aDappter - a Blockchain-Based Incentive System to Reduce CO_2 Emissions

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BETH Report
April 2019

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Abstract

To reach the United Nations (UN) sustainability goals, Switzerland needs to cut the yearly CO_2 emissions considerably until 2050. However, recent trends show that major improvements in this regards are still necessary. Energy consumption is one of the major drivers for CO_2 emissions in Switzerland. Often, financial incentives misalign with the needed behavioural changes and investments of people. BETH2019, a hackathon hosted at ETH Zurich, focuses on blockchain and IoT to tackle this problem. In the "SwissEnergy Challenge" at BETH, our team created the winning solution *aDappter*, an incentive system for Swiss households to cut CO_2 emissions. The decentralized application based on the Hyperledger Fabric blockchain automatically tracks the CO_2 emissions of households trough IoT sensors and rewards successful CO_2 savings with tokens. Participants can spend these tokens in a web app and fund sustainable projects that benefit themselves and their local communities. It is a system created to empower the Swiss citizens to shape their environment as they wish and without involvement of third parties, aligned with the sustainability goals of decreasing CO_2 emissions through less energy usage in Switzerland.

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Introduction

1.1 aDappter at BETH2019

The project *aDappter* was developed during the BETH[1] hackathon hosted at ETH Zurich in February 2019. BETH intends to advance the field of blockchain in combination with the Internet of Things (IoT) to address shortcomings of the system we have today, especially the misalignment of financial incentives with the global climate and sustainability goals. This report describes the solution of aDappter - a blockchain based incentive system for reducing CO_2 consumption in the Swiss energy market. It won the "SwissEnergy challenge" at BETH2019.

The following seven team members were involved in the aDappter team:

- Bühler Marcel, Switzerland - IoT
- Bruseghini Lara, Italy - Web app
- Hunhevicz Jens, Switzerland - Blockchain
- Jouda Kenana, Palestine - Web app
- Magdy Raef Michael, Egypt - Blockchain
- Shafik Farida, Egypt - Web app
- Tollini Marco, Italy - IoT

[1] `http://www.coss.ethz.ch/education/BETH.html`, accessed 05.04.2019

1.2 Motivation

The United Nations (UN) introduced 17 sustainability goals[2] as a blueprint to target a more sustainable world until 2030, which should be at the core of every decision taken. However, the reality is that these goals often do not align with the financial system we have in place nowadays. People have no financial incentives to change behaviour in order to meet these goals. Switzerland agreed to respect the UN sustainability goals[3]. Regarding actions towards climate change, the government wants to cut the yearly CO_2 emissions from 4.72t CO_2 per person to 1-1.5t CO_2 per person in 2050. Having said that, Switzerland still seems to have a considerable amount of work ahead in this regard. A recent news article [SRF Media] claimed that the Swiss CO_2 emissions in 2018 were higher than ever before. One of the main drivers for it is the high energy consumption, reinforced through an above average hot summer and cold winter. This is why there should be put more thought into additional incentive systems for consumers to encourage the purchase of more sustainable heating/cooling systems, as well as the reduction of their energy consumption. The "FuturICT 2.0"[4] initiative tries to use the potential of new technologies such as blockchain and IoT to introduce new mechanisms for incentive systems that are better aligned with the UN sustainability goals. This is why BETH particularly intends to tackle the core topics aligned to the UN goals, e.g. in the area of higher energy efficiency and energy saving, which was the topic of our challenge.

1.3 Challenge

The "SwissEnergy challenge" was one out of seven challenges at BETH. The task was given as follows:

> *How could blockchain technology benefit the climate twice - with a solution that documents in a ledger:*
>
> 1. *the CO_2 emission reduction by households (e.g. in the fields of electricity, heat and mobility)?*
> 2. *the reinvestment of saved costs in (local) sustainable projects with direct payments from the consumer who saved energy to sustainable projects without costly/untrustworthy middlemen?*

The sponsor of this challenge was SwissEnergy[5], a platform to cluster all activities of the Swiss federal office of energy (SFOE) regarding renewable energies and energy efficiency. One of their activities is fostering innovative projects and technologies that help address these topics. We would like to thank at this point Matthias Galus, Leoni Jossen, and Marine Pasquier-Beaud from the SFOE for their support and the challenge.

