Proc. Blockchain in Kyoto 2022 (BCK22)
JPS Conf. Proc. **40**, 011008 (2023)
https://doi.org/10.7566/JPSCP.40.011008

First Demonstration Experiment for Energy-Trading System EDISON-X Using the XRP Ledger

Yuichi Ikeda[1], Yu Ohki[1], Zelda Marquardt[1], Yu Kimura[2], Sena Omura[2], Emi Yoshikawa[3]

[1]*Graduate School of Advanced Integrated Studies in Human Survivability, Kyoto University, Kyoto 606-8306, Japan*
[2]*CauchyE Ltd., Kyoto 602-8061, Japan*
[3]*Ripple Labs Inc., California 94104, USA*

E-mail: ikeda.yuichi.2w@kyoto-u.ac.jp

(Received December 1, 2022)

We developed a blockchain-based energy-trading system called EDISON-X to manage the buying and selling of electricity usage rights (i.e., tokens). Students buy UPX and SPX tokens to use electricity supplied from the utility company ’ s distribution lines and solar PV panels installed on the roof of the school building, respectively. In July 2022, 17 students from our school dormitory participated in an experiment to validate the operation of the EDISON-X system. Based on the results of this experiment, we describe an energy-trading system using blockchain technology for the effective usage of renewable energy. We developed topology and network science methodologies to understand the characteristics of energy trading. This study examined the hypothesis that market transactions become less active when “ cavities ” appear using topological data analysis. The preliminary results suggest that this hypothesis is plausible.

KEYWORDS: energy-trading system, blockchain, token, renewable energy, demonstration experiment, hypergraph, persistent homology

1. Introduction

Blockchain has the potential to be a fundamental technology for addressing various global issues, such as low-cost international remittance for migrants, fast and reliable digital ID for medical services for refugees, financial inclusion to provide everyone with non-discriminatory financial services, commerce management, such as supply chains and commodity markets, economic support for financing and talent matching, and trade of distributed energy, such as renewable energy, solar insolation energy, and wind energy [1]. However, to use blockchain and crypto-assets to resolve these issues, the price of the crypto-assets must be stable, the amount of electrical energy required for transaction validation must be appropriate, the cost of the transaction must be low, the speed of the transaction must be high, and the occurrence of anomalous events such as money laundering and fraud must be prevented.

In this study, we focus on energy-trading systems that use blockchain technology. In energy-trading, the use of distributed energy sources, such as renewable energy, is essential. Blockchain technology is often utilized in energy-related cases because it enables peer-to-peer transactions. One prime example is the Brooklyn Microgrid [2], a distributed electricity marketplace powered by blockchain technology that enables consumers and prosumers to share electricity demand and supply information and transact electricity with each other without an intermediary. The Power Ledger, an energy technology company, has also been developing a trustless, transparent, and interoperable energy-trading platform [3] powered by a token to align participants ’ incentives. Other examples of blockchain energy-related applications include a simulation study on electric vehicles charging using renewable energy [4] and the development of a microgrid management system [5]. Comprehensive information for related works can be found in review papers [6, 7].

Based on these precedents, we developed an energy-trading system using blockchain technology in the dormitory of our school, which accommodates approximately 80 students. The existing system for collecting electricity charges is slightly complicated and strains the accounting students and staff. To address the problems of complexity and transparency in collecting electricity charges, we developed an energy-trading system, EDISON-X, which uses blockchain technology to manage the buying (bid) and selling (ask) of electricity usage rights (i.e., tokens) for students residing in the dormitory of our school.

We then conducted a small-scale demonstration experiment with 17 student participants in our school dormitory from July 1 to July 31, 2022. Based on the results of this experiment, we describe an energy-trading system using blockchain technology for the effective deployment of renewable energy. The goal is to demonstrate the operation of the energy-trading system, EDISON-X, and to develop methodologies based on topology and network science to understand the energy-trading characteristics and predict market changes.

2. Energy-Trading System EDISON-X

2.1 System Architecture

We developed an energy-trading system, EDISON-X, that uses blockchain technology to manage buying (bid) and selling (ask) electricity usage rights (tokens). Here, EDISON-X stands for energy distribution and integration systems either on “campus”, “small office”, “home”, “remote area”, “island region”, or “rural areas in developing countries” It is based on various open-source technologies and frameworks developed by Google, Ripple Labs, and others. EDISON-X uses a cloud-based database called Firestore [8], which is developed on Google Cloud and has high stability. The electricity usage of the school dormitory and the amount of electricity generated by the solar photovoltaic (PV) system were monitored and controlled by Panasonic ’ s energy server, WeLBA, which sent the data to Firestore.

