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Review

Electricity Usage Settlement System Based on a Cryptocurrency Instrument

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Abstract: This article reviews the issue of the use of cryptocurrencies (crypto-assets, in general) for an electricity settlement system. The development of digital techniques, including blockchain-based mechanisms, has meant that an increased interest in blockchain-based solutions is to be expected. Blockchain and similar approaches are characterised by decentralisation, so they are concurrent with the trends of the transforming power sector. Decentralised energy generation based on a high proportion of prosumer installations requires the implementation of a new settlement system for grid activities related to electricity use. The first projects of such systems based on a dedicated cryptocurrency have emerged. Based on these, the general concept of such a system with its own cryptocurrency called CCE is presented, including variants implementing net-metering and net-billing. Furthermore, issues requiring interdisciplinary research work and discussion before implementing such systems were identified. A settlement system in which a cryptocurrency is linked to a unit of energy used could be a first step towards introducing a new universal means of value exchange, linked to energy as the primary measure of the value of goods.

Keywords: cryptocurrency; cryptocoin; energy settlements; energy market; blockchain; DLT; prosumer; smart grid; smart contract; electricity user

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1. Introduction

Isolated power systems, i.e., those not using an interconnection with another, larger power system, should be energy self-sufficient. At any time during the operation of this system, energy demand should be balanced with generation. In order to balance the system, both generation and consumption levels can be controlled, as far as the technical means and possibilities allow. The trend towards decarbonisation in the power sector is directing interest towards renewable energy sources, whose generation profile does not have to correspond to the typical load profile in grids. Therefore, tools are needed to enforce the matching of energy supply and demand profiles, enabling energy management in such a system. One of the simplest and most motivating tools for users is price signals (variable energy prices), indicating in which periods the use of energy from the grid is most desirable and in which periods it is least desirable. Thus, the development of an energy settlement system that stimulates the most efficient use of low-cost renewable resources is an important problem to solve from the point of view of the economics of sustainable system operation and the electricity grid. Modern information technology provides new tools and methods. The possibility of better observability, controllability and prediction in such a structure is related to the desirability of adjusting the settlement methods between the participants forming the power system.

Settlement methods are also changing due to technological advances and new financial management technologies (fintech), including digital settlements and cryptocurrencies [1]. The settlement system should keep pace with technological changes, both in the area of the changing energy sector and the financial world. To this end, it is also necessary to take advantage of the opportunities offered by new technologies and financial system concepts. In this respect, special attention can be given to the concept of a cryptocurrency dedicated to energy settlements between users in a particular grid. At the same time, such a cryptocurrency can be seen as a way of transferring information about energy use into the world of digital information.

Cryptocurrency itself is one form of measure of value (including digital money). The prefix "crypto" comes from cryptography, which is intended to ensure the security of the system (rather than hiding the rules of operation). A cryptocurrency integrates the function of carrying the value of money with a programmable machine algorithm. Due to the growing popularity and interest in cryptocurrencies, the EU plans to regulate this sphere with the so-called MiCA Regulation. This draft regulation introduces a generalised definition of crypto-assets as digital representations of value or rights that can be transferred and stored electronically using distributed ledger technology or similar technology [2]. The issue of legalising cryptocurrencies as an innovative tool is also being considered in other European countries (e.g., [3]). For further consideration, let us define a cryptocurrency as a digital asset of community-recognised value that can function as a currency and therefore also be used outside its network as an independent asset. The prerequisites for an asset to be recognised as a cryptocurrency are:

- reliance on cryptographic systems in the users' network for storing account and balance information, authentication and verification of transactions, thus enabling management without a central authority,
- the existence of accessible and verifiable open source code,
- the availability of a project description (white paper).

Technically, it can be stated that appropriately collected units of cryptocurrency for trading purposes are token(s), understood as units of specific values and, according to one of the basic functions of money, accepted by a specific community. Generally, a token represents a value (tangible or non-tangible) that a given participant holds. Tokens have their own value but are generally limited to specific concepts. Tokens can be created as part of the implementation of a so-called smart contract [4] so that they can also be used for other purposes, including investment, while a cryptocurrency is primarily intended to fulfil the function of money.

Cryptocurrencies are issued and traded with the support of technologies from the distributed ledger (DLT) group (the most common form being blockchain) [5,6]. Blockchain should be imagined as a chain of blocks in which data is stored. From an accounting point of view, a blockchain is a ledger containing a list of transactions (which can be made in cryptocurrency as long as it is provided for in the contract specification) and, at the same time, a transaction system. From a technical point of view, blockchain is a decentralised database, with this database in many identical copies for individual users and each copy containing a complete of data in interconnected blocks.

Cryptocurrencies are a chain of blocks in which data is recorded—a ledger containing a list of transactions made on a given blockchain network. New transactions are recorded in a single block on the cryptocurrency chain, and new units are issued (according to an established protocol). Cryptocurrencies are based on a peer-to-peer network. An application is used to transfer them, and the entire network of users is responsible for disseminating the transfer information. A cryptocurrency coin is a digital version of a base value, which can be considered a unit representing the value of electricity produced by a specific technology under specific conditions and sent through a specific electricity network to a user.

The idea of an energy use settlement system based on a proprietary cryptocurrency is to create a dedicated means of settlement in the form of a special digital currency, exchangeable for other units of value in an external market and used to settle energy use activities in the area of a specific electricity system. The nature of this cryptocurrency's quantities flow between users (actors) mirrors the energy flows on the grid between these actors. Blockchain technology and smart contracts enable automatic and instantaneous cash flows and the implementation of reward rules for specific desired activities.

It is not the intention of this article to answer the question of whether instruments such as cryptocurrencies are appropriate for the creation of energy settlement and trading systems, as this requires in-depth, interdisciplinary research and analysis, including, among other things, the identification of evaluation criteria, system objectives, cost-effectiveness conditions and justification of the ranges of the potential impact of the solutions.

The aim of the article is to analyse the issue of the application of instruments treated as cryptocurrencies for the settlement of electricity use in grids with prosumer installations and to set it in the context of considerations about the possibility of treating electricity as an asset of universal value. A general concept of a cryptocurrency-based settlement system based on various publications with elements of the author's modification is presented. Reflecting on the analysed matter, the authors of this paper make the following conclusions:

- Decentralised power sector should correspond to a decentralised form of settlement for energy use.
- The energy flow should be linked to the simultaneous flow of monetary units, realising automatic settlements without unnecessary delays.
- Digital, DLT and fintech technologies can be used for energy settlement, including the tool of a cryptocurrency linked to the electricity system.
- The new cryptocurrency can reflect the value of energy in a given network of users.
- In the long term, electricity, as the most convenient and desirable form of energy, can be treated as a universal value equivalent and the associated cryptocurrency as a universal means of payment (synergy of energy and monetary systems in the field of digital integration).

These are not the theses of this article, as proving them requires a broad, interdisciplinary analysis and in-depth research, which should be the subject of many publications (especially the last sentence). Instead, our intention at this stage is to outline the situation, identify the issues, and indicate areas of research and future issues for consideration.

The article is organised as follows: Section 2 presents a review of the literature related to the topic of crypto-actives in the context of applications within the modern and transforming energy sector. Section 3, based on available sources and publications, presents, according to the author's interpretation, the general concept of a settlement system for energy use using a proprietary cryptocurrency. Section 4 presents the author's comments and discussion of the presented system, highlighting issues that require in-depth discussion and further research. Section 5 provides concluding sentences.

2. Overlook

2.1. Evolution of Forms of Energy Use and Settlement

Technological developments are causing changes in energy use. New types of loads appear, on the one hand, more energy-efficient, but on the other hand, the energy demand is increasing [7]. The lockdown experience of 2020 has shown that some work activities can be carried out away from the workplace, so consumers' energy use profiles are changing and will continue to change [8]. On the other hand, technology provides opportunities for RES power generation in distributed sources, which have their own specificities [9,10].

Users become prosumers who can exchange energy with each other. If the prosumer has the ability to transfer energy at the desired time (having, for example, their own energy storage), they become a so-called flexumer [11]. Sharing economy becomes a modern-day energy trading scheme based on dispatching the energy directly from prosumer (flexumer) to end-user depending on smart grid technical possibilities.

With the proliferation of prosumer installations and the energy sharing model, the term "Transactive Energy" [12] has emerged as a term for conducting energy production and trading using automated control [13]. The pillars of this approach are decentralised energy nodes that address different energy production and consumption levels. These nodes can continuously communicate with each other. A natural feature of the structure is interoperability, understood as the ability to communicate and share energy data while maintaining operational and service constraints [14]. In this concept, both network operators and individual customers can act as a single layer and interact with each other to achieve the ultimate benefits of optimisation. The cited definition of Transactive Energy states that it consists of "techniques for managing the generation, consumption and flow of electricity in the power system that allow a dynamic balancing of demand and supply taking into account the constraints of the overall network" [15]. This approach in particular should be applied to isolated power systems. It is a systemic linkage of technical methods of controlling network traffic and ways of influencing users by means of economic-market mechanisms based on well-designed settlement methods for the energy used. Thus, structures and forms of settlement for energy use need to be adapted to the evolving energy paradigm.

A settlement between users can take place directly in a peer-to-peer (P2P) system [12] or via a special entity—the "Community-based p2p market" (the function of a community manager can be fulfilled, for example, by a DSO) [16]. It is also possible to combine the possibility of settlement in both forms in one system (Hybrid P2P market) [14]. Increasingly, the creation of local energy markets is being considered as part of new operational models for the control of local (distributed) generation units [17], a solution that is predestined for isolated systems. Energy sharing within the smart grid, supported by modern communication and IT technologies (e.g., Internet of Things, machine learning, artificial intelligence, cloud computing, blockchains, payment interfaces), means that we are no longer dealing with a transformation towards a "smart grid", but with an "Energy Internet" [18].

2.2. Blockchain and DLT for Energy Settlement

Proposed transactive management platform architectures for such structures are typically based on blockchain technology [17,19]. However, blockchain is only the most popular implementation of structures, generally forming Distributed Ledger Technologies (DLTs). Although, other DLT technologies also exist, for example, Tangle, Hashgraph, Sidechain, Holochain, Plasma, solutions different from blockchain are based on the Direct Acyclic Graph (DAG) approach [5,6,20,21].

In the case of energy trading, adequate control of access to the registration and settlement platform is desirable, as false orders can lead to imbalances in the power system. In addition, here we are dealing with sensitive data, which must be made available to the relevant institutions and energy companies. In addition, the mechanism should provide sufficient capacity for transaction possibilities. Hence, at present, among DLTs it is blockchain that seems appropriate [22]. A decentralised approach to trading in the era of prosumption and distributed generation is much needed. Blockchain technology provides the basis for peer-to-peer energy transactions and eliminates the problems associated with centralisation [23]. Blockchain tokens can be used to represent both payments (units of currency) and units of transactable energy, possibly taking into account the source of origin (e.g., an energy certificate such as a Guarantee of Origin according to EU Directives [24]). Simulations of a marketplace using the blockchain where prosumers can sell tokenised origin certificates to users willing to subsidise renewable energy producers were presented in [25].

Issues related to blockchain-based energy trading, based on a literature review of research and implementation attempts, are grouped in the paper [26] into four areas: construction of the trading platform; economics, privacy and security of the trading mechanism; redundancy and scalability of the trading platform; and implementation of specific trading platform technology. These issues thus relate to the technical issues of conducting transactions. Among the identified areas, the issue of settlements using modern techniques was not singled out. It should be noted that the issue of settlement formulas is fundamental from the users' point of view, as the entities for whom all these solutions are created. Settlements for energy use between the participants of such a system should provide clear incentives for appropriate activities and investments rationalising the use of infrastructure and available cheapest and ecological energy resources.

