SmartBlocks

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SmartBlocks

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Executive Summary

This report describes the SmartBlocks high level architecture, the SmartBlocks integrated prototype, use case evaluation and potential routes to market for exploitation of the SmartBlocks technology.

Keywords

Blockchain, Sawtooth Ledger, Smart Contract, Validator, Energy Performance Auditing, ESCO, Smart Contract, Business Model, SmartBlocks Services, Energy Performance Contracting, Demand Prediction, Renewables.

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1 Introduction

This report covers the SmartBlocks project progress relating to WP1 – Platform specification and use case definition, WP2 – BlockMeter prototype development and WP3 – BlockContract & blockservices prototype development, WP4 – Demonstration & Evaluation and WP5 – Business modelling & development strategy. The specific milestones are as follows:

- MS1 – Architecture Specification
- MS2 - SmartBlocks BlockMeter
- MS3 - SmartBlocks Integrated Prototype
- MS4 – SmartBlocks Evaluation

The progress under each of these milestones is outlined in Sections 2-5 and the achievements under these act as a means of verification for each milestone, namely:

- Architecture Specification
- SmartBlocks BlockMeter
- SmartBlocks Integrated Prototype
- SmartBlocks Services
- SmartBlocks Evaluation
- Business Modelling

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2 Architecture Specification

Blockchain technology is based on the premise of a peer-to-peer distributed ledger that initially garnered favour in the financial sector because of its ability to issue, trade, manage, and service assets both efficiently and securely. Distributed ledger technology makes it possible to create cost-efficient business networks without the need for a centralised point of authority and as such it is required for stakeholders to separately maintain their own individual ledger systems, which is typically costly, inefficient and non-standardised among stakeholders. Smart contracts are a series of business rules/logic that are used to automate business processes in a trusted and secure manner and are deployed across a blockchain where they are then shared and validated collectively by the members of the blockchain.

Blockchain technology is a peer to peer transaction platform that is based on decentralised storage that records all transactional data among peers. Opportunities for the energy sector view Blockchain as offering individual consumers and prosumers a stronger role in the energy marketplace by supporting the creation of autonomous decentralised trading. While the current legal and regulatory framework offers protection for its stakeholders, the market must consider a shift towards a decentralised marketplace to provide "simplified and less burdensome authorisation procedures in respect to producing energy from renewable sources, where appropriate‟ (Directive 2009/72/EC concerning common rules for the internal). SmartBlocks proposes to leverage blockchain technology to investigate its potential in developing a decentralised energy transaction and verification framework for smaller independent prosumers or communities and would offer the potential for bilateral trading or offer aggregation among such independents as an alternative route to market for smaller-scale dispersed generation.

A **public blockchain** platform allows anyone to read or write to the platform, provided they are able demonstrate proof of work. On the converse a **private blockchain** has a single controlling entity who has the rights over any changes that need to be done. Finally a **hybrid blockchain** is a consortium based blockchain which could be a mix of both the public and private. Where the ability to read and write could be extended to a certain number of people/nodes.

2.1 Blockchain Platform Review

A subjective qualitative assessment motivated by the reviews presented in (1, 2) is presented as a means of selecting a suitable platform for SmartBlocks development and prototyping. The following criteria were used in this assessment:

- Development/Maturity: development history and popularity measure, based on GitHub's commit history where a longer history indicates that a platform is more developed.
- Network Type: public, private or permissioned blockchain network
- Pricing: free, open source, paid pricing
- Supported Languages: programming languages supported by the platform's SDK
- Cryptocurrency: native currency or not
- Scalability: how well a platform scales with the network size and number of transactions per second that need to be validated
- Security: in terms of transaction data, user anonymity and the security of the blockchain itself

[1] The Blockchain: A Comparison of Platforms and Their Uses Beyond Bitcoin, M. Macdonald, L. Liu-Thorrold, R. Julien, DOI: 10.13140/RG.2.2.23274.52164

[2] http://radiostud.io/eight-blockchain-platforms-comparison/

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- Flexibility & Limitations: Scope to include general purpose platforms as well as singular or very limited application fields.

Platform	**Etherium** – plaform for decentralised application (Dapp), MIX IDE for solidity (similar to Java).
Development/Maturity	Widely used.
Network Type	Public, Smart Contract based, permissionless.
Pricing	Ether for transactions & computational services.
Supported Languages	Python, Go, C++, Solidity.
Cryptocurrency	Ether.
Scalability	Blocksize limited based on 'block gas limit', where gas is # of computational steps required to execute a contract, need to set the block gas limit (dynamic).
Security	Data and contracts are encoded but not encrypted and all data is publically available so would need to encrypt data first at source.
Flexibility & Limitations	Ether is only available through mining.

Platform	**NRGCoin** – plaform for NRGcoin makes use of Smart Contracts that run on the Ethereum blockchain. The smart contract mints new NRGcoins for green energy. Energy is bought and sold (i.e. not traded) through smart contracts. NRGcoin is a mechanism that facilitates the integration of renewable energy in the local grid by making it more profitable for producers and utilities and cheaper for consumers and governments.
Development/Maturity	Academic endeavour between two universities, low activity at present.
Network Type	Public, Smart Contract based on Etherium.
Pricing	Different tiers of pricing, information provided does state that NRGcoin comprises of several components, there are a number of business models that can be applied. Moreover, the concept itself can be deployed and integrated in different ways, offering a variety of revenue streams for different market players and stakeholders.
Supported Languages	Developed over Etherium so assumption is that the languages supported are those of Etherium.
Cryptocurrency	NRGCoin, concept relies on a currency that is minted when green energy is injected in the grid. All existing (crypto) currencies are issued according to other criteria. Using a new currency allows the smart contract to create incentives for producers and consumers from within the mechanism, as opposed to relying on external subsidy. Using an internal currency lowers the initial barriers for entry and the overall cost of the solution.
Scalability	Not available.

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Security	Assume similar to that of Etherium.
Flexibility & Limitations	Assume similar to that of Etherium.

Platform	**INTEL SawTooth Lake**, part of Hyperledger open source collaborative project effort, targets digital asset marketplace. Hyperledger Sawtooth is a modular platform for building, deploying, and running distributed ledgers. SwaTooth Lake is a distributed ledger technology and smart contract engine.
Development/Maturity	High & good documentation via GitHub.
Network Type	Private & Public.
Pricing	Free, Open source, Apache license.
Supported Languages	Python (For Sawtooth Lake).
Cryptocurrency	Users can define their own, token asset type.
Scalability	Limited information available but consensus mechanisms are designed for networks of different sizes with different requirements.
Security	Built on INTEL's trusted execution environment – SGX, consensus mechanisms partially implemented so not as secure as it should be.
Flexibility & Limitations	Deploy using Docker or without, relies on SGX so this may be a drawback as reliant on 3rd party software, however Hyperledger includes support for modular, plug-and-play consensus and as such the possibility to reduce computation cycles, scale efficiently, and support a variety of use cases by utilising the most appropriate consensus algorithm as well supporting permissioned blockchains.

Platform	**IBM Open Block Chain**, part of Hyperledger Fabric project and available as part of Bluemix service suite.
Development/Maturity	Medium.
Network Type	Private, permissioned – authority on network issues identities.
Pricing	Limited free plan with paid upgrade to enterprise plan.
Supported Languages	Go, Javascript.
Cryptocurrency	No native currency– can create one using chain code.
Scalability	Aim is to achieve 100,000 transactions per second with 15 nodes validating.
Security	Pseudoanomity of users ensuring transactions cannot be linked to users or other transactions using public keys, control policies for access and network security.
Flexibility & Limitations	Still under development, best suited for business orientated applications intended for streamlining record keeping processes and deploying smart contracts in a secure manner.

