Cryptocurrency as Guarantees of Origin: Simulating a Green Certificate Market with the Ethereum Blockchain

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Abstract—**The diversity of energy prosumer types makes it difficult to create appropriate incentive mechanisms that satisfy both prosumers and energy system operators alike. Meanwhile, European energy suppliers buy Guarantees of Origin (GoO) which allow them to sell green energy at premium prices while in reality delivering grey energy to their customers. Blockchain technology has proven itself to be a robust paying system in which users transact money without the involvement of a third party. Blockchain tokens can be used to represent a unit of energy and, just as GoOs, be submitted to the market. This paper focuses on simulating marketplace using the Ethereum Blockchain and Smart Contracts, where prosumers can sell tokenized GoOs to consumers willing to subsidize renewable energy producers. Such markets bypass energy providers by allowing consumers to obtain tokenized GoOs directly from the producers, which in turn benefit directly from the earnings. Two market strategies where tokens are sold as GoOs have been simulated. In the Fix Price Strategy prosumers sell their tokens to the average GoO price of 2014. The Variable Price Strategy focuses on selling tokens at a price range defined by the difference between grey and green energy. The study finds that the Ethereum Blockchain is robust enough to functions as a platform for tokenized GoO trading. Simulation results have been compared and the results indicate that prosumers earn significantly more money by following the Variable Price Strategy.**

Keywords-blockchain; ethereum; smart contracts; energy; guarantees of origin

I. INTRODUCTION

A. *The Energy Sector*

The liberalization of the European energy markets marked the end of the energy monopolies that reigned throughout Europe since the twentieth century. On September 2009, the European Commission took the decision to carry out the Ownership Unbundling, effectively starting the partition of all European energy monopolies. This was a legislative solution which aimed to increase competition in the energy markets by opening the field for more actors to participate in the sector. It would also accelerate the deployment of competitive solutions to classic problems like the ageing energy infrastructure, integration of renewable energies into the network and implementation of Internet of Things solutions. This initiative was met with friction in the energy industry, as it meant the surgical split of monopolies into smaller companies that would focus on every part of the energy value chain: generation, transmission, distribution and retail [1].

Many big corporations argued that the monopolistic structure suited the energy sector, as centralized control made it easier to administer the network. The advantages were clear since activities within the energy value chain are all made easier when done under one the same roof. However, the European Commission saw in the unbundling process a chance to increase transparency in retail markets, reduce energy prices and mitigate the obstruction of access to infrastructure [2].

Suddenly, companies which had forever thought of the energy business as one-sided (where the customer had little to no influence on the offered products and services) had to compete with new and agile companies which brought innovative user-centered businesses models. At the same time, investors had access to new markets and started importing business models from other areas into the energy sector.

The next years were crucial for the energy sector, as customers switched to newer energy providers which offered better tariffs, better products or innovative services like home energy management. Economies started seeing an increase of participation in the deregulated activities of the energy sector. Before the unbundling, Germany had 4 energy companies where customers could get their energy form; now there are over 1,190 energy suppliers and 920 network operators [3].

Offering green energy tariff became an important strategy for energy providers who wished to attract new customers, as green energy acceptance grew. In 2005, there were 590,000 German households with a green energy tariff. In 2014 that number grew to 6,002,000 [4]. Green energy became an important differentiation for energy providers, which developed new business models to market green energy which largely consisted on charging a premium on the kilowatt hour (kWh) price. For a household with a yearly consumption of up to 3000 kWh, in 2017 the four biggest energy providers in Germany (EON, Vattenfall, EnBW and RWE/innogy) charge an average premium of €20.76 per MWh of green energy [5]-[8].

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B. *Guarantees of Origin*

In 2009, the EU DIRECTIVE 2009/28/EC came into force and defined an instrument that would label energy coming from renewable sources. The directive defines Guarantees of Origin (GoO) as electronic documents which have the sole function of providing proof to the final consumer that a given share or quantity of energy was produced from renewable sources [9]. It also states that the standard size of a GoO is of 1 MWh and no more than one GoO can be issued in respect of each unit of energy produced. Furthermore, it specifies the information which must be contained in each GoO, mainly:

- The source from which the energy was produced.
- Whether it relates to electricity, heating or cooling.
- The identity, location, type and capacity of the installation where the energy was produced.

The European Energy Exchange (EEX) together with the European Commodity Clearing (ECC) provide a market platform for energy providers to enrich their product portfolio by purchasing GoOs. Holding GoOs allows energy suppliers to sell gray energy as green at a premium price. Currently, German residential electricity consumers pay in average a premium of €20.76 per MWh of green energy. In contrast, the average trading price of one GoO in the EEX on April of 2014 was of €0.43 [10]. Gaining access to such markets is not easy as there are many regulatory barriers and high costs associated to them, making it practically impossible for individuals to participate in them. Some of the costs which are directly related to the trading of GoOs have been gathered from [11] and [12] and can be seen in Table I.