[2] `https://www.un.org/sustainabledevelopment/sustainable-development-goals/`, accessed 05.04.2019

[3] `https://www.eda.admin.ch/agenda2030/en/home.html`, accessed 05.04.2019

[4] `http://www.coss.ethz.ch/research/FuturICT20.html`, accessed 05.04.2019

[5] `https://www.energieschweiz.ch`, accessed 05.04.2019

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Background

2.1 Blockchain

Bitcoin[1] is a blockchain based crypto-currency introduced by Satoshi Nakamoto [Nakamoto 2008], and emerged as a combination of existing technologies (e.g. distributed ledgers, public-key encryption, merkle tree hashing, consensus protocols) [Tasca and Tessone 2017]. At the core of blockchain lies its so-called ledger, which records transactions over time. As transactions are made, they are clustered into blocks. A block is always inherently linked to the previous block through cryptographic seals. This ensures, that once data is changed after entering the blockchain or a block is removed, the system will notice the change and prevent it. Often called a disruptive technology, blockchain enables applications beyond the specific case of Bitcoin as currency. With this new kind of distributed software architecture, it is possible to operate a trusted, immutable ledger. Parties can execute and store any kind of peer-to-peer transactions over the internet without the need of a trusted intermediary party. The technology evolved over time and various other blockchain-implementations exist to date. They satisfy different requirements for other use cases. At BETH, two of them (Ethereum and Hyperledger Fabric) were introduced and the teams encouraged to use them for their solutions. We will provide a short description of them here with their most important characteristics. Afterwards, we summarize benefits of blockchain in general.

Ethereum[2] is one of the most well known blockchain technologies. It introduced the possibility to execute code on the application layer of its blockchain, the so called *Ethereum Virtual Machine* (EVM). This enables the use of smart contracts, described the first time by Szabo [Szabo 1994]. These self-executing and unchangeable scripts open up a large scope of applications.

[1] `https://bitcoin.org/en/`, accessed 08.04.2019

[2] `https://www.ethereum.org/`, accessed 08.04.2019

They allow for automated and self-executing conditions based on the state of the ledger. At the same time, the unchangeable ledger can be accessed and read by everyone, leading to high transparency. Furthermore, transactions can be initiated with no restrictions and everyone is allowed to own a node by creating a copy of the blockchain and add it to the network. We call this a *public permissionless blockchain*. How the blockchain ensures that no one can alter the ledger is beyond the scope of this report. But such systems imply a high level of trust and transparency in the technical system.

Hyperledger Fabric[3] is a blockchain that also allows the use of smart contracts. But in contrast to Ethereum, it is a private permissioned blockchain, which means that only allowed parties can access the ledger and initiate transactions. Fewer nodes are owned by known parties. Such a more centralized system offers a better performance (scalability and latency). In addition, privacy can be of concern with public blockchain technologies, if data encryption is considered too weak of a protection or parties want to have the possibility to control more aspects (e.g. for easier implementation of system changes). However, using a private blockchain often still requires trust in the party operating the system, something that is not needed in public permissionless blockchains. Finally, these private systems consume considerably less energy than public blockchains[4].

Independent from the used technology, the general promise of blockchain includes the following benefits (based on [Viryasitavat et al. 2018]):

- Potential to increase trust between parties and devices and reduce the risk of collision and tampering due to the transparent, immutable record of transactions.
- Potential to accelerate and automate transactions through the use of smart contracts.
- Potential to reduce cost by removing overhead related to middlemen and intermediaries.

2.2 IoT

The *Internet of Things* (IoT) describes an environment where physical objects connect with the digital world, having sensors and connected devices allowing to monitor and sense the environment with high spatial and time resolution [Fleisch 2010]. Each device is identified by a unique ID (UID). The devices communicate independently and do not require human interaction. An example for such a system is smart home automation where sensors register the presence of a human and adjust the lightning, heating or air conditioning accordingly allowing for a more efficient use of energy [Meola 2016].