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Platform	**MultiChain**, – targets financial sector, enhanced version of bitcoin by providing privacy and control within a private peer-to-peer network, backward compatibility with bitcoin.
Development/Maturity	Medium.
Network Type	Private, permissioned blockchains either within or between organisations.
Pricing	Free, open source.
Supported Languages	Python, C#, JavaScript , PHP, Ruby.
Cryptocurrency	No cryptocurrency is required, but can be configured to use a native currency.
Scalability	Private blockchain so problems relating to scale are easily resolved as the chains participants can control the maximum block size.
Security	Private, permissioned blockchain.
Flexibility & Limitations	Limited application field, targets financial sector

Platform	**Openchain**, enterprise based digital asset management, uses partionned Consensus where every Openchain instance only has one authority validating transactions. Instead of one single central ledger, each organisation controls their own Openchain instance. Instances can connect to each other. Gateways create 2-way pegging between two Openchain instances.
Development/Maturity	Medium.
Network Type	Private.
Pricing	Free, open source.
Supported Languages	JavaScript.
Cryptocurrency	Tokens, tokens on an openchain can be optionally pegged to bitcoin
Scalability	Openchain can process thousands of transactions per second as it does not use proof of work consensus. Extensible through smart contract modules.
Security	Open chain is digitally signed. Keys are fully compatible with bitcoin.
Flexibility & Limitations	Deploy using Docker or without, modular design, more efficient than systems that use proof of work consensus.

Platform	**Ripple**, distributed financial technology enables banks to send real-time international payments across networks
Development/Maturity	Commercially available

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Network Type	Ripple is a real-time gross settlement system (RTGS), currency exchange and remittance network protocol rather than blockchain technology.
Pricing	Open source and permissively licensed under the ISC license.
Supported Languages	Built around open, neutral protocol (ILP) to interoperate different ledgers and networks.
Cryptocurrency	-
Scalability	Capacity to process the world's cross-border payments volume, Direct account-to-account settlement with no central operator.
Security	Transactions are cryptographically signed using ECDSA or Ed25519, Ripple has multi-signing capabilities. It offers a cryptographically secure end-to-end payment flow with transaction immutability and information redundancy.
Flexibility & Limitations	Limited use – financial payments.

Platform	**ERIS**, targets enterprise applications, uses Docker & is based on Etherium VM, intended use is process auditor to track whan and where some process was created, executed, etc rather than as a transaction auditor.
Development/Maturity	Low but growing, based on etherium VM.
Network Type	Capabilities based permission, only certain nodes can validate.
Pricing	Open source.
Supported Languages	Etherium Solidity.
Cryptocurrency	No – intended for business logic.
Scalability	Modular system, scalability is dependent on that of the components used.
Security	Security depends on the components used.
Flexibility & Limitations	Need Etherium VM, tendermint socket protocol for consensus, mint client for talking to tendermint, solidity compiler.

Platform	**Blockstream Sidechain Elements**, allows for the transfer of assets between blockchains, also uses elements – standalone features which can be arbitrarily combined and added to a side chain.
Development/Maturity	Limited, still in alpha phase.
Network Type	-
Pricing	Open source.
Supported Languages	-
Cryptocurrency	No – value comes from other sources and is conceptually. represented by tokens

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Scalability	As sidechains are likely to have less nodes it should scale.
Security	No information available.
Flexibility & Limitations	Modular design implies flexibility once it matures but it is still an experimental platform.

Platform	**IOTA**, beta version implementation based on a blockless distributed ledger called Tangle, focused on machine-to-machine (M2M) payments, enables feeless M2M payments. IOTA is aimed at IoT. No miners and so no transactions fees.
Development/Maturity	Low.
Network Type	Public, Permissioned.
Pricing	Based on IOTA Token, pricing not clear as yet.
Supported Languages	Python , C, Javascript.
Cryptocurrency	IOTA tokens can be purchased at crypto currency exchanges and wallets are available. for all operating systems Open-source, decentralised cryptocurrency, engineered specifically for Internet of Things.
Scalability	Instead of blocks (regular blockchain), Tangle uses the form of a Directed Acyclic Graph (DAG), which offers infinite scalability.
Security	Quantum security.
Flexibility & Limitations	Ongoing development.

In summary based on the needs of the SmartBlocks project we find that Sawtooth Hyperledger platforms to be the most suitable platforms to investigate for development of the SmartBlocks proof of concept. All the platforms investigated have their own advantages and disadvantages. Key features were medium to high development maturity, ability to support private/permissioned and/or public block chains, free & open source, multiple application fields, support for smart contracts, and use of common development languages as well as being compatible with multiple operating systems or preferably be deployable via containerisation technology such as Docker. Based on these requirements the Sawtooth Hyperledger platform was selected for implementation.

2.1.1 Blockchain based Energy Trading Initiatives

In addition to the platform discussed above there are other commercial trading platforms like NRGCoin together with cryptocurrencies that are available specifically for energy trading, some of which are briefly summarised[3] next:

- DAISEE[4]: considers energy as a commons (i.e. a shared resources) with the objective being the design of the common rules, infrastructure together governance for people to share electricity.
- BankyMoon[5] facilitates the pre-payment of energy using bitcoin, this can be done by the homeowner themselves or can be paid for by donors located elsewhere.

[3] Based on http://nrgcoin.org/faq,

[4] http://daisee.org/

[5] http://bankymoon.co.za/

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- Brooklyn MicroGrid[6] (for profit cooperate entity owned by LO3 Energy) based in Brooklyn being run as a peer-to-peer energy trading pilot to show how blockchain technology can be used to trade renewable energy between homes in a community.
- PowerLedger[7] is blockchain platform that enables the sale of surplus renewable energy produced by residential or commercial entities connected to existing electricity distribution networks, or within micro-grids.
- Dajie[8] is developed based on IoT technology and blockchain where networks of peers can exchange energy in a local micro grid using simplified energy transaction management.
- GridSingularity[9] are creatinga decentralised energy data exchange platform to support energy applications.
- EnergyCoin[10] is an alternate crypto currency cloned from PeerCoin to be used as part of future energy applications and to facilitate the energy transition towards local generation and renewables.
- SolarCoin[11] is an alternative crypto currency and used as part of a solar electricity reward program that uses Bitcoin technology to incentivise global solar electricity generation where the SolarCoin Foundation gives solarcoin to the owners of solar panels for their energy production, who then in turn trade it as a speculative asset.
- The SunExchange[12] is a blockchain based market place that connects people wanting to invest in solar energy and generate income with people that want to access it.

SmartBlocks provides a supporting framework to encourage the promotion and use of renewables and provides a basis for the development of an energy trading platform similar to other initiatives, However SmartBlocks focuses on the smart building market and in particular ESCO service offerings targeting energy use and saving verification related to typical energy services company (ESCO) business models (such as the guaranteed model, the delivery contract model & Chauffage and energy supply contract). SmartBlocks is a proof of concept platform that will link the physical building infrastructure (meters, energy systems, networks) with a blockchain based transactional platform for the delivery of ESCO services.

2.2 Requirements

Architecture Requirements

AR1: Modular architecture that can be scaled depending on application scenario requirements

AR2: Well defined component interfaces to support extensibility (e.g. new consensus mechanism)

AR3: Open application programming interfaces (APIs) for integration with 3rd party products

AR4: Reliable data flow from edge to enterprise tier

AR5: Easy to deploy architecture (full or elements of) across multiple piers (e.g. through the use of containerisation)

[6] http://brooklynmicrogrid.com/

[7] https://powerledger.io/

[8] https://www.dajie.eu/

[9] http://gridsingularity.com/#/

[10] https://energycoin.eu/

[11] https://solarcoin.org

[12] https://thesunexchange.com/

Stakeholder Requirements (ESCOs, building owners, consumers, prosumers)

SR1: Secure and trusted access current the state of energy performance

SR2: Transparent record of energy related transactions

SR3: Independent verification of energy usage, generation and performance

SR4: Mechanism to specify, agree, deploy and execute energy contracts among peers.

SR5: Integration of blockchain services with existing energy management software

Blockchain Requirements

BR1: Autonomous decentralised trading

BR2: Transaction verification/consensus for energy related transactions (energy usage & renewable penetration)

BR3: Bilateral trading between consumers, generators and prosumers

BR4: Ability to create & deploy smart contracts

BR5: Support private and public blockchains

BR6: Reputation building

2.3 Architecture

SmartBlocks is a set of software services that allows independent entities (energy services companies (ESCOs), Building Owners, Utility providers, energy traders) to leverage the concept of Smart Contracts and Blockchain technology to create a trusted and verifiable ledger of energy transactions. The cornerstone of blockchain technology is the decentralised storage of transactions, however more and more applications are emerging that extend this with mechanisms (digital protocols), known as "smart contracts" that can be integrated to allow actual transactions to be executed on a decentralised basis. The smart contract constitutes a set of rules or specification of how a transactions should be invoked and processed, from an energy management perspective this can be viewed as the autonomous matching of distributed providers (prosumers, utilities, ESCOs) and consumers considering demand, price and source (renewables) to automatically regulate supply, price and payment.

