# From centralized to decentralized blockchain-based product registration systems: the use case of lighting and appliances

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***Abstract*—In the last years, lighting only accounted for more than 15% of global electricity consumption. Moreover, we expect a high increase of energy consumption in the next years due to the large growth in lighting and appliances usage in developing economies. As the United Nations Secretary-Generals Sustainable Energy for All initiative identified, there exists a high potential of reducing the world's greenhouse gas emissions by improving the energy efficiency of lighting and appliances. For that, we have developed in the past a "centralized" product registration system to allow suppliers, manufactures, or traders to register their products to enter into a market. This product registration system is a crucial tool for identifying non-compliant, inefficient products. It serves as an entry-point for testers and regulators to examine the energy efficiency of the registered products, verify if they satisfy the minimum standards, and decide to let them enter into their markets. Our product registration system, as well as any other centralized implementation, suffers from isolated data storage hindering the collaboration between different markets from both governance and technical perspectives. In this paper, we examine the limits of centralized product registration systems and the advantages of a decentralized model based on the blockchain. Our analysis and prototype suggest that a blockchain-based product registration system can help to reduce the barriers between markets and play an important role in the quest for energy efficiency.**

***Keywords*—blockchain, energy, distributed systems.**

## I. Introduction

Nowadays, lighting and appliances such as refrigerators, washing machines, and air-conditioners are almost ubiquitous in households -and businesses- in developed countries; for example; UK homes having a washing machine in rose from 65% in 1970 to 97% in 2017[1]. The global home appliances market is experiencing steady growth with the growing middle-class economy, improved disposable income levels in a number of countries, busier lifestyles, and the availability of a range of appliances at competitive prices[2]. Particularly, we focus our work on developing and emerging economies where we expect a large growth in lighting and appliances usage (see the Accelerating the Global Adoption of Energy-Efficient Lighting guide for more details[3]). There is no doubt that lighting and appliances offer more comfortable lives to people, sparing them the burden of the most menial, routine tasks and chores in ever-increasing busy lifestyles.

But not everything is positive. Lighting and appliances such as refrigerators, washing machines, and air-conditioners consume an important amount of energy. Indeed, these products have played a key role in the world's energy consumption and carbon emission [1]. According to the Australian Department of Environment and Energy, household appliances account for about 30% of total residential energy consumption and, with lighting, an additional 12%[4]. At the same time, the average household electricity consumption has been falling for the last decade, despite the fast growth of the numbers of appliances, due in part to energy efficiency standards often lead by governments. For example, The National Appliance Energy Conservation Act of 1987 is a United States Act of Congress that regulates energy consumption of specific appliances [2]. Today, modern refrigerators and air conditioners, for example, use significantly less energy than older models. This trend has proved that it is indeed possible to improve the energy efficiency of lighting and appliances while producing significant economic and environmental benefits.

Consumers, from their side, can know and compare the energy efficiency of products and know how much power a particular model will use thanks to endorsement labels. Endorsement labels are seals of approval indicating that a product meets certain specified energy efficiency criteria. Some examples are the energy rating label or energy rating (http://www.energyrating.gov.au) introduced in Australia and New Zeland in 1986; Energy star (http://www.energystar.gov), launched in 1992, which is a program managed by the Environmental Protection Agency (EPA) and U.S. Department of Energy (DOE)

[1]https://www.statista.com/statistics/289017/washing-machine-ownership-in-the-uk

[2]https://www.researchandmarkets.com/research/2vbw2r/global$_home?w=5$

[3]https://united4efficiency.org/wp-content/uploads/2017/11/Lighting-Policy-Brief.pdf

[4]https://www.energy.gov.au/government-priorities/energy-productivity-and-energy-efficiency/appliances-lighting-and-equipment

that helps businesses and individuals save money and protect the environment through energy efficiency; and the EU energy label (https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products) which shows total energy consumption and provides other relevant information such as water consumption and noise levels for washing machines, and screen size for televisions.