One of the first applications was established at Carnegie Mellon University in 1982. Three computer science students, Mike Kazar, David Nichols, John Zsarnay and Ivor Durham, implemented sensors into a coke machine. It was then possible to query the number of remaining coke bottles via the Internet [Kazar et al. 1998].

[3] `https://www.hyperledger.org/projects/fabric`, accessed 08.04.2019

[4] This is only true for public blockchains operating on "proof-of-work". Ethereum intends to switch to "proof-of-stake", which would considerably decrease its energy consumption. For further information see: `https://github.com/ethereum/wiki/wiki/Proof-of-Stake-FAQ`, accessed 24.04.2019

In 1991, Mark Weiser published a paper on ubiquitous computing [Weiser 1991]. He described how technology became more and more important in people's lives, but without them being aware of it. His vision aligns with many of characteristics of what we call IoT today.

The term *Internet of Things*, however, was only first mentioned by Kevin Ashton in 1999 when giving a presentation about radio frequency ID (RFID) to Procter & Gamble. Over the years, more and more devices were added to the network. According to the Cisco Internet Business Solutions Group, the number of connected devices surpassed the number of people on this planet between 2008 and 2009 [Evans 2011]. They predicted a number of 25 billion devices by 2015 and double as many five years later. The reason for this increase is the increasing number of people connected to the Internet, the relatively cheap costs of producing devices and the opportunities that a connected world offers, in particular for economic reasons.

Since its beginnings, the Internet of Things has gone a long way and it has become increasingly important. More and more devices are densely connected with each other and the Internet. Oftentimes, the devices are sensors collecting data that are then saved in a database for further processing. In many traditional applications, IoT requires a centralized instance where the IoT devices send their collected data. Centralized instances can fail or be tampered with. On the contrary, a distributed ledger like blockchain tends not to suffer from bottlenecks and handles data integrity by design. Therefore, using a blockchain for managing sensor data solves many of these challenges and allows for more autonomy in the system.

Moreover, the value of blockchain stems from the immutability and transparency of the data in the ledger and its automation (see chapter 2.1). One challenge with this is the entry of data into the ledger. If the process is manual, human error and data manipulation can occur before or while entering data. IoT is also seen as a promising solution in this regard, acting as so-called automatic oracles for data input to the blockchain. The data entering can be automated, and multiple redundant devices can increase the likelihood that entered data is trustworthy.

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Solution

3.1 Overview

The team aDappter created a solution for the "SwissEnergy challenge" (see Section 1.3) at BETH2019 - a decentralized application (Dapp) to incentivize Swiss households to reduce their CO_2 consumption. Dapps are distributed applications based on blockchain technology. They consist of the back-end for the data processing and application logic, in our case the Hyperledger Fabric blockchain, and a front-end to allow for user interaction, in our case a browser based web-application. Data input (oracles) is solved through IoT sensors that automatically measure the oil consumption in households. In this chapter we describe the functionality and idea of our solution. Section 3.2 describes in more detail the blockchain back-end, Section 3.3 the IoT part,

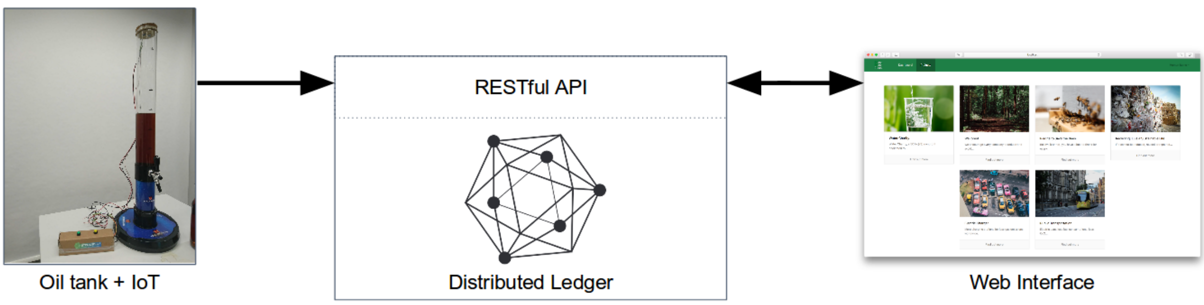

Figure 3.1: *The three main components of our prototype. On the top left we have our IoT device, called Olga. It measures the volume of the consumed oil and sends this information to the distributed ledger. As an interface, we use a RESTful API. The third component is a web app, that allows the user to view consumption statistics and invest aDappter Tokens into sustainable projects.*