The SmartBlocks solution consists of the integration of three key innovations (smart blocks) as represented by the architecture shown in Figure 1:

a. **BlockMeter**: BlockMeter incorporates secure connector modules that are deployed in a building to interface with existing electricity meters (via appropriate communications protocols). The connector provides a secure interface to capture the data (actual energy usage and in some cases energy generated) needed to evaluate actual energy performance. BlockMeter enhances the concept of a smart meter that allows connectivity to energy data, with added intelligence in order to learn and predict the energy demand for a specific site using thermal and electrical historical data. BlockMeter abstracts the underlying complexity of buildings systems and converts the physical energy usage to a digital asset (energy demand) for processing within the blockchain.

b. **BlockContracts**: BlockContracts provides Blockchain services to securely manage energy transactions between the relevant stakeholders. The objective is not to develop a new Blockchain infrastructure but rather to leverage existing solutions and apply it to an energy management marketplace, as described in Section 2.1. For the purposes of this project the first prototype utilised a private blockchain. This ensures that only trusted parties (ESCO, Building Owners, Utility Providers etc.) who have entered into an agreement can read and write blocks to the blockchain. A private Blockchain also allows for simpler governance structures at a lower cost compared to public applications. Each Blockchain instance consists of a secure communications backbone (Event Hub) and API to enable reliable transmission of block data utilising the Blockchain. The Blockchain services manage the distributed ledger through a peer-to-peer protocol. The execution of the smart contract is done by the smart contract manager that invokes the specified rules, the smart contract manager can also incorporate access to secure business networks to access relevant inputs required to execute the contract (e.g. market price). The validation of transactions is completed via the consensus manager before being committed to the shared ledger. The distributed ledger is the single source of truth and stores the entire history of validated transactions on the blockchain network. Any inconsistencies in the shared ledger across nodes are resolved through consensus across all parties. For SmartBlocks a transaction can consist of timestamped energy related transactional data (i.e. when and how much energy was used or generated by whom).

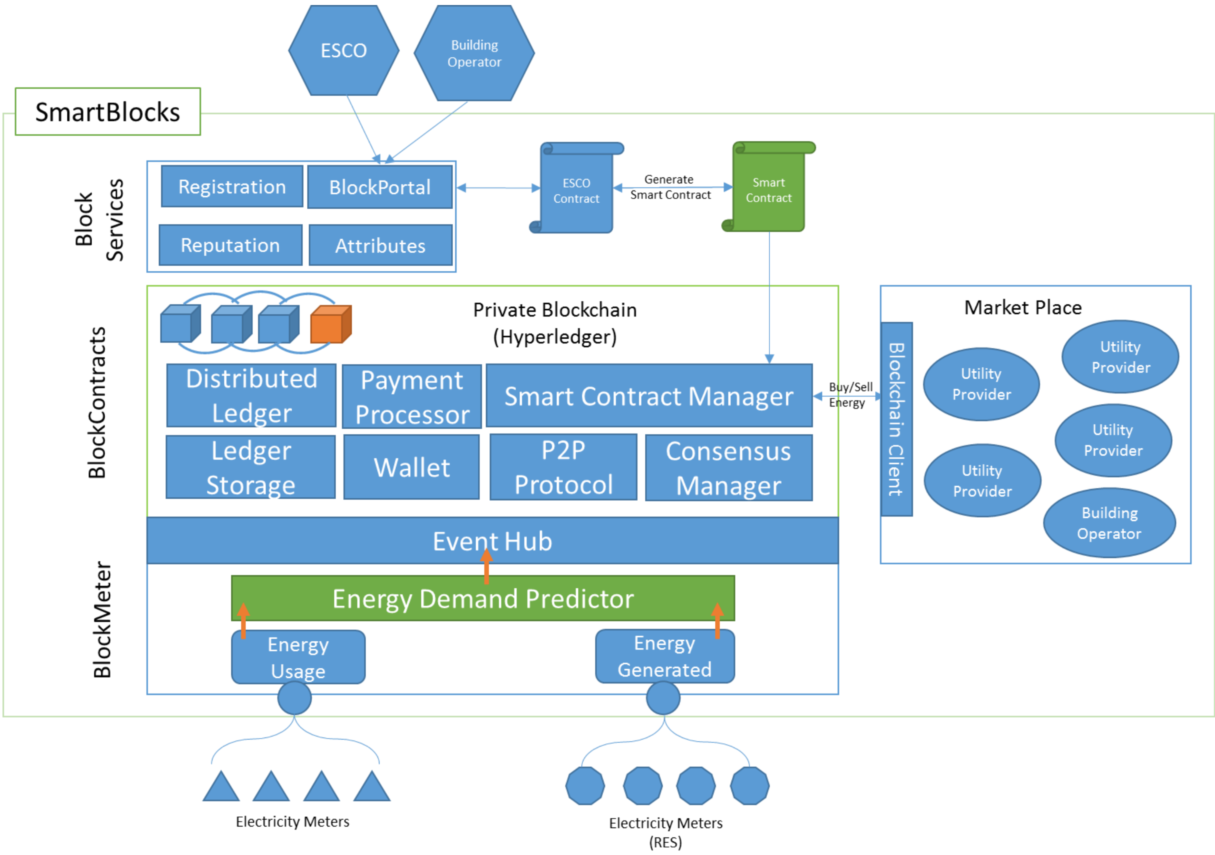

Figure 1: SmartBlocks Conceptual Architecture

c. **BlockServices**: As the administration of a Blockchain is not the responsibility of a sole entity, member services are required to enable registration and to monitor the reputation of each party in the Blockchain through a web based portal known as BlockPortal. The major advantage of blockchain technology is the distributed nature of the ledger, this maintains an auditable trail of energy transactions (e.g. how much renewables have been used). As a blockchain will reside with each stakeholder they can instantly and independently verify the performance based on their energy contract. Typically a Blockchain developer will write the smart contracts, and client-side applications will invoke the smart contracts. This project will investigate the use of templates and management tools to auto generate the smart contracts. In essence the parties involved will agree a set of rules (e.g. energy saving

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targets, renewable energy utilisation, cost) that is translated to a digital smart contract and deployed across the blockchain network. This constitutes the business logic in terms of how energy is used, distributed, purchased and audited. The logic is used by a validator to ensure only valid blocks are added to the chain.

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3 SmartBlocks Integrated Prototype

An integrated prototype for the SmartBlocks systems has been developed to support demonstration and evaluation of a Blockchain approach for continuous energy auditing. The first prototype of SmartBlocks is focused on **decentralised documentation of energy transactions**, and is composed of four integrated functional blocks as shown in Figure 2. These map across the layers of the reference architecture defined as part of Section 2. These include:

1. **Energy Data Extraction**: Ability to extract reliable energy data from buildings including usage, generation and demand prediction.
2. **Distributed Ledger**: The use of the Blockchain concept to record energy usage for transparent energy auditing between stakeholders
3. **Data Visualisation & Management**: Functionality to store, monitor, visualise and analyse energy related data and trends that is extracted from the buildings
4. **Energy Auditing Application**: An end-user application is required to encapsulate Blockchain functionality and make it usable for continuous energy auditing.

