How Blockchain-based Data Coordination Could Improve the Dutch Intraday Electricity Market

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Abstract

The current wholesale electricity markets lack the ability to react to the volatility of renewables. The intraday market shows potential to deal with the volatility, but lacks liquidity due to the high transaction costs. Blockchain technology provides an opportunity of lowering transaction costs as it does for the financial sector, but these effects are unresearched in electricity. This paper looks into the functioning and characteristics of blockchain data coordination to provide insight into the potential beneficial effects it could bring for the intraday market. The effects are assessed using literature review, transaction cost theory and structured expert interviews. Increased transparency proves to be the biggest benefit for lowering transaction costs. However, whether this will be enough for a blockchain to outperform a conventional database is doubtable. Future research should consider applying a similar analysis on value transfer blockchains.

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1. Introduction

Large growth in renewable energy sources (RES) across Europe causes a significant amount of volatility in the electricity network, which existing wholesale markets lack the ability to react to in real time (Monacchi & Elmenreich, 2016). This causes a need for increased real-time balancing to cope with differences between electricity-programmes (e-programmes) and actual generation (Wang, 2017). The intraday market provides opportunities to deal with the volatility of RES, as trade can be performed close to real-time, reducing generation flexibility requirements (Scharff & Amelin, 2016; Verzijlbergh, De Vries, Dijkema, & Herder, 2017). The Dutch intraday market however, shows little trading activity - liquidity -, as only 1,8 percent of electricity trade was performed on the intraday market in 2016 (Tennet, 2016, p. 14). A reason towards this liquidity problem is the lack of transparency of bilateral pay-as-bid trading, which lowers confidence of traders and their willingness to participate (Weber, 2010).

One innovation that shows potential for the transparency issues of the intraday market is blockchain. Blockchain technology has started to disrupt the management processes in the financial sector, and disruption in other sectors is imminent (Hileman & Rauchs, 2017; Macdonald, Allen, & Potts, 2016). One of the promises of blockchain is that it can lower transaction costs through transparency and lower effects of opportunistic behaviour (Davidson, De Filippi, & Potts, 2016). With blockchain use cases in electricity related activities being identified and piloted in rapid pace, already 21 percent of electricity stakeholders view blockchain as a complete game changer in the energy industry (Burger, Kuhlmann, Richard, & Weinmann, 2016).

Blockchain can either be used for the facilitation of value transfer or for data coordination. Thee facilitation of value transfer considers replacing the incumbent market system, while data coordination can be applied alongside the incumbent system and thus receive less pushback from participants (Hijgenaar, 2018; Pitkevich, 2018). This first look on blockchain implementation on the intraday market will thus mainly consider data coordination. The research question of this paper is therefore:

"How can the Dutch intraday electricity market benefit from the characteristics of blockchain facilitated data coordination?"

Breaking down this question into several components brings topics that need to be researched before the research question can be answered. Insights are needed in 1) the functioning of the intraday market, 2) functioning and characteristics of blockchain technology, and 3) in the effects of implementing blockchain technology for the intraday market.

This paper is structured as follows. Section 2 provides background information on the functioning of the intraday market and blockchain technology. Section 3 provides the methods used in the analysis of blockchain effects. Section 4 will present the results of the research, after which the results are discussed in section 5. Lastly, in section 6 will present the conclusions and recommendations for future research.

2. Background

In this section we present background information into the basic functioning and characteristics of the intraday market and blockchain technology, respectively in 2.1 and 2.2. This provides the foundation for the method choices in section 3 and the results in section 4.

2.1. Intraday Market

The intraday market provides electricity traders with the opportunity to trade between the day-ahead market and delivery time (Scharff & Amelin, 2016; Tennet, 2016, p. 12; Weber, 2010). This market is required mainly for two reasons. First, when sudden outages in electricity generation occur, the associated producers are still responsible for any sold capacity on the day-ahead, futures or forwards markets, as settled in their electricity programme (e-programme). Therefore, this general supplier needs the ability to buy extra capacity on the intraday market in order to adhere to its electricity programme. The e-programme contains all settled trades for each trader and is used to provide the transmission system operator (TSO) with information on expected electricity flows through the system. This helps the TSO with balancing of the network flows.

Second, producers of intermittent RES electricity are highly dependent on the weather in their production capacity. The inaccuracy in weather predictions makes it difficult for these RES suppliers to adhere to exact electricity programmes originating in day-ahead, futures, and forwards trading. The changes in capacity due to changes in weather predictions, both increases and decreases, provide the second need for trade in the intraday market.

