Tracing Soybeans with Blockchain

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Contents

1 Introduction

The present report outlines and illustrates the outcomes of an interdisciplinary student project on blockchain technologies in sustainability, which took place in 2019, February 11 to 15 at ETH Zürich. Our particular challenge reads as follows: how can we ensure traceability and sustainability of an organic soybean harvest from the field in the Ukraine to the warehouse in Switzerland using blockchain and internet of things (IoT) technologies.

It is directed at the course instructors, the industry-partner *Peterson and Control Union* as well as the interested reader. Therefore the report does at its core reflect the work of our team, consisting of five students from scientific and engineering backgrounds, achieved during the two days hackathon. Beyond that the report aims at embedding these efforts into a bigger picture of global relevance. First we will begin by providing the motivation for our challenge, the problem we are tackling, our proposed solution, followed by our implementation and reflections.

2 Background and Statement of Challenge

Agricultural products in general and soybeans in particular are at the beginning of a long supply chain of processed foods and other products. In many cases these supply chains span around the globe.

The soybean, commonly referred to as the 'King of Beans' is considered to be one of the five oldest cultivated crops on the planet. Originating from ancient China it made its way to become one of the major sources for oil and protein only towards the end of the 20th century. After crude oil, it is the second most exported commodity of the USA, where more than 50% of the world's demand is being harvested every year: 4.54 billion bushels (equal to 123.5 million metric tons) were reported harvested in 2018. [2], [9], [10]

The price for organic beans [14] can easily double the price for non-organic beans [15]. The high demand together with the broad spectrum of soybean quality ranging from organic to much cheaper (e.g. genetically optimized) hybrids and the resulting price range provide a natural incentive for fraud. In order to guarantee its certified quality, the application of new cutting-edge technologies (e.g. blockchain and smart sensors) is therefore currently explored to track beans along the whole supply chain.

Cultivation. Soybeans grow in temperate climates of 20 - 30°C, and require well-drained soil to grow. The soybean has a variety of uses, explaining the world's growing dependence on this legume. The beans are a rich source of nutrients for animals and people alike. They are used as a cheap source of livestock feed, and as a key ingredient in many meat/dairy-substitute foods. Most commonly known are the beans uses in soy milk and soy sauce, the cornerstones of much of Asian and Western cuisine. In agriculture the beans are also often used to replenish damaged soil with nutrients. [11]

Harvesting. It takes 80 - 120 days for soybeans to reach their harvest height of one meter. Typically soybeans are harvested in multiple hectare spaces in Autumn. Combine harvesters traverse the fields cutting and collecting the soybeans. When the combine's tank is full it will empty the beans into a storage truck, positioned next to the field. Afterwards they are transported to a grain dealer or the farmers storage facility.

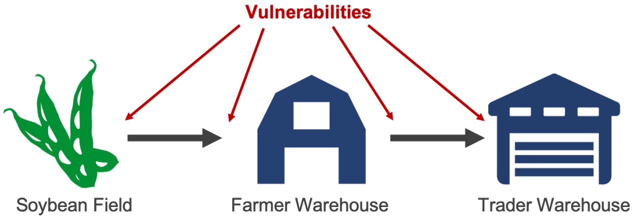


Figure 1: Schematic of the soybean supply chain.

2.1 Global Supply Chain

Being a major source of protein and oil, the soybean marks the initial point of long supply chains, be it of processed food or other products. In the frame of the given challenge we want to focus on the transport and storage of raw soybeans.

Transport. Soybeans are usually transported in large volumes by train, road trucks or ships. The most important factor, concerning transportation is the water content of the soybeans. In the first weeks after the harvest, the soybean is still losing some of its weight in a drying process. The risk of soybeans being damaged during transport can be minimized, if their water content is kept below 13 percent. Constant monitoring of temperature and humidity conditions is therefore imperative. Additionally, their mass is closely tracked to ensure that the harvest has reached its destination. [6]

Storage. There exists a whole set of regulations which vary between different countries and certification standards. However the standards for organic products are by nature very high. In particular, retailers demand traceability of organic soybeans from the field to the warehouse. This includes separate storage rooms for specific farmers, field-clusters and a clear division of organic and non-organic beans.