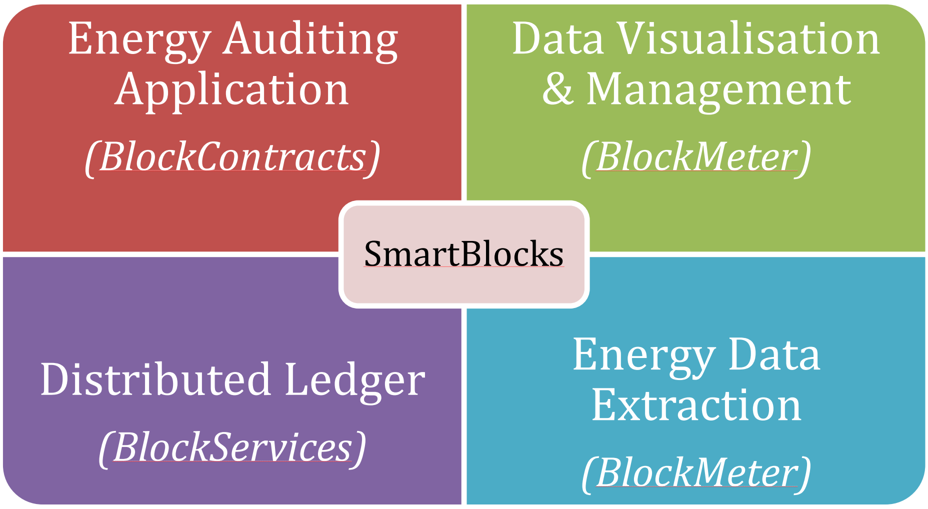

Figure 2: Component blocks of SmartBlocks Prototype

The SmartBlocks prototype is built on the following premise, SmartBlocks is a distributed, secure and transparent system of record comprising a log of all energy transactions shared across a digital network. Each node on the network maintains a complete replica of the blockchain data. The origin of the transaction is with the BlockMeter that is deployed at a site, energy information is recorded and extracted from a single or set of meters installed in a building, the data is packaged together to create a group of transactions (or block), using cryptographic methods this data is validated by a network of nodes and added to the blockchain if consensus is found across each node (BlocksServices). The ESCO or building owner then receives this transaction and can use it to construct an immediate view of energy performance. An example of the information flow across the SmartBlocks is shown in Figure 3.

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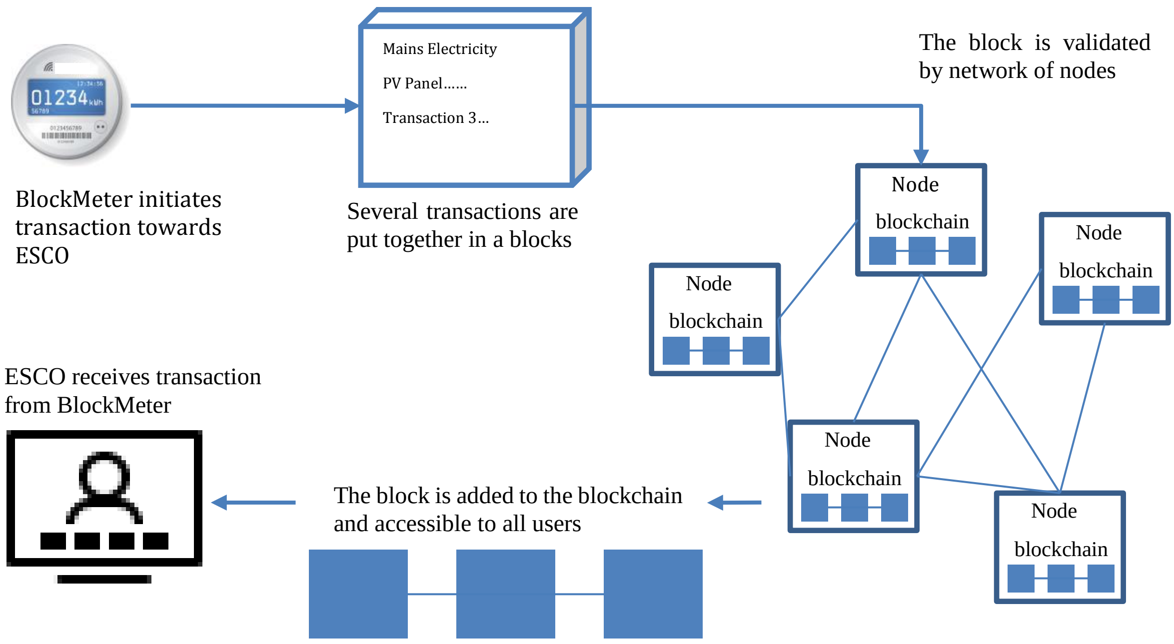

Figure 3: SmartBlocks Information Flow

The remainder of this section is broken down as follows: an overview of the prototype implemented that provides the required functionality to realise the data flow presented in Figure 3. This is followed with details of the *BlockMeter* implementation at the CIT site and a detailed specification of the developed *BlockServices,* including the specification of the 1st version of the distributed ledger for energy tracking.

3.1 Prototype Overview

The SmartBlocks integrated prototype is presented in Figure 4, the prototype is developed with the demonstration building at CIT in mind, therefore integrates the core functionality to extract energy meter data, Microgrid generation data and the integration of this into a Blockchain. To support the demonstration, data dashboards are created using the R4Platform (Section **Error! Reference source not found.**). Based on the review of existing platforms Sawtooth Hyperledger was selected to implement the distributed ledger as part of BlockServices. All of these components were integrated and deployed at the CIT test site, the first version is focused on reliably collecting energy data and committing these to the Blockchain.

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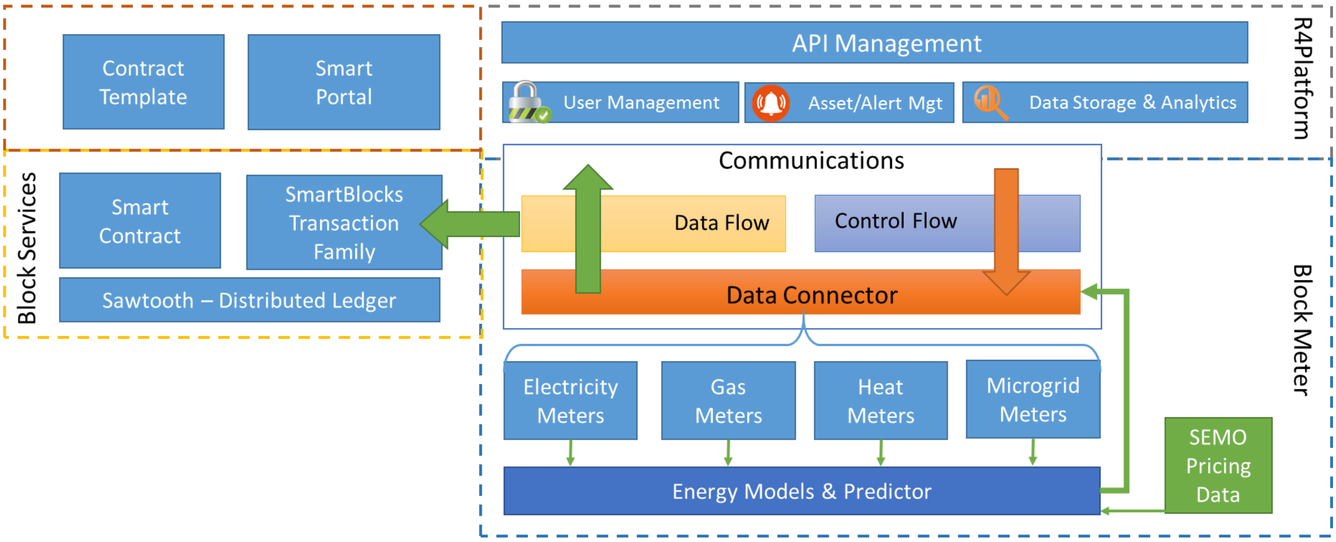

Figure 4: SmartBlocks Integrated Prototype

3.2 BlockMeter Prototype

The BlockMeter prototype was developed and deployed at the Nimbus building in CIT. The Nimbus building was built c. 2010, adjacent and connected to a pre-existing Building. It is a modern construction with structural insulated panels and large glazed areas. The building provides about 970 m^2 work space over two floors in the building front. It is primarily utilised as a research facility for undergraduate, postgraduate and PhD students. The building has a microgeneration system comprising of a 50 kWe/80 kWth CHP plant, a 10 kW wind turbine and a battery storage system. The CHP plant acts as the lead boiler and is the primary heat source for the building. The microgeneration system is controlled by a dedicated SCADA system which controls the CHP operation according to a set time schedule and also a set electrical output. The electrical output is set at the minimum of 30 kWe to minimise heat dumping. The SCADA incorporates charge controls for the battery storage which can store any excess electricity generated by the CHP and wind turbine. The charge control can also charge the batteries during periods with low electricity tariffs and discharge the electricity to minimise usage during peak tariff periods.