Before entering into a market, manufacturers must test their products and submit those test results to a *product registration system* to certify that the product performance meets the minimum energy performance standards and labeling requirements. A registration system provides an initial compliance gateway wherein manufacturers register eligible products with the regulatory authority [3]. The regulatory authority can approve or reject product applications or revoke existing ones. A product registration system can also store additional information such as energy performance data, technical product specifications, sales figures, and product prices. The UNEP-GEF (UN Environment-Global Environment Facility) guide for product registration systems [3] states that: "robust monitoring, verification and enforcement schemes are crucial to safeguarding the energy efficiency benefits of performance standards and regulations". That is why product registration systems for lighting and appliances play a crucial role in the quest for energy efficiency. They contribute to the improvement of product compliance and the success of policies aiming for the transition of markets to energy efficient markets.

Currently, product registration systems -as well as many other kinds of systems- are implemented in a centralized fashion. From a governance perspective, a single entity holds all the power and controls all products' data; from a technical perspective, a centralized system has a central point of failure and hinders the data sharing between organizations. In fact, we have developed a product registration system for lighting and appliances and we are implementing it within the Southeast Asia and Pacific region (http://registrationprototype.enlighten-initiative.org). In this paper, we examine the limitations of the centralized model of our system and highlight the advantages of using blockchain to build a decentralized version of it. Some advantages are intrinsic to the blockchain technology such as verifiability, immutability and no single point of failure [4]. Our vision is to: i), easily share product data to allow products entered into one market to also qualify for entry into another market of another country; ii), reduce the need of (re)testing products for each market, and iii), provide transparent, auditable and reliable information to different stakeholders such as consumers, retailers, suppliers and customs officials, or even researchers for energy consumption analysis.

## II. An Overview of Product Registration Systems for Lighting and Appliances

### A. The UNEP-GEF enlighten initiative Lighting Product Registration System

A product registration system is a software platform allowing suppliers, manufacturers or traders to register their products to apply for entry in a particular market. Regulator authorities, using data that testers enter in the product registration system, can check if the product satisfies the different requirements for their corresponding markets.

In previous work, we have developed the UNEP-GEF enlighten initiative Lighting Product Registration System as part of the UNEP-GEF en.lighten initiative Southeast Asia and the Pacific Monitoring, Verification and Enforcement (MVE) Project (see Figure 1). This registration system aims at illustrating the capabilities and highlighting the benefits of product registration systems for lighting and appliances. Our idea is to provide a reference implementation to enable policymakers to implement a fully operational system following the best global practices.

The UNEP-GEF enlighten initiative Prototype Lighting Product Registration System considers four types of actors: applicants, testers, regulators, and administrators:

- *Applicant*. An applicant is a supplier, manufacturer or trader whose goal is to sell his products in a particular market. For that, they must register in the system as applicants and register the products they want to sell. An applicant can track the status of their applications.
- *Tester*. A tester represents the testing facility examining a product before it enters into a market. In our context, we focus on energy efficiency but testing can also cover other areas such as safety. Testing is a key aspect of product registration systems to identify non-compliant products.
- *Regulator*. A regulator is an entity responsible for reviewing and analyzing product applications to approve, reject, or revoke them. For that, regulators rely on the data that testers provide. They can also get additional information such as sales and testing facilities data.
- *Administrator*. It is a typical system administration with superuser rights and access to the same functionalities of applicants and regulators.


Fig. 1. Screenshot of the UNEP-GEF enlighten initiative Prototype Lighting Product Registration System (http://registrationprototype.enlighten-initiative.org). Applicants register their products details before submitting the application for entry into a market.

### *B. The problem with centralization*

Figure 2 illustrates the current centralized model of product registration systems -in fact, it is the current model of many types of systems-. As the figure shows, each market -e.g., regional or national markets- has its own registration system developed under its particular standards, technological choices and data models. Applicants register into the product registration system corresponding to the market where they want to sell their products and then submit products for entering into the market. This submission will be then validated, rejected or revoked by regulators using the data provided by the testers. From this centralized model, we can spot issues at two levels: *local* and *inter-market*, which we explain in the following:

- *Local*. It refers to the exchanges within a market. Applicants, which can compete between them, trust a regulator to validate their products and the product registration system to handle their data. Regulators know and trust applicants who submit applications through the Web interface of the product registration system. Probably, a different entity such as an IT consulting firm is in charge of the administration of the product registration system.
- *Inter-market*. It refers to the exchanges and relationships between different markets. The most common scenario is when the same product enters into different markets. In this case, applicants need to repeat the process of registering their products in different systems. Even worse, due to data sharing barriers, products have to undergo new tests for each different market despite having been already tested. Notably, testing is a costly process that creates trading barriers when having to perform new tests for each market. A solution will be the data exchange between regulators or product registration system administrators, but it is subject to trust between exchanging entities, inter-market policies and data and system interoperability.