and Section 3.4 the front-end web-application. Finally, we discuss our solution, its limitations, and future improvement possibilities in Section 3.5.

Using blockchain and IoT for our solution brings various benefits. The blockchain ensures a high level of transaction automation with transparency towards the users. The system can operate in a fully automated way without any middleman. The token distribution and funding of the projects is done through smart contracts. This ensures towards the users, that if they allocate the funds through voting with their tokens, these projects also really get funded. Furthermore, the transaction record of CO_2 consumption is very transparent and cannot be altered. Combined with IoT, no human involvement is needed to enter the data into the blockchain. It is a system created to empower the Swiss citizens to shape their environment as they wish and without involvement of third parties, aligned with the sustainability goals of decreasing CO_2 emissions through less energy usage in Switzerland.

3.1.1 Vision

The vision of aDappter is to track and reduce CO_2 consumption of all households in Switzerland. The CO_2 emissions may come from any source (heating, mobility, consumer behaviour, etc.). The tracking allows for a comparison between similar households (based on properties of the household, such as size, building age, etc.) and identifying households with large potential for improvements. These households are incentivized to take actions for reducing their CO_2 emissions. Such actions may be an improvement of their building isolation or heating system, a change in the mobility behaviour, etc.

The system works in the following way: aDappter tracks the CO_2 savings and awards aDappter Tokens for households who produce fewer emissions than an average household in the the same category. The awarded tokens represent a monetary value, which can be invested into sustainable projects benefiting their local communities.

aDappter includes both a competitive aspect (households might want to show off their improvements compared to others), as well as a gamification and empowerment aspect (collecting Tokens and using them for a good cause). The competitive environment increases the motivation to be better than the other participants. As the ledger is public, each one can compare its consumption to others. The system is created as a so-called opt-in system. This means that it is optional to participate. Furthermore, everyone can start participating without needing to fear that they can loose something. There is no punishment for being above the threshold. Like this, there is no need to enforce of the system by law. The downside is that the funding pool for the sustainable projects that can be voted for by earned aDappter tokens, needs to be partially financed externally. A potential setting could be that the government or NGOs (like ProNatura, WWF, ...) put a price on each ton of CO_2. These are the funds that are then represented by the aDappter tokens. An alternative could the a tax-based solution[1].

[1] *CO_2-levy.* Currently, Switzerland puts a price of 96 CHF on a ton of CO_2 produced by fossil fuels. `https://www.bafu.admin.ch/co2-abgabe`, accessed 22.4.19

3.1.2 Prototype

One of the heaviest producers of CO_2 emissions today are oil-based heating systems. Therefore, in our prototype implementation, the CO_2 consumption is calculated for oil heating systems. Figure 3.2 depicts the high-level process of our system in more detail. aDappter sensors measures the oil consumption per time interval (e.g. month) and stores a record on the distributed ledger. The savings of oil can be converted into savings of CO_2. If the consumption was less than a baseline (based on the household size), aDappter tokens are awarded. Those tokens can then be invested into sustainable projects.

The token distribution is explained in Figure 3.3.