The large consumers and retailers are the intraday counterparties to the suppliers discussed above. These buyers have no direct need for trade on the intraday market, but can increasingly make use of the intraday market to reduce their electricity costs. The growing potential of home-level storage and demand response methods provide buyers with the means to achieve higher price elasticity. Demand can be moved over time from higher towards lower priced timeslots, providing economic benefits for the buyers.

The current intraday market provides trade opportunity through bilateral contracts over set timeframes. This means that traders need to find counterparties themselves or use brokers to find them, and negotiate the quantities and prices over fixed trading timeframes. In the Dutch intraday market, trade happens over hourly timeframes and can be settled up until five minutes before delivery time. This deadline is set to provide enough time to deliver the adjusted e-programme to TenneT (the Dutch TSO) and for TenneT to adjust their balancing mechanisms accordingly.

2.2. Blockchain Technology

Blockchain technology was introduced to the world in 2008, when Satoshi Nakamoto (2008) published a paper describing cryptocurrency transfers which would not need an intermediary financial institution. Blockchain in essence provides a technology which keeps track of transactional data through an encrypted distributed ledger on a peer to peer network (CGI Group Inc., 2017; Swan, 2015). What this means is briefly explained by using the main components and options of a blockchain application.

2.2.1. Blockchain Components

There are four main components that make up the basis of each blockchain implementation (Hileman & Rauchs, 2017).

1. Distributed Ledger

Information gets registered as transactions onto a ledger which is copied to all participants in the blockchain network at an interval.

2. Peer-to-Peer Network

All participants that are connected to the blockchain network do so in a flat hierarchy. This means that there is no central node that controls the rest of the network, but that the network is self-governed.

3. Consensus Mechanism

To avoid a double spending problem when the transaction information is gathered by the blockchain, this information is grouped at a set interval to form ‘blocks’. The consensus mechanism, which is executed by all the nodes of the network, provides verification of the information blocks, so that only information that is accepted by the network gets added to the distributed ledger.

4. Cryptography

Multiple forms of cryptography are used in a blockchain. The main purpose is the use of ‘hash functions’, which convert information into a simple line of code, to make the distributed ledger immutable. A second purpose of cryptography is the encryption possibilities for data and data exchanges, providing security and privacy.

5. Validity Rules

For the network to be able to function on a peer-to-peer basis, there is a need for a set of rules which dictates when transactions can be considered valid, how the ledger gets updated, how management gets remunerated, etc.

2.2.2. Blockchain Options

Apart from the main components, there are also three options that need to be considered when implementing blockchain (Hileman & Rauchs, 2017).

1. Read & Write Access

Read and write access, which together form the typology of blockchains, determine who can view the information on the ledger, and who can provide contributions to the ledger. Read access can either be public, in which case anyone can view the data, or private, in which case you would need to get access to the blockchain network from an operator or through network voting. Write access can either be permissionless, in which case anyone can put transactions and information up for validation, or permissioned, in which case you would need authorisation from an operator or through network voting before you can add transactions.

2. Tokenisation

The second choice considers the use of tokenisation. This choice is important when considering the purpose of the blockchain. Blockchains can either be used for value transfers, or for better data coordination. Data coordination can be provided through mutualisation of data among all participants. However, for non-cryptocurrency value transfers, there is need for a data representation of this value for the blockchain to be able to register and transfer the value. For this purpose, value is linked to a blockchain counterpart in the form of a small piece of code, a ‘token’.

3. Smart contracts

The third choice concerns the use of smart contracts. A smart contract is a piece of code that can facilitate, verify, or enforce the negotiation of a transaction, without the need of both parties or a third party (Hileman & Rauchs, 2017). Smart contracts can thus be used on any value transfer purposed blockchain.

2.2.3. Blockchain Challenges

This section provides a brief overview of the main characteristics of blockchain that can be seen as challenging to the potential of blockchain over conventional data and value transfer systems (Burger et al., 2016; CGI Group Inc., 2017; Hileman & Rauchs, 2017; PricewaterhouseCoopers, 2016).

There are five main challenges for blockchain implementations. These are processing speed, regulation, security, privacy, and standardisation.

A. Processing Speed

Through the intensive communication and processing needed for mainly information distributions and consensus mechanisms, the transaction processing speed of the blockchain is often lacking for grand-scale implementation (Hileman & Rauchs, 2017, p. 19). This processing speed is however highly dependent on the topology of the blockchain and the choice in consensus mechanism.