2.2 Organic Fraud

Organic food generally underlies rigorous control mechanisms and is more costly in production, compared to non-organic foods. This leads to an increased risk of fraud. Some of which have been recorded and made public. The most obvious form being a trader or/and farmer selling goods wrongfully labeled as ‘organic’. In a recent article *Forbes* reported a soybean-shipment of 36 million tons, which "... was miraculously labeled ‘organic’ once entering the US [8]."

2.3 Peterson and Control Union

The Peterson and Control Union (PCU) is a conglomerate of companies, that provide a set of specialized supply-chain solutions for multiple industries. At its root stands the traditional dutch family business of Peterson. Founded in the year 1920, the Peterson company originally specialized in the inspection of grains traded in the dutch canals. Over time the Peterson Control Union expanded from the agricultural to the sector of mineral oil and gas. Today it offers worldwide supply-chain strategy consulting and services in various industries. Their core business revolves around agricultural inspection. Specifically they provide quantity inspections and quality assessments through farm and warehouse based sampling and monitoring. [7]

2.4 The Challenge

The name Peterson and Control Union stands for trust. PCU acts as a Certification Authority for agricultural processes and labeling. It guarantees high standards during all the different phases of the production process and logistics of an agricultural good. One market that is particularly growing and subject to strict certification is that of organic soybeans. Like their conventional cousins organic soybeans are globally cultivated, but they underlie rigid surveillance and regulations including the tracking of all nutrients, water or fertilisers used before and during plantation. Due to its significantly higher prices, organic soybeans are subject to fraud, as described above. Our challenge is the following:

How can blockchain help ensuring full traceability of organic-certified soybeans produced in Ukraine and transported to Switzerland?

The challenge includes the following list of goals as well as (fictional) sample data of field size, harvest, harvesting machines and storage space from three farms in Ukraine: [1]

- Volumes recorded for all units
- Link of harvested soybeans to specific area/field
- Farmer sells only what he harvests
- Trader sells only certified soybeans to Buyer
- Buyer has traceability to certified farms

In order to solve this quest a tracking solution with a technological implementation of an IoT sensor-network including smart contracts and blockchain is suggested.

3 Concept and Solution

In this section, we will introduce and discuss the concept used to secure the supply chain. Firstly, we will reiterate the discussions that led to the current concept, meanwhile explaining why other solutions fail. Secondly, we will formally present the current concept and state the assumption under which it operates successfully. The concept includes supply chain actors (e.g. farmers, traders), their assets (e.g. fields, trucks, storage yards), IoT sensors and their respective data and blockchain with smart contracts.

3.1 Finding a Solution

Harvest. The discussion on how to secure the supply chain revolved around the schematic of the supply chain depicted in Fig. 1. We started off by contemplating the field. Beans are harvested by a combine, regularly offloaded to a trailer attached to a tractor and finally transferred to a truck which transports the produce to the farmer's or a trader's warehouse. Our initial idea was to weigh the beans harvested by the combine. Then whenever beans are transferred from one vehicle to the next, weigh the amount of beans offloaded from the first vehicle and received by the second vehicle and check if the quantities match. We identified a challenge for this procedure however. Usually neither of the vehicles is closed off. Hence, for example, while the tractor transports the beans from the combine to the truck, organic produce could be removed from the trailer while simultaneously adding inorganic produce nullifying the above efforts.

To resolve this issue, we briefly considered closing off transportation vehicles and only allow them to open if vehicles are engaged in a handover (we will frequently call this a transaction) of beans (measured by an NFC chip). Ultimately, this does not prevent the exchange of organic for inorganic beans during a transaction, so we discarded the idea.

Since, we were unable to find a solution for securing the processes on the field, we decided to ignore them for a moment and instead move on to the transportation of produce from the field to the trader's warehouse (with the possible halt at the farmer's warehouse).

Transportation to Farmer's Warehouse. Again, we decided to track the transport of produce from the field to the warehouse in trucks by weighing throughout. However, the above issue still applies: organic and inorganic beans can be exchanged simultaneously. One way to prevent this, is to utilise GPS data to monitor long unplanned stops. But clearly there is a range of valid reasons for (long) unplanned stops, e.g. traffic or railway crossings, reason why this method is not feasibly.

Instead we considered sealing the trailers of trucks before transport. Then if we ensure that entire trailers cannot be exchanged, e.g. by equipping them with GPS trackers or assigning them unique identifiers like unique QR codes on the inside, we prohibit exchange of organic and inorganic produce during shipment. However, the current supply chain does not (necessarily) include sealing of trailers and many manual steps are required. Thus the solution would be expensive and require an intervention in the current supply chain.