Figure 1 shows the configuration of the EDISON-X system. We used an XRP ledger (XRPL) that consumes a small amount of electric energy for validation because it uses an algorithm instead of mining [9, 10]. XRPL is a public, permissionless blockchain that has been operating since 2012; it is one of the largest blockchain networks in the world. A key difference between XRPL and other major blockchain networks, such as Bitcoin and Ethereum, is that XRPL uses the Federated Byzantine Agreement as its consensus mechanism, rendering its settlement extremely fast (3–4 seconds per settlement), low cost ($\leq$ \$0.001 per transaction), and scalable (1,500 transactions per second). Owing to these properties, XRPL is ideal for use cases involving payments and settlement. In addition, XRPL enables a wide range of other use cases, including non-fungible tokens and decentralized finance (DeFi), and became the first major blockchain to achieve carbon neutrality in 2020.

Any process on the Google Cloud that changes the token balance is sent to the XRPL as a transaction. Many transactions occur in EDISON-X over a short period of time. Therefore, XRPL, which has a faster processing time, was adopted to address the issue of fast transaction time. Typically, transactions are processed in seconds. These functions and the web application described here are powered by Firebase [11], a platform on Google Cloud. Firebase has the advantages of ease of management and high security through an authentication system developed by Google.

Electricity usage rights are fungible UPX and SPX tokens, which are recorded on XRPL as a send transaction. Users need UPX and SPX tokens to use the electricity provided by the utility company ’ s distribution lines and PV panels, respectively. Users can buy tokens from other users who wish to sell them on the token market via the EDISON-X system. In addition, users can sell their tokens to others who wish to purchase them through the token market via the EDISON-X system. In the case of a shortage of tokens in the entire dormitory during a month, the EDISON-X system issues additional tokens at a higher price than those issued at the beginning of the month.

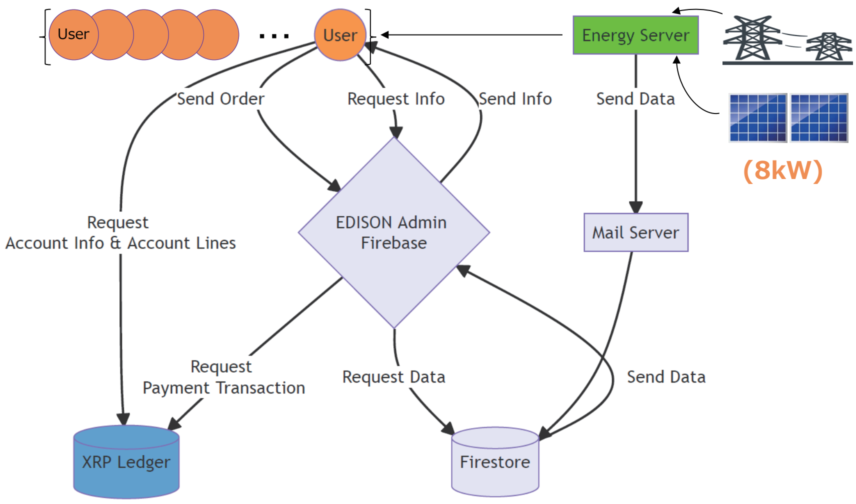

Fig. 1. EDISON-X: system configuration. EDISON-X is powered by various open-source technologies and frameworks developed by Google, Ripple Labs, and others.

2.2 Web Application

EDISON-X has a web application that enables users to access data and place orders. This application was developed in Angular. Angular is a TypeScript-based open-source web application framework developed by Google. This application has three main functions: creating orders, retrieving transactional data, and checking balances. Users access Firestore through the application to check their token balance and create orders. Furthermore, some of the information can be checked on XRPL using the XRPL application programming interface.

EDISON-X ' s graphical user interface (GUI) uses Material Design [12]. Material Design was introduced by Google in 2014 and features simple designs inspired by materials such as paper and ink. The primary colors in the EDISON-X web application are white and indigo, with pink as an accent. In addition, because it is a single-page application with no page transitions in the browser, it can run as fast as a native application.

Figure 2 shows the GUI screens for viewing important EDISON information in one location. The essential information in panels (a)–(c) includes the "current account balance", "last traded price", "this month's electricity usage", "ranking of electricity usage", "percentage of tokens held", and "daily change of electricity usage". Figure 2 (d) shows GUI screens for viewing buy/sell order. Participants can check the remaining available capacity (UPX, SPX, or at capacity, if any) and the latest transaction price, decide on the type, price, and quantity of tokens, and issue buy/sell orders.

2.3 Monthly process

2.3.1 Beginning of the month

The system estimates the students ' electricity usage for the current month by dividing the actual dormitory usage of the last month by the number of students. The system generates UPX and SPX tokens to ensure that the students have the right to use electricity based on their estimated consumption. The price of SPX tokens for electricity generated on solar PV panels will be higher, and the tokens will be sold to students who wish to use them.