We state the problem of keeping all data and processes in information silos under the control of one organization and isolated from the rest of the world from the following perspectives:

1) *Governance.* Centralized products registration systems store their corresponding data. Nowadays, a single entity such as non-profit organizations, governmental entities or third party actors has the responsibility of managing these centralized repositories. Relying on a single entity requires a great deal of trust and poses two main dangers: the ethical danger of misusing data or yielding power towards its own interests; and the technical danger of correctly securing the data against corruption or hacking, for example, and providing an effective service overcoming the single point of failure problem.
2) *Interoperability.* This item relates to the well-known problem of interoperability between distributed heterogeneous systems [5]. Distributed heterogeneous systems, such as product registration systems of different markets, can use different technologies, underlying middleware protocols, functionalities and granularity of functionalities, and application data models. All of these differences make the exchange of data between them a complex, error-prone and time-consuming task [6][5].

## III. Product registration systems: the decentralized blockchain-based model

### *A. State of the Art*

As the popularity of Bitcoin [8], Ethereum [9] and other similar technologies increased, there has been an ever-growing interest in exploring and applying blockchain technology to the most diverse use cases beyond finance. Just to mention a few of them, SolarCoin (https://solarcoin.org) is a cryptocurrency aiming at encouraging the production of photovoltaic electricity, while Midasium (https://midasium.herokuapp.com) manages real state with the goal of making its processes more transparent, efficient and secure and protect people from fraud, corruption, and financial instability. LeVote (http://levote.orange.com) proposes a tool for voting and citizen participation, and Bitnation aims at providing decentralized governance at a global scale (https://tse.bitnation.co).

The closest applications to the one we present in this paper are those concerning supply chains. For example, in [10], the authors presented the idea behind a blockchain-based supply chain, although there is no prototype implementation. Walmart is working towards making the supply chain process of food more traceable, transparent and digitally available with the goal of improving food safety [11]. Provenance (https://www.provenance.org) also aims at improving transparency, security, authenticity, and auditability of supply chains, allowing customers to get high-quality information to make their choices regarding which products they will buy. Generally, these are commercial solutions, so apart from the marketing information on their website, there is little technical information about them. We are convinced that there is not only the need to illustrate blockchain applications but also to provide technical details and blueprint system architectures.

Nonetheless, practitioners are exploring blockchain technology and its possible applications within different fields with the hope of overcoming the same governance and technical barriers imposed by centralized systems that we face. In the energy sector, researchers are working towards blockchain-based solutions for trading energy generation in local markets [12] or in Industrial Internet of Things (IIoT) scenarios [13] without the need of a central intermediary. In the medical sector, MedRec [7] is a blockchain-based solution to share medical data among the different -and also heterogeneous and distributed- medical stakeholders securely and confidentially.

To the best of our knowledge, we are the first to evaluate the relevance of using blockchain for product registration systems and to introduce a functional blockchain-based prototype for the lighting and appliances use case, including its technical details and code samples.

[5]In [7], authors highlighted this problem when discussing the interoperability challenges when exchanging health data in the context of blockchain.