B. Regulation

Regulation proves to be one of the hardest challenges, as there is almost no existing regulation on blockchain implementations in the electricity sector. Forming regulation is especially hard for public platforms that are open to anyone, even across borders (PricewaterhouseCoopers, 2016)

C. Security

Security proves to be an issue as information is kept secure through the use of data encryption keys. These encryption keys are proving to be a weak point in the security of the blockchain, as they often provide complete access to the blockchain at hand and can be easily lost or stolen. To improve the security of blockchain applications, the key-handling behaviour of network participants and service operators should be considered.

D. Privacy

Privacy can be an issue for blockchain implementations that are aimed at information sharing. When transparency of data is needed, current blockchain platforms often do not provide the simultaneous possibility of selective privacy. This is the case in for instance the ownership or amount of certain value exchanges.

E. Standardisation

The blockchain requires all participants to use the same data formats. This provides a challenge for systems that do not have these formats already standardised, as agreement from the participants is needed for this standardisation. Another issue related to standardisation is that it increases difficulty in interconnecting systems whenever data formats do not align.

2.2.4. Blockchain Benefits

This section provides a brief overview of the main characteristics of blockchain that can be seen as challenging to the potential of blockchain over conventional data and value transfer systems (Burger et al., 2016; CGI Group Inc., 2017; Hileman & Rauchs, 2017; PricewaterhouseCoopers, 2016).

There are five main benefits from blockchain technology over conventional database technologies. These are disintermediation, reliability, transparency, automation, and traceability.

F. Disintermediation

Through the distributed ledger and consensus mechanisms, blockchain "achieves consistent and reliable agreement over a record of events (e.g. "who owns what") between independent participants, who may have different motivations and objectives" (Hileman & Rauchs, 2017, p. 13). The blockchain therefore takes away the need for a trusted third party to mediate in keeping such a record. An example of disintermediation is Bitcoin, as these currency transfers do not move through a central bank, the third party, anymore, but directly from peer-to-peer. Removing the third party can lead to economic gains and brings control over assets and information back to a peer-to-peer basis.

G. Reliability

The hashing principle and consensus mechanism mentioned in 2.2.1 provide the blockchain with immutability. This essentially means that any change to information in previous blocks will automatically be rejected by the system, making these changes impossible.

Another increase in reliability of blockchain systems over conventional systems is achieved through the distributed ledger. The distribution of the ledger to all nodes removes the 'single point of failure' traditional databases often have. Any changes made to a block which is about to be linked to the chain through the hashing principle, will therefore be rejected by the other nodes in the network.

H. Transparency

The distributed ledger provides all nodes with a copy of the transaction data. Everything that happens on the blockchain is therefore viewable for each participant, given they have the proper key for reading access.

I. Automation

The smart contract functionality can be used to omit several manual contracting tasks, saving costs and speeding up processes. In addition, the use of smart contracts can cause greater certainty of reconciliation, as the smart contracts can check the account details on both parties to assure that the deal can be made or even provide the reconciliation itself instantly. (PricewaterhouseCoopers, 2016)

J. Traceability

The blockchain provides improved traceability through its transparency and immutability. Any previously made transaction can be found from any node, given the person is in position of an access key providing decryption. This is especially useful for regulators and controlling entities in a system. (PricewaterhouseCoopers, 2016)

3. Methods

As there is little data on the effects of blockchain on incumbent electricity trading systems, this research makes use of a theoretical framework and expert interviews for the assessment of effects. Transaction cost theory is used as the theoretical framework, as it takes into account all resources needed for the facilitation of trade, including time and effort needed. These transaction costs will need to be lowered to make the intraday market more attractive and increase its liquidity.

The two functionalities blockchain can bring, value transfer and data coordination, will be considered as two separate implementation options for the intraday market. They will be analysed and evaluated on four factors, 1) the blockchain options that are needed for implementation, 2) the benefits and 3) challenges of blockchain, and 4) the process steps needed for implementation.

Before the results of these analyses are provided, a brief overview of the transaction cost theory and expert interviews is provided.

3.1. Transaction Costs Theory

Transaction costs (TCs) are part of the New Institutional Economic theory and considers all costs, time, and efforts needed to facilitate a transaction between two entities. TCs contain three main cost components (Hazeu, 2007, p. 79):

1. **Searching** trading partners
2. **Negotiating** deal details
3. **Monitoring** deal compliance

These cost components form through bounded rationality and opportunistic behaviour, which are seen as the source of transaction costs. Both sources are briefly explained below.

Opportunistic behaviour is when a party takes advantage of their superior knowledge or market power, in order to further their interests (Hazeu, 2007, p. 56). This often comes to a disadvantage of the counterparty.