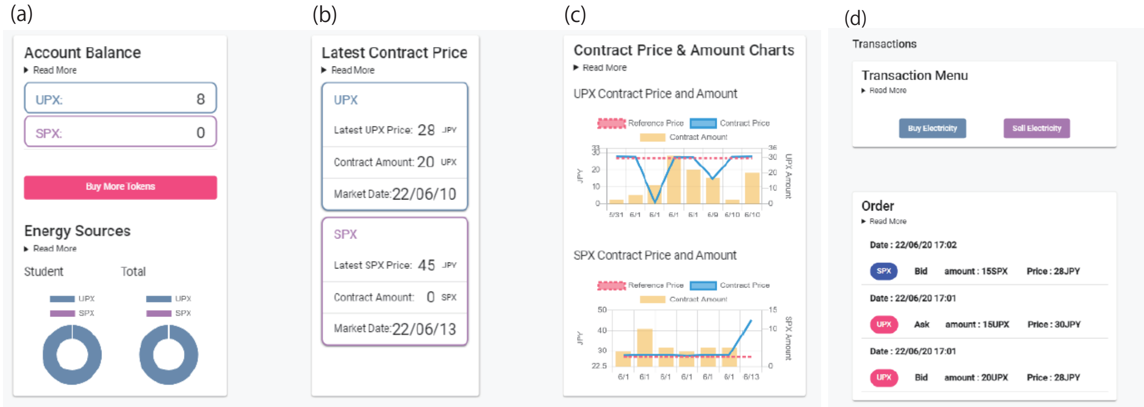

Fig. 2. EDISON-X: various GUI panels (a) (b) (c) show GUI screens for viewing important EDISON-X information in one place. Panel (d) shows GUI Screens for viewing buy/sell order.

2.3.2 During the month

Students can buy tokens from other students who wish to sell their tokens and sell their tokens to other students who wish to buy tokens, through the token market on the EDISON-X system. In the case of a shortage of tokens in the entire dormitory, the system issues additional tokens at a higher price than those issued at the beginning of the month.

Every day, the transaction price and volume are determined at the point where the buy and sell order curves intersect, as shown in Fig. 3. The market close and contract times are 9:00 JST for UPX tokens and 9:15 JST for SPX tokens. Student orders can be placed 24 hours a day for bid (buy orders), with downtime from 9:00 to 11:00 JST for ask (sell orders). Buy orders higher than the transaction price and sell orders lower than the transaction price are accepted. All orders that do not satisfy this condition are rejected. Examples of the transactions of UPX and SPX tokens recorded on the XRPL Testnet are listed in Tables I and II, respectively. The XRPL Testnet, prepared on XRP, is a suitable tool for experimenting with and testing new functionality. Notably, the token prices for the beginning of the month and the token prices for market transactions are recorded in the EDISON database on Firestore.

Table I. Transaction example of UPX token recorded on XRPL Testnet

Item	Data	Remark
Amount UPX	"1000000"	1UPX
Ask ID	"7puQkSLxbdfQhePHKcd7"	Student A's account
Bid ID	"qkTMaElqlst9Lg7Q2ZRY"	Student B's account
Time of creation	"9:00:26 UTC+9, July 22, 2022"	Transaction date
ID	"Y2yel9168Ab57ArnuUUl"	specific transaction ID
Price	"27000000"	27JPY

2.3.3 End of the month

At the end of the liquidation month, the system buys unused tokens at a discounted price from students. The system charges students who do not have tokens a higher price for additional tokens. The buy and sell prices are determined in such a way that the monthly income and expenses are zero. Users who purchase more SPX tokens receive an incentive at the end of the month. Liquidation includes this type of incentive.

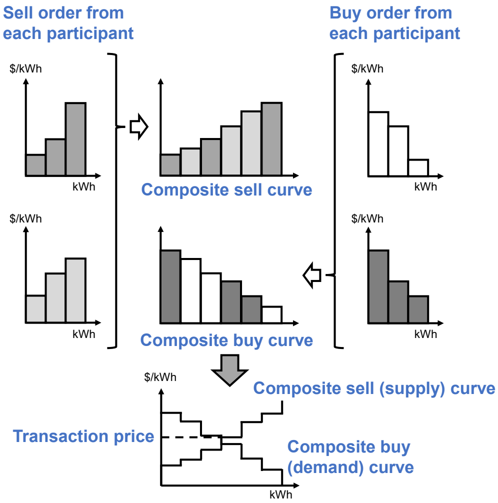

Fig. 3. Token Market: single price auction, the transaction price and volume are determined at the intersection of buy order and sell order curves.