TABLE I. PRICE LIST FOR FUTURES ON GUARANTEES OF ORIGIN

Concept	***Collector***	***Price***
Annual Membership	EEX	€ 2,500 p.a.
Transaction Fee	EEX	€ 0.006 per MWh
Clearing Fee	ECC	€ 0.0025 per MWh
Delivery fee	ECC	€ 0.0002 MWh

II. BLOCKCHAIN

A data structure is a particular way of organizing data so that it can later be easily accessed and used. A Blockchain is a data structure which uses a Peer-to-peer (P2P) network to store information in a computer file. This means that a copy of the file resides in every computer, or node, who decides to use a Blockchain and participate in its network [13]. By analogy, a Blockchain could be seen as a company's network storage, where every employee can access or store data.

Blockchain data structures take information about transactions between peers and organize them into timestamped blocks. Every time a transaction occurs, all nodes are made aware about its contents: the peers involved and transacted amount. For this transaction to be permanently stored in the Blockchain, a consensus needs to be reached, meaning that the nodes need to verify and agree that the data inside this transaction is correct. When the block reaches a certain size, it's timestamped and linked to the previous block though a cryptographic hash, thus forming a chain of timestamped blocks or rather, a *Blockchain* [13], as seen in Fig. 1.

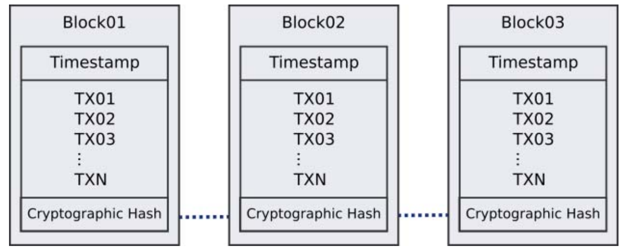

Figure 1. General block structure in a Blockchain.

Their P2P nature awards Blockchains the following core characteristics:

- Distributed: a copy of the Blockchain file exists in every node. Every node is free to read and write data into the Blockchain.
- Transparent: every node is free to inspect the Blockchain and view its contents.
- Permanent: the Blockchain will live as long as a copy of it exists, including offline copies.
- Secure: the Blockchain is maintained by its participants and its underlying protocol ensures that only valid data is stored.

The transparency Blockchains offer and the sensitive information that they contain has been the driver for creating other types of Blockchains. For this reason, Blockchains can be placed in the following categories, as done by [14]:

- Public: anyone in the network can read/write from/to the Blockchain, as well as participate in the consensus process.
- Consortium: the consensus process is controlled by a pre-selected set of nodes.
- Private: all permissions are kept centralized to one organization.

Since Blockchains are distributed technologies, appending data to them can be done by any node in the network. This poses a challenge since malicious nodes could be motivated to attack a Blockchain by appending false transaction data to it. This problem is solved by using Cryptographic Tokens as an incentive for honest nodes who actively maintain the network and who make sure that only valid data exists in the Blockchain. These people are commonly referred to as Miners.

Miners collect transactions and verify that the data contained in them is correct. Typical verifications include checking for syntactic correctness, checking that the sender and receiver addresses are valid or verifying that the funds sent are in the legal range [15]. After the verifications are complete, Miners need to use CPU resources to solve a cryptographic problem, a concept commonly known as Proof of Work (PoW) [16]. The first Miner to solve the problem can append a block of transactions to the Blockchain, while being rewarded with Cryptographic Tokens for this service. These tokens can later be traded for any other currency, like

USD or EUR. For this reason, tokens are commonly referred to as Cryptocurrency. The conversion service is given by online-only exchanges where users buy and sell crypto- and regular currencies.

As tokens are only rewarded after a Miner has carried out the PoW process, their sole existence is evidence that work has been done. This concept has been applied to create Cryptocurrencies which use tokens as Proof of Provenance. SolarCoin is a Cryptocurrency which mimics the GoO system by replacing PoW with Proof of Generation: every time one certified photovoltaic system has generated 1MWh of electricity, one SolarCoin will be awarded to its owner [17]. SolarCoins, just like GoOs can later be sold in exchanges.

III. Development Environment

The Energy Token Market has been developed using the Ethereum Blockchain and a Smart Contact written in the Solidity programming language. The smart contract acts both as market operator and market place at the same time, as it defines the rules of how the trades occur while also executing them. The main objective of the smart contract is to allow people with no access to energy markets, like the EEX, to trade cryptographic tokens designed to mimic GoOs and keep a register of the participants and their balances. In detail, the main functions of the smart contract are:

- to allow the registration of consumers and prosumers into the market.
- to allow the transaction of tokens for Ether (ETH) between prosumers and consumers.
- to keep a database of participants and their corresponding token/ether balances.
- and to allow prosumers to cash out.