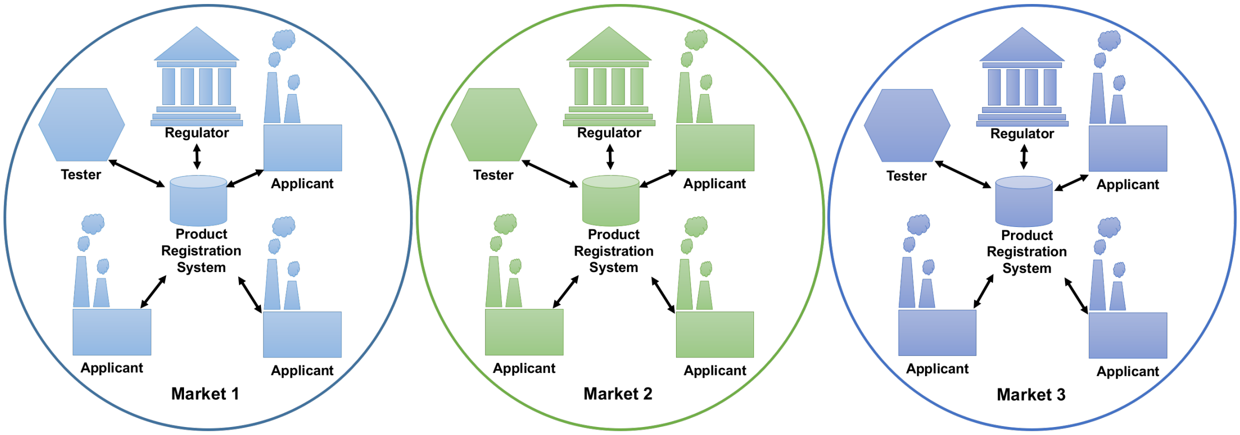


Fig. 2. Illustration of the current deployment and governance model of product registration systems. There are three markets in this figure, each one with its own centralized product registration system. Existing product registration systems are not designed to be inter-institutional and inter-market platforms that provide transparent product information such conditions under the products were built and their test results; instead, all information is kept in data silos.

### B. Model

Figure 3 illustrates the idea of a decentralized model for product registration systems. Here, every actor has a copy of the shared data, reducing the availability and single point of failure issues. There is still the need to protect the data against hacking and corruption. After all, someone can modify a record in its copy of the database and replicate it to the others. How can we know the state of that particular record before the modification? How can we ensure every participant accesses this data following a common process? This is where blockchain comes into action.

A blockchain is a *distributed ledger* where every participant maintains a copy of every transaction since the beginning of the network. Its most relevant properties are [4]: *public verifiability*, allowing anyone to verify the correctness of the state of the distributed ledger; *transparency*, where every participant knows the data and the processes to access and update it. It is a requirement for public verifiability; *integrity*, which is linked to public verifiability and transparency, allowing any participant to verify the integrity of the distributed ledger; and *redundancy*, which comes from the fact that the ledger is distributed.

These properties provide a solution for the governance and interoperability problems of centralized product registration systems we discussed in Section II. The governance model changes by having the data distributed and verifiable among participants and it solves interoperability by collaborating on the basis of a common data model and process. For the product registration system scenario, we have chosen the *permissioned* model of the *Hyperledger fabric* blockchain platform fabric [14]. In the permissioned model, there are only known participants whose identities are registered and verified within the network. Our recommendation for a first approach is to give write access to the ledger only to known and semi-trusted participants such as governmental institutions, NGOs, research and academic institutions, and verified suppliers, manufacturers or traders.

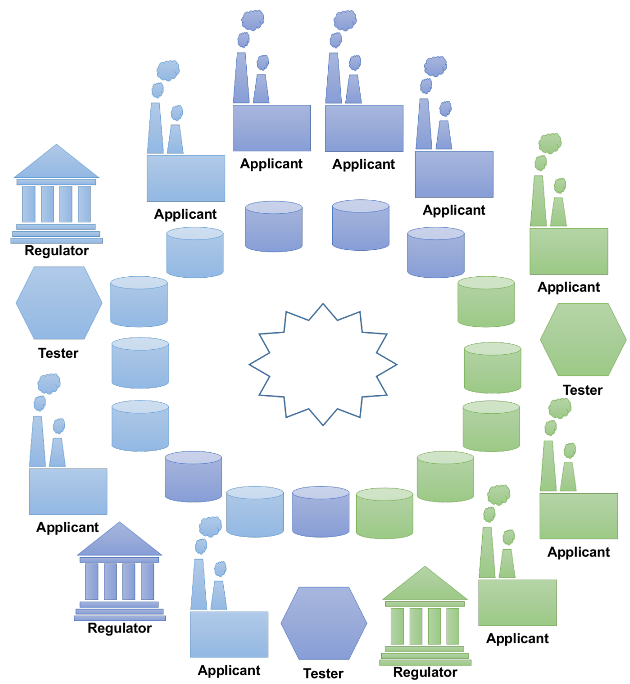


Fig. 3. A general illustration of a decentralized product registration system. In this scenario, all participants maintain a copy of the shared data.