An Elegant Solution. Finally, we found a much simpler and more elegant solution by observing the issue from another perspective. Instead of devising ways to prevent adding of inorganic beans, we pondered the actual implications of adding inorganic beans. As we will explain in Subsection 3.2.2, if we can determine the amount of harvested beans with certainty, whoever inflates this quantity by adding inorganic beans to the supply chain will not be able to sell the surplus. Similarly, if someone replaces organic with inorganic produce, they will not be able to sell the organic produce removed from the supply chain. Thus there is no incentive to attack the supply chain with a single exception: in a warehouse it might be logistically easier to mix organic and inorganic produce (e.g. for storing or processing purposes). As a result, to secure harvest and transportation, it suffices to weigh the amount of beans harvested by the combine. For warehousing we must discuss additional safeguards.

Underlying principle of our solution

If we can determine the amount of harvested beans with certainty, whoever inflates this quantity by adding inorganic beans to the supply chain will not be able to sell the surplus.

Warehouses. As alluded to above, the challenge in securing warehouses is that for operators of the warehouse it might be logistically and thus economically advantageous to mix beans from different fields, different farmers or even organic and inorganic beans. For example, it simplifies the work flow to fill up storage yards sequentially, instead of directing produce to different yards depending on their origin. Hence storage yards must be monitored. More precisely, when the cargo of trucks is unloaded into storage yards, the change in weight at the storage yard has to be registered. Moreover, the origin, i.e. the field, geographic location, or farmer of origin (based on the desired granularity of traceability), of the storage yard must match that of the field.

3.2 Detailed Description of Concept

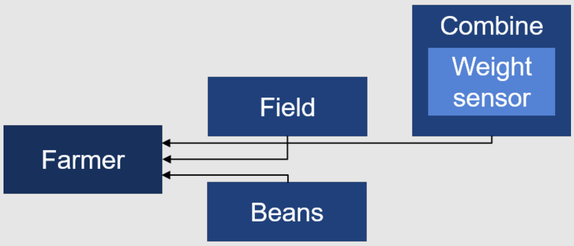
As described above, our concept encompasses actors, called participants (e.g. farmers, traders), their assets (e.g. fields, trucks, storage yards), IoT sensors and their respective data and blockchain with smart contracts. Each asset is assigned a participant, namely its owner. For instance, a combine is assigned to a farmer. Similarly, an IoT sensor is attached to an asset. Think of a weight sensor in a combine (see Section 3.2.1 for a schematic representation). The underlying blockchain is now at once a log and the location where business logic (in form of smart contracts) is stored and executed. It registers participants, assets, and sensors and logs the processes of the supply chain as recorded through the execution of smart contracts.

At three points in the supply chain smart contracts are invoked: harvest, transfer from trucks to the farmer's warehouse, and transfer from trucks to the trader's warehouse. In the following we will outline these smart contracts.

3.2.1 Smart Contracts

Harvest

Participants, assets, IoT sensors

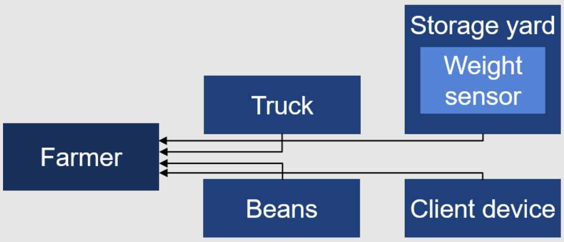


Procedure

1. Weighing: the *combine* harvests *beans* on the *field*, the *weight sensor* records the weights of harvested *beans* and invokes a smart contract to store it on the blockchain.

Transfer from trucks to farmer's warehouse

Participants, assets, IoT sensors



Procedure

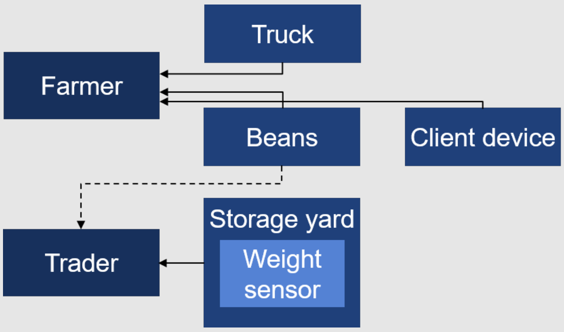
1. Transfer: the *beans* in the *truck* are transferred to the *storage yard*. The truck driver enters the origin of beans from the truck manually into the *client device* (e.g. smart phone). Then the truck driver scans a QR code identifying the *storage yard* and invokes a smart contract.