Table II. Transaction example of SPX token recorded on XRPL Testnet

Item	Data	Remark
Amount SPX	"2656250"	2.65625SPX
Ask ID	"Q3IteweJm7CgSVMULlRa"	System account
Bid ID	"YJDOWZZ0tectKAkiKwdj"	Student C's account
Time of creation	"9:15:09 UTC+9, July 3, 2022"	Transaction date
ID	"l6HHkP8LolvTDV5fi7eA"	specific transaction ID
Price	"29000000"	29JPY

3. Aquired Data of EDISON-X Demonstration Experiment

Approximately 80 students reside in the dormitory of the school. The existing system for collecting electricity charges is slightly complicated and taxes the accounting students and staff. From July 1 to July 31, 2022, we conducted a small-scale demonstration experiment with 17 student participants in the school dormitory to validate the operation of the EDISON-X system. Students buy UPX and SPX tokens to use electricity supplied from the utility company ' s distribution lines and solar PV panels (8 kW) installed on the roof of the school building, respectively. We recorded the usage data for the previous month in a database. We used these data as a reference and assumed the following electricity usage for the students: trading was performed in a single-price auction, with the previous day ' s bid and ask orders being processed at midnight each day. In addition to the participants ' orders, the system issued sell orders for the UPX and SPX tokens when the participant ' s aggregated remaining tokens were insufficient.

Figure 4 shows the daily number of orders for buying (bid) and selling (ask) UPX tokens, which are the rights to use electricity from utility companies. The bottom panel of Fig. 4 shows the number of contracted buy and sell orders. At the beginning and end of the month, fewer bids exist for both buy and sell orders. On average, the number of buy orders is lower than the number of sell orders during the month.

Figure 5 shows the daily number of orders for buying (bid) and selling (ask) SPX tokens, which is the right to use electricity from solar PV panels. The bottom panel in Fig. 5 shows the number of contracted buy and sell orders. In this experiment, nearly all the sell (ask) orders were placed in the EDISON-X system. The temporal variation in the number of SPX buy and sell orders shows a trend similar to that of the UPX.

Figures 6 (a) and (b) show typical composite demand and supply curves for the UPX token and SPX token, respectively. The top SPX user is rewarded for the lowest CO_2 emissions. The intersection of the demand and supply curves determines trading price and volume. We can observe that the trading price is higher and the volume is lower on the SPX than on the UPX, reflecting that the higher trading price on the SPX is because the system sets the sell order price higher than the market price on the UPX. The low trading volume reflects the small installed capacity of solar PV. Notably, it was a particular user who purchased the most SPX tokens and received the incentive at the end of the month. These results indicate that setting up an incentive program for environmentally conscious users is effective in promoting renewable energy.

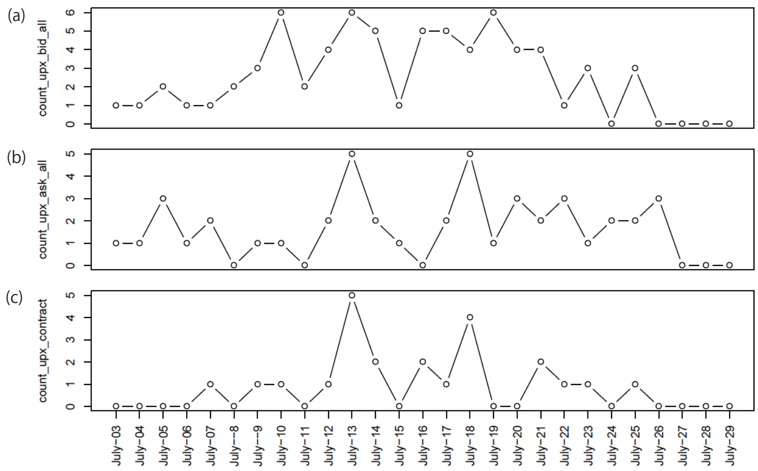

Fig. 4. Bid and ask for UPX token. The daily number of orders for (a) buying (bid), (b) selling (ask), and (c) contracted buy and sell orders.

4. Topological Characterization of Acquired Data

4.1 Hypergraph of Transactions

In an ordinary network [13], each edge (link) connects two vertices; however, in the case of the EDISON-X energy market, we observe that an edge (link) must connect any number of vertices. The EDISON-X energy market is traded daily, implying that a contract to buy or sell tokens is concluded between market participants on that day rather than between two specific users. If the number of contracted orders each day equals n, then the number of users involved in the contracts equals n+1. The EDISON-X energy market can be regarded as a higher-order network. A higher-order network is represented by the concept of topology, that is, a simplicial complex formed by a set of simplices that is closed under the inclusion of the faces of each simplex. In network science, we often use hypergraphs [14–16], which are an alternative representation of higher-order networks to simplicial complexes.