There are three different metering systems in the Nimbus Building that record and log metering data. The BMS records metering data for the Ground Floor, First Floor, three separate laboratory areas, the server room, lighting and the main electricity incomer to both the Nimbus and the adjacent Rubicon Building. The SCADA controlling the microgrid records the CHP electrical output, the wind turbine output, the input/output from the battery storage, gas use in the CHP and het dumped or sent to a thermal store. Finally a separate proprietary system (ResourceKraft) records gas use in the boilers. BlockMeter is used to abstract data from all three underlying metering systems and creates a consolidated view of energy usage in the building. Figure 5 shows an extract of the main meters used. Any meter can become a candidate for a BlockMeter, for SmartBlocks the main interest is on the energy aggregate rather than verifying sub-meters, therefore the four green blocks, Main Incomer, Microgrid, CHP and Main gas meters were chosen to become BlockMeters. For each individual meter an R4Platform OPC connector was used to extract the energy data from the meter, as BlockMeter is akin to a virtual meter a single instance can manage multiple meters once a protocol specific connecter is available for communication with the physical meter. This also means that BlockMeter can run on a single device or clustered across a number of host devices.

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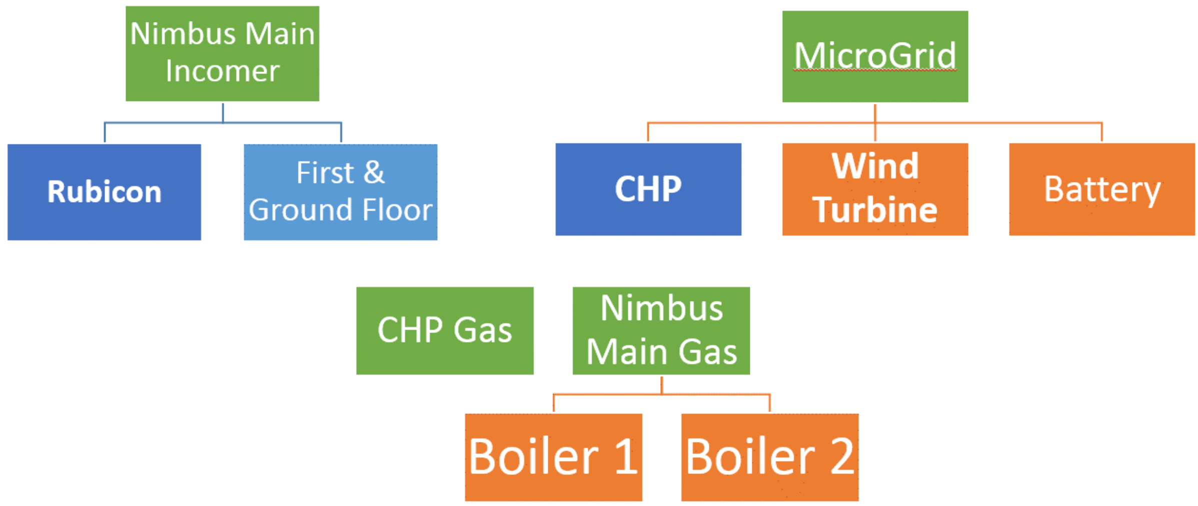

Figure 5: Meter Hierarchy extract for the Nimbus building

The R4Platform was used to create an initial dashboard as shown in Figure 6, this visualises the current energy usage in the building. This dashboard can also be extended with other building data that is available for example weather station data.

Figure 6: Example of BlockMeter Energy Dashboard for the Nimbus building Main Electricity Meter

The BlockMeter is used to extract the data and packages it into a set of transactions that are posted to BlockServices for processing on the blockchain.

3.3 BlockServices Prototype

The SmartBlocks distributed ledger was developed using the Intel ledger, Sawtooth[13], distributed ledgers are essentially a shared database that does not have a central authority or intermediary. Each participant maintains and operates a copy of the ledger (or database), verifies transactions, and agrees to a protocol that ensures universal agreement (consensus) on the current state of the ledger. The Sawtooth platform is distributed in source code form with an Apache license.

[13] https://intelledger.github.io

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In line with the general structure of a distributed ledger, Sawtooth is composed of three key elements

1. A **data model** that defines the current state of the ledger (e.g. Energy Usage)
2. A **language of transactions** that change the ledger state (i.e. how to commit to the ledger)
3. A **protocol used to build consensus** among a group of mutually distrusted participants around which transactions will be accepted by the ledger (Sawtooth uses a custom algorithm called Proof of Elapsed Time (PoET)).

In Sawtooth the data model and transaction language are implemented in a "transaction family". The SmartBlocks prototype leverages the core Sawtooth platform and implements a custom transaction family that reflect the requirements of SmartBlocks ledgers, this is done utilising the Sawtooth SDK[14]. The main underlying principle with Sawtooth, is to distribute a ledger among participating nodes. The ability of blockchain technology to ensure a consistent copy of data across all nodes in Byzantine consensus is one of its core strengths. Sawtooth represents state for all transaction families in a single instance of a Radix Merkle Tree on each validator. The process of block validation on each validator ensures that the same transactions result in the same state transitions and that the resulting data is the same for all participants in the network. Modifications to state are performed by creating and applying transactions. A client creates a transaction and submits it to the validator. The validator applies the transaction which causes a change to state.

Transactions are always wrapped inside of a batch. All transactions within a batch are committed to state together or not at all. Thus, batches are the atomic unit of state change.

[14] https://github.com/hyperledger/sawtooth-core

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4 SmartBlocks Evaluation

There are two main scenarios that the SmartBlocks proof-of-concept addresses, firstly the ability to document and maintain a tamper proof record of energy transactions that occur in the building and secondly the ability to define and deploy smart contracts that can automatically execute interactions between peers (e.g. transfer assets) based on previously agreed logic.

4.1 SmartBlocks Platform: Documentation of Energy Transactions

SmartMeter and SmartBlock services provide a mechanism for transparent metering of energy resources, be it usage (electricity, gas, and heat, waste) or generation (wind, PV). The blockchain provides a tamper proof and transparent representation of the meter states at specific instances in time with the ability to create an adaptive baseline for continuous energy auditing. The SmartBlocks integrated prototype was deployed at the Nimbus building in CIT. Figure 7 shows an overview of the integrated prototype as deployed at CIT which incorporates the main BMS of the Nimbus building and subsequent meters (electricity, gas and renewables). BlockMeter is deployed at the site creating a virtual smart meter for each of the key assets. This communicates with the SmartBlocks validator network which manages the distributed ledger (Hyperledger Sawtooth). And the user can access the SmartBlocks instance via the BlockPortal web based application.