Appropriate methods are still being sought to allow blockchain-based trading platforms for renewable energy to function, enabling the efficient processing of increasing ranks of information [27–30]. The trading platform should also be suitable for EV clearing, including in a V2G service [31,32]. In [33], a transaction platform for prosumers, electric vehicle owners and energy companies based on exchanges of six different types of tokens related to the fulfilment of different functionalities in the system was proposed, comparing their implementation in the form of FT (Fungible-Tokens) and NFT (Non-Fungible-Tokens) in blockchain technology. Energy assets can be granted additional attributes, such as Guarantees of Origin [24], which affects their exchangeability so that they can be implemented as NFTs. If energy assets are considered interchangeable, the tokens representing them can also be exchanged in parts and implemented as FTs. An NFT or FT implementation requires an algorithmic definition of the life cycle of tokens from issuance to redemption. The choice of implementation depends on the specific use case, and no absolute attributes are found to indicate an absolute advantage of one implementation over the other [33]. A comparison between FT and NFT is presented in Table 1.

Table 1. Features of Fungible Tokens (FT) and Non-Fungible Tokens. Own elaboration based on information from [4,29,34,35].

Features	FT	NFT
Divisibility	Possible division of token value into smaller units	The value of a single token is indivisible
Price differentiation for energy assets	Ensures uniformity between tokens of the same type, there should be a finite set of possible token types for possible activities	Allows different prices to be set for different tokens of the same type, possibility to set different reward conditions for a given activity (depending on the current situation)
Access to information	The acquisition of all tokens for a customer can be performed on the chain	The acquisition of all NFTs may require off-chain operations
The problem of token capacity	A single token accepts multiple bids and the size of the token increases, which may degrade network efficiency.	There is no need to set a maximum number of unprocessed offers that the token can have at any given time
Problems for implementation	• Reading performance less sensitive to increase in number of tokens • Limitations in concurrent execution of transactions, at most one operation succeeds.	• As the number of tokens increases, reading efficiency decreases • The problem of accepting multiple bids for the same token does not arise • When creating or transferring a token value, a new one is created each time with a separate key
Refers to	Replaceable objects	Unique objects
Popular contract standards	ERC20	ERC721

A collective overview of blockchain-based energy trading models, together with the identification of the scope of research on them, is provided in [36]. An overview of projects investigating the feasibility of using blockchain technology in electricity grids is provided in [37]. In addition, a broader overview and descriptions of blockchain applications in the modern energy sector (especially regarding smart grid operation) can be found in [19,38–42]. The review of blockchain-based energy trading schemes is provided in [43]. Investigation of implementing a demand response mechanism with the use of blockchain technology is reported in [44,45]. In addition, the issue of smart grid cyber security in the context of blockchain is discussed in the [46]. Implementation of a token-based transaction system to enable users to anonymously negotiate and perform transaction security in decentralised smart grid trading is also deliberated in [47].

Energy trading using blockchain technology involves the concept of a smart contract. The progenitor of smart contracts, Nick Szabo, defines smart contracts as "a set of promises, specified in digital form, including protocols within which the parties perform on these promises" [48]. An overview and analysis of smart contract-based solutions in the energy industry can be found in [49–51], and of energy trading in particular in [52,53]. In cryptocurrency, the smart contracts can also be deemed as wallets because they contain balance and account addresses like traditional cryptocurrency accounts [54].

The blockchain architecture implemented for the energy market can be divided into three layers [55] (Figure 1):

- Protocol Layer—the software implementation with all rules that manage the energy market, and the protocol for the actual blockchain creation process (initialisation, configuration, evolution, etc.);
- Network Layer—creating a peer-to-peer network of users (prosumers); and
- Application Layer—energy trading smart contracts, providing the possibility of defining and implementing energy using specific business rules.

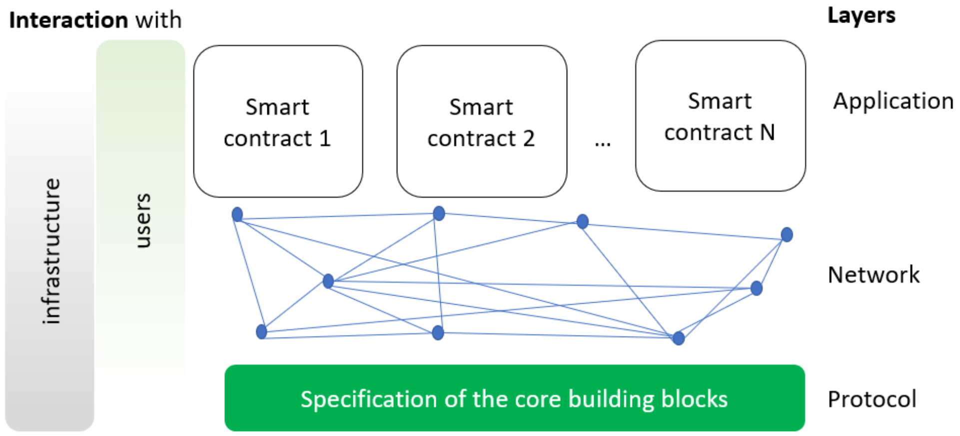

Figure 1. The blockchain based electricity settlement system layers.

Appropriate use of blockchain technology for settlement purposes allows for:

- Simultaneous acquisition of information from energy meters with the execution of a settlement contract algorithm for energy use;
- Integration of energy consumption and cost signals with other parameters as input signals to various smart contracts;
- Integration of this activity with the automatic control of energy use processes at the level of:
  - ○ Customer/end-user installations;
  - ○ A structure that is a physical or virtual cooperative of users and/or prosumers/consumers (cooperatives, clusters, VPPs);
  - ○ Cooperation of the user with different energy suppliers (e.g., in an island system, contracts triggered by specific characteristics of the consumption profile); and
  - ○ Grid area.
- Achieving a high degree of reliability in the collection of current consumption and settlement data;
- Speeding up and automating the settlement execution process (blockchain-based currency can automatically transfer itself after each settlement time interval, e.g., every 15 min, with almost zero overhead);
- Stability and a high degree of certainty in transactions—participants cannot change the smart contract formula;
- The implementation of a settlement system based on a dedicated cryptocurrency to be exchanged for other units of value on a transparent basis; and
- Increasing the accessibility of the service to the mass user.

As such a form of settlement develops, gaining popularity and trust, the system may be expanded. The cryptocurrency used may find applications as a more common means of payment and as an intermediary for exchanging other goods and services. It should be noted that the currency itself has a value assigned precisely by the user community or social group as a means of payment and circulation of value.

2.3. Cryptocurrencies and Energy Assets

One of the most popular applications of blockchain is the operation of cryptocurrency. Indeed, the capabilities of blockchain have enabled the emergence of efficient, decentralised and independent cryptocurrency systems. However, attempts to create such non-independent and anonymous systems were made much earlier. These attempts were unsuccessful due to the lack of technology to enable decentralisation (e.g., the DigiCash System [56]).

Often, the terms token, coin and cryptocurrency are used interchangeably, which can lead to confusion in interpretation. Although coins and tokens are considered to be forms of cryptocurrency, they provide different functions. Coins are built on their own blockchain and were originally intended as a form of currency. When developing a settlement system that is intended to promote and stimulate certain attitudes and activities, it is important to determine whether it is to use only reward utility tokens or whether it could be the beginnings of a new cryptocurrency system.

A digital coin is created on its own blockchain and functions similarly to fiat (traditional money). It can be used to store value and as a medium of exchange between two parties. Tokens, on the other hand, are created on an existing blockchain and can function in many more ways than as currency (representing an exchange of value). They are programmable assets on which smart contracts can be executed. In particular, these smart contracts can establish ownership of assets outside the blockchain network.

The issue of cryptocurrencies in relation to energy often comes up in the context of the increasing energy demand associated with the handling of cryptocurrency-based transactions, especially Bitcoin (BTC) [57] or carbon footprint analysis [58]. A positive correlation is observed between trading volumes of cryptocurrencies and energy consumption [59]. The reason for the energy intensity of handling BTC is related to the protocol of this cryptocurrency and the proof-of-work transaction consensus mechanism. However, other more energy-efficient solutions of consensus algorithms for use in handling cryptocurrencies are possible [60]. In addition, it is possible to create special utility tokens and cryptocurrencies, mainly dedicated to specific types of transactions handled via blockchain (or another DLT). This is the second area of thematic connection between cryptocurrency issues and energy, namely the creation of settlement systems for the use of different forms of energy using dedicated cryptocurrencies. Properly designed, such a system can reward specific energy user behaviours, promote specific generation technologies and desired investments, and accelerate settlement, thus developing the ideas mentioned above of "Transactive Energy" and the "Energy Internet".

The roles that a cryptocurrency can have involve not only settlement functions (medium of exchange), but also functions of verifying the transfer of assets and motivating the creation of new values (also social), supporting grassroots movements or desired activities. To a limited extent, a number of schemes to implement reward tokens have already been implemented, including cryptocurrencies related to energy settlements (Table 2).

Table 2. Examples of published and implemented energy settlement concepts using tokens in DLT, also interpreted as offers of special cryptocurrencies.

Name	Description	References
	Cryptocurrency or tokens	
ATOM	Cosmos (ATOM) has been used as a cryptocurrency for energy trading in the proposed microgrid system. ATOM is one of the famous Asian cryptocurrencies. The pricing strategy of the microgrid for intra-trading purchase and sell is developed using the cryptocurrency "Cosmos Atom".	[61]
Charg Coin	Serves as settlement for electric vehicle charging services on a dedicated network.	[38,62]
CyClean Coin	Rewarding platform users with coins for using the energy use products offered, including settlement for electric vehicle rental.	[63]
Eco coin	Its aim is to promote sustainable assets and activities, especially the smart use of energy.	[64]
Electronic Energy Coin (E2C)	Cryptocurrency for renewable energy trading and control over energy transactions.	[65]
EnergiToken	Rewarding energy-saving behaviours with their own tokens (including using low-carbon transport and buying energy-efficient appliances), the token can then be used for energy trading or EV charging.	[66]
KWHCoin	Virtual energy grid settlements between prosumers, consumers and distributed energy resources using the KWHCoin cryptocurrency. A KWHCoin represents a kilowatt-hour of delivered energy or its equivalent that has been generated and distributed within the platform.	[67,68]
NRGcoin	It is used for the purchase and sale of generated energy on the low-voltage grid, settlement of users and prosumers with DSO, and can replace traditional renewable support policies	[16,69,70]
SEB	Sharing Electricity in Brazil (SEB) is used to settle energy exchange operations between users within mini/microgrids in Brazil.	[71,72]
SolarCoin (SLR)	P2P settlement between user and PV energy producer. Units awarded for the generation of energy from solar sources, a transaction recording algorithm applied that uses a fraction of the energy required by Bitcoin.	[23,73–75]
TerraGreen (TGN) Coin	TGN tokens can be used to purchase electricity and heat as well as other products derived from biomass waste. TerraGreen is where renewable energy is tokenised and can be used by the community in exchange for fiat currency or payment for energy consumed.	[76,77]
Veridium—CARBON	Supports CO_2 emission reduction. CARBON is a stable-coin token representing a unit of carbon reduction.	[78,79]
	Trading and data exchange platforms	
DAJIE	Distributed Autonomous Joint Internet Platform for microgrid where prosumers exchange energy in neighbourhood area.	[80,81]
Energy Web Chain	Platform to support decarbonisation-friendly transactions and end-user positioning.	[82]
EXERGY/LO3 Energy	Data platform for Transactive Energy operations.	[81,83]
Greeneum	Platform for renewable energy as incentive for contributing to CO_2 emission reduction.	[84]
ImpactPPA	A platform to enable financing, distribution and payment for distributed energy.	[85]
PowerLedger	Energy trading platform, supporting cooperation with various energy markets worldwide.	[81,86]
Pylon Network Blockchain	Platform for collecting data on energy generation and consumption.	[87,88]
Sunchain	Platform for the management and exchange of solar energy.	[89]
SunContract	Initiative for P2P energy trading between households and prosumers.	[90]
WePower	Platform for renewable energy contracting and trading.	[81]

Some of the projects cited are directly related to electromobility. However, the potential of the concept of a dedicated cryptocurrency system can be used to conduct settlements for user energy use on the electricity grid, primarily with prosumer sources. Examples of such solutions include NRGcoin [16] and SEB [71]. New units of currency (tokens) are generated when electricity is generated at a grid-connected energy source and they are transferred to the owner(s) of the generation source in proportion to the kWh generated (NRGcoin), or in proportion to the capacity of the source, taking into account the individual contribution made by the investor in the creation of the energy source (SEB).