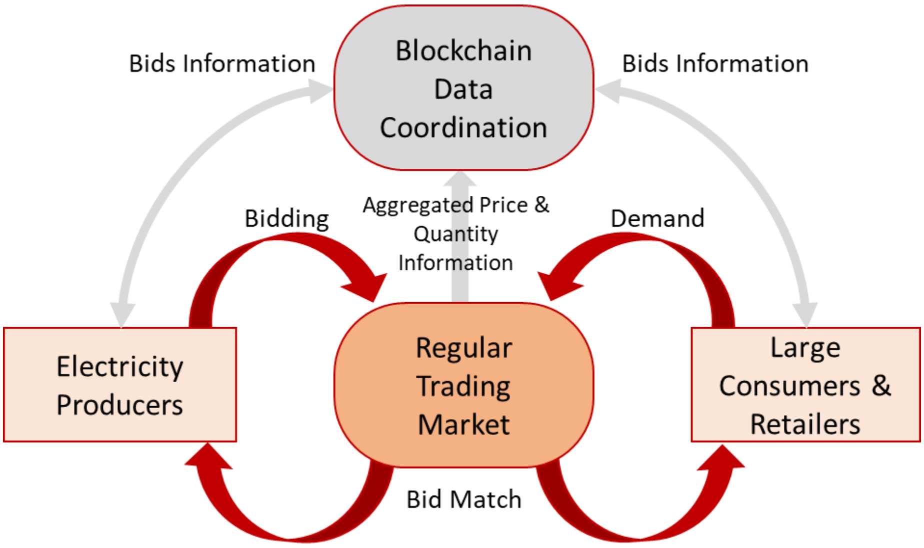

Figure 1: Blockchain Data Coordination in the Intraday Market

Bounded rationality considers that actors in a transaction never have full information on the context of the deal (Hazeu, 2007, p. 52).

As the transaction cost theory not only considers the direct costs of trade facilitation, but also the time and effort needed for these activities, it is operationalised in a qualitative manner.

3.2. *Expert Interviews*

To reduce bias on the qualitative analysis on transaction cost, a set of structured interviews were performed on experts in blockchain technology. The structured interview brings same sets of answers from each interview, providing possibility of comparing the answers of each expert, increasing validity of the resulting evaluations (Bogner, Littig, & Menz, 2009).

4. Results

This section will conceptualise the implementation of a blockchain facilitating data coordination in the intraday market, followed by an evaluation of the effects of such an implementation. This section provides a description of how the blockchain would function in 4.1, what blockchain options should be chosen for proper functioning in 4.2, which of the generic benefits could be achieved in 4.3, which of the generic challenges should be taken into account in 4.4, what is needed for the implementation process in 4.5, and what effects are expected on transaction costs in 4.6.

4.1. *Data Coordination by Blockchain*

This section considers a blockchain implementation on the Dutch intraday market which facilitates data coordination (DC) between the traders and potentially other trading stakeholders (Figure 1).

The traders would in this case provide the information of their expected extra demand or supply as bids to the blockchain ledger, which will in its turn relay this information to other traders. The traders can then use this collection of information to find a counterparty and negotiate the bilateral contract as it would normally do in the intraday market. Information is taken from the regular market on what the average prices are in the market. This provides valuable information for the traders to base their own bid requirements on.

4.2. *Options needed for DC*

This section considers the selections needed in the blockchain options; read and write access, tokenisation and smart contracts.

Read and Write Access

The main purpose of the blockchain data coordination is to provide transparency on trading in the intraday market. Considering the read access, either a public or private topology can be chosen. Both can function in the purpose of data coordination, although for the private topology, access must be granted to all traders. For a public topology, this grant need not be made, but the information would also become available for non-traders. Whether traders would agree to such a topology is therefore doubtable.

Read access could also be provided to the TSO and market regulators. The read access for the TSO can then be used to provide them with instant provision of e-programme changes. This reduces transaction costs in monitoring, as the traders do not have to perform the actions needed in sending the e-programme information. Read access for the regulator can provide transaction cost reductions for the same reasons, as the physical actions needed to adhere to reporting obligations are no longer necessary.

Considering the write access, either permissioned or permissionless can be chosen. Both can function in the purpose of data coordination, although for the permissioned topology, this permission must be granted to all traders so they are able to submit their bidding information. Also, if the read-access is chosen to be private, only a permissioned write access can be chosen. Otherwise, participants would be able to make changes to the information on the chain, but not see the actual information itself.

Tokenisation
As the data coordination only needs the bidding information, no tokenisation is needed. The management of electricity flows and the financial settlements will still happen outside of the blockchain application.

Smart Contracts
As the data coordination does not contain any facilitation, verification, or enforcement of negotiations, there are no uses of smart contracts for this application.