The calculation of the baseline and token distribution works as follows:

1. IoT sensors measure the volume of the consumed oil V_{cons} in liters on a monthly basis.
2. The measurement is recorded on the ledger.
3. The consumption V_{cons} is then converted into tons of CO_2 emissions. 1000 liters of oil correspond to 3.16 tons of CO_2 emissions[2].
   $E_{org} = \frac{V_{cons}}{1000} \times 3.16$
4. The emissions E_{org} are divided by the household area A yielding the normalized emissions per square meter.
   $E_{norm} = \frac{E_{org}}{A}$
   Then, the normalized emissions E_{norm} are compared to a baseline. For our prototype, we used a baseline consumption of $V_{base} = 1.25l/m^2$ per month, which corresponds to a monthly CO_2 emission of
   $E_{base} = \frac{V_{base}}{1000} * 3.16 = 0.00395$ t per m^2.
   We calculate the difference Δ by subtracting the actual normalized CO_2 emissions E_{norm} from the baseline emissions:
   $\Delta = E_{base} - E_{norm}$
5. If the normalized consumption is higher than the baseline ($\Delta \leq 0$), the household did not do well enough and hence, does not receive any aDappter Tokens.
6. If the consumption is lower than the baseline ($\Delta > 0$), the household did well and receives aDappter Tokens. In order to calculate the monetary value of the CO_2 emission savings, we apply the current price of the CO_2 levy on fuels (96 CHF per ton of CO_2[3]). The household receives the following number of aDappter Tokens.
   $T_{aDappter} = \Delta \times 96 \times A$
7. The received aDappter Tokens accumulate over time and can be invested into sustainable projects benefiting the local neighbourhood.

[2] `https://www.bafu.admin.ch/bafu/de/home/themen/klima/publikationen-studien/publikationen/projekte-programme-emissionsverminderung-inland.html`, accessed 26.4.19

[3] `https://www.bafu.admin.ch/bafu/de/home/themen/klima/fachinformationen/klimapolitik/co2-abgabe/erhebung-der-co2-abgabe-auf-brennstoffen.html`, accessed 26.4.19

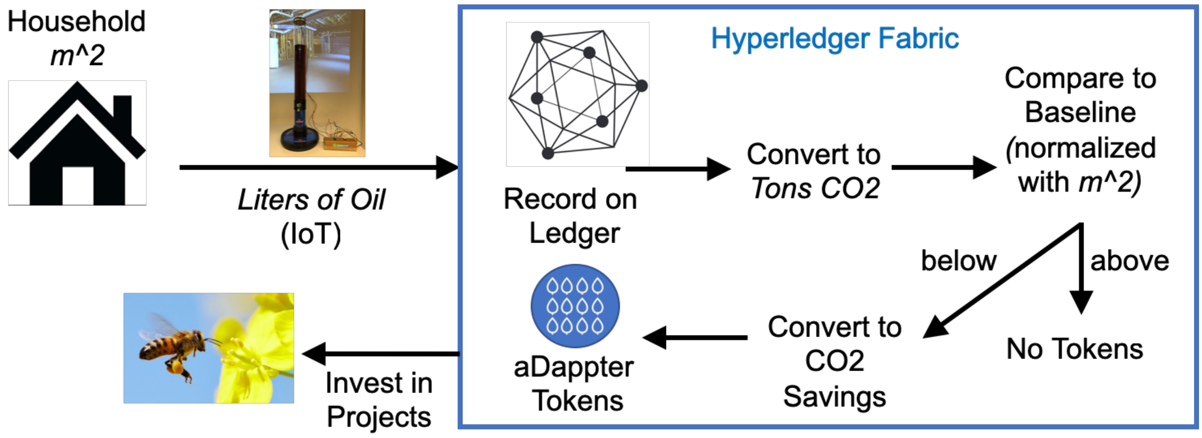

__Figure 3.2:__ Example workflow for our prototype. We have a household of a certain size (given in m^2). This household has an oil tank. aDappter measures the oil consumption per time interval (e.g. month) and stores a record on the distributed ledger. The savings of oil can be converted into savings of CO_2. If the consumption was less than a baseline (based on the household size), aDappter tokens are awarded. Those tokens can then be invested into sustainable projects.