2. Check of origin: the record of the *storage yard* on the blockchain contains an entry with the origin of beans in the *storage yard*. If the *storage yard* is empty, the origin of beans in the record of the *storage yard* is set to the origin of beans in the *truck*. If the *storage yard* contains beans, the origin of beans in the *truck* is compared with the origin of beans in the *storage yard*, and an error is generated if they do not match.

3. Weighing: the *weight sensor* in the *storage yard* records the weight. If the weight of beans in the *storage yard* exceeds the weight recorded at harvest an error is generated.

Transfer from trucks to trader's warehouse

Participants, assets, IoT sensors



Procedure

1. Transfer: the *beans* in the *truck* are transferred to the *storage yard*. The truck driver enters the origin of beans from the truck manually into the *client device* (e.g. smart phone). Then the truck driver scans a QR code identifying the *storage yard* and invokes a smart contract. The *beans* are reassigned to the *trader*.

2. Check of origin: the record of the *storage yard* on the blockchain contains an entry with the origin of beans in the *storage yard*. If the *storage yard* is empty, the origin of beans in the record of the *storage yard* is set to the origin of beans in the *truck*. If the *storage yard* contains beans, the origin of beans in the *truck* is compared with the origin of beans in the *storage yard*, and an error is generated if they do not match.

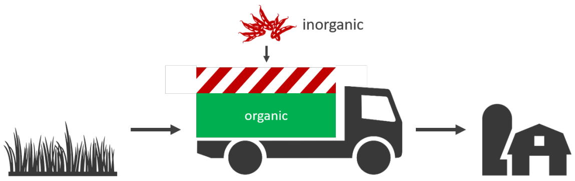
3. Weighing: the *weight sensor* in the *storage yard* records the weight. If the weight of beans in the *storage yard* exceeds the weight recorded at harvest (corrected for average weight loss due to storage in farmer's warehouse) an error is generated.

We note that if the farmer has no trucks and warehouses, the second procedure does not take place. In that case in the last smart contract the truck, beans and client device are assigned to the subcontractor handling transportation. Moreover in the third step of the procedure, we do not account for weight loss, since beans have not been stored in a farmer's warehouse.

3.2.2 How our Solution secures the Supply Chain

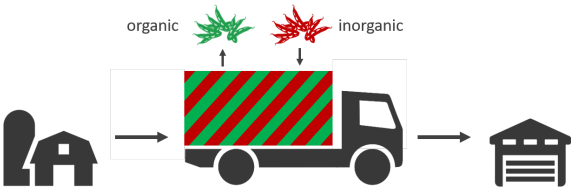
We will illustrate by two examples how the first smart contract essentially secures the entire supply chain.

Adding of beans to the supply chain.



Suppose during the transport of beans from the field to the farmer's warehouse, the farmer mixes inorganic produce bought from a third party into her organic produce. The first smart contract "harvest" records the amount of organic beans at harvest. However, the beans will be weighted again in the farmer's warehouse in course of the second smart contract. Because of the additional inorganic beans the latter weight will be higher than the weight recorded at harvest. The fraud is detected.

Exchange of organic with inorganic beans.



Suppose during transport of beans from the farmer's to the trader's warehouse, the farmer exchanges his organic produce with inorganic produce bought from a third party in a one-to-one ratio. Then the weight recorded at harvest and in the farmer's warehouse will match the weight recorded in the trader's warehouse (after accounting for weight loss). Hence, the fraud is not detected.

Does the farmer have an incentive to deceive? The farmer can pass off the inorganic beans – now part of the supply chain – as organic to the trader. However, to earn a profit he must sell the organic beans diverted from the supply chain at the price of organic produce to an outside buyer. He cannot sell to a buyer who cares for traceability, since the beans cannot be traced back to their origin, whence there is no way to verify they are truly organic. But if the outside buyer does not care for traceability, the farmer could have simply passed off the inorganic beans to him as organic, in which case the exchange is superfluous.