4.3. Challenges of DC

This section considers the applicability of the generic blockchain challenges for data coordination implementation (Hijgenaar, 2018; Pitkevich, 2018).

Processing Speed
Whether the processing speed of the blockchain is a challenge is dependent on two factors, the required time interval at which information is added to the blockchain, and the processing speed itself. The processing speed of a blockchain is highly dependent on the number of nodes over which consensus is needed and the consensus mechanism itself. Considering that the application of a trade data coordination interface would most likely be a private permissioned topology with less than a hundred participants (TenneT, 2017), there is a high likelihood that the processing speed of such a system would be more than sufficient for a market that needs information updates at a quarter of an hour (or longer) interval.

Regulation
There is a possibility that the data coordination to all participants of the blockchain will not be legal due to current and up-and-coming privacy regulations. The newly altered General Data Protection Regulation (2016/679) for instance prohibits the permanent storage of personal data (European Union, 2016), which happens automatically on the blockchain due to the immutability trait. It is highly likely though that these regulations will change or blockchain specific regulations would form in the coming years. Being one of the first blockchain applications in this greenfield situation can be used to help form regulation, reducing any potential barriers.

Security
The problem of security is not in the blockchain technology itself, but with the people operating on and around the blockchain. Current pilots and applications show that most loss of security happens when participants share decryption keys in unsecure ways or lose them (Hijgenaar, 2018). To reduce the challenge of security for the blockchain, the participants behaviour should be considered, and not the technology itself.

Privacy
There are methods of increasing privacy on the blockchain, but these often reduce the transparency. Whether the privacy or transparency is more important for the traders is therefore of significant importance for the determination of the blockchain interface design.

The transparency vs privacy issue can be approached from two different axes, data exchanges and the data itself. In terms of data exchange, there are privacy protecting methods like zero knowledge proofs, or homomorphic encryption. These would be able to keep details on the actors private, whilst revealing information on the bidding of these actors. In this case there is an increase in privacy, but transparency for the rest of the system is lost.

In terms of data transparency itself, the data could be encrypted, causing information only to be viewable if you have the correct decryption key. This could for instance be used to only provide transparency to the traders that have entered their own information onto the blockchain.

Standardisation
Standardisation can be a challenge for a blockchain implementation as all participants need to agree on the formats of information to be entered. If there is already standardisation of trade information in the intraday market, then there is no challenge in making the information fit for the blockchain. As the intraday traders need to deliver their e-programme in a standardised format to the TSO for balancing, the standardisation needed for the blockchain interface would only be a small step for these traders.

Conclusion on Challenges
Taking these views on the five generic blockchain challenges provides the following conclusions on blockchain data coordination validity. No generic

blockchain challenge was found to be of such high likelihood and/or impact to make implementation of the data coordination interface impossible. Processing speed, regulation, and standardisation are moving in favourable directions for better blockchain functioning, security is a matter of behavioural change within the participants, and privacy should be considered in a trade-off with transparency (Hijgenaar, 2018; Pitkevich, 2018).

4.4. Benefits of DC

This section considers the applicability of the generic blockchain benefits for data coordination implementation (Hijgenaar, 2018; Pitkevich, 2018).

Disintermediation

Whether disintermediation can be achieved for the data coordination interface depends fully on the implementation process.

Reliability

Two forms of reliability of data coordination can be discussed here. First, the immutability and distributed ledger characteristics provide the blockchain with reliability of data recording and keeping. The immutability of a blockchain will provide that all trade information entered into the distributed ledger will stay available on the ledger. The validity of the information entered to the ledger could be questionable however. As the number of traders on the intraday market is probably under a hundred (TenneT, 2017), the consensus mechanism choice becomes vital. In the case of a proof-of-work mechanism, only half of the traders would need to agree to be able to make changes to the information made immutable in the ledger. A second reliability form is that the blockchain functions deterministically. Through its algorithms and data processing, a blockchain will provide the same outputs whenever presented with identical inputs.

Transparency

Whilst the transparency of the blockchain can provide benefits for the intraday traders, it also provides a challenge in the form of a transparency vs privacy trade-off. Having transparency in all trading information would provide other traders with the opportunity to link your actions to your identity using algorithms, even when these identities are kept behind encryption. Either transparency or privacy would therefore be possible on the blockchain, but not both at the same time.

Automation

There is little automation possible for a strictly data coordinating interface. When the blockchain interface would be expanded to a trading facilitating platform, then the automating properties of smart contracts can be used on managerial tasks, providing reductions in their costs.