In the case of the NRGcoin project, the amount of NRGcoin a generator receives comes from two sources: from the DSO, as a network manager and transaction broker, and newly generated units awarded by the NRGcoin Protocol. (This is thus a direct analogy to the reward of a Bitcoin miner, who may be paid twice: for validating the transaction in the form of a commission on it, and additional units for mining a blockchain block with a record of the event). The user, to purchase energy, must pay a certain amount of NRGcoin to the DSO. The NRGcoin currency can be exchanged for other monetary units on the foreign exchange market. The algorithm causes the NRGcoin/kWh price to depend on the energy balance situation on the grid. As intended, NRGcoin, analogous to SolarCoin, is dedicated to settlements for energy from selected sources.

In [16], the exact NRGcoin billing formulas related to one-unit energy generation are given. However, there is no in-depth discussion in the literature on the motivation for adopting the formulas and their parameter ranges defined there. Therefore, it seems advisable to carry out a more in-depth analysis and discussion of such formulas in terms of their impact on the (short- and long-term) objectives of the postulated settlement system, particularly the impact on the system's stability, the development of the network and technical infrastructure and the promotion of desired attitudes and activities of users.

Energy is an asset, allowing its possessor to achieve economic benefits (an indispensable activity factor), so it can be treated as a sub-carrier of value. Energy-related money can offer a means to improve the monetary system, also stimulating the low-carbon energy transition [91]. Thus, the concept of an energy-based currency made available to the grid or a selected DeKo user has been proposed [92]. The concept of replacing the existing gold-backed currency system with one based on an "energy currency" was proposed in 1921 by Henry Ford ("New York Tribune", 4 December 1921) [93]. In the DeKo-based currency concept, its issuer must hold a portfolio of assets providing electricity. These assets can be claimed in the form of contracts for purchasing and delivering electricity from an energy producer. A practical mechanism implementing this concept to some extent is the SolarCoin project. The concept of P2P energy transactions using a blockchain model based on the digital currency SolarCoin in the smart grid was analysed in [23]. The idea behind SolarCoin is that a unit of 1 SolarCoin cryptocurrency (SLR) is credited for every MWh of electricity generated from the sun, regardless of where in the world this energy was produced. Here, there has been a change in the consensus mechanism of the transaction from "proof-of-work" to "proof of generation". This approach to money is intended to offer a combination of stable value with economic utility and to be characterised by the social utility for a specific community.

Finally, it is worth emphasising that money is constantly evolving, and its development is not straightforward. There is an informational component in the substance of money—it is tough to have a universal definition of money, just as it is challenging to have an ideal form of money [94]. Currency is a shared informational protocol for enabling and accelerating value flows across potential economic networks [95]. Whether cryptocurrencies linked to available units of energy will be an appropriate form of monetary units will depend on the details of the concept and social evaluation. A first test may be to open up new settlement systems for smart grid energy use based on cryptocurrencies or utility tokens.

3. Settlement System Concept

3.1. Motives

The unfolding climate catastrophe necessitates measures for the decarbonisation of the economy, particularly the power sector. This process, especially in regions heavily dependent on the fossil economy, should involve all actors and system users [96,97]. Popular RES generation technologies have reached sufficient maturity [98]. In order to achieve the suggested targets of reducing emissions and increasing the share of renewable generation, appropriate mechanisms should be used to promote specific behaviours and preferred generation technologies. An incentive of a financial nature appears to be one of the most effective. An appropriately designed settlement system should support sustainable development, in line with the postulates of an ecological approach to energy use.

Maintaining the electricity system requires ongoing financial investment to ensure that efficient technologies and appropriate management methods can be invested in. Regardless of the financial flows between actors in the energy market, in the final calculation, the end-user pays for all activities related to the generation and supply of energy. These costs must be distributed among users in a way justified by their individual consumption share. The specifics of the traditional electricity grid structure categorise users by tariffs. New methods to track flows, decentralise the structure and bring generation closer to consumers should be reflected in the settlement system. The problem of covering network operation costs should be solved, with users with specific technologies, especially prosumers, being able to use their own potential in this process by providing specific system services (becoming flexumers). All users should be rewarded for their contribution to system balancing, reduction in energy distribution losses and improvement of power supply quality and reliability, considering the demands of sustainable development in proportion to their involvement. A DSR-type programme should also be universally addressed to smaller user groups and extended to the possibility of providing appropriately identified ancillary services to the grid.

Research into the design of an appropriate settlement system between network users seems essential. The functionality of the settlement system should promote a balanced approach to the use of energy resources and ensure proper financing of the fulfilment of the functions assigned to electricity grids and systems. However, the available literature lacks an analysis of the concept of settlement for system services provided by energy users (flexibles) within a coherent energy settlement system, especially one based on a dedicated cryptocurrency.

An appropriately designed settlement system can exploit the advantages of the opportunities offered by cryptocurrencies, with the system being based on its own cryptocurrency, not linked to others already in existence (such as Bitcoin). The expected advantages include that a dedicated cryptocurrency system makes the billing layer for energy use independent of the macroeconomic situation (the linking will only occur at exchanging this cryptocurrency for other monetary units, such as traditional fiat currency). Furthermore, this approach will show which activities are desirable for the sustainability of the electricity grid, regardless of the current economic situation. That is, from the user's point of view, the difference will be clearly shown between the operation of the electricity system, whose operation will directly translate into the flows and deployment of cryptocurrency units, and the economy-wide situation affecting commodity prices and exposure to speculation.

Another advantage is the transparency of currency flows. According to the blockchain principle, the users themselves can remain anonymous, but all the transactions carried out for energy will be visible to all participants. Furthermore, transaction information will be recorded on the subsequent blockchain. The visibility of the activities of individual users can motivate others to optimise and increase their own participation in the system, especially in terms of energy efficiency.

Other possible advantages of the system are achieving transparency and simplifying the settlement form between energy users and the chance for additional profits from energy and currency exchange activities (new business niches). A settlement system covering various activities related to energy use, using the concept of a dedicated cryptocurrency, should be further investigated from the point of view of its impact on the development of the power sector, including the financial sector, particularly by identifying opportunities and threats and pointing to elements for achieving the intended development goals.

3.2. Basic Assumptions

Among the emerging blockchain-based settlement concepts and energy trading platforms for systems with connected prosumer installations, one can distinguish between approaches proposing the use of dedicated cryptocurrencies (in the sense of coins), e.g., NRGcoin, SEB [70,71] or using a blockchain model based on an existing digital currency (such as SolarCoin [23,99]), and proposing the distribution of proprietary utility tokens (e.g., [33]). In this paper, we focus on the concept of using a dedicated cryptocurrency for the settlement of energy use in an electricity system with a high proportion of prosumer installations.

Cryptocurrency can be a convenient measure of value due to the elimination of the issuer. The guarantee of the authenticity of the unit is provided by blockchain technology. Moreover, there is an integration of the value of money with a programmable machine algorithm. The open nature of blockchain (as the most popular DLT) motivates participation in the system from the bottom up. The basic form of activity realisation according to the ideas of the system in question is smart contracts, which combine the logic of technical processes with a layer of civil law contracts. The information in the publicised libraries of smart contracts is publicly available and enables the creation of new business systems of the desired complexity. Smart contracts can be established between two or more parties, with contracts being able to influence each other during execution as they themselves have the ability to undertake and participate in transactions. The cryptocurrencies or certain utility tokens required for smart contract execution, as carriers of value, combine the characteristics of a convertible means of payment with those of a control signal. They thus integrate responsibility and financial obligations with process control automation. This results in a reduction in the effort and time required to create and operate individual relationships, both business and technical. The creation of complex multi-partner structures is possible here without the need for centralisation and mediator involvement [100].

Based on the descriptions in [16,70–72,100], a general concept of a settlement system for energy use in a designated electricity system using a proprietary cryptocurrency can be formulated. The basic elements of this system can be assigned to two layers:

- Physical—related to the flow and recording of energy in a specific electricity grid; and
- Digital—related to the flow and recording of values stored on cryptocurrency tokens in the blockchain network.

As the implementation of the contract concerns an event that takes place in real space, concerns a physical quantity and can be objectively measurable (the amount of energy at a specific moment in time), it is necessary to define a linking element between the realm of physical events and the realm of representation in the digital layer by means of technology. Such a link should be a technological interface. The responsibility for creating such an interface could be entrusted to the grid operator, who would simultaneously use it to control the compliance of the contracts with the accepted rules and technical capabilities of the grid itself and the power system.

The technological interface can be understood as the place of technical (physical) and financial and legal (including business, tax, etc.) interactions integrated into the blockchain environment. It enables the automatic execution of contracts with automated technical processes through the communication methods of the nodes of the blockchain network with the environment within the execution of the smart contract code. There is an exchange of information and a flow of values stored in the form of cryptocurrency tokens. The interface thus understood has an IT layer and a hardware layer, enabling the execution of the contract programme according to the established algorithm. At the same time, as these areas are at the border of environments, the processes themselves in these areas no longer need to be covered by the authentication and access control methods characteristic of blockchain. Instead, they require using the usual means (for common and regulated activities). Specialised interface areas should therefore be subject to interest and safeguards by the relevant regulators. For example, for energy applications, areas of technological interfaces to ensure trading and settlement compliance can be found at the interface level with:

- Market participants in a broad sense: grid operators, metering operators, settlement intermediaries, generators, energy sales intermediaries (independent sellers), service aggregators, energy cooperatives, energy clusters, virtual power plants, users, additional grid service providers (including prosumers and flexumers);
- Power grid infrastructure and IoT technology devices, also smart grid, smart building, smart city;

- Financial institutions, including entities that allow the conversion of cryptocurrency into another monetary unit (exchange offices); and
- State authorities (fulfilment of tax or other obligations arising from current legislation governing the power sector).

At the digital layer is the possibility to exchange the accumulated units of account (cryptocurrencies) for other carriers of value (including fiat currency) in an external exchange market (currency exchange office). The unit of account in this concept is a dedicated cryptocurrency referred to in the paper as CCE (Cryptocurrency for Energy) as a means of payment for energy use activities in a designated electricity system. The rules related to its issuance, flows and exchange are defined in the CCE Protocol. The protocol is also intended to define the structure of the blockchain as a distributed database to ensure the secure exchange of digital money in the virtual realm. CCE is to be understood as a recognised value equivalent and intermediary for exchanges enabling energy use by networked participants. The characteristics of CCE as money are outlined in Table 3. However, cryptocurrencies are not considered to have many of the characteristics of money and do not fulfil all the functions that should be ascribed to money [101].

Table 3. CCE as a form of money.

Attribute of CCE	Comment
Security	Technology: DLT (blockchain)
Circulation range	Within a specific electricity system (grid)
Interchangeability	According to user consensus: into energy units, into other currencies (via the exchange office), into other values (with the agreement of the parties to the transaction)
Issuer	Non-institutional (blockchain technology)
Value guarantor	Blockchain technology
Value-assessment function	kWh values under given conditions of network operation status
Exchange medium	As intended, it acts as an intermediary in energy purchase and sale transactions
Value medium Payment instrument Global money function	Functions limited by the purpose of the currency
Durability	Like the Internet
Portability	Like digital versions of documents
Divisibility	Made possible by digital records
Uniformity	According to the protocol
Limited supply	According to the protocol (defined cases of generation of new units after a certain energy activity, amortisation function mechanism)
Acceptability	Based on agreement and consensus of system users

DLT and blockchain technology (smart contracts and cryptocurrencies), together with a technological interface aggregating smart metering capabilities, enable faster settlement for energy actually delivered and consumed (without the need for estimation and forecasting) and without holding up payments until the end of the billing period, in addition to the implementation of dynamic tariffs and DSR programmes. Participants can only transact with each other based on predefined rules consistent with the developed system specification. A full settlement system based on a dedicated cryptocurrency can consist of multiple cryptocurrencies, convertible into other monetary units (traditional currencies—fiat), just as a larger electricity system can consist of multiple subsystems, able to self-balance and which do not need to have constantly active connections between each other (systems that can operate as islands—isolated). The operations used for asset management are available to regulators and energy companies, who can track changes to maintain the reliability of the electricity network.