The smart contract has been developed with help of the Truffle development framework, which amongst other things, compiles the Solidity source code and deploys it onto the Ethereum Blockchain. Once the smart contract is deployed, it lives in the Ethereum network, which means that the contract can be called upon by any node which is connected to the Ethereum Blockchain.

In order to interact with the deployed smart contract, the web3 library has been used. The library works as an interface between the Ethereum network and a web application by communicating with a local node through RPC calls, meaning that it can access any function or variable from any deployed smart contract.

To control the simulation, a web application with its corresponding user interface has been developed. The main purpose of this web application is to trigger simulation events, display real time data and export simulation results to CSV files.

Every line of code that is executed in the Ethereum network has a cost, represented in the unit of Gas. While simple tasks like additions and subtractions might cost small amounts of Gas, storing data in the Blockchain can be more expensive. A Gas price list for all usable commands in the Ethereum Blockchain can be seen in [18], while the average Gas price can be found in [19].

For this simulation, the Ethereum test Blockchain *testrpc* has been used, as it doesn't require paying for used Gas when deploying or testing smart contracts. The *testrpc* tool is a Node.js based Ethereum client for testing and development. It uses *ethereumjs* to simulate full client behavior and make developing Ethereum applications much faster [20]. Fig. 2 shows the dataflow between the development environment modules.

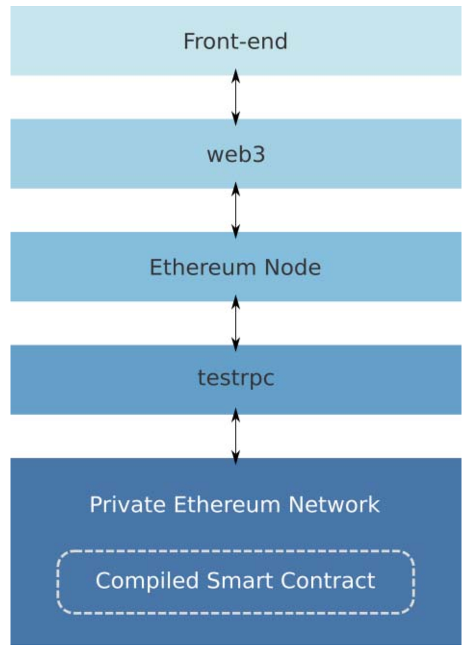

Figure 2. Dataflow between modules.

IV. Energy Token Market Simulation

A spot market has been developed in which cryptographic tokens used as Proof of Energy Provenance are traded for ETH, the native crypto currency of the Ethereum Blockchain. The market functions are independent from that of the energy market, and has no influence in the energy flow. Within the Energy Token Market, each token represents 1 MWh of generated solar energy, mimicking a Guarantee of Origin or a SolarCoin.

To simulate the market, solar generation data form 20 German prosumer households with photovoltaic installations ranging from 5.2 to 107.32 kW peak has been taken. The dataset has been gathered by accessing measurements of SMA Solar Inverters which are publicly available in [21]. The number of tokens each household receives has been calculated by taking their generation per annum and awarding one token for every 1 MWh of generated solar energy.

The previous dataset has been used to simulate energy consumption of 20 German households and calculate the number of tokens that each household is willing to buy. It's assumed that each household will buy one token per 1 MWh of energy consumed and will buy enough tokens to cover their energy consumption needs. For this, two strategies have been developed, tested and compared.

The first strategy simulates a prosumer selling its tokens at fix price directly to the market at the average GoO price. In the second strategy, prosumers sell tokens at various prices which fall between the cost of fossil and green energy.

A. Fixed Price Strategy

This strategy simulates the selling of GoOs directly in the energy markets at the average market price on April 2014 in the EEX: €0.43. Each prosumer is awarded one token for every 1 MWh of generated solar power per annum. Instead of selling the token through the traditional energy market, the prosumer sells it though the Energy Token Market.

Market clearing happens through a randomized function which pairs prosumers who have tokens and consumers who wish to buy a certain number of tokens. The clearing algorithm ensures that all tokens will always be traded at the end of the simulation. The operating costs derived from interacting with the Ethereum network will be recorded throughout the simulation.

B. Variable Price Strategy

For this strategy, the prosumer doesn't sell one token at the average GoO price, but rather at price which falls between the cost of fossil and green energy. The price is defined by a function which generates a random number in the range between €12.9 and €30. These range limits are the minimum and maximum premium price per 1 MWh charged by the four biggest German energy providers: Vattenfall, EnBW, E.On and RWE/innogy.