In the EDISON-X energy market, transaction relationships involving more than two users can be represented by a hypergraph rather than a simplicial complex. Figure 7 shows a hypergraph of transaction relationships for UPX tokens in the month of July 2022. Figure 7 (a) shows the daily

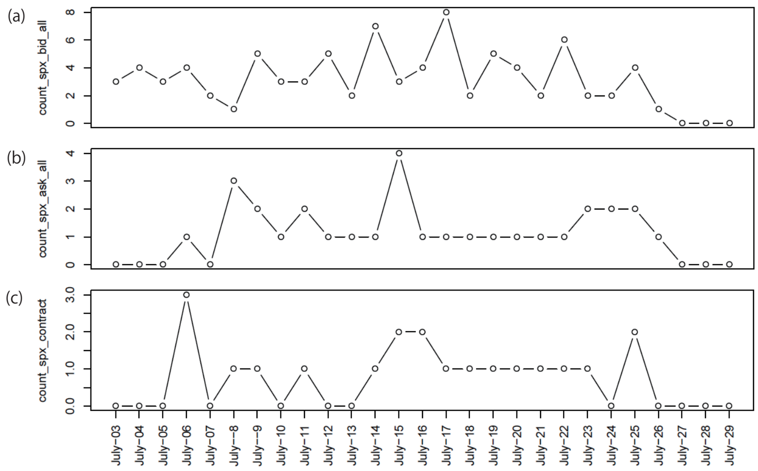

Fig. 5. Bid and ask for SPX token. The daily number of orders for (a) buying (bid), (b) selling (ask), and (c) contracted buy and sell orders.

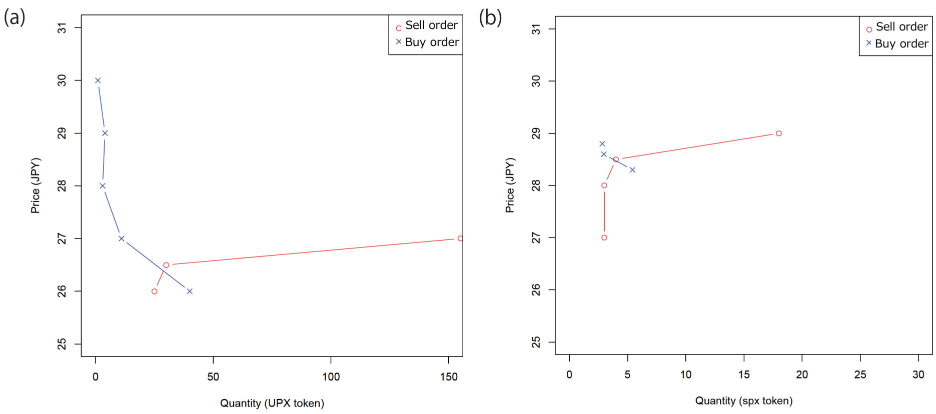

Fig. 6. Typical demand and supply curves, (a) UPX token (b) UPX token. Transaction prices are higher on the SPX than on the UPX, and transaction volume is lower on the SPX than on the UPX.

transactions on the selected days. The orange circles represent users, and the area surrounding two or more users represents the transaction relationship. Transactions were concluded for four days for two users, one day for three users, and one day for six users. Figure 7 (b) shows a hypergraph of transactions contracted on July 7, 9–10, 12–14, 16–18, 21–23, and 25, 2022. The closer the user position is to the center of the graph, the more significant its involvement in the market.

Figure 8 shows a hypergraph of the transaction relationship for the SPX tokens in July 2022. The orange circles represent users and the area surrounding two or more users represents the transaction relationship. Figure 8 (a) shows the daily transactions on the selected days. Transactions were concluded for three days between two users and for three days between three users. Figure 8 (b) shows a hypergraph of transactions contracted on July 8-9, 11, 14-23, and 25, 2022. Because the EDISON-X system is responsible for selling new SPX tokens, the node in the center of the graph is referred to as “admin”, which stands for system administrator.

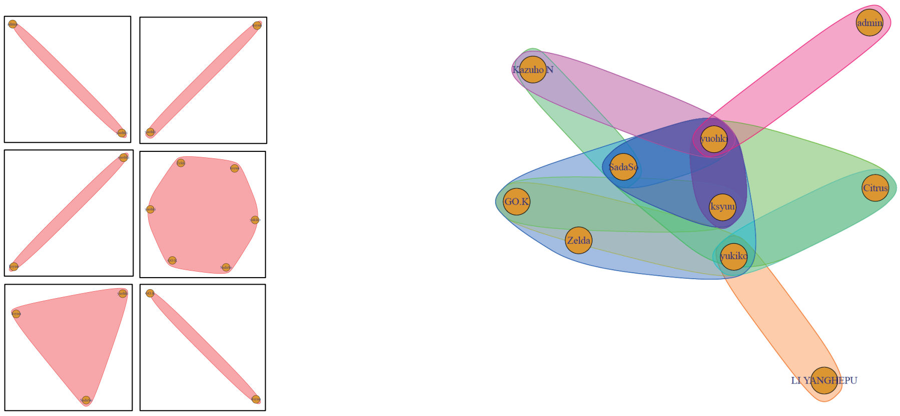

Fig. 7. Hypergraph of transactions in July for UPX token, The orange circles are users, and the area surrounding two or more users represents the transaction relationship. The closer the user's position is to the central part of the graph, the more important role it can be interpreted as playing in the market.