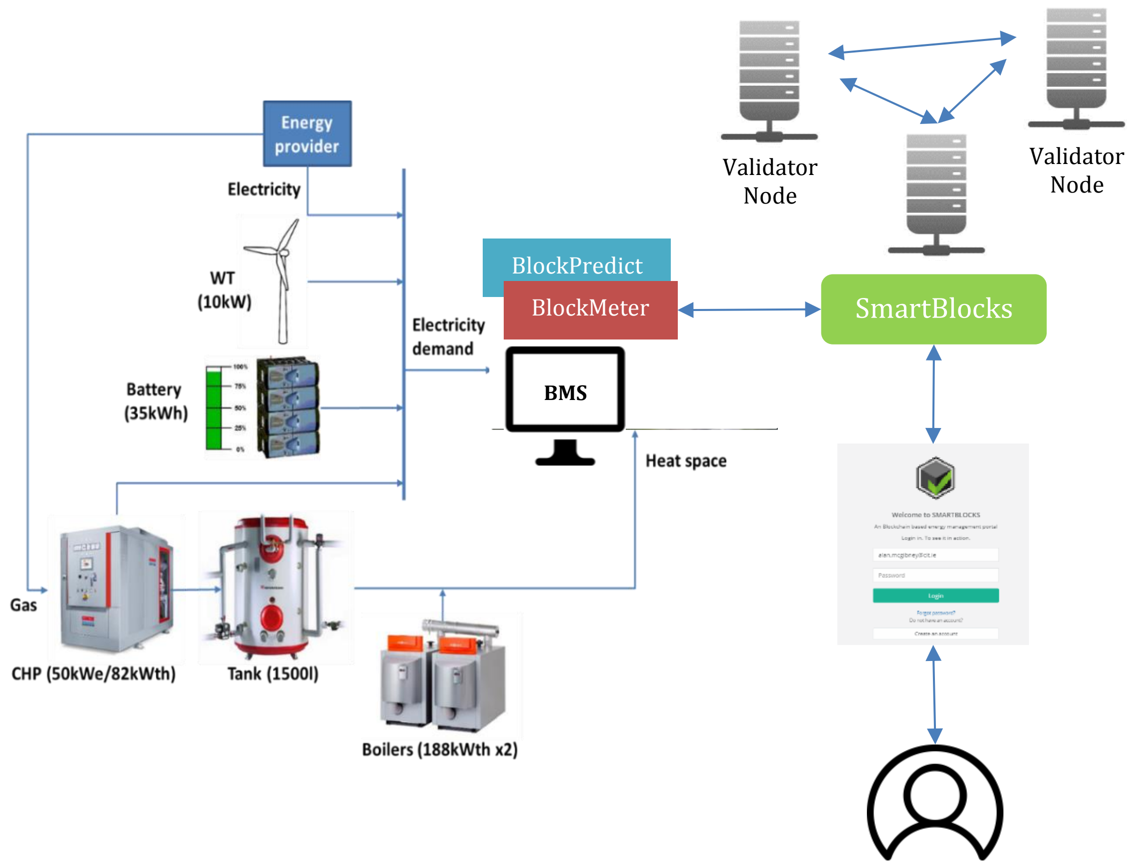

Figure 7: SmartBlocks deployment at CIT

SmartBlocks is used in Nimbus to supporting decentralised documentation of transactions for energy auditing. This requires the deployment of the appropriate transaction processors and registering them across peers in the validator network. The validator essentially maintains a registry of transaction processors (SmartBlocks includes transaction families for BlockMeter and BlockPredict) on the blockchain, when a transaction arrives to be processed it verifies it is one of

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the registered transactions families if so the transaction is submitted for validation. If the transaction family is not it is dropped and not processed further. As well as the transaction processors, the validator nodes encapsulates the other processes/components of Hyperledger Sawtooth that constitute the distributed ledger (i.e. consensus, journal, blockstore, blockcache etc).

In order to provide administration of the SmartBlocks a web based portal known as BlockPortal has been developed. The portal provides authorised access to view and manage a SmartBlocks instance and visualise current blocks, batches and transactions. This can be a standalone portal or integrated into a third party application. Figure 8 presents the view provided to an authenticated user, the validator is queried to get a list of blocks (left side panel), this provides information on the block including number, public key of signer, consensus and link to previous block. It also provides the number of batches that were committed as part of the specific block, when the user clicks this button each batch is loaded (middle panel), this includes the header signature and the number of transactions encapsulated in the batch. When the user presses this button all transactions are loaded (right side panel). The data includes the signer key, payload and decoded payload where the transaction family is known. The user can use this view to oversee and visualise the status of the blockchain.

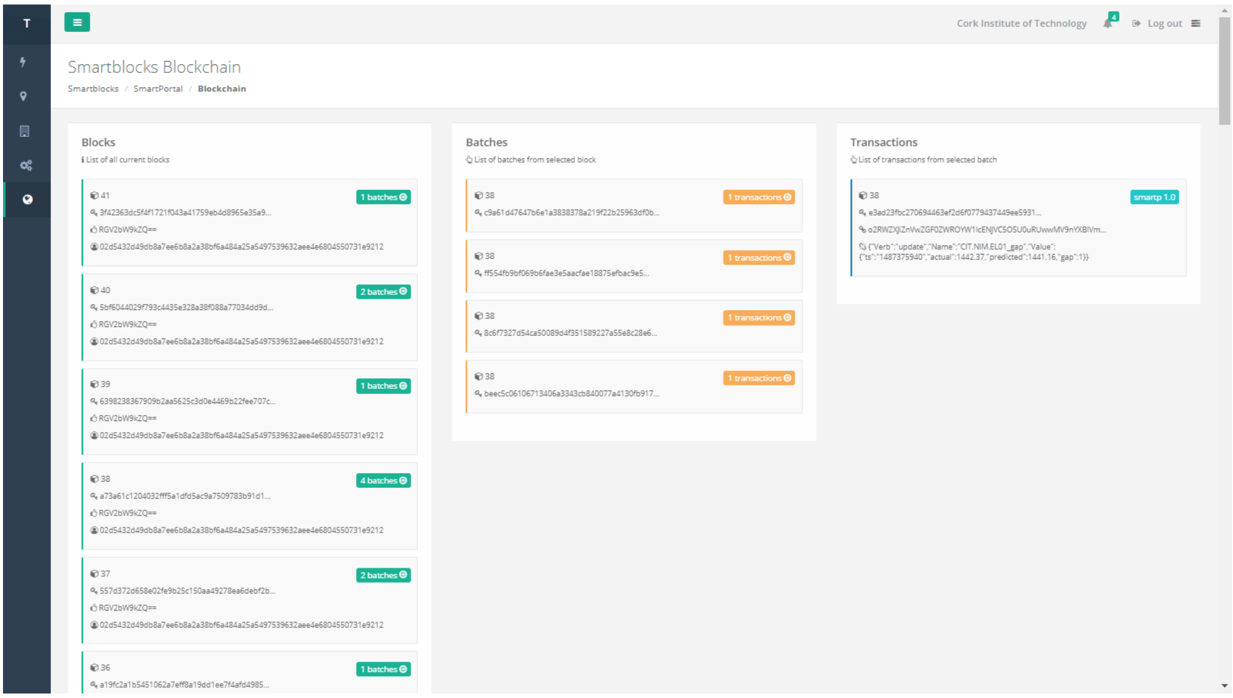

Figure 8: SmartBlocks Blockchain visualisation

The SmartBlocks ledger maintains the various states generated from energy related transactions (energy usage, energy prediction, energy generated). Figure 9 shows the top panel of the SmartBlocks ledger view created for the user, it demonstrates how data related to ledger states (i.e. transaction history) can be visualised for use by an ESCO or a building manager, the example it shows a graph of data from a BlockMeter instance measuring actual electricity usage versus predicted electricity usage generated from a BlockPredict instance. Site level metrics are also provided as an example where the user can see how their specific energy performance characterised by defined key performance indicators.

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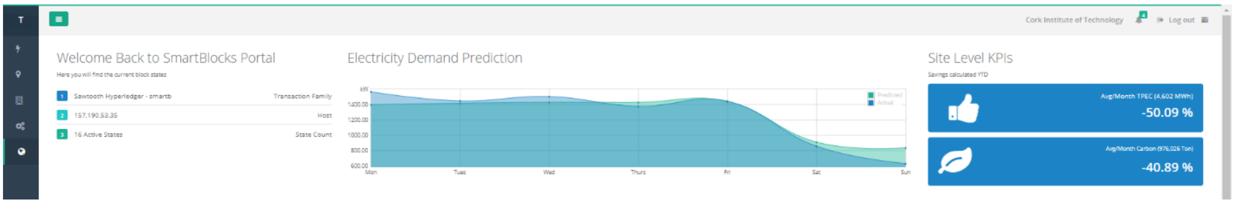

Figure 9: SmartBlocks Ledger states visualisation

Figure 10 presents the visualisation of ledger listings. The panel to the left of the view shows all current states in the ledger, included a decoded payload and icon representing data type, the user can click on state history to view the list of transactions that have been submitted and validated on the blockchain, each modifying the selected state in some way, for example the history of energy used during energy performance contract period.