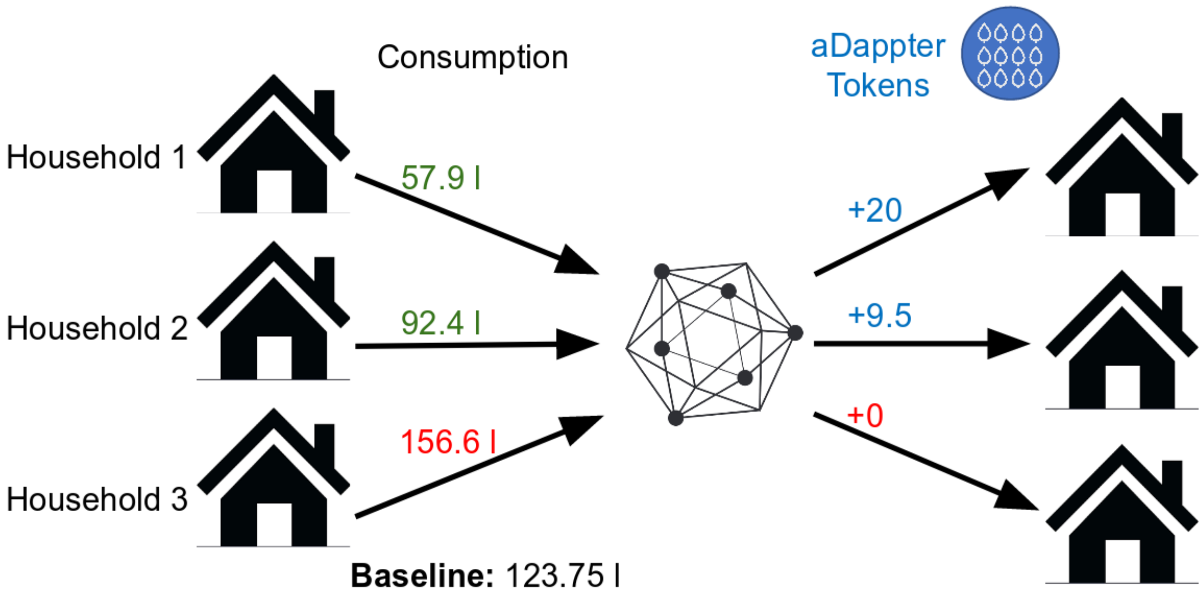

__Figure 3.3:__ Exemplary illustration of the aDappter token distribution for an average-sized household ($A = 99m^2$). For each household, the volume of the consumed oil is recorded on the ledger. The ledger compares the consumption with the baseline and awards aDappter Tokens to households who did better than the baseline.
In this example, we have three households of the same size. Household 1 only consumes 57.9 liters of oil, which is significantly below the baseline. Hence, the ledger yields 20 aDappter Tokens. Household 2, who does not do as well, but still better than the baseline, is awarded 9.5 aDappter Tokens. Household 3 consumes more than the baseline and does not receive any Tokens.

3.2 Blockchain

We created an interactive, distributed network for CO_2 emission tracking using the Hyperledger Fabric Framework. Data about household energy consumption is stored in the ledger, converted into CO_2 emissions, and incentive tokens are distributed based on the achieved CO_2 savings compared to the overall baseline of all households.

One additional prerequisite to the stated "SwissEnergy challenge" (see Section 1.3) was that the blockchain should consume as little energy as possible, since the ultimate goal of the whole solution is to save on CO_2 emissions. This was one reason to choose the private blockchain-framework Hyperledger Fabric over the public Ethereum framework. This means that nodes need to be hosted and payed for by some known parties, that are also trustworthy when it comes to validating transactions. Since the Swiss government is assumed to be trustworthy and has a neutral stance towards this solution, we assumed that it is feasible that they host nodes without compromising the trustworthiness of the decentralized application. If also other parties like cantons or third party organization host nodes, the network should be sufficiently decentralized. More benefits of Hyperledger Fabric over Ethereum include the faster transactions and no transaction fees.

We used Hyperledger Composer[4], which comes with components to develop and test the business logic and fire up a RESTful server to connect the web app and IoT sensors via a REST API. The Composer components connect to the Hyperledger Fabric blockchain to facilitate and store transactions.