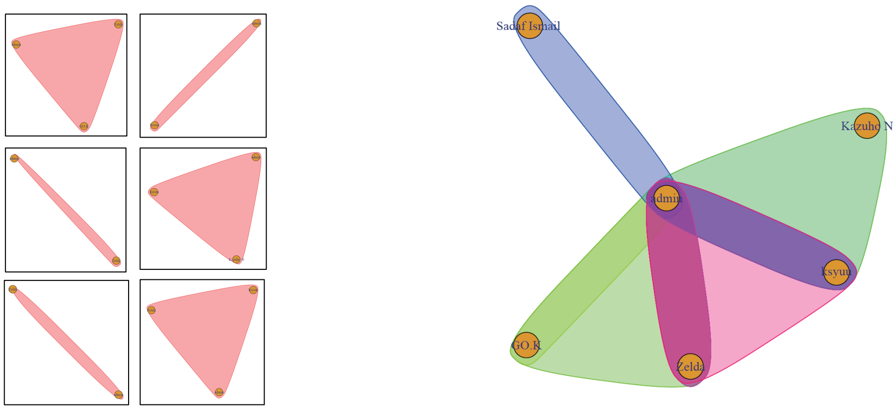

Fig. 8. Hypergraph of transactions in July for SPX token, Since the EDISON-X system is responsible for selling new SPX tokens, the node in the center of the graph is written "admin", which stands for the system administrator.

4.2 Cavity Detection using Persistent Homology

The "data shape" a feature of the distribution of many data points, can be characterized by the existence of "cavities (rings, holes)" rather than "clusters" of data points. The topology field is useful for studying the characteristics of the shape of the data. In particular, cavities can be detected using homology by drawing a sphere of an appropriate radius centered on each data point. Furthermore, by using persistent homology [17, 18], which extends the concept of homology, it is possible to determine the existence of a cavity as well as to obtain detailed geometric characteristics, such as its size and stability. This methodology is called topological data analysis (TDA) and has recently attracted considerable attention [19, 20].

Market transactions are expected to become more active when electricity consumption increases from the previous day. In such a case, the correlation between electricity consumption and market transactions is high. By contrast, disturbances in the correlation between electricity consumption and market transactions would be detectable as a "cavity". We hypothesized that market transactions become less active when "cavities" appear. Therefore, we use TDA to quantify disturbances in the correlation between electricity consumption and market transactions by detecting one-dimensional "cavities".

Figure 9 illustrates the concept of persistent homology. Persistent homology has been recognized as an essential tool in TDA. The characteristics of the overall market are represented as a data point on a two-dimensional plane, with the volume of transactions by each user on the x-axis and the increase in electricity usage from the previous day on the y-axis. A circle of radius r is drawn from each user's data point. The circles do not overlap if the radius r is small, as shown in the middle left panel of Fig. 9. As radius r increases, three circles collide with each other at $r = r_b$. A cavity appeared at the center of the radius of the three adjacent circles. As the radius r is further increased, the cavity disappears at $r = r_d$, as shown in the middle-right panel. The radius r is called the filtration parameter, and the larger $r_d - r_b$ is, the more robust the cavity.

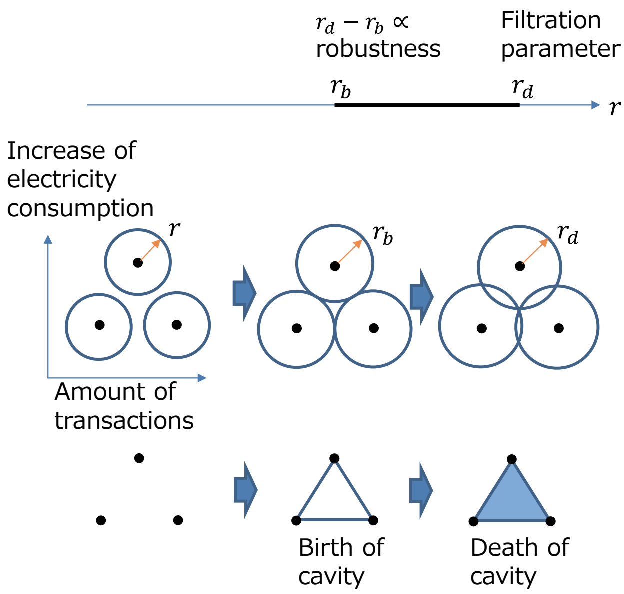

Fig. 9. Persistent homology. The characteristics of the overall market are represented as a data point on a two-dimensional plane, with the volume of transactions by each user on the x-axis and the increase in electricity usage from the previous day on the y-axis.