Traceability

Traceability of data and metadata is not viewed as essential for this specific interface, as the information does not need to be specifically linked to its owner for it to be useful for other traders, as well as the timespan of the intraday market only being a maximum of 36 hours (between day-ahead closure and the last delivery time ending). When the blockchain interface would be expanded to also provide trading possibilities on the blockchain, then the traceability would become of great value. This would then be used to increase transparency for trade settlement and payments.

Conclusions on Benefits

Taking these views on the five generic blockchain benefits provides the following conclusions. The context of the intraday market might prove difficult for disintermediation. The functioning of the interface cannot benefit from automation, and will cause the benefits of traceability to be minimal. However, with proper choices in validation mechanism and privacy protection where needed, the blockchain interface could be able to provide better reliability and transparency than incumbent database and interface services.

4.5. Implementation of DC

The governance of the implementation process s consider of the utmost importance for the blockchain’s success (Hijgenaar, 2018; Pitkevich, 2018). One stated that it will be very hard to get the trading parties to come together and agree on all the standards, functions and responsibilities needed for a complete blockchain design. The other went a step further in stating that the implementation of the blockchain by just the trading parties is highly unlikely. These actors are relatively change averse and inert, as well as lacking the knowledge needed for blockchain implementations. Accordingly, it is more likely that the current intraday operator would facilitate the steps needed for the implementation of the blockchain interface. With this central operator at the helm of the blockchain implementation however, the disintermediation potential and associated benefits would be nullified.

4.6. Transaction Costs in DC

This section considers the transaction costs in intraday markets and how the data coordination blockchain could impact these transaction costs. Only part of the beneficial transaction cost effects as discussed in Davidson et al. (2016) can be conceptualised, as the data coordination does not facilitate the used of smart contracts.

4.6.1. Current Searching Costs

The intraday works with bilateral contracts, for which traders need to find counterparties for themselves, or hire a broker to find one for them. Both activities would provide the traders with corresponding transaction costs. With the current low liquidity and transparency of the market, it is difficult to find a counterparty for trade. These difficulties in searching for a counterparty increase the transaction costs of searching.

Opportunistic Behaviour:
No identified possibility to behave opportunistically in counterparty searching.

Bounded Rationality
The time pressure of the intraday market worsens bounded rationality of traders, as they have less time looking for potential counterparties.

4.6.2. DC Effect on Searching Costs

The data coordination provides information on aggregated prices and quantities in the market, as well as information on who is looking for a supplier or buyer. This increased transparency reduces searching costs, while traders know who else is active in this market.

Opportunistic Behaviour
No identified opportunism in searching

Bounded Rationality
The increased transparency as discussed above will reduce bounded rationality.

4.6.3. Current Negotiation Costs

Trading negotiations take place between the two trading parties. These negotiations include timeframe, quantity, and price of electricity.

Opportunistic Behaviour
The time pressure of the intraday market can increase the effects of opportunistic behaviour, as counterparties have a higher sense of urgency in making a deal and are thus less likely to look for a new counterparty.

Bounded Rationality:
The time pressure of the intraday market also worsens the bounded rationality in negotiations, as traders have less time for investigating their options.

4.6.4. DC Effect on Negotiation Costs

This information reduces the uncertainty on trade possibilities, while traders know what the (average) market volumes and prices are. However, the physical act of negotiation stays the same as in the normal market. Thus, the transaction costs of negotiations will still need to be made but are potentially lower.

Opportunistic Behaviour
With the knowledge on what the average price in the market is, traders will be less likely to deviate far from this average price to increase their own benefit. If they do, the other trader will most likely look for a different trading partner.

Bounded Rationality
Increased information on prices and trading amounts in the market will reduce bounded rationality for negotiations.

4.6.5. Current Monitoring Costs

Monitoring deal compliance on the intraday market is easier than for the other bilateral contracts in forwards and futures, as the deals and delivery are only a maximum of 36 hours apart.

Opportunistic Behaviour
No identified effects from opportunism in monitoring.

Bounded Rationality
No identified effects from bounded rationality in monitoring.

4.6.6. DC Effect on Monitoring Costs

The transaction cost for monitoring are harder to impact with the data coordination. Increased insight in the amounts traded and prices within the market do not provide the traders with the exact information needed for deal compliance monitoring. The number or size of the monitoring activities needed are also not impacted sizably by the interface.

Opportunistic Behaviour
No identified effects from opportunism in monitoring.

Bounded Rationality
No identified effects from bounded rationality in monitoring.

4.6.7. Transaction Costs Conclusion

This section has structurally analysed the effects of blockchain data coordination on intraday transaction costs. What can be concluded from this analysis is that blockchain data coordination can mostly reduce transaction costs in searching and negotiation. The potential increase in market transparency reduces bounded rationality in these trading activities and makes it harder for traders to behave opportunistically.