Isolated systems in which settlement would occur based on the concept of a dedicated cryptocurrency could use an internal cryptocurrency to set the price of services offered on the electricity grid and to settle transactions for energy use between users connected to the grid within the isolated system. Cryptocurrencies from different systems could be exchangeable in pairs in an asymmetric manner. The exchangeability of pairs in a given direction would be conditioned by the technical possibilities of transferring energy between systems (existence and capacity of interconnections), including the network topology. Asymmetric exchange ratios would generate exchange rate spreads (analogous to the classical currency market), as depicted in Figure 2.

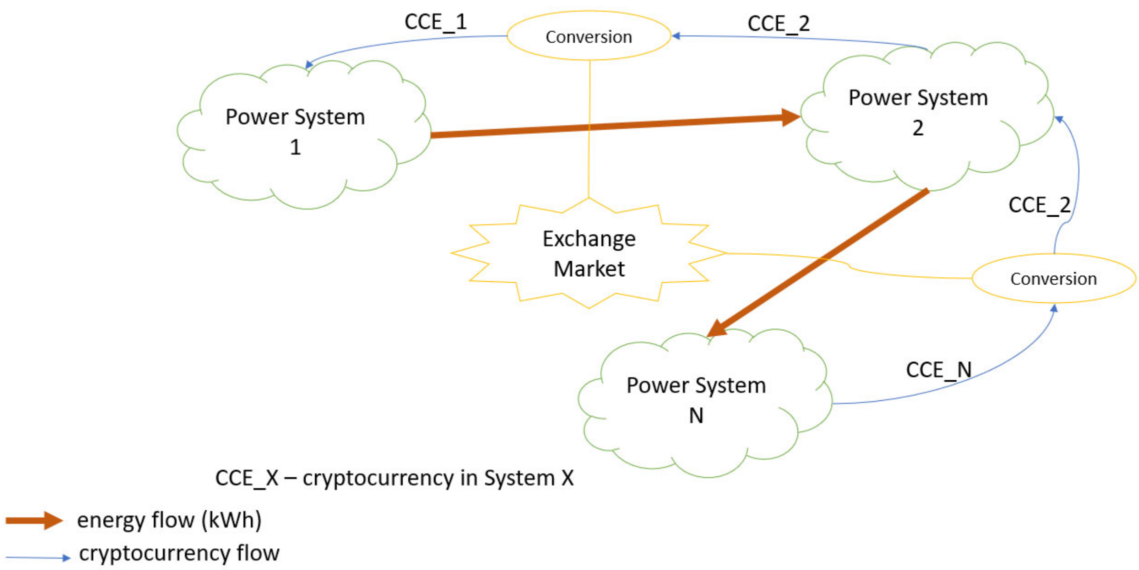

Figure 2. The ability to convert cryptocurrencies between energy exchange systems.

3.3. Participants

A participant in this conception can be presented as a node of a network to which four streams flow: electricity, fiat money and dedicated cryptocurrency, as well as measurement and control signals (information), while in general, these streams may come to the participant in both directions (depending on the role of the participant and the situation in the system—Figure 3).

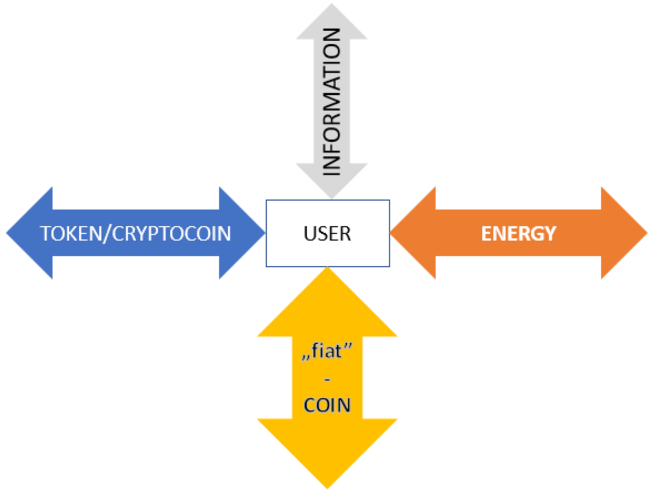

Figure 3. Streams reaching a user in the system.

Within the overall structure, participants can be divided into groups:

- Customer group (entities)
  - Energy generators (G)—in addition to the typical generators, this group includes prosumers and flexumers ready to feed surplus electricity back into the grid, as well as facilities with the generation and storage (including, for example, electric vehicles).
  - Consumers (C)—typical (conservative) end-users, including prosumers who do not cover their entire demand themselves, including storage units used for arbitrage (stationary and mobile).

The customer group has been subdivided above from a functional point of view for the system, as one of two modes of operation in relation to the grid (energy input or energy output) is possible at any given time. The belonging of a particular entity to Group G or C is not absolute and depends on the technical possibilities and the current situation (market and network). The customer group may also include other electricity systems (networks) connected to the system in question in a way that allows energy exchange. In addition, there may be aggregators and intermediaries in the structure as entities representing other participants who are unwilling or unable to participate directly in the cryptocurrency-based structure. These entities may also aggregate smaller participants into relevant groups to be functionally more visible in the structure. In particular, this group can also include providers of ancillary services for the stable operation of the electricity system (Group G).

- Intermediaries
  - Distribution System Operator (DSO)—an entity that manages the technical operation of the power distribution grid, responsible in particular for infrastructure maintenance and grid operation.
  - Metering Operator (MO)—depending on legal requirements, a separate entity or one that is within the DSO structure, dealing with customer meter service issues and managing metering on the grid.
  - Platform for the exchange of cryptocurrency into other monetary units (exchange office)—a structure operating on a market basis allowing the exchange (purchase, sale) of cryptocurrency units into other currencies (including fiat currencies).
- Additional elements
  - Cryptocurrency protocol—a set of rules and an algorithm for the generation (also possible redemption) of cryptocurrency units, and also the creation of records (blocks) according to the Distributed Ledger Technologies (DLT) blockchain.
  - Technological interface—providing connectivity between the physical layer (monitoring and recording of energy flows) and the digital informative layer (transla-

tion of energy use facts and events into the DLT settlement sphere, smart contract recording).
- Information platform—an area for the exchange and collection of information on the state of the network and the power system, aggregating data on the current generation and energy demand in the grid area, taking into account the current constraints; a place used by the grid operator to form the demand for ancillary services to the grid.
- The power grid as a medium for the transmission of energy between participants.

Strictly technical objects are not participants in the structure, as by definition, participants by their actions influence the way the structure works and can be parties to smart contracts. Customer entities and intermediary entities can be parties to smart contracts. Within a smart contract, it is possible to pay network charges and taxes to the DSO from coins paid by the user. The smart contract validates and records user-reported energy flows and payments.

Among the participants in Group G and Group C, users can be distinguished:

- Flexible, i.e., able to adapt their energy use position (supply and off-take respectively) to a certain extent to the current situation (signals) on the power grid; and
- Rigid, i.e., enforcing certain states of grid operation due to the technology used—forced generation (RES units without direct cooperation with storage) and rigid off-take (e.g., critical loads).

The characteristics that Transactive Energy should have (economical, efficient, reliable and resilient) translate into a demand to use energy when it is cheaper. Thus, the supply of energy (from RES sources) is primary, to which demand should be adjusted. A variable price is a tool to stimulate such an effect.

3.4. Outline of the General Concept of the CCE Cryptocurrency Settlement System

We present a generalised concept, based on the idea of dedicated cryptocurrencies, for a settlement system for electricity use in the power grid. The concept developed is based on publications [16,70–72,74,100], including our modifications.

The schematic flow of signals, energy and value between potential participants and objects in the generalised version of the concept is depicted in Figure 4. The CCE and information flows are realised in the execution of the smart contract. CCE units can be accumulated by the participants (G and C energy users and the grid operator) in virtual accounts after smart contract execution. This information is stored in blockchain technology. CCE units can be exchanged for other values (fiat currency) via an exchange market (exchange office). Fiat currency, as a more universal store of value, can be held in an account at a bank. The CCE–fiat exchange market is a place of possible speculation, so appropriate mechanisms should be provided to safeguard CCE users. This issue is a separate research topic. The structure's purpose is to dispatch the energy generated by the producer to the end-user on the grid via a kind of chain within the power system. In parallel, there is a reverse chain for the conversion of local cryptocurrencies (with any spreads covering the costs of subsequent contract stages). The flow of value of cryptocurrencies is thus opposite to the flow of energy along the path between the essential participants (generator and user). The identical direction is, of course, the case with traditional forms of settlement (fiat currency); however, there are other intermediaries in the path of the payment flow.

Consumption of energy from the grid can be treated as an implementation of a smart contract in blockchain technology. A user searching for energy supply offers can use a mechanism to aggregate market information. In order to effectively integrate automatic search functions, the access point for such functionality should be the blockchain environment. The signing of a contract by the user takes place after market selection by calling the function of the selected contract. This call contains an attribute with the amount transferred from the orderer's account to the contract account at the time of the call (i.e., not immediately to the producer's or operator's account). The funds deposited in the contract account are distributed between the participants in the contract, depending on the contract. Calling and transferring the monetary value are prerequisites for the performance of the contract. The parties to the contract can track and detect a change in its status. The system operator (or metering), in addition to the generator and user, should be a party to the contract, as it is responsible for the technical implementation of the delivery through the grid and should therefore have access to information about the transaction, retaining influence over its course. This operator can be considered as an intermediate link in the execution of the transaction. Each party is identified by its public address, which is its individual account number. It is, therefore, not possible to trigger anonymous activity [100].

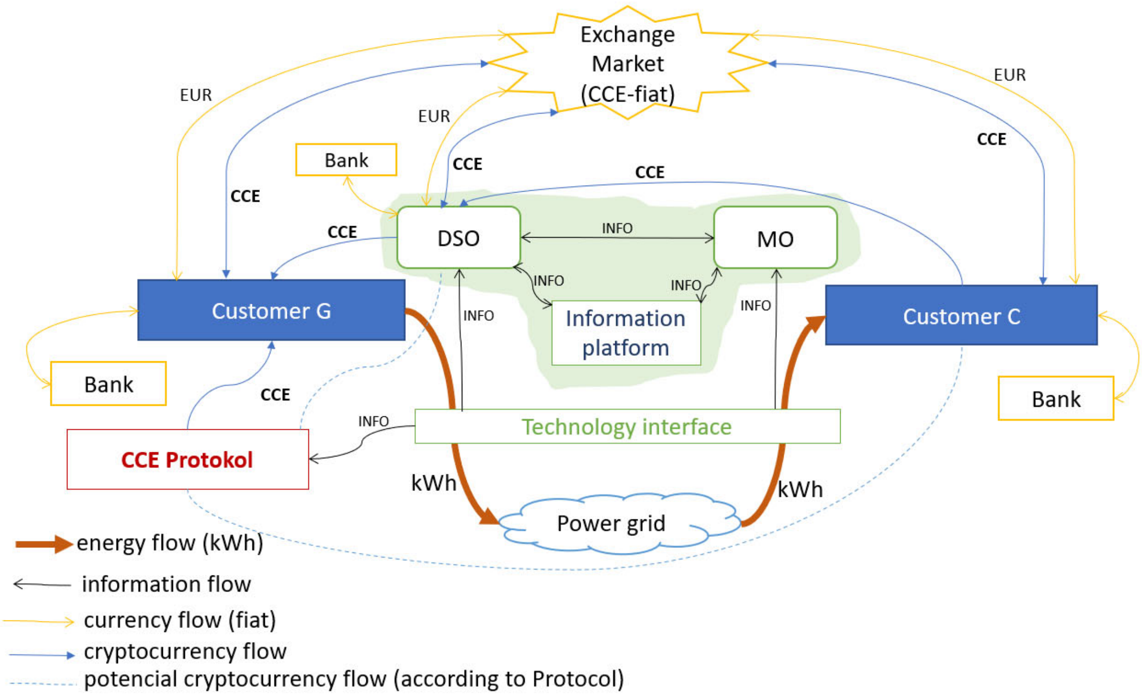

Figure 4. General functional diagram of a CCE-based settlement system.