## IV. Prototype

We implemented a proof-of-concept prototype of a blockchain-based product registration system. We focused on the use case of lighting and appliances, but anyone can extend it to serve the needs of different types of product registration systems. Figure 4 illustrates the product registration system architecture. Its main components are: *Hyperledger fabric network* which is created by *peer* nodes. Peer nodes are part of the backend services of the organizations contributing to the network. We describe these components in detail in the following:

- *Hyperledger fabric network*. Hyperledger fabric [14] is an open source blockchain platform -i.e, a distributed

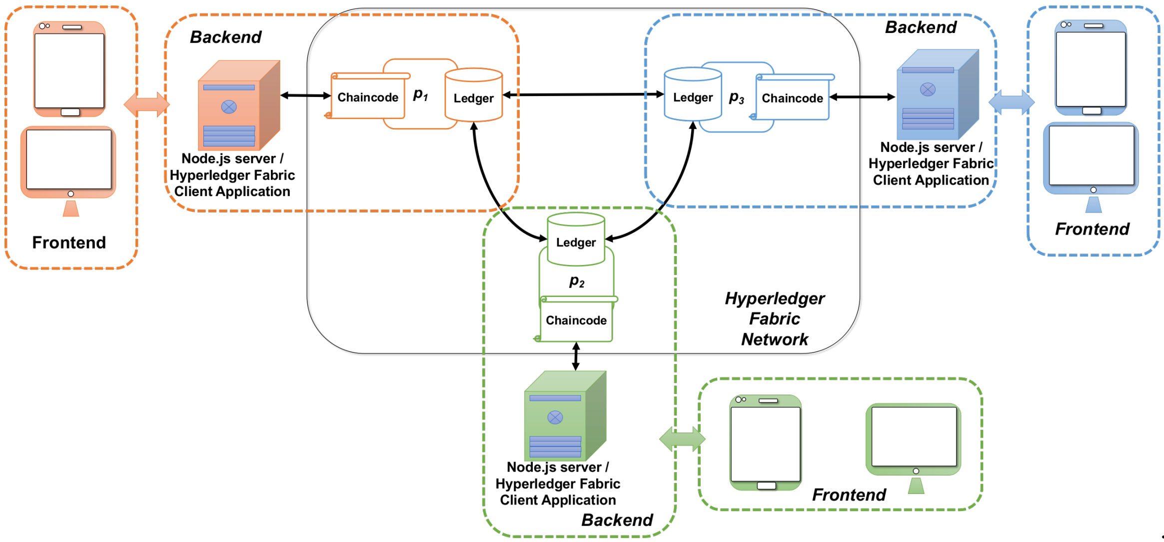


Fig. 4. Blockchain-based product registration system high-level architecture. There are three organizations contributing each one with one peer ($p$). These peers are nodes forming the blockchain network and they maintain copies of the ledger and chaincode. These peers maintain their ledgers by applying transactions that have been validated by a consensus protocol. Other participants wanting to contribute to the network by providing peer nodes or client applications need to ask for *permission* to the network membership consortium.

ledger technology-. Copies of immutable databases -*ledgers*- containing all the transactions since the inception of the network are kept by distributed *peer* nodes -or simply *peers*. In the Hyperledger fabric *permissioned* model, participants are known rather than anonymous, in contrast with public permissionless networks such as Bitcoin [8] and Ethereum [9]. This means that while the participants may not fully trust one another (e.g., they may be competitors in the same industry), a network can be operated under a governance model that is built off of what trust does exist between participants, such as the procedure for registering, approving, rejecting or revoking applications. In this context, there is a network membership consortium who can approve the entry of new participants offering peers or client applications. New participants can also join or quit this consortium.