Market clearing and operation costs are both processed exactly as in the Fixed Price Strategy.

V. RESULTS

Individual results will be presented in the form of tables compiling market size as well as market operation data. As the Energy Token Market is an Ethereum Smart Contract market platform, operation costs refer to the price paid per line of code executed in the smart contract. All prices in euros are calculated with the exchange rate of February 27, 2017 at 11:20 which is €13.4694 per 1 ETH

A. Fixed Price Strategy

Market simulations show that selling tokens at the price of one GoO is viable using the Ethereum network at current Gas prices and ETH/EUR exchange rate. In the simulation, a total of 313 tokens have been traded, which at the price of €0.43 add up to a market size of €134.59 as seen in Table II. In order to clear the market of all tokens, a total of 31 transactions were necessary, where each transaction had an average cost of €0.017 as it can be seen in Table III. In contrast, the total fees for transacting one GoO in the EEX are €0,0087.

Market operation costs reflect the cost of executing the lines of code contained the smart contract. These costs have shown to be 0.79% of the market size, or €1.074 as seen in Table III.

B. Variable Price Strategy

Market simulations show that selling tokens at a price between €12.9 and €30 is more profitable than that of selling it at the average GoO price. In the simulation, a total of 313 tokens have been traded, which at variable prices added up to a market size of €7,401 while the average token price was €21.98 as seen in Table IV.

TABLE II. FIXED PRICE MARKET DESCRIPTION

Concept	*ETH*	*EUR*
Token price	0.0319242	0.43
Market Size	9.9922787	134.59

TABLE III. FIXED PRICE MARKET OPERATION COSTS

Concept	*ETH*	*EUR*
Average seller registration cost	0.0234972	0.316
Average buyer registration cost	0.0153856	0.207
Average transaction cost	0.0013233	0.017
Market clearing cost	0.0397002	0.534
Total costs	0.0799063	1.074

TABLE IV. VARIABLE PRICE MARKET DESCRIPTION

Concept	*ETH*	*EUR*
Average Token price	1.6325529	21.980
Market Size	549.4675225	7401.040

TABLE V. VARIABLE PRICE MARKET OPERATION COSTS

Concept	*ETH*	*EUR*
Average seller registration cost	0.0271228	0.365
Average buyer registration cost	0.0132856	0.178
Average transaction cost	0.0012767	0.017
Market clearing cost	0.0255358	0.343
Total costs	0.0672209	0.903

The average earnings per prosumer were of €370 being €61 the minimum amount that a prosumer earned and €2,236 the maximum. The total market operation costs of €0.903 have proven to be negligible compared to the market size.

Transaction costs were similar to those of the Fixed Price Strategy, as the price value has no effect on the lines of code executed by the smart contract.

VI. Conclusions

A. About the Simulation Results

Participation in traditional market places like the EEX imply big expenses in the range of thousands of euros per year, which stops the small producers form participating in such markets. The Ethereum Blockchain has proven to be a useful alternative for developing market platforms which have low operation costs and where prosumers and consumers of energy can trade tokens without needing a big initial investment.

Although transaction costs in the Energy Token Market are currently higher than in regular trading markets, optimizing the source code of the Energy Token Market Smart Contract might lead to a reduction in transaction costs. However, the volatility of Gas and Ether prices make it difficult to guarantee. Moreover, setting a minimum token volume per transaction would also lower the transaction price per token and would also cause less strain in the Ethereum network.

Both strategies show the important role that markets developed with Smart Contract could play in the future energy markets. Consumer who use the Energy Token Market to "offset" their consumed fossil-based electricity by purchasing tokens will not see a significant difference in their electricity price compared to consumers who buy their green energy directly with their energy provider. However, prosumers who sell their tokens in the Energy Token Market bypass the traditional energy markets and get directly compensated.

B. About the Development Environment

Although Blockchain technology has proven to be a stable system in which its users can rely on, the experience of developing applications for the Ethereum Blockchain has been troublesome, to say the least. The absence of a proper Integrated Development Environment gives the developer the liberty to create his own. However, this can be more of a burden than an advantage for the inexperienced developer.

The limitations of the Solidity programming language make the development of a smart contract a tricky process. The lack of *float* data types as well as the absence of a proper *string* manipulation library are small examples which make the Solidity language compare poorly against other high level programming languages like Java or C#. These and other limitations are however very understandable, as the Solidity language is fairly new and in constant development.

Development frameworks like Meteor, Embark or Truffle address the previous mentioned issue by streamlining some processes. Not only do they help in the interaction with the Ethereum Blockchain, but they also help in the testing of smart contracts and in the development of web applications. It's important to notice that these frameworks are in a continuous development loop themselves.

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