The execution of the contract itself involves a chain of operations: matching–clearing–settlement–payment. In a smart contract, the individual phases of contract formation and exchange execution do not require the participation of a guarantor or the crediting of obligations and their subsequent enforcement, so there is no need for forward contacts. The smart contract code in the blockchain network defines the rules for the virtual coexistence of the commercial and technical layers. The role resulting from the capabilities of blockchain technology is to register an event and execute a programme in the virtual space of the contract (transaction).

The settlement system in this model is primarily dedicated to isolated power systems capable of self-balancing with significant energy storage capacities and with a high proportion of prosumer installations, for which energy exchange with the grid would be a second-choice option (after self-consumption). Purchasing energy from the grid would practically have the characteristics of a spot market transaction through the CCE exchange market, organised on the principle of a CCE exchange (buying as close to the moment of demand as possible and selling at the moment of feeding energy into the grid, price depending on the current relationship between supply and demand, which brings the de facto settlement method closer to a time-varying pricing scheme [102]).

Purchases analogous to the forward market in this model would be possible in the form of P2P transactions for CCE purchase options so that they would occur in the financial market, i.e., outside the structure of the relevant CCE-based settlement system for energy use.

The initiation and progression of the basic settlement operation according to the presented concept would follow the following steps (Figure 5):

1. Prosumer gives back to the grid the energy he/she has not consumed as a G generator (this is registered by the grid operator and/or metering operator, the technological interface initiates the start of the smart contract transaction).
2. Prosumer, as generator G, is allocated an appropriate number of CCE units according to the protocol (in the general warrant, there is the possibility to vary the rates of CCE units/kWh allocated depending on the generation technology, promoting specific RES solutions).
3. Prosumer, as generator G, puts the received CCE units up for sale on the CCE–fiat exchange market (in the form of a spot exchange or directly to another user in the form of a P2P); user C declares payment of a certain amount in the desired currency for the corresponding number of CCE units.
4. Prosumer G receives payment in the desired currency; user C receives the desired number of CCE units.
5. User C transfers the appropriate number of CCE units to the system operator.
6. The system operator enables the delivery of the appropriate amount of energy according to the amount paid in the CCE. The technological interface records the flow and allows the transaction to be closed.

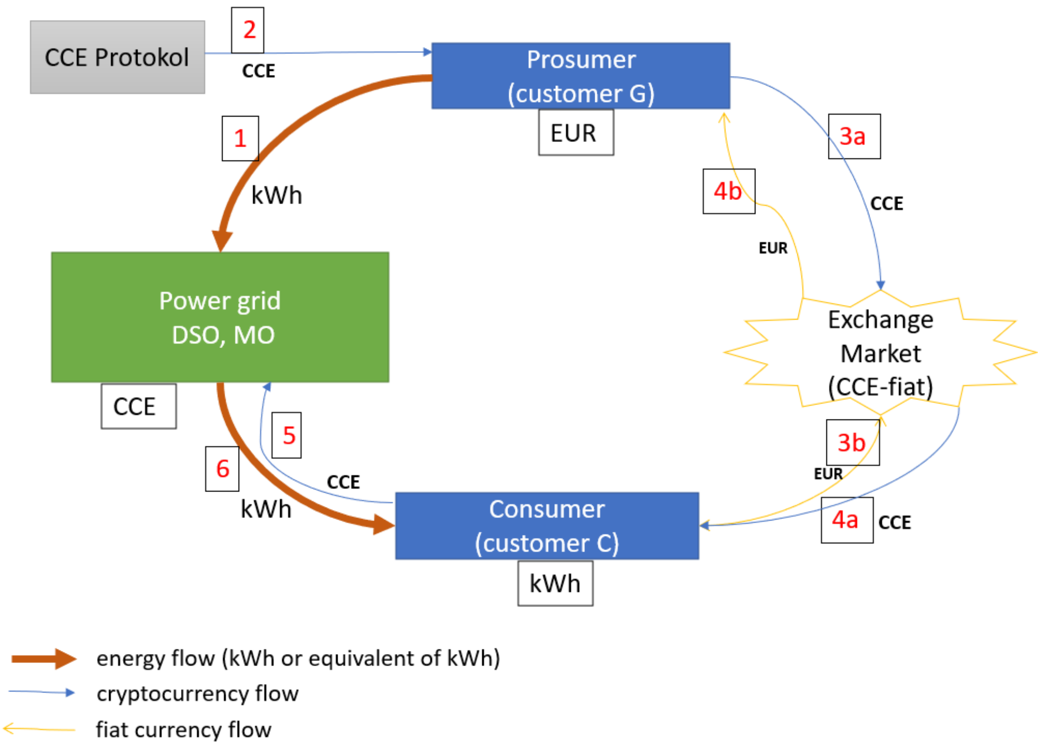

Figure 5. Flow chart of basic settlement operations in a CCE-based concept.

As a result of a full cycle of energy delivery through the network of the designated system between users, the C-consumer has received the corresponding amount of energy (kWh), the prosumer delivering the energy has accumulated the corresponding value in fiat currency and the operator has accumulated the corresponding amount of CCE units. As the clearing system, the CCE–fiat exchange market and the network within the designated system (the number of users) develop, the structure will become more complex, new functional links between participants will be possible and complex participation strategies will be built. In particular, an operator could feed stored CCEs into the exchange market to increase momentary energy demand, reducing their price in fiat currency. Furthermore, the network operator's operating costs could be covered by a mandatory subscription fee paid by all participants (G and C) connected to the network outside the CCE system. In this way, the operator would not have to speculate in the CCE exchange market to generate revenue.

In this concept, an energy storage entity (including the dispatcher of the electric vehicle) could participate. When taking energy from the grid, this entity would have the status of a consumer C and, when handing over, the status of a generator G. The profitability of these activities would result from the respective strategy of the manager of this entity based on the detailed rules within the concept and the current price on the CCE–fiat exchange market. Two smart contacts would thus be realised separately for the purchase and sale of energy.

The settlement of prosumers for the energy given to the grid is commonly implemented on a net-metering or net-billing basis [103]. The settlement method influences the profitability of the investment in the installation from the prosumer's point of view [104]. The settlement concept presented here, based on dedicated CCE cryptocurrencies, can be realised in more detail by adapting to both forms.

3.4.1. Net Metering with CCE

Net-metering is based on the fact that an entity injecting energy into the grid can take it back within a set period in an amount correspondingly less than the amount of energy supplied. The grid, in this case, acts as a kind of energy store for the entity (the prosumer with surplus energy produced). Such a service cannot be free of charge due to the need to maintain the grid, and prosumers would also incur losses if they had their own energy storage, depending on the technology. Therefore, the smaller amount of energy to be withdrawn relative to the amount of energy handed over models the losses in the storage system and considers the DSO costs.

The concept of a dedicated cryptocurrency in net-metering model settlements (Figure 6) could be the following pattern of activities:

1. The prosumer in the role of generator—customer G receives x_1 units of CCE cryptocurrency (i.e., 1 CCE/1 kWh) for feeding x_1 units of energy (x_1 kWh) into the grid at time interval t_1. The technological interface (which includes a two-way energy meter) generates a token with information about the amount of cryptocurrency and the time and date of the event, assigning it to the prosumer's account (a block in the chain has been created). Thus, an ordered pair of numbers (t_1,x_1) is associated with the prosumer's account, indicating that the prosumer has x_1 units of CCE, which, at time t_1, are worth x_1 kWh.
2. According to the net-metering principle, the amount of CCE units in the prosumer's account is reduced over time—at time $t > t_1$, there are actually y_1 CCE units in the prosumer's account; instead of (t_1,x_1), there is the state (t, y_1), according to the relation:

$$y_1 = x_1 \cdot f(t - t_1) \tag{1}$$

where y_1 is the current number of CCE units on the prosumer's account at time t for the energy release operation at time t_1; f is the amortising function.

1. A prosumer injecting successive portions of energy x_2,..., x_i into the grid accumulates on his/her CCE account at time t worth y_2, . . . , y_i, respectively, according to the relationship (1), i.e., at the moment t, the account has $y = (y_1 + y_2 + \ldots + y_i)$ CCE. Further blocks are added to the chain.
2. The prosumer in the role of the user, customer C: by taking x_c kWh of energy from the grid at time t_c, he/she pays with his/her own cryptocurrency according to his/her account balance. If the number of CEEs is $y < x_c$, the prosumer can buy the missing CCE units from another participant, particularly the DSO. The power purchase transaction is recorded in the blockchain.
3. The prosumer can resell the accumulated units y_1, y_2,... in whole or in parts in the CCE–fiat currency exchange market, gaining income and defending against a loss in the value of the CCE account. The prosumer thus enters into a transaction whereby specific CCEs are transferred to another account without holding back the function $f(t)$ on these values.

4. An entity wishing to take energy from the grid would need to source (purchase) from the CCE currency exchange market the appropriate number of CCE units and then exchange them for kWh.

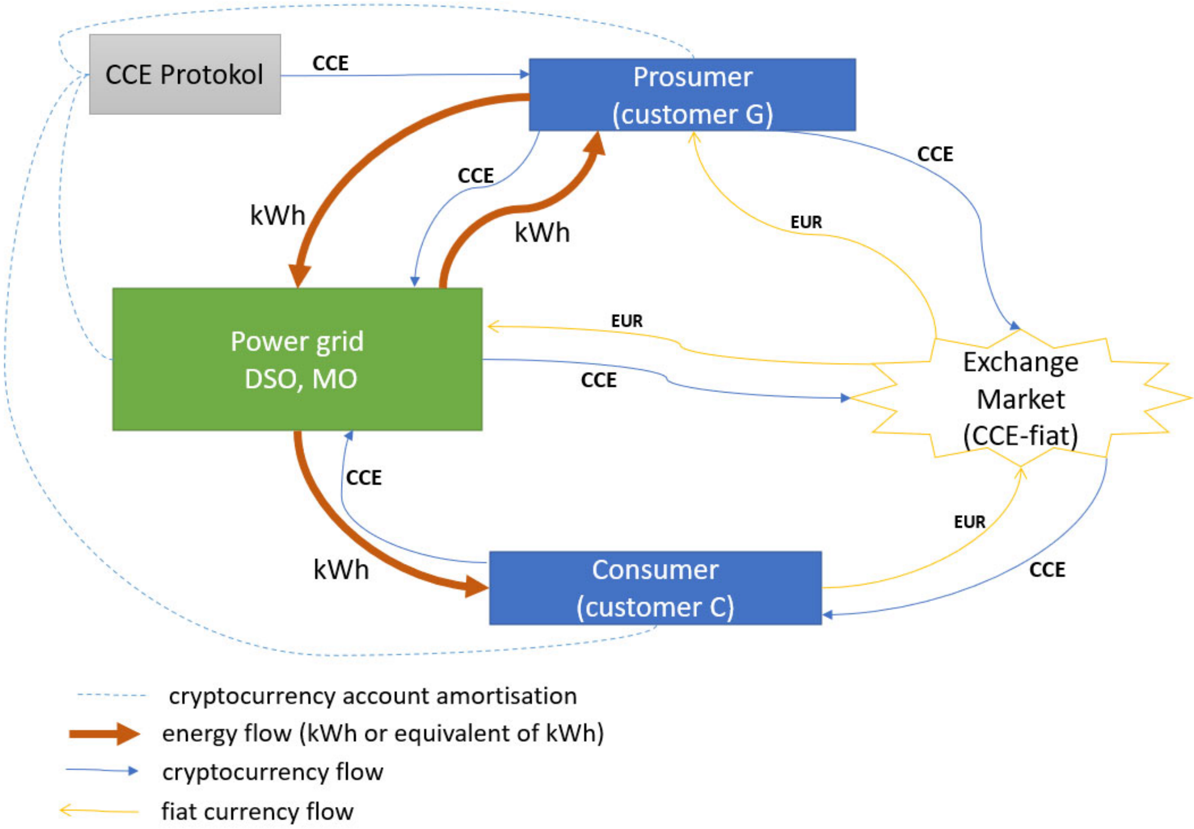

Figure 6. Functional diagram of CCE system for net metering.