Figure 10 (a) shows the overall market characteristics; on July 20, 2022, no market transactions were executed. Figure 10 (b) plots r on the x-axis when the cavity appears and r on the y-axis when it disappears; the cavity becomes more robust as it shifts further from the 45-degree line. From this figure, we can observe that one cavity is robust. Figure 10 (c) shows the filtration parameter from the onset to the disappearance of the cavity, as indicated by the red line. The longer this line, the more robust is the cavity. On July 20, robust cavities were observed.

Figure 11 (a) shows the overall market characteristics; on July 21, 2022, market transactions were executed, in contrast to the previous day. As shown in Figs. 11 (b) and (c), one cavity is robust. Figure 11 (d) shows three users ' transactions. On July 21, a market transaction occurred, although robust cavities were observed.

Table III lists the relationship between market transactions and "cavities". When market transactions were executed, the number of days in which robust cavities were observed was twice (=8/4) as many as the number of days in which they were not observed. However, in the case of no market transactions, the number of days with robust cavities was 2.5 times (= 5/2) the number of days

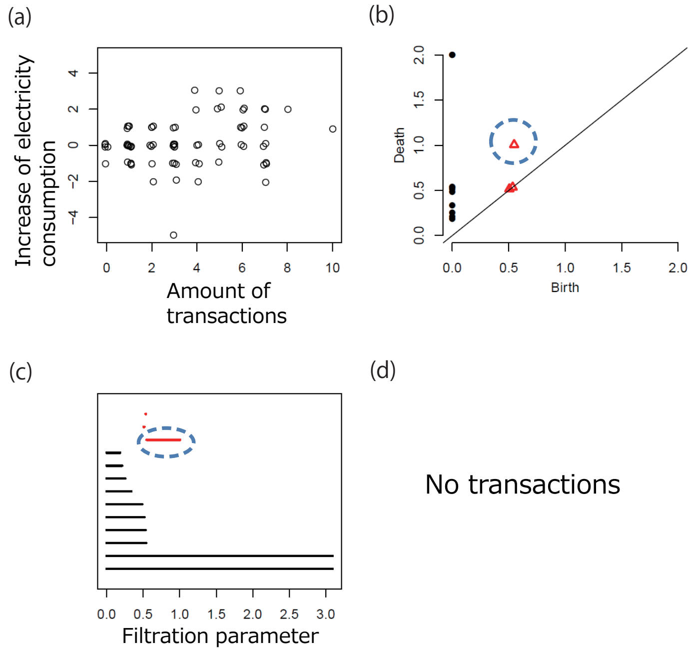

Fig. 10. Market characteristics on July 20th, 2022. The black circles in panel (a) indicate the position of each user, and the red triangles in panel (b) indicate robust cavities. Panel (c) shows the filtration parameter from the onset to the disappearance of a cavity, indicated by the red line. Panel (d) shows that when one robust cavity was observed, no market transactions were executed.

without robust cavities. The results indicate that market transactions become less active when "cavities" appear. This result implies that the hypothesis that market transactions become less active when "cavities" appear seems plausible.

Table III. Number of days of UPX Token Market in July 2022

	Market transaction concluded (in days)	Market transaction not concluded (in days)
No cavity observed	4	2
Cavity observed	8	5

5. Conclusions

To address the problems of complexity and transparency in collecting electricity charges, we developed EDISON-X, which uses blockchain technology to manage the buying and selling of electricity usage rights for students residing in a school dormitory. In this study, we proposed a blockchain-distributed energy-trading system and conducted a small-scale demonstration experiment in the school dormitory. In July 2022, 17 students participated in the experiment to validate the operation of the EDISON-X system. We demonstrated that an energy-trading system using blockchain technology could contribute to the effective deployment of renewable energy.

In addition, topology and network science methodologies were developed to understand the characteristics of energy-trading. We demonstrated that the developed methodologies help to understand energy-trading characteristics and predict market changes. We studied the hypothesis that market

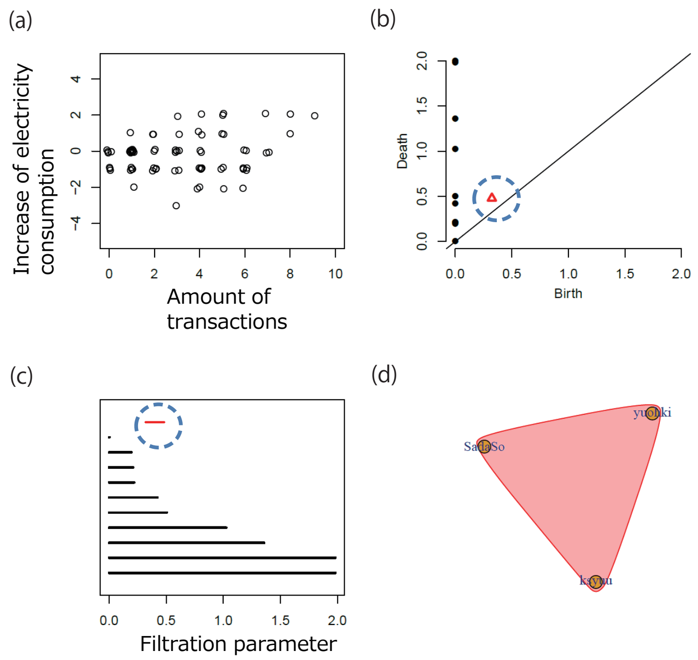

Fig. 11. Market characteristics on July 21st, 2022. The black circles in panel (a) indicate the position of each user, and the red triangles in panel (b) indicate robust cavities. Panel (c) shows the filtration parameter from the onset to the disappearance of a cavity, indicated by the red line. Panel (d) shows the market transactions executed among three users, with robust cavities.