In the following, we explain the most important business logic of our implementation. Detailed instructions about how to install the prerequisites, deploy the business network, and start the REST Server can be found in the documentation of Hyperledger Composer[5]. The application code is located in the blockchain folder of our Github repository[6].

The *org.energy.network.cto* file defines the participants, assets, and transactions. We define two participants:

- *ProjectOwner*: A project owner has the right to create and delete projects (see project asset). The owner has the following attributes:
  - *"ID"*: unique identifier.
  - *"name"*: name for more context.
- *Consumer*: A consumer represents one household. The consumer has the attributes:
  - *"consumerID"*: unique identifier.
  - *"zipCode"*: zip code to know where the consumer is located for comparison.
  - *"flatArea"*: area in m^2 to normalize the CO_2 emissions.
  - *"balance"*: is 0 after creation and indicates the earned tokens over time.

[4] `https://hyperledger.github.io/composer/latest/`, accessed 09.04.2019
[5] `https://hyperledger.github.io/composer/latest/business-network/business-network-index`, accessed 09.04.2019
[6] `https://github.com/betherworld/aDappter/`

  - *"assignedTokens"*: is 0 after creation and shows how many tokens have been assigned to projects.

We define three asset types in our blockchain ecosystem:

- *Emission*: Created once per month for each consumer to carry all the data of the emission. Attributes:
  - *"emissionID"*: unique identifier.
  - *"litersOil"*: liters of oil consumed this month.
  - *"delta"*: difference to the baseline.
  - *"savedAmount"*: dollars amount of savings to issue tokens.
  - *"timeStamp"*: time of creation.
  - *"baseLine"*: baseline for comparison.
  - *"owner"*: consumer of this emission.
- *Project*: defines a possible project consumers can donate their tokens to. Attributes:
  - *"projectID"*: unique identifier.
  - *"projectTitle"*: title.
  - *"projectDescription"*: detailed description.
  - *"projectBalance"*: balance of tokens donated to the project.
  - *"tokensGoal"*: needed tokens to fund the project.
  - *"status"*: either "open" or "completed" when the funding goal was reached.
  - *"owner"*: projectOwner of this project.
- *Token*: this asset will be generated when consumers are below the baseline and assigned to the respective consumer. They can be donated to fund projects. Attributes:
  - *"tokenID"*: unique identifier as the tokens are non-fungible, meaning they can only be used by the consumer and the funded project and will not be redistributed afterwards.
  - *"owner"*: owner of this token at the moment. First the consumer, then the funded project.

Transactions are responsible to execute the business logic (smart contracts), defined in the JavaScript file *logic.js*. They need to be triggered by a participant using the Hyperledger Playground web interface, or through API calls of the IoT sensors or the aDappter web app. The following transactions can be called:

- *createEmission(litersOil, owner)*: This function is called monthly when an emission transaction is submitted from a particular household (consumer) through an API POST request of the IoT sensor. The necessary input parameters are the liters of oil consumed, as well as the consumer (household). The logic creates a new asset *Emission* and calculates the saved CO_2 emissions in $ in this household using the *CalculateEmission* function in the *logic.js* file. It generates the *Token* asset for the respective *consumer* on a 1:1 basis to $ saved, calling the *GenerateToken* function. It then updates the token balance of the owner with the newly earned tokens. These emission transactions persist in the Hyperledger Fabric blockchain and form an emission history of each participating household.

- *assignToken(amountTokens, owner, assignedProject)*: This function lets homeowners donate their tokens to projects. They need to call the function with the input parameters of the amount, their ownerID, and the projectID they want to assign tokens to. The idea is to let homeowners do this via the aDappter web app via a POST API request. The logic of the function checks whether the transaction is valid, by checking the balance of the owner and the status of the project.
- *getToken()*: This transaction queries all tokens and returns tokens owned by a specific consumer. It can be called by the aDappter web app via an GET API call to check the balance of a homeowner.
- *getAreaEmissions()*: This transaction queries and returns all emissions. The function can be called by the aDappter web app for statistical analysis and representation of the data.

