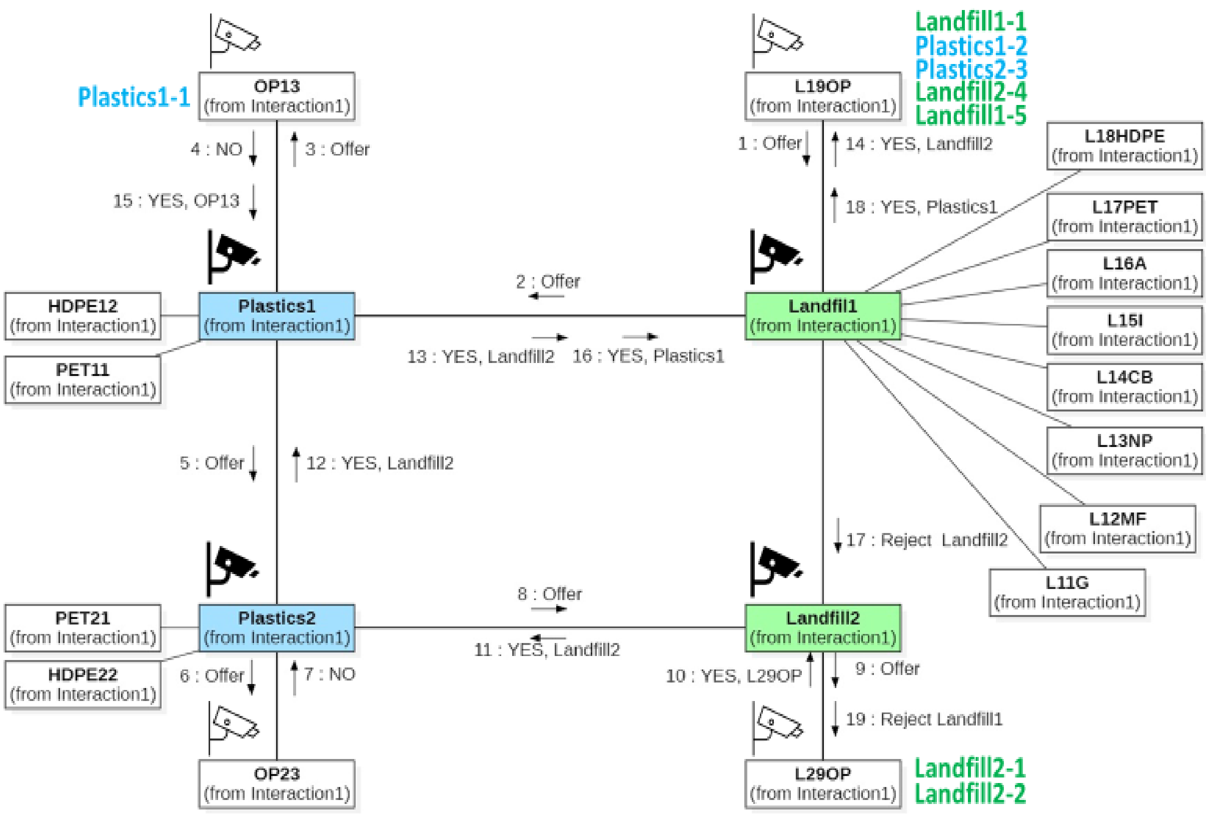

Figure 6. Communication diagram of plastics offer with rejection.

Figure 5 traces Communication Diagram for paper offer from bunker of Landfill1 (L12MF-Mixed Fibre). The process is the same as in Figure 4 Glass Request. The Light node issues an offer instead of a request.

Figure 6 demonstrates Communication Diagram for plastics offer with subsequent rejection. The messages are the same as in Figure 4 and Figure 5. The difference is that the Full node Plastics1 says NO and then YES. So, the Full node Landfill1 rejects the former YES from Landfill2 because the recycling factories have a priority.

Conclusion

Green economics and waste recycling are pressure issues of moder society. A method for environmental conservation is waste sorting and their reuse as raw materials. The management of these raw materials needs a mechanism for transaction balance between all actors. The article depicts the solid waste sorting with optical sorters and magnet for iron. At the end of each sorting there is an AI-camera, which estimates the quantity and quality of the collected material and communicates with the main camera on the landfill, when it performs supply and demand of raw materials. At the same way recycle centres have main AI-camera, which participates in requests for waste trading, and other AI-cameras, located in each shop. Peer-to-peer interconnection of landfills and recycling centres for different materials and their Blockchain communications are illustrated. The future work includes research of: (1) Further cooperation of Blockchain and AI for security increasing by information exchange about materials; (2) New functions and energy saving performance of cameras; (3) AI development with reporting of geographic and social-economic diversity of waste in the world. The long-term aim is the economic, environmental, and social effectiveness and efficiency of Blockchain in waste trading.

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