transactions become less active when "cavities" appear using TDA. The preliminary analysis validates the hypothesis. Currently, data acquisition and analysis are underway to obtain more reliable results.

Acknowledgment

The authors thank the graduate students (alphabetical order): K. Futsuki, R. Hirata, S. Ismail, Y. Kasuya, G. Kazawa, T. Mizuguchi, Y. Morishita, T. Muraoka, K. Nomura, S. Sada, H. Sato, N. Shinohara, H. Shinto, Y. Li, and Z. Zuo, for their participation in the demonstration experiment.

References

[1] D. J. Galen, et al., "2019 Blockchain for Social Impact", Stanford GSB Center for Social Innovation, September 2019.

[2] S. Khalil, V. Disfani, D. Ahmadi, G. Rollins, "Impact of Blockchain Technology on Electric Power Grids - A case study in LO3 Energy", arXiv:2106.05395, 2021.

[3] Power Ledger White Paper, `https://www.powerledger.io/company/power-ledger-whitepaper`.

[4] N. Lasla, M. Al-Ammari, M. Abdallah, and M. Younis, "Blockchain Based Trading Platform for Electric Vehicle Charging in Smart Cities", IEEE Open Journal of Intelligent Transportation Systems, Vol. 1, 10.1109/OJITS.2020.3004870, July 14, 2020

[5] M. B. Mollah, J. Zhao, D. Niyato, K-Y. Lam, X. Zhang, A. M. Y. M. Ghias, L. H. Koh, and L. Yang, "Blockchain for Future Smart Grid: A Comprehensive Survey", IEEE Internet of Things Journal, Vol. 8, Nn. 1, pp.18-43, January 1, 2021

[6] W. Tushar, T. K. Saha, C. Yuen, D. Smith, and H. V. Poor, "Peer-to-Peer Trading in Electricity Networks: An Overview", IEEE Transactions on Smart Grid, Vol. 11, No. 4, pp.3185-3200, July 2020

[7] G. Gao, C. Song, T. G. T. A. Bandara, M. Shen, F. Yang, W. Posdorfer, D. Tao and Y. Wen, “FogChain: A Blockchain-Based Peer-to-Peer Solar Power Trading System Powered by Fog AI”, IEEE Internet of Things Journal, Vol. 9, No. 7, pp.5200-5215, April 1, 2022
[8] Cloud Firestore, `https://firebase.google.com/docs/firestore, accessed 2022-11-09`.
[9] D. Schwartz, N. Youngs, and A. Britto, “The Ripple Protocol Consensus Algorithm”, Ripple Labs Inc, 2014.
[10] The XRP Ledger Foundation, `https://xrpl.org/xrp-ledger-overview.html`.
[11] Developer documentation for Firebase, `https://firebase.google.com/docs, accessed 2022-11-09`.
[12] Material Design, `https://m3.material.io/ Material.io, accessed 2022-11-09`.
[13] A.-L. Barabasi, M. Pósfai, “Network science”, Cambridge: Cambridge University Press. (2016). ISBN: 9781107076266 1107076269
[14] A. Bretto, “Hypergraphs: Basic Concepts”. In: Hypergraph Theory. Mathematical Engineering, Springer, Heidelberg (2013).
[15] F. Battiston, E. Amico, A. Barrat, et al. “The physics of higher-order interactions in complex systems”, Nat. Phys. 17, 1093–1098 (2021).
[16] G. Bianconi. “Higher-Order Networks, An introduction to simplicial complexes”, (Elements in Structure and Dynamics of Complex Networks), Cambridge, Cambridge University Press (2021).
[17] H. Edelsbrunner, D. Letscher, and A. Zomorodian, “Topological persistence and simplification”, Discrete & Computational Geometry, 28(4):511–533, Nov 2002.
[18] A. Zomorodian and G. Carlsson, “Computing persistent homology”, Discrete & Computational Geometry, 33(2):249–274, Feb 2005.
[19] H. Edelsbrunner and J. Harer, “Computational topology: an introduction”, American Mathematical Soc., 2010.
[20] G. Carlsson, “Topology and data”, Bull. Amer. Math. Soc., 46:255–308, January 2009.