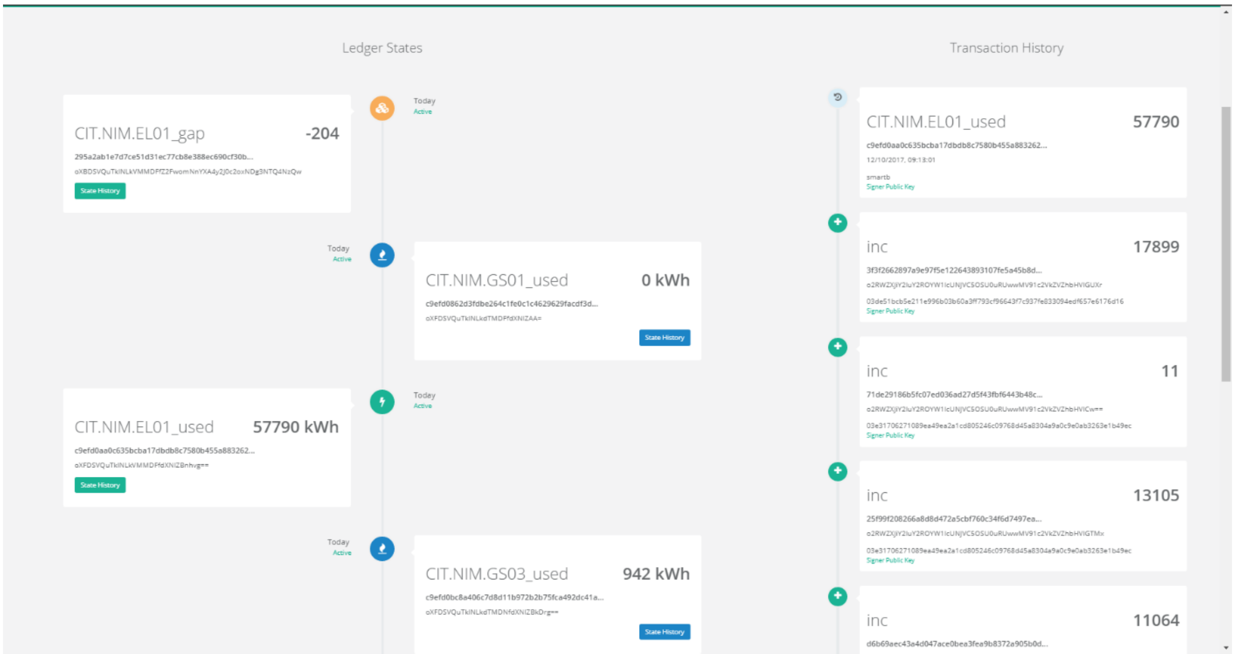

Figure 10: Ledger listing for SmartBlocks deployed at Nimbus

The presented scenario forms the basis for the SmartBlocks solution, this involved the deployment of BlockMeter and BlockPredict components at the Nimbus building, the buildings main electrical meter, CHP gas meter and two boiler meters were used for the evaluation. BlockMeter was run for a one month period pushing all usage data to the blockchain. It is also possible to push historical data, for example baseline assessments that can be used by BlockServices and the execution of smart contracts. The BlockPortal was developed to visualise the outcome of transactions submitted and executed within the SmartBlocks services. The combination of these elements have demonstrated the capability of the distributed ledger to maintain a trusted, untampered history of energy transactions that can be used for energy auditing and managing energy usage in a building.

4.2 SmartBlocks Platform: Smart Contracts

SmartBlocks aims to provide a framework for the definition, creation and deployment of Smart Contracts that interact with a blockchain to link the digital world (auditing for the purposes of SmartBlocks) with the physical (energy meters, systems, network infrastructure, buildings) entities. This offers a consensus based approach to verifying energy savings as part of an agreed

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energy management contract as well as independent verification of energy consumption and load profile with respect to energy services contracts. A smart contract is a self-executing piece of code that implements the logic of an agreement, for example that can result in a transfer of assets. They are generally stored and replicated on the blockchain system and supervised by the network of nodes that run the blockchain. There are three steps required for the realisation of smart contracts:

1. Both parties agree on the terms of the contract, it is written in code and deployed on the blockchain.
2. Based on a triggering event the contract self-executes and invokes the conditions of the agreement.
3. As the results are on the blockchain it can be regulated based on transactional history

For SmartBlocks smart contracts offer a mechanism for parties (ESCO and Building owner) to agree terms of an energy contract, this could be for example performance related payment where the contract ensures guarantees for energy savings are met and if so transfers payment or if they are not met then penalties are automatically applied. The use of Smart Contracts offers many benefits including autonomy from third party brokers, trust and duplication as it is deployed and replicated across a distributed ledger, accuracy and cost savings as only what is agreed is executed and less prone to manual error. However, as with software systems in general there are always possibilities that bugs can appear in code that could cause an in accurate execution of a contract. To overcome this in SmartBlocks, we provide a generic execution environment for the smart contracts that leverage a contract template populated via the BlockPortal and deployed as a contract agreement on the blockchain. This way the user is not required to have specific coding skills rather can set out the terms using straight forward form filling and automate the deployment in a SmartBlocks instance. This also supports easy of update if circumstances change over time and both parties agree to re-negotiate the terms of the contract, changes can take effect immediately by simply updating the template and as such the logic of execution for the contract.

BlockPortal was extended to include a user interface that provides a proof-of-concept for smart contract deployment in SmartBlocks, this is shown in Figure 11. The top panel of the view is used to provide the status of currently active contracts, the panels below capture the different type of contracts that were developed, the first panel is around energy performance contracts within this the user can select a specific contract (for example electricity savings). Once selected the template is loaded where the user can fill in site specific details such as contract period, baseline data, fees for energy savings and penalties for when energy savings were not achieved. Once the contract has been agreed between both parties it is encoded and submitted to SmartBlocks services and committed to the ledger once verified.

Once committed the contract manager of SmartBlocks is notified of a contract template update (via websockets), the manager loads the template and executes the contract logic with user defined parameters defined. Energy savings contracts are triggered based on a user defined period, i.e. weekly, monthly, yearly and linked to existing SmartBlock states for example electricity usage. The output of execution of the smart contract is updated assets (e.g. invoice amount), this can be extended further through the integration of a cryptocurrency wallet that automates payment between parties at the end of contract period.

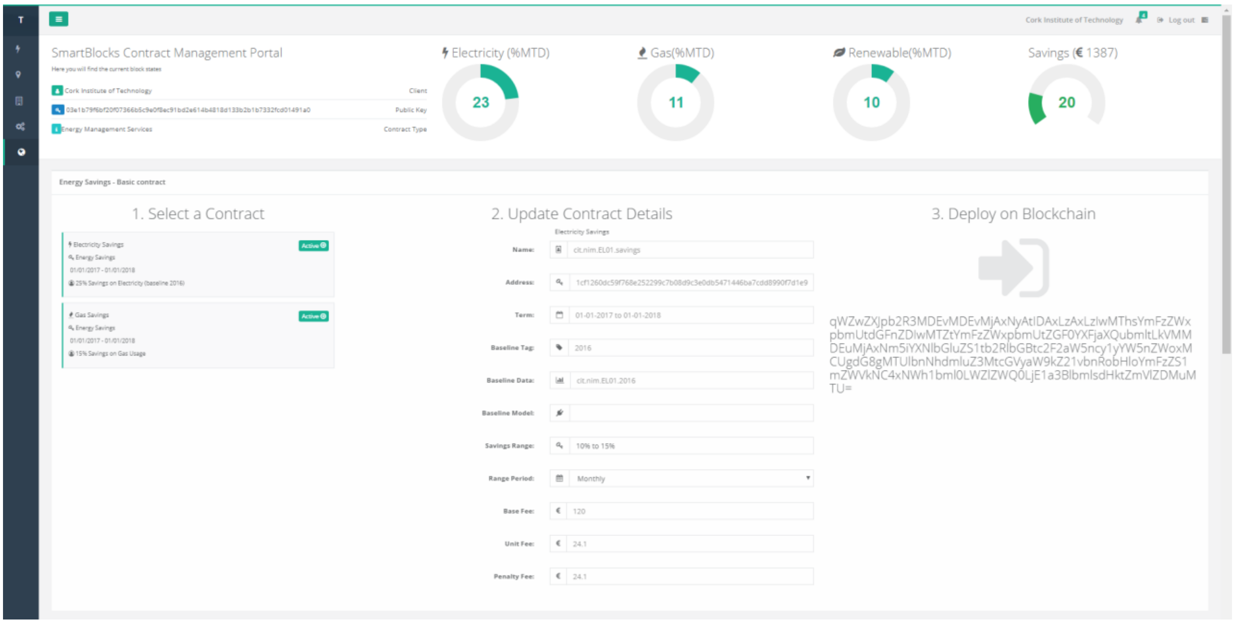

Figure 11: SmartBlocks smart contract management framework

As part of the smart contract logic the energy use must be compared against the relevant energy baseline to ensure ongoing savings in accordance with the agreed energy service contract. This creates an undisputable record of energy use versus savings. If this is violated then alternative actions must be taken which may result in additional smart contracts being created and deployed. The SmartBlocks smart contract paradigm can be used to automate the aggregation and calculation of energy related metrics, once deployed the contract is triggered by and update from specified meters (SmartBlocks states) and the subsequent calculation is executed and results posted to the distributed ledger.