In this settlement model, a rigid conversion rate (purchase price) of energy per CCE unit can be set, e.g., any participant with 1 CCE at his/her disposal at any given time can obtain 1 kWh from the grid for it at that time. Additional rewards for preferred generation technologies (e.g., additional CCE units for RES generation) or ancillary services are possible during the operation phase of the CCE Protocol. The variation in the economic value of purchasing energy units at different times is due to the operation of the CCE–fiat exchange market.

The introduction of a function $f(t)$ of the depreciation of the CCE account balance results in the following:

- The amount of CCE available on the market is derived from the amount of energy available in the system.
- CCE inflation is limited.
- The cost-effectiveness of the accumulation of CCE by users is reduced, limiting speculation on CCE–fiat values involving excessive profits while artificially creating a deficit of CCE in the exchange market.
- Limits the possibility of CCE to be used as a means of exchange in markets other than for energy trading.
- Incentivises the ongoing take-up of available produced energy (encourages self-balancing by participants).
- Can reflect the state of infrastructure related to energy storage efficiency and unit flexibility.
- Can encourage investment in storage units adapted to the prosumers' capabilities.

- Can practically introduce time-varying pricing for energy users (including consumers); the CCE exchange market takes on the characteristics of a spot market for available energy on the grid.

The function $f(t)$ itself, by the nature of the issue, should be monotonic and non-increasing. It remains to be determined whether it is continuous or stepwise, linear or exponential (Figure 7). The question of determining and justifying the appropriate shape of the function $f(t)$ for a given power system is a separate research task.

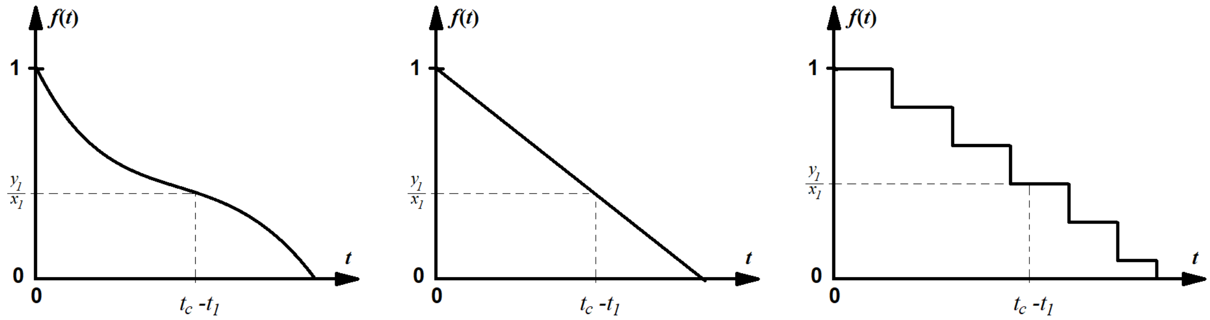

Figure 7. Examples of the waveforms of the CCE account value limiting function $f(t)$: continuous degressive, linear, gradual degressive.

The function $f(t)$ in relation (1) should be established based on the technical conditions of the system, the expectations and possibilities of the prosumers and the expected effects of the solution, and it should be preceded by in-depth analyses. As the availability of energy storage in the system changes, the function $f(t)$ can be modified. A variant of the settlement system could be to vary the curves of the $f(t)$ function according to generation technology, thus promoting specific sources. A uniform and linear or equally graded (with equal step heights and step widths) function $f(t)$ would simplify this settlement system, as the loss of value in CCEs would be identical for all entities. The amount of CCEs held does not depend on when and where they were obtained.

The purpose of decreasing the value of the function $f(t)$ to 0 is to prevent an oversupply of CCE. Of course, whether this function should reach 0 or not exceed a certain level can be a research topic in the context of possible other uses of CCE as a means of exchange in other markets. In this case, the CCE is a value reflecting the availability of energy in the system, and that energy injected and used by the user does not return to the system. Therefore, the time after $f(t)$ reaches 0 should be reasonably chosen. This is the form of implementation of the considered mechanism and expiry date on digital currency balances [105].

When selecting $f(t)$, technical, economic as well as social factors should be taken into account, in particular:

- The potential for energy storage in the system (including available storage capacity depending on the technology, storage losses, response times);
- Possible strategies to be taken by prosumers and users (taking into account their specific motivations);
- The use of additional demand-side mechanisms (DSR);
- The possibility of using additional flexible DSO generation units;
- Investment and operating costs of system components affecting the maintenance and operation process;
- Public acceptance and assessment of the readability of the solution by the average user;
- The users' preference for speed of response to changes in the value of the portfolio;
- The degree of expected simplicity of the settlement system; and
- The impact on future investments in the power system and energy management practices.

3.4.2. Net Billing with CCE

The concept is to reward the prosumer injecting energy into the grid with an amount that depends on the wholesale energy price. This price can fluctuate due to the current relationship between supply and demand. Using a special CCE cryptocurrency in this approach can involve creating flow paths of different numbers of CCE units between participants in the system. The magnitudes of these flows can be conditioned by appropriately defined functions depending on the time, the moment of execution and the magnitude of the energy flow. CCE payments pass between the participants, which include the grid and metering operator (e.g., DSO), and through the technological interface.

In the following, we present the general provisions of the formulas determining the charges between system participants, indicating possible dependencies of these formulas on other parameters (Figure 8). The motivating role of price signals should be used here to influence users' desired attitudes and actions, aiming at full utilisation of energy from local RES and balancing the system.

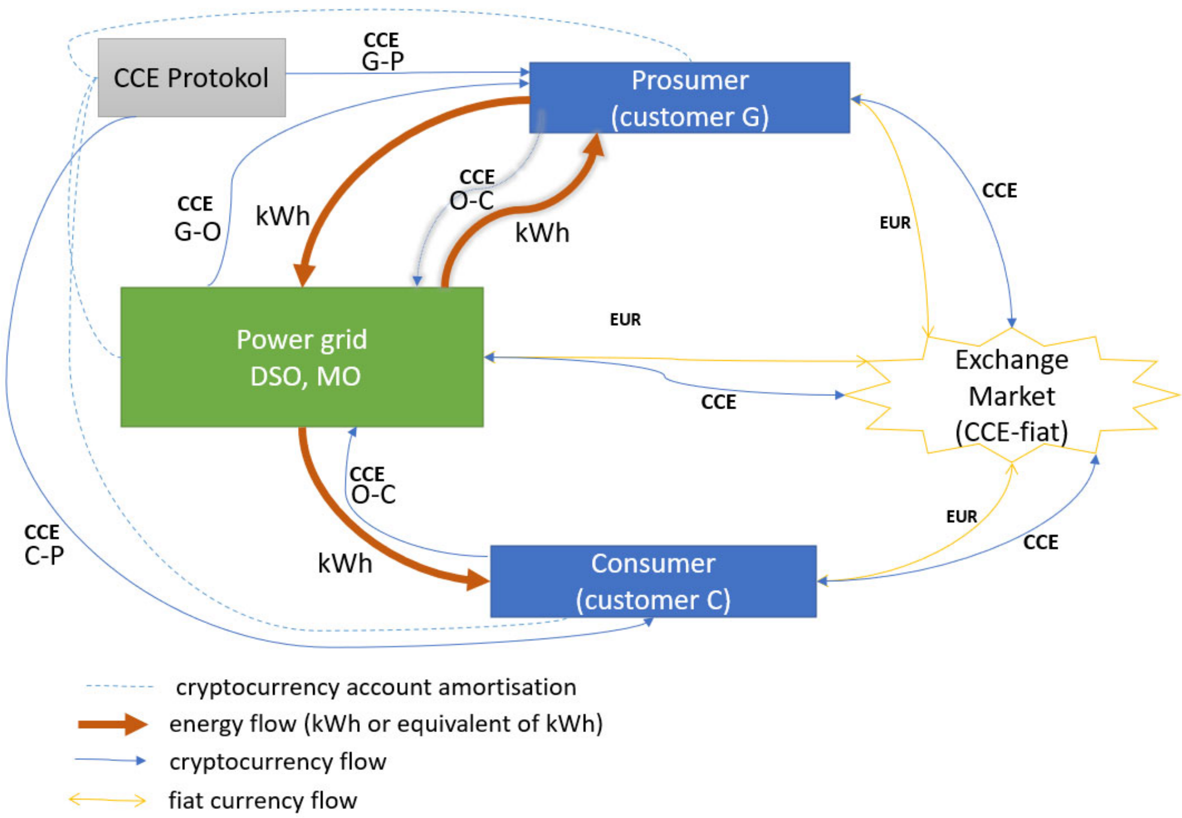

Figure 8. Functional diagram of the net billing CCE system.

Purchase price (as a value transferred from consumer C to grid operator O):

$$O - C: \ \ x_c = f_c\left(E_g(t) - E_c(t), t, u_c\right) + p_c \tag{2}$$

Selling price (as a value reaching generator G from grid operator O):

$$G - O: \ \ x_g = f_g\left(E_c(t) - E_g(t), t, \ u_G\right) - p_g \tag{3}$$

where:

x_g, x_c—prices for the sale and purchase of energy from the grid at time t, respectively;
p_g, p_c—additional commissions to DSOs (operators) for the transmission service (maintenance of the system and grid infrastructure), unless the details of the settlement system provide for another mechanism, e.g., subscription outside the CCE system for connected users;

f_c, f_g—functions determining the number of CCE units due;
E_c—amount of energy taken from the grid by all users during the time interval;
E_g—amount of energy supplied to the grid during the time interval;
t—moment of energy use (time interval during the day); and
u_c, u_G—user group or technology of use in consumption or generation, respectively (possibility to diversify participants to promote specific generation technologies or energy use objectives).

The C-P and G-P relationships depend on the adopted settlement rules and also concern possible additional rewards for specific desired activities (e.g., power generation by a source from a preferred technology, reduction in consumption during peak demand or on a signal from the operator DSR mechanism, provision of reactive power). The participant managing the energy storage (also in the form of an electric vehicle battery) can act in this model once as a consumer C and at other times as a generator G, subject to the relevant rules. The specificity of the energy storage can be taken into account in the settlement formulas with an appropriate component depending on the parameters u_c and u_G.