The above reasoning fails if the outside buyer can verify if beans are organic by another method, e.g. chemical or biological testing. However, the intended recipient of the beans could employ the same techniques. Moreover, this would supercede the need for traceability in the first place.

4 Implementation

Taking into account the limited time frame of the hackathon and the lack of experience in both working with sensors and blockchain implementation, our goal was to build a proof of concept. We wanted to collect data with a sensor, and push it to the Hyperledger blockchain, where it would be used to accept or reject one of the transactions in the supply chain. In the previous section we described how weighing the amount of soybeans from the different fields that enter the Trader's warehouse, is important to ensure traceability of the beans along the supply chain. To keep it simple, we assumed that the farmer fills his beans in separate containers for each field. Those containers are weighed directly (as simulated by the pressure sensor), so the Trader can keep track of the amount of soybeans coming from each field of his client farmers. By comparing those soybean purchases to the total amount of soybeans harvested on the respective field, the Trader will notice if the Farmer tries to cheat him.

In our implementation we use sensors connected to an Arduino microcontroller to collect data, which are then pushed to the blockchain via a REST API, using an Arduino microcontroller (see Fig. 2). In the following we describe our process of implementing this proof of concept.

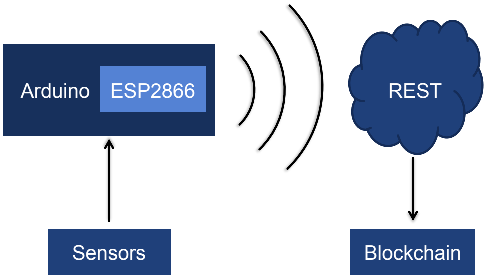


Figure 2: Outline of our implementation of the IoT device.

4.1 Wiring up the IoT Sensor

The soybean weight data are captured by a sensor. We used two sensors: a DHT temperature and humidity sensor and a Force Resistive sensor. A Force Resistive Sensor can be used for assessing the weight of the beans harvested, while a DHT sensor allows for close monitoring of the bean's storage environment as outlined below. The sensors chosen to monitor soybeans could be different. We chose them because of the relevance of their data measurements to our concept and because they are available in the Student Project House. Moreover, they are extremely low cost, and are easily programmable with Arduino.

4.1.1 The DHT sensor

This 10mm x 10mm x 8mm DHT sensor is composed of two parts, a thermistor and a capacitive element to measure humidity. It measures temperature and humidity. An analog digital converter is housed within the casing to convert the analog signal to digital, which the Arduino can read.

For our pilot these sensors work very well, because they are easy to configure, however their sampling rates are slow (0.5Hz). Their cost is 0.2CHF.

4.1.2 The Force Resisitive Sensor

The force resistive sensor (FRS) consists of an 8mm diameter sensing area, connected to a positive and negative wire which can be connected to an Arduino. The FRS voltage varies depending on the pressure applied to the sensing area. Resistance increases with force measurement. The measurement range of this sensor is 100g – 10kg.

The limitation of this sensor is its low accuracy. In our configuration, we squeezed the sensor in order to simulate the weight of beans.

4.1.3 Arduino + ESP2866

The Arduino microcontroller allows us to read the voltage signals from these sensors, and convert those signals to meaningful data. We connected the sensors to the AnalogInput Read terminals of the Arduino to monitor the data acquisition. To deliver the collected data to the blockchain we incorporated an ESP8266 WiFi module into our microcontroller system. This allowed us to transmit our data to the blockchain.

4.2 Control Software for Arduino

The Arduino microcontroller is programmed using the Arduino IDE which can be obtained from [3]. In order to facilitate the integration of the ESP and the DHT sensor, libraries for the respective element were used [4], [5]. As with the other parts of our code, our Arduino control software can be found on our GitHub page.

Looking at this code, one can divide it into three main parts: establishing connection with our local WiFi network and initializing the sensors, followed by a loop of alternating data acquisition and pushing the data to our REST server. From there the data are integrated into our blockchain using the Hyperledger Fabric framework.