The SmartBlocks prototype demonstrates the concept of distributed ledgers and smart contracts applied to ESCO services, it can significantly enhance the continuous auditing process through near real-time calculation of key performance metrics, deployed based on user defined site specific considerations. In addition it is possible to execute and energy performance contract, with different requirements, condition considerations and models, once agreed between both parties the contract self-executing once the triggering event occurs. The BlockPortal user interface reduces the complexity of defining, updating and committing smart contracts within the SmartBlocks instance.

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5 Business Modelling

5.1 Blockchain Applications in the Energy Sector

Blockchain is a pioneering technology that enables users to perform direct, fast, and tamper-proof transactions. While the majority of well publicised applications have been in the financial sector, the use of Blockchains in other sectors, including energy has so far been limited to a few small scale pilot projects.

Blockchain applications in the energy sector are foreseen in 3 primary areas[15] namely – automation of transaction, the decentralised documentation of transactions and documentation of property relations as shown in Figure 12 below with applications that are immediately offered by SmartBlocks (partially or wholly) being circled in green and potential future applications relating to energy trading, billing and recording of micropayments being shown in orange:

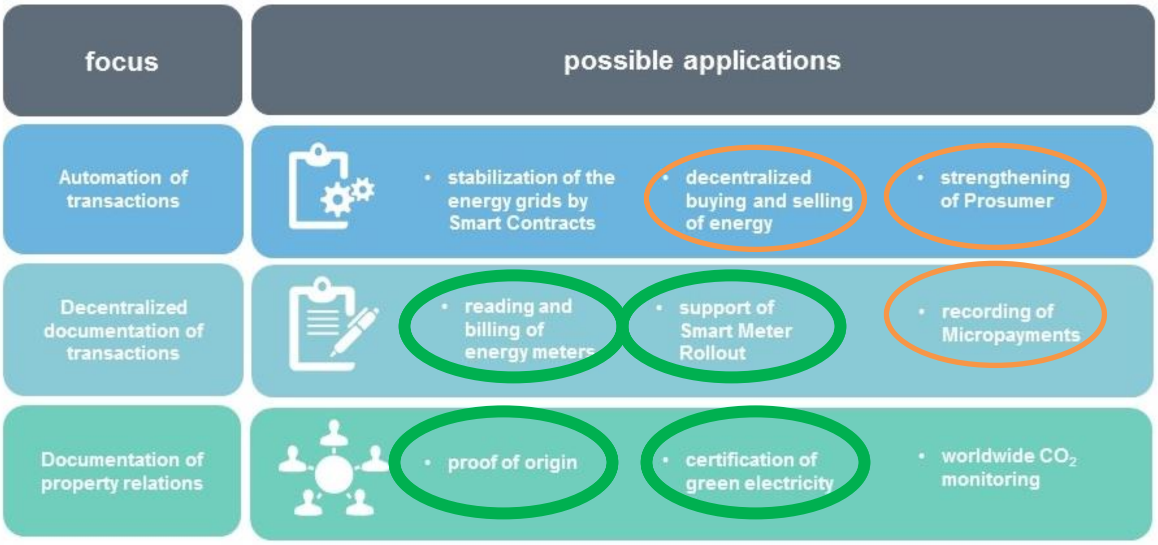

Figure 12: Blockchain Applications in the Energy Sector[15]

Automation of transactions: Blockchain in conjunction with smart contracts can automate the execution of transactions without the need for the intervention of humans.

Decentralised documentation of transactions: For future smart meter rollout programs intelligent measuring and data transmission systems are required. For this blockchain technology can support the automatic recording of meter data, transferred, documented and invoiced. This means that energy consumptions can be recorded in real time and transferred to an online portal. Through this users can then see at any time how much energy they have consumed, how much they can buy from whom or to sell for how much.

Documentation of property relations: Blockchain offers decentralised and tamper-proof recording of transactions with the origin of each transaction being easily tracked through the blockchain state.

[15] http://blog.exxeta.com/energy/2017/03/16/blockchain-applications-in-the-energy-sector/

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5.2 Blockchain Obstacles & Risks for the Energy Sector

While blockchain is poised to bring many changes to the energy sector there are still obstacles to overcome. In particular blockchain technology is still in its infancy with many arguing that it is not sufficiently scalable in terms of the demands for computing power and storage as network sizes increases. Any blockchain platforms relating to energy trading and the manifestation of a completely decentralised grid, where control of electricity supply and consumption is handed back to consumer would pose further concerns relating to who is responsible in the case of failures, how will security of supply & balancing be manged, how can these markets be regulated, how does contractual law and liability apply (who is responsible for ensuring obligations under payments are properly settled), how can competition in such a market be managed and regulated, who is the electricity supplier? Blockchain based energy platforms and in particular trading ones must overcome these challenges in order to survive in the energy market.

5.3 ESCO & Related Markets Overview

The primary customer segment for SmartBlocks is through ESCOs or more generally via service providers who take a more integrated approach to the provision of building energy management and energy efficiency as a service model.

According to recent forecasts and the increased focus on energy efficient buildings will lead to significant expansion of the energy management market with compound annual growth rates for example in the Building Energy Management System market growth of 15.3% (€0.9bn in 2013 – €1.9bn by 2018), Building Automation Systems of 3% (€1.8bn in 2013 – €2.2bn by 2017), Performance Contracting of 8.2% (€4.6bn 2013 – €7.4bn by 2018) and Smart Metering 26.9% (€1.2bn in 2013 – €3.7bn by 2016). ESCOs managing networks of buildings and blocks of buildings are a key target for SmartBlocks and in particular, the expected growth and demand for ESCOs opens market opportunities for the SmartBlocks solution.

The EU JRC has published regular market reports on the ESCO markets with the latest reporting on the 2013 markets in Europe and internationally[Error! Bookmark not defined.]. The 2013 report notes that the ESCO market has grown between 2010 and 2013 but that the market is far from reaching its potential. There are only a few mature markets, such as Germany, the Czech Republic, France, and Austria. The report projects future growth of the European ESCO market but does not quantify the aggregated current market or make future projections. However, for example, the German ESCO market is estimated at €3-4 billion in 2013 and is projected to grow to €20-30 billion. This is larger than the market in all the other countries combined with other countries reporting markets in the region of 10-100 million.

There is a significant move towards the delivery of energy efficiency projects through ESCO models, where the service provider takes a financial interest in the post installation energy performance throughout Europe and internationally and this is motivated by policy and regulatory drivers, such as the Energy Efficiency Directive (2012/27/EU), which contains strong measures to promote the market for ESCOs in particular:

- Article 7.7(b) – Energy efficiency obligation schemes: certified energy savings achieved by energy service providers or other third parties
- Article 10.3(a) – Billing information: Member States shall require that, to the extent that information on the energy billing and historical consumption of final customers is available, it be made available, at the request of the final customer, to an energy service provider designated by the final customer.
- Article 18 - Energy services Member States shall promote the energy services market and access for SMEs and Member States shall support the proper functioning of the energy services market.

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6 Conclusions

This report has presented a proof of concept implementation and evaluation the SmarkBlock blockchain based energy management platform. This included the specification of a high level reference architecture based on an analysis of the current state of the art in blockchain and application specific requirements for energy management services. The first version of the BlockMeter component was developed, which acts as a secure intelligent edge device for energy data extraction, as well as including services for thermal and electrical energy demand prediction together with a renewable energy prediction service based on wind. BlockSerivces were developed with the Sawtooth Lake Hyperledger platform at its core to implement the blockchain functionality that stores energy related transactions pushed by BlockMeter. Support for the definition and deployment of smart contracts has been considered based on the use cases defined and demonstrate how SmartBlocks can be used to create an enriched source of data for building owners, ESCOs, auditors and regulators alike. Finally a brief overview of the ESCO based energy market has been presented along with a review of possible blockchain based energy applications and risks for the energy sector.

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