The concept of dedicated cryptocurrency in net-billing settlements can be based on the following activities:

1. The prosumer in the role of the generator—customer G for feeding units of energy (kWh) into the grid at time interval t_1 receives x_g units of CCE cryptocurrency from the operator and an additional generation technology bonus in the form of newly generated CCE units based on the CCE Protocol, i.e., $x_{G\text{-}P}$. A technological interface (including a bi-directional energy meter) enables the initiation of a smart contract and the creation of a block in the CCE currency chain.
2. The prosumer can put the accumulated CCE units for sale in whole or in part on the CCE–fiat exchange market or make an exchange for the amount of energy units taken from the grid at another time according to the applicable price in the CCE at the time of consumption (relation on x_c), becoming a C participant. The effects of a transaction taking place in the form of a smart contact are recorded on the blockchain.
3. The user in the role of a customer—customer C: when taking energy in the amount of E_c kWh from the grid at time t, he/she pays with the held cryptocurrency according to the applicable price x_c. He/she should acquire the required CCE units in advance on the CCE–fiat exchange market. The transaction of purchasing CCEs and exchanging them for the corresponding amount of energy is recorded in the blockchain.

Here, too, the CCE depreciation function $f(t)$ can be used for the reasons and purposes presented in the subsection with the net-metering model.

The purchase price of energy *fc* for the consumer should be shaped to reflect the market laws of supply and demand, incentivising the self-balancing of the grid and using as much energy as possible from cheaper least-emitting sources when it is generated. Once established and socially accepted, the shape of the function can be implemented in smart contract algorithms. The *fc* function should depend on:

- The energy balance in the system (expressed as the absolute difference between the energy generated in the system and the demand during a given interval);
- The time of day, i.e., indirectly from the predicted energy demand profile in a given interval (which determines the current RES energy production in the interval); and
- User characteristics—rewarding attitudes towards sustainable energy use through a price reduction component for users who declare and implement certain attitudes and behaviours (e.g., using energy-efficient appliances) or as an instrument to help poorer, vulnerable or excluded users (social and safety policy mechanism).

Similar considerations also apply to the shaping of the f_G sales price function for generators. However, here too, an upward component may be included to reward the development of desirable technologies in the system. The precise determination of the shape of these functions should be preceded by technical, economic and social analyses and is a particular research problem.

The function of the power system operator has to be fulfilled, as an entity is needed, also in an automated system, which will be responsible for the maintenance of the network infrastructure, expansion and traffic management. Financial resources are needed for this activity. In the settlement model presented here, there must be an inflow of money from energy-using participants (generators and consumers). The difference between the selling price (G-O relation) of a unit of energy and its purchase price (O-C relation) can serve this purpose. In order to ensure a certain level of income from this difference, the formulas for these prices can be enriched with components that explicitly guarantee this difference: x_g and x_c to the G-O and O-C relations, respectively.

The net-billing model appears more complex due to the differentiated functions of selling and buying energy. The economic value of purchasing a unit of energy at a given moment is derived from the f_c formula (possible different instantaneous kWh/CCE relationships) and the situation of the CCE–fiat exchange market (current CCE–fiat rate). This model, in its general version, leads de facto to real-time pricing formula settlements.

4. Discussion

4.1. Potential Synergies of the Currency and Energy Systems

Energy flows, like money flows, are a kind of bloodstream of the economy. Energy, like money, is a necessary factor for the creation of new value or the initiation of desired activities. Among publications, there is currently a lack of in-depth analyses oriented towards the study and exploration of the interconnectedness of the possibilities of financial and monetary systems with the transforming structure of energy.

Current trends in the energy sector towards the decentralisation of generation through prosumption overlap with new concepts in the financial world, also leading to decentralisation (the search for alternatives to central banks), of which cryptocurrencies are an emanation. Cryptocurrencies, moreover, can form the basis for the creation of systems of local currencies as a tool for the strengthening and development of small communities [106], formed on the basis of common goals, interests and the technology used (e.g., prosumers) rather than a geographical criterion.

New structures in the energy sector require new approaches to the settlement of energy activities. Successive economic crises cause a constant search for sources of monetary stability and measures to protect purchasing power. It is worthwhile to undertake research leading to the identification of the conditions for synergies between the electricity industry and the financial world in the area of financial systems and monetary stability issues. Research into the possibility of introducing new settlement systems for energy use using fintech tools (tokenisation and special cryptocurrencies) could be a starting point for analyses of such concepts.

Until 1971, a dollar/gold currency system was in place, maintaining a fixed parity in gold for the US dollar currency. Gold is still regarded as a fiscal and fiat expression of the economic desire for price and monetary stability. However, the use value of electricity can also prove to be a stable means of protecting purchasing power (like gold or foreign exchange). Therefore, the use value of 1 kWh can be regarded as a stable quantity. Improvements in economic energy efficiency may change this relationship in favour of an increase in the use value of a unit of energy. However, there is a maximum limit due to the physics of energy transitions.

Treating electricity (the most common and practical form of energy) as an asset that is a measure of value and an essential factor for any economic activity creates the possibility of introducing a new monetary unit linked to the electricity generated. Such a currency system can be linked to the operation of the electricity system. Both structures should be compatible with each other and share common features. The use of blockchain technology favours the decentralisation of the system for transactions and enables the creation and distribution of utility tokens, which can then take the form of a special, dedicated cryptocurrency.

4.2. Energy Settlements through Cryptocurrencies (CCE)—Objectives and Means

The natural interface between the energy and currency systems at the level of the individual user is the settlement of energy usage. Technological development is changing both fields, enabling new solutions and posing new challenges.

When implementing an energy settlement system, it is important to identify the objectives it should pursue in promoting a sustainable approach to using energy resources. Appropriately applied technology based on DLT and fintech solutions, including cryptocurrencies (such as CCE), can provide some mechanisms to foster the achievement of the identified objectives, detailed in Table 4.

Table 4. Goals of the settlement system and mechanisms to help achieve them related to the cryptocurrency instrument.

Mechanism	Goal
Mechanisms favouring cost-effective demand–supply matching: • Appropriately defined functions in the formulas for purchase and sale prices in net-metering. • A depreciation function, reducing the account value of accumulated crypto-asset units in net-metering. • The operation of a currency market in the form of an exchange.	Enforcing self-balancing of the system.
• Additional units of cryptocurrency generated when energy is generated at the relevant source and attributed to their owners, possibility to make the number of cryptocurrencies allocated (or the original value of the token) dependent on CO_2 emissivity. • Use of an energy transaction chain to track RES energy flow. • Possibility to integrate the operation of the green certificate mechanism with settlements using cryptocurrency tokens. • Possibility of direct settlement with an RES-generating supplier.	Promoting specific manufacturing technologies through additional rewards.
Additional units of cryptocurrency generated for specific user activities (including from the recipient) and attributed to that user; participation in DSM, energy efficiency improvement activity, etc.	Promoting specific pro-efficiency behaviours and attitudes.
• Possibility to introduce additional mechanisms (e.g., subscription paid by users). • Operator participates in smart contracts. • Possible access to currency exchange market.	Revenue of DSO, MO or analogue entities.
• Possibility of intermediaries. • Component in formulas for prices depending on user category.	Protecting vulnerable, excluded and poor users.
• Settlement schemes dedicated to local grids and isolated systems. • The structure allows settlement between members of the local community in an automatic way, defined by a smart contract.	Development of local energy sources and energy user cooperatives.

Table 4. *Cont.*

Mechanism	Goal
• The visibility and transparency of transactions recorded on the blockchain can provide comparative information about users' energy use, mobilising those with higher consumption (against the community) to make savings. • Automation of the settlement process based on a smart contract algorithm will minimise activities and hardware and personnel involvement on the part of participants. • Use of an alternative consensus algorithm to Proof-of-Work (PoW), e.g., Proof-of-Stake (PoS) [107], Proof-of-Storage, Proof of Elapsed Time (PoET) [108], Proof of Authority (PoA) [109], Proof of Activity (PoAc) [110], Proof of Burn (PoB), Proof of Inclusion (PoI), Practical Byzantine Fault Tolerance (PBFT) or others [38]. • Settlement formulas that promote the current consumption of energy supplied to the grid (reducing storage losses).	Improving energy efficiency.
CCE account balance depreciation formula.	• Making it more difficult to speculate on the value of cryptocurrency. • Limiting the phenomenon of CCE inflation. • Bringing the amount of CCE remaining in circulation closer to the amount of energy available. • Stimulating the ongoing receipt and use of generated energy.
• Properties of blockchain technology (or DLT equivalent). • Constant cryptocurrency protocol. • The established smart contract algorithm.	Transparency and speed of transactions.

A cryptocurrency such as CCE, as digital money with coverage of a unit of energy at the time of its creation, is sub-value money in relation to fiat currency, which is legal tender in the country. Thus, according to Copernicus–Gresham's law, which states that money with an inferior relationship between monetary material value and face value disappears from circulation money with a better relationship, a CCE-type cryptocurrency has the potential to become widespread and willingly used. Holders of fiat currency will tend to hoard it rather than releasing it into circulation (hoarding). Of course, a critical point is the legibility, legitimacy and fairness of the rules for executing transactions (smart contract code, CCE Protocol formula, reliability of technological interfaces), allowing for public confidence in this form of settlement.

4.3. Advantages and Disadvantages of Energy Settlements Using a Cryptocurrency Instrument

The features of energy settlement system solutions based on a special cryptocurrency in the form of the CCE concept presented and shown in Table 2 (especially NRGcoin, SolarCoin, SEB) represent significant advantages:

- Certainty and clarity of settlement rules—the smart contract cannot be changed by market actors; prosumers are guaranteed remuneration at the blockchain level, according to announced rules, and consumers have stable energy prices (especially from RES) in cryptocurrency units.
- Stability of energy values in a dedicated cryptocurrency—there is a decoupling of energy settlements from other markets, i.e., prices in a dedicated cryptocurrency can show users the value of a given energy activity from the point of view of the operation of the electricity grid, regardless of the macroeconomic situation; there is a derivation of the periodic volatility of the kWh price in fiat currency to an external cryptocurrency exchange market.
- Speeding up settlement—cryptocurrencies can be transferred when consumption is detected automatically every 15 min, for example; values are credited immediately to the user's account; no transaction limits.

- Lower transaction handling costs—transactions are settled without intermediaries (banking sector), a kind of linking of energy flows with simultaneous flow of valuable settlement units.
- Security of transactions is guaranteed by DLT (blockchain) technology.
- With the consent of the users, improvements to the system can be implemented through a fork in the blockchain technology.
- Information on transactions, while remaining anonymous, is publicly available (to network users, who can thus compare their consumption and this can motivate savings).
- Coin convertibility—the possibility to exchange a unit of cryptocurrency for energy or another monetary unit (at an exchange office).
- Facilitation of market entry for small energy producers (prosumers)—conclusion of smart contracts and additional rewards according to the cryptocurrency protocol.
- In the long term, as the solution becomes more widespread (accepted), the possibility of increasing the use of CCE-type cryptocurrency as a means of exchange in other markets—a potential alternative to, for example, Bitcoin, not requiring such significant energy requirements associated with cryptocurrency mining.
- The emergence of a new business niche for advisory and intermediary activities for users who are less advanced or do not wish to participate directly in the system with cryptocurrencies.

This solution, of course, also has features that can be considered disadvantageous from the point of view of users or the energy system, in particular:

- Until this solution becomes widespread, there will be a need to operate in different currency systems within the energy market (cryptocurrencies such as CCE and fiat currencies).
- Unidentified opportunities to speculate on the value of a unit of cryptocurrency denominated in another currency, especially fiat, depending on the size of the market (also user networks, grid infrastructure, generation and energy storage capacities) and possible strategies adopted by participants.
- Possible labile public perception of the solution due to incoming information on the situation in selected cryptocurrency markets and lack of understanding of the cryptocurrency topic.
- Unexplored effects of the potential for cryptocurrency inflation phenomenon—in some solutions generating cryptocurrency units for generating new amounts of electricity in specific technologies, e.g., NRGcoin, SolarCoin (electricity is converted to other forms of energy, while cryptocurrency units remain in circulation), hence the amortising function mechanism in the CCE concept.
- The possibility of too many competing versions of a cryptocurrency in one system, according to the hard fork process, if the original version was not properly refined; this can create confusion among participants.
- Limiting the operation of the tool to a defined network of users who accept its objectives.
- The individual solutions in Table 2 are dedicated to selected forms of energy generation, activities or networks and do not in principle constitute a comprehensive settlement system.