- *Chaincode*. Also known as *smart contract*, is the code that client applications invoke. It manages access and modifications to the data stored in the blockchain. We implemented the product registration chaincode in Node.js [15] and it exposes the interface to create a product, get a specific product, get all products, validate, reject or revoke a product application. This chaincode is available at a git repository[6] and it contains lighting and appliances data to initialize the ledger. There is also a script to initialize a peer node with the chaincode[7].
- *Backend*. It comprises all the services implemented by a participant and the components accessing and contributing to the Hyperledger fabric network. *Peers* forming the network and maintaining a copy of the *chaincode* and the *ledgers* are also part of the backend, since they are deployed, run and managed locally by the participants. Apart from peers, a crucial part of the backend is the *Node.js server / Hyperledger Fabric Client Application* which consists of the following components:
  - *Chaincode client application*. It implements the required operations to join the network and invokes the operations exposed by the chaincode. We implemented a chaincode client application in Node.js and it is available in a Github repository[8].
  - *Rest API*. It exposes the back-end operations, including the ones linked to the chaincode interface, so that clients can invoke them via HTTP without the complication of dealing directly with the chaincode operations. We implemented it using the Node.js Express Web application framework.
- *Front-end*. The user interface is basically the same as the UNEP-GEF enlighten initiative Lighting Product Registration System we showed in Figure 1. However, this time we built it in a modular way so that it can consume Rest services from any backend. Another improvement is the integration of QR (“quick response”) codes [16], which are two-dimensional bar-codes used to store data. The data it stores is accessed by capturing a photograph of the code using a camera (e.g., built into a smartphone) and processing the image with a QR reader. We envision to leverage QR codes and smart tags to automate product registration and link physical products to those registered in the system. We implemented a QR code reader using the Javascript QR Code Scanner library[9]. This QR reader

[6]https://github.com/AlexandreDejous/PRP-Chaincode-HF/blob/Alexandre/chaincode/PRS/node/PRS.js

[7]https://github.com/AlexandreDejous/PRP-Chaincode-HF/blob/Alexandre/PRS/startFabric.sh

[8]https://github.com/AlexandreDejous/PRP-Chaincode-HF/tree/Alexandre/PRS

[9]https://github.com/nimiq/qr-scanner

can be used with a smartphone, a personal computer or any other device equipped with a camera.

Going back to Figure 4, note that all participants manage peers with copies of the same ledger and chaincode. This illustrates the fact that they collaborate on top of common shared agreement about the business model logic. This shared agreement solves the interoperability problem we discussed previously by providing a common data representation and functionalities for product registration systems.

The backend and frontend components of this prototype are reference implementations. Different organizations can implement them or extend them differently to present and process data in diverse ways; for example, in different languages, with specific visualization and analytics purposes, or to satisfy different technological requirements. We use Hyperledger Fabric v1.3 for this prototype, which provides SDKs (Software Development Kit) for writing chaincode client applications in Java and Node.js, but a developer can write the rest of the application in any programming language. In any case, it is important to realize that any other implementation will have to comply with the operations exposed by the chaincode interface to access and update data in the shared ledger. The chaincode is the only entry point to the shared ledger.

## V. Conclusions

We have presented a blockchain-based product registration system for lighting and appliances. This work parts from the product registration system we developed as part of the UNEP-GEF en.lighten initiative. We presented a technical architecture for our blockchain-based system with the goal of becoming a reference architecture for decentralized product registration systems illustrating the best practices from both technical and functional aspects. This prototype is a step forward towards the harmonization of data and processes between markets to reduce the barriers between them -e.g., having to re-test products-. Moreover, this work contributes to the set of use cases illustrating useful blockchain applications apart from those of financial- and cryptocurrency-related ones. Indeed, at this time of hype around blockchain, we believe it is important to continue to analyze the impact that blockchain will have on how we conduct business, organize governments and society.

For future work, we will continue to develop the integration of physical devices to automate product registration and energy consumption performance tracking. We also advocate the examination of the technical and legal restrictions for such a distributed marketplace in the current technological and regulatory environment, e.g., the General Data Protection Regulation in EU. Another important aspect to explore is the automation or semi-automation of regulators via chaincode -aka smart contracts- to support the approval, rejection, revocation of product application and their validity within different markets. From the final consumer side, we plan to develop a QR code-based mobile application for our blockchain-based solution to improve the transparency and product information and to invite consumers to buy energy-efficient products. Finally, since this project is part of an energy efficiency initiative, it is imperative to analyze and have a clear understanding of the trade-off between the benefits of deploying such a system and the energy it requires to run.

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