5. Discussion

This section provides discussion of the research results and process. First, the scope of the research will be discussed, followed by a discussion of general blockchain knowledge. Lastly, the methods used in this research will be reflected upon.

Scope of the Research

The scope of this research was limited to a data coordination blockchain, as it showed potential of creating more transparency for the intraday market, whilst keeping the incumbent trading system intact. The topics discussed in this research have shown that the resulting conceptualised data coordination system does not provide the full potential of blockchain technology. Disintermediation is unlikely due to the inert and change averse nature of the traders. There should be concrete benefits from a blockchain implementation before these traders would consider adopting such a technology. However, the DC considered here can only provide added benefit in terms of reliability and transparency. A legitimate question thus arises if a highly reliable central database that sends regular updates for increased transparency could potentially outperform the blockchain application considered in this research.

Blockchain Knowledge

One of the main findings during the process of this research was the lack of scientific research on blockchain effects for electricity trading systems. On the one hand this is to be expected as blockchain is still a relatively new technology. On the other hand, multiple sources from corporates and non-profit organisations were found that provided comprehensive overviews of blockchain benefits and challenges, discussing implementation processes and use cases. However, the validity of these researches is not guaranteed, and the researcher noticed that the most detailed information on blockchain effects and designs is kept secret by companies to retain the competitive advantage of this knowledge. The lack of data and scientific sources provides the link to the last point of discussion.

Research Methods

This research has based most of its findings on three types of sources. First, grey literature from consultancies and non-profit organisations were used to create insight in the components, benefits and challenges of generic blockchain applications. Second, transaction costs theory was applied on a high-level system overview of the intraday market. Third, two structured interviews were performed on blockchain experts to assess the effects of data coordination on the intraday market.

The grey literature sources are already briefly discussed under 'blockchain knowledge'. The information in these sources is less reliable than scientific sources, but provide this research with the basic understanding of blockchain technology, challenges and benefits.

The transaction cost theory has proven valuable in providing a first assessment of blockchain data coordination on the transaction efficiency in the intraday market. However, the assessment is of only a qualitative nature and not independent of the interpretation of the researcher. The results of this assessment should therefore only be used as a starting point for further, more elaborate, research on the effects of blockchain on trading.

The assessment of data coordination challenges and benefits was performed using structured interviews on two blockchain experts. The results of both interviews were completely coherent. However, due to the small number of interviews performed for this assessment and validation purpose, the conclusions on benefits and challenges should be carefully applied.

This paper has provided a first outlook on how to assess blockchain performance for electricity markets. The factors considered in this assessment can be used as a starting point for future research on blockchain applications in electricity trading.

6. Conclusions

This paper started with the statement that current wholesale markets are unable to cope efficiently with the variability of RES electricity. The intraday market has most potential in dealing with these problems, as it provides trading possibilities close to delivery time. However, the non-transparent market needs high transaction costs for trading which reduces the liquidity of the market. As blockchain has shown the potential to provide increased transparency in data coordination, the following research question was posed:

"How can the Dutch intraday market benefit from the characteristics of blockchain facilitated data coordination?"

To provide an answer to this question, four main evaluations on blockchain performance were considered; the challenges -, the data related benefits -, the implementation process - and the effects on transaction costs in intraday trading, provided by blockchain data coordination. These evaluations provided the following insights which lead to a general conclusion.

No generic blockchain challenge was found to be of such high likelihood and/or impact to make implementation of the data coordination interface impossible. Processing speed, regulation, and standardisation are moving in favourable directions for better blockchain functioning, security is a matter of behavioural change within the participants, and privacy should be considered in a trade-off with transparency.

The functioning of the interface cannot benefit from automation, and will cause the benefits of traceability to be minimal. However, with proper choices in validation mechanism and privacy protection where needed, the blockchain interface would be able to provide better reliability and transparency than incumbent database and interface services.

The governance of the implementation process is of the utmost importance, as stakeholders need to agree on all standards, functions, and responsibilities within the blockchain application, if disintermediation is to be achieved.

The increased transparency provided by the blockchain data coordination can reduce bounded rationality and the effects of opportunism in the transaction costs of intraday trading. The most effect is to be expected for searching and negotiation activities.