4.3 Hyperledger Composer

As outlined in the previous sections, the problem we face to date with many supply chains is the lack of trust in labels and doubt in the validity of products' metadata from the customer side. Using blockchain, we can implement smart contracts, that condition transactions on sensor data to minimize the risk of cheating. We decided to use a permissioned blockchain, which enables us to clearly define who can propose new blocks (which correspond to new transactions). This blockchain is hosted and maintained by one party, for example the company selling the end product. One might argue, that this again creates the need for a central authority and thus defeats the benefit of using a blockchain in the first place. But this is not the problem in the context of supply chains. The goal is to minimize the risk of collusion between single stakeholders within the supply chain.

Hyperledger Composer is a toolset based on the Hyperledger Fabric framework, that allows out of the box development of blockchain applications. Since none of us had prior experience in blockchain development, it was a sensible choice for our proof of concept. A number of tutorials and examples on the Hyperledger Composer website provide a good introduction into the topic. [12]

The core part of every Hyperledger Composer application is the model file. We defined the stakeholders Farmer and Trader as participants and represented IoT sensors (in our case only the pressure sensor) as a participant as well. The sensor data were treated as an asset with a data array that would be continuously updated with the new data from the sensor. Throughout the supply chain, the soybeans are transferred from the field to trucks, containers, etc. Those "storage types" are represented as assets that are connected to their owner and their field of origin. In addition they have a "weight" property that represents the amount of soybeans stored in them. During a transaction like the sale of soybeans from the farmer to the trader, this property is updated in the respective storage assets.

We realized there are many different ways to represent the physical reality of the supply chain. It seems like the most natural option is to represent soybeans as assets themselves, that simply change their owner in a transaction. However, this raises the issue of defining a minimal unit, like a single bean or one kilogram of beans. Weight is not a good measure though, because the beans drastically reduce their weight when they dry, so volume might be an option. Alternatively, batches of beans (e.g. all beans in a truck) could be defined and tracked. This would require splitting and merging functions for those assets, but might be a nice representation in a future version.

4.4 Limits of our implementation

Being limited by resources as well as time, our implementation is to be understood as a proof of concept. We demonstrated the ability to continuously stream data relevant for the supply chain of soybeans from an IoT device to our blockchain. However, when thinking about how to take our idea beyond just being a concept, we identified two major changes that will be necessary when actually implementing our idea. First, using cellular network instead of WiFi will enable the chip to be used on fields and during transportation. As the sensors would be installed directly on the combines and trucks, power can readily be provided by these machines. Secondly, and more importantly, instead of saving all the data directly on the blockchain, the computationally more feasible approach is to store the acquired data centralized on a conventional server and only the calculated hashes corresponding to this data set on the hyperledger. Authenticity can then be verified by calculating the hash and comparing the result with the hash stored on the immutable blockchain.

5 Conclusion

Throughout the course of the BETH - Blockchain for Sustainability week we were exposed to a wide range of new concepts and real world challenges that require smart technological solutions. Even though the introductory sessions about the topic blockchain gave us a first impression about what technologies and concepts exist, we faced many technical challenges when we actually started hacking together the prototype. For example, we spent a significant amount of time on setting up the local environment for Hyperledger Composer, in order to actually start implementing the solution. However, with great support from the Student Project House and experts at 4_eyes [13] we managed to build both, the IoT and the Hyperledger Composer site, and in the end got a connected proof of concept up and running.

The short time-frame of the hackathon also challenged us in good time management. We learned to divide tasks efficiently among the team, set realistic milestones, but also be constantly open to adjustments or complete pivots. As supply chain traceability is a very complex problem, we could have spent many more days going into details. But in order to have a working prototype after two days we had to find the right balance between working out important details and moving on to the next problem.

In the scope of this challenge we focused on securing the supply chain of soybeans, ensuring traceability and thus increasing trust in organic labels. Thinking ahead, we had some ideas for further improvement of the customer experience. In buying organic products, customers pay for the promise of healthier and more environmentally friendly food. However, customers are becoming more and more interested in the details of how their food was produced and transported, and labels do not provide those pieces of information. By ensuring traceability, detailed information about the supply chain of each end-product is already gathered, so why not make these data available to the consumer? Products in the supermarket shelves could be equipped with QR codes, that would provide tangible information like the travel distance or CO_2 emissions. Even more, the product could warn the customer if it does not comply with a predefined set of preferences, dietary restrictions or allergies. Providing this information is an important step towards a more responsible consumer – a consumer, who thinks more consciously about which products end up in her or his shopping cart. Blockchain could therefore become one key technology to allow consumers a fully conscious buying decision.

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