The risks, resulting from the mentioned disadvantages of the solution, may result in a reluctance to develop the grid and to invest in new energy sources and infrastructure. However, these aspects can be marginalised or even eliminated with appropriate utility development. What is required, however, is a more thorough understanding of the nature and phenomena involved in the operation of a cryptocurrency-based system in order to propose desirable solutions. Interdisciplinary research and analysis into the specifics of this matter are therefore needed.

4.4. Scope of Research and Analysis Needed on the Issue

When carrying out considerations towards the detailed implementation of a system based on cryptocurrencies or other utility tokens for the settlement of energy use, research, multi-variant analyses and discussions of issues that can be treated as research problems should be carried out. These topics can be grouped under the following issue areas.

1. Economy, finance and monetary systems
    - Methodology for determining the value of a unit of energy in the system under given operating conditions, taking into account the technical possibilities and economics of the generating and consuming units, the technical state of the network, the storage technology and the intrinsic value of the energy from the point of view of the user's needs.
    - The question of the significance of the inflation/deflation phenomena of the cryptocurrency being introduced: how these phenomena may affect the efficiency and objectives of the system, the rules for the generation of new cryptocurrency units (the criterion of energy or power introduced), whether mechanisms should be provided for the redemption of these units, the mechanisms for the expiry time of the currency units, the nature and shape of the amortising function—the rationale for how the value of the accounts should be forced down (whether units withdrawn due to the passage of time should be taken over by someone or should be redeemed).
    - Legitimate ranges and spread levels when transforming different cryptocurrencies.
    - The problem of pricing ancillary services provided to the network and system.
    - Justification of the relationship between the number of cryptocurrency units in circulation and the amount of energy or generation capacity available.
    - The extent to which the introduced cryptocurrency system interacts with other currency systems and the economy.
    - Opportunities for other financial engineering instruments and mechanisms based on the introduced cryptocurrency and their impact on the functioning of the system (e.g., derivatives, leverage, contracts, additional exchanges).
    - Conditions for improving liquidity and reducing the negative effects of crypto-asset market shallowness.
    - Special rules for the use of cryptocurrencies by a DSO or analogous institution (possible extent of impact on the cryptocurrency exchange market).
    - Possible incentives and sources of funding for necessary investments in the power grid and system development.
    - The extent and desirability of a possible decoupling of the cryptocurrency and energy market system from other markets and the macroeconomic situation.
    - Detailed settlement formulas (shape of the function, amount of components and parameter values of these formulas), whether the different groups of formulas should be identical for a given activity or whether it would be advisable to vary the parameter values of these formulas according to the type of user (e.g., electric car, domestic, industrial, service, social, etc.); length of the settlement and balancing interval; catalogue of possible activities for which the user can be rewarded with the transfer of a certain amount in cryptocurrencies.
    - Conditions under which a cryptocurrency used for settlement of electricity usage on the power grid can become a unit of settlement for other commodities and act as money in other markets.
    - Special cryptocurrency as a tool of monetary autonomy for system users.
    - Electricity as a measure of the value of goods and services and as a means of stable coverage of the value of cryptocurrency, studies of the change in the use value of 1 kWh in relation to technological progress (including improvements in energy efficiency), energy consumption patterns, equivalence with other forms of energy.
2. Technical aspects
    - The problem of standardisation of measurements, devices and protocols for communication and technological interfaces.

- System for monitoring the correct operation of technological interfaces.
- Tasks and requirements for automation systems.
- Optimisation of energy flows during contract execution.
- Reflecting grid constraints in the ability to establish smart contracts.
- Emergency procedures in the event of an inability to balance energy in a managed system.
- Division of competences between those acting as operators, managing infrastructure and maintenance.
- The scope of necessary system services (ancillary to the network) and the capabilities of system participants to deliver them, an assessment of the value of these services within the cryptocurrency system, additional requirements for technological interfaces.
- Issues of the choice of DLT technology on which the system would be based, the form of utility tokens, the possibility of other types of tokens, cryptocurrencies, the choice of FT and/or NFT-based solutions.
- List of generation sources (technologies) that are particularly desirable from an environmental (ecological), economic and technical point of view and that can be further rewarded for generation.

3. Social factors
    - Willingness and ability of the public to assimilate the techniques and rules of the system, openness and public acceptance of new solutions.
    - Breakdown of system implementation into clear and comprehensible stages.
    - The issue of user education.
    - The problem of digital exclusion and fuel poverty of a part of the population—impact on the development of such systems.
    - Range of expectations in terms of benefits, functionality and own involvement by the participant.
    - Sources of motivation of participants to choose given solutions and activities.
    - Impact on the strengthening and development of local, virtual communities (prosumer group).
    - Network reach (how the number of participants affects the success of a cryptocurrency project as a carrier of value equivalent to fiat currency).
4. Environmental factors
    - The actual impact of the system operation options on the decarbonisation of energy sources, RES development and energy efficiency.
    - Impact of the system on the structure of energy consumption at the individual, regional and global levels.
    - Impact of whole-system infrastructure on the local and global environment.
5. Legal environment
    - The need to adapt legislation on cryptocurrencies, the use of blockchain technology and agreements between users of such systems.
    - Status of possible intermediaries and user representatives who do not wish to participate directly in the system.
    - Status of cryptocurrency markets and exchanges.
    - Scopes and subjects of possible disputes between users of the system.
    - Tax issues related to the use of cryptocurrencies and utility tokens and direct settlements.
    - International common principles for the treatment of cryptocurrencies and cryptocurrency transactions.

The aspects and problems outlined above do not cover all possible topics that may arise during the detailed work on solutions. They are intended to signal a number of identified issues to gain insight into the implementation and development of a new settlement system using an approach based on the functioning of instruments such as cryptocurrencies and the like. The identified issues interact with each other, and although they have been assigned to domain groups, their solutions require an interdisciplinary approach. An additional task may be to search for correlations between the effects of the solutions to the problems listed (synthesising the results).

5. Conclusions

The development of information technology has meant that today, in the power sector, the typical engineering approach to resource and infrastructure management (defining problems only in the technical domain) is increasingly shifting towards methods that integrate technical information with financial information, as well as organisational or environmental (ecological) information. Current systems supporting supervision in the power industry, in line with the idea of a smart grid, make it possible to assess the quality of the effects of decisions not only in technical terms (especially reliability) but also in economic terms, and prospectively in environmental and social terms. The current legal regulations represent a barrier to the implementation of flexible mechanisms for valuing energy and energy services. On the one hand, they stabilise the settlement system, protecting conservative users and users at risk of energy poverty. However, on the other hand, they negatively affect the system's self-regulatory capacity to assess the competitiveness of solutions and to search for optimal development paths.

Assessing the suitability of new solutions takes on significance in the context of the availability of alternative technologies for energy generation, transmission and storage, as well as changes in the structure of energy demand in the era of Industry 4.0. Adapting desirable solutions in the energy sector, as a sector providing the base product for all activities, results not only from economics but also from the need to ensure the operational security of the energy system also through the use of available distributed technologies. This implies the need for new methods of coordinating the operation of systems, including through decentralised structures, performing regulating and balancing functions at different levels of the energy system. The integration of technical and settlement processes in the management of energy infrastructure, especially distribution infrastructure, is becoming desirable. The implementation of such concepts requires the use of appropriate information integration technologies, which should be characterised primarily by:

- Efficient and strong access control;
- Transparency;
- Possibility of sharing knowledge and competencies among users;
- Possibility of widespread market implementation; and
- Possibly low costs for participants.

DLTs are finding applications in this area, and blockchain technology currently appears to be the most popular. The blockchain structure itself does not require the oversight of a central authority. However, in order to enable an open prosumer economy integrated with the electricity system in the digital blockchain sphere, technological interfaces are needed, which by their nature should be subject to appropriate regulation and overseen by public authorities. Blockchain eliminates central authority for transactions, but there will still need to be a physical intermediary in charge of the grid providing the energy (the DSO, which can be a party to the smart contract).

The irreversibility of changes to blockchain registers corresponds to the irreversibility of the flow of value in the electricity system and can be integrated into a smart contract algorithm executed in the shared resources of the nodes of the blockchain network. Smart contracts belong to a class of risk-free transactions typical of futures contracts (in which payment is deferred). In smart contracts, the parties' interests can be secured a priori. The execution of a smart contract is made possible by crypto-assets, combining the characteristics of a convertible means of payment with a control signal (automatic integration of financial obligations with process control).

The war triggered in 2022 by the Russian side has shown the importance of energy independence. From the point of view of energy security, it would be desirable if energy generation was carried out in renewable, low-cost sources as close to the point of demand as possible. Climate change further determines energy policy (demand for decarbonisation). In order to adapt the settlement system for energy use to the structure of the evolving energy industry, new ICT technologies and digital settlement and financial management (fintech) methods can and should be used. An interesting concept is the use of cryptocurrencies. The idea is to automatically convert the energy put into the system into the corresponding amount of cryptocurrency according to its protocol.

Existing concepts of such cryptocurrencies can be divided into those that are mainly intended to serve as settlements for the use of electricity (e.g., NRGcoin) and those that have ambitions to become a more universal means of payment, competing with Bitcoin (e.g., SolarCoin). The first group includes dedicated cryptocurrencies that, thanks to the market for exchange into other currencies (including fiat currencies), can also be treated as a means of exchange to some extent.

Features representing the advantages of a blockchain-based approach to implementing cryptocurrencies in settlement for energy use include, inter alia:

- Security and anonymity of users;
- Automatic settlement of transactions without the involvement of the banking sector;
- The possibility of making energy settlements independent of other markets, regardless of the macroeconomic situation;
- Derivation of the temporal volatility of the kWh price in fiat currency to an external cryptocurrency exchange market (exchange office);
- Linking energy flows to the simultaneous flow of valuable units of account; and
- Identifying energy as the primary carrier of value.

Each participant in the overall structure can be regarded as a node of a network of energy flows, fiat currency and cryptocurrency tokens, and depending on individual capabilities in the general case, can be (from a structuring point of view) a reservoir of energy, tokens and fiat currency money.

Currently, despite the emergence of the first concepts and implementation of cryptocurrency projects or utility tokens programs intended to be used for settlement purposes for energy supplied to the grid by prosumers, there is a lack of publications analysing such concepts in terms of their impact on participant behaviour, the technical functioning of the electricity grid, interaction with the financial system and econometric analysis. The range of analyses needed to better understand the operation of the system and its implementation according to the chosen assumptions is interdisciplinary. In determining the details of the system, a particular account should be taken of the specifics of the electricity system network concerned and the nature, preferences and capabilities of the users.

A settlement system dedicated to end-users should promote local sources. On the one hand, the settlement system should not discriminate against any entity. However, on the other hand, it should create conditions conducive to investments favoured by the climate/energy policy being implemented (postulate of decarbonisation). In addition, the interests of the poorer part of society at risk of energy poverty should be taken into account. This makes short-term expectations (the lowest charges today) of the settlement system potentially in conflict with long-term expectations (additional costs of necessary investments in smart grid infrastructure). The appropriate balancing of these proportions while still taking into account energy security issues is a political decision.

A settlement system for energy use based on one's own cryptocurrency could be the starting point for creating a universal, global stable currency (a measure of value), a unit of which would be covered by a unit of energy needed. The aim of politicians, scientists and entrepreneurs is to seek means and ways to make access to resources for the sustainable development of civilisation as smooth as possible, and energy and capital in the form of available money are fundamental factors in this process so that synergies can be found between the two.

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Abbreviations

BTC	Bitcoin currency
CCE	cryptocurrency for energy settlements
DLT	distributed ledger technologies
DSO	distributed system operator
DSR	demand-side response (program)
EU	European Union
EUR	Euro currency
fiat	fiduciary currency
kWh	kilowatt-hour
MO	measurement operator
P2P	peer-to-peer
RES	renewable energy sources
VPP	virtual power plant

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