A good point for future research would be what effects a value transfer based blockchain could bring for the intraday market. Providing value transfers on the blockchain instead of just data coordination would provide a couple of certain changes compared to this analysis, both positively and negatively:

- Tokenisation is needed to be able to trade physical artefacts (electricity)
- Smart contracts can be used on the facilitation, verification, or enforcement of negotiations
- Processing speed becomes a larger issue, as traders would like to know as fast as possible if their trade is processed
- Regulation could become a larger issue due to smart contract use
- Automation becomes possible through smart contracts, impacting possibilities for financial settlement and reconciliation
- Traceability becomes a larger benefit as the information on the blockchain can be used for financial settlement and reconciliation
- The automation and traceability benefits provide more incentive to traders to join a consortium on blockchain implementation, which would increase the potential of disintermediation

References

Bogner, A., Littig, B., & Menz, W. (2009). Interviewing Experts. https://doi.org/10.1057/9780230244276

Burger, C., Kuhlmann, A., Richard, P., & Weinmann, J. (2016). Blockchain in the energy transition. A survey among decision-makers in the German energy industry. *German Energy Agency*, 41. Retrieved from https://www.dena.de/fileadmin/dena/Dokumente/Meldungen/dena_ESMT_Studie_blockchain_englisch.pdf

CGI Group Inc. (2017). *Opportunities for Blockchain in the Energy Sector*.

Davidson, S., De Filippi, P., & Potts, J. (2016). Disrupting Governance: The New Institutional Economics of Distributed Ledger Technology. *Ssrn*, 1–27. Retrieved from http://ssrn.com/abstract=2811995

European Union. (2016). Regulation 2016/679 of the European parliament and the Council of the European Union. *Official Journal of the European Communities*, *2014*(October 1995), 1–88. https://doi.org/http://eur-lex.europa.eu/pri/en/oj/dat/2003/l_285/l_28520031101en00330037.pdf

Hazeu, C. A. (2007). *Institutionele Economie. Een optiek op organisatie- en sturingsvraagstukken* (2nd editio). Bussum: Uitgeverij Coutinho.

Hijgenaar, S. (2018). *Personal Structured Interview*. Delft.

Hileman, G., & Rauchs, M. (2017). *Global Blockchain Benchmarking Study*. Retrieved from https://www.jbs.cam.ac.uk/fileadmin/user_upload/research/centres/alternative-finance/downloads/2017-09-ccaf-globalbchain.pdf

Macdonald, T. J., Allen, D., & Potts, J. (2016). Blockchains and the Boundaries of Self-Organized Economies: Predictions for the Future of Banking, 1–16. Retrieved from http://papers.ssrn.com/abstract=2749514

Monacchi, A., & Elmenreich, W. (2016). Assisted energy management in smart microgrids. *Journal of Ambient Intelligence and Humanized Computing*, *7*(6), 901–913. https://doi.org/10.1007/s12652-016-0392-1

Nakamoto, S. (2008). Bitcoin: A Peer-to-Peer Electronic Cash System. *Www.Bitcoin.Org*, 9. https://doi.org/10.1007/s10838-008-9062-0

Pitkevich, A. (2018). *Personal Structured Interview*. Den Haag.

PricewaterhouseCoopers. (2016). Blockchain – an opportunity for energy producers and consumers?, 1–45. Retrieved from www.pwc.com/utilities

Scharff, R., & Amelin, M. (2016). Trading behaviour on the continuous intraday market Elbas. *Energy Policy*, *88*, 544–557. https://doi.org/10.1016/j.enpol.2015.10.045

Swan, M. (2015). *Blueprint for a new economy*. *O'Reilly Media, Inc.* https://doi.org/10.1017/CBO9781107415324.004

Tennet. (2016). Market review 2016, *8*(3), 285–288. https://doi.org/10.1080/09599919108724045

TenneT. (2017). Balance Responsibility. Retrieved November 2, 2017, from https://www.tennet.eu/electricity-market/dutch-market/balance-responsibility/

Verzijlbergh, R. A., De Vries, L. J., Dijkema, G. P. J., & Herder, P. M. (2017). Institutional challenges caused by the integration of renewable energy sources in the European electricity sector. *Renewable and Sustainable Energy Reviews*, *75*(November 2015), 660–667. https://doi.org/10.1016/j.rser.2016.11.039

Wang, X. (2017). *Advances in Market Management Solutions for Variable Energy Resources Integration*. *Renewable Energy Integration: Practical Management of Variability, Uncertainty, and Flexibility in Power Grids: Second Edition*. Lawrence E. Jones. https://doi.org/10.1016/B978-0-12-809592-8.00008-1

Weber, C. (2010). Adequate intraday market design to enable the integration of wind energy into the European power systems. *Energy Policy*, *38*(7), 3155–3163. https://doi.org/10.1016/j.enpol.2009.07.040