With these functionalities, our blockchain backend supports the most important features of our application. Future work would need to refine and extend these. Especially, more endpoints for more detailed requests could be implemented. Most importantly, the access control and permissions of the blockchain need to be defined in the *permissions.acl* file. At the moment, every user has the right to create new participants. With this, also new assets can be created, leading to full control of the blockchain's features.

3.3 IoT

Every month, the oil consumption of each household is shared with the blockchain to eventually receive tokens due to the lower consummation compared to a baseline. We wanted to create a solution that didn't need any human interaction, therefore we decided to program an IoT device to calculate and to publish the monthly oil consumption in the Hyperledger Fabric blockchain.

The first main functionality of the IoT is to calculate the oil consumed in cubic meters between each measurement. To achieve this result we decided to use an ultrasonic sensor glued on top of the cap of the oil tank, pointing towards the liquid. The device is then able to calculate the volume of the empty part of the tank by using the distance (called Δ_{height}) between itself and the fluid surface. In our demonstration (shown in Figure 3.4) we used a cylindrical tank, therefore we used the following formula to calculate the volume: $V = radius^2 * \pi * \Delta_{height}$.

The consumed amount of oil between different measurements in cubic meters is calculated as the difference between the current volume and the volume of the previous measurement. To be more precise, upon refilling of the tank, an operator can reset the initial volume (V_{init}) to the current volume value by pressing a button. When a new measurement is needed, the new volume value (V_{new}) is calculated and the consumed volume is the difference between V_{new} and V_{init}. After the measurement, V_{init} is set to V_{new}.

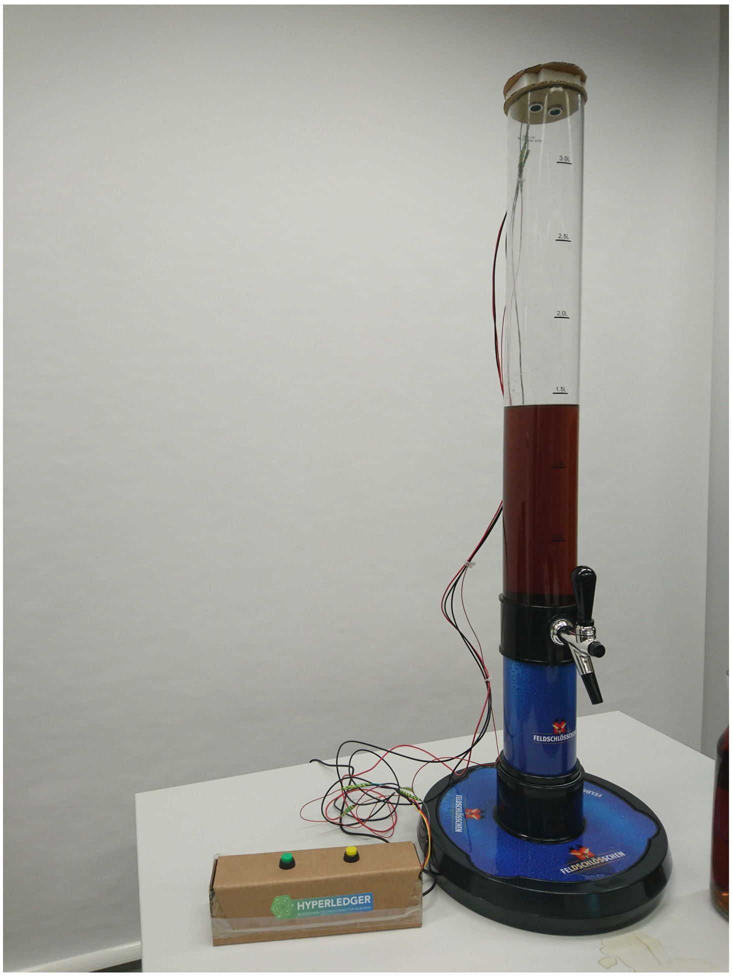

Figure 3.4: *Olga - our IoT demonstration tower simulating the fuel tank. The cardboard box contains the Wemos D1 mini board. The ultrasonic sensor is glued on top of the tower to measure the liquid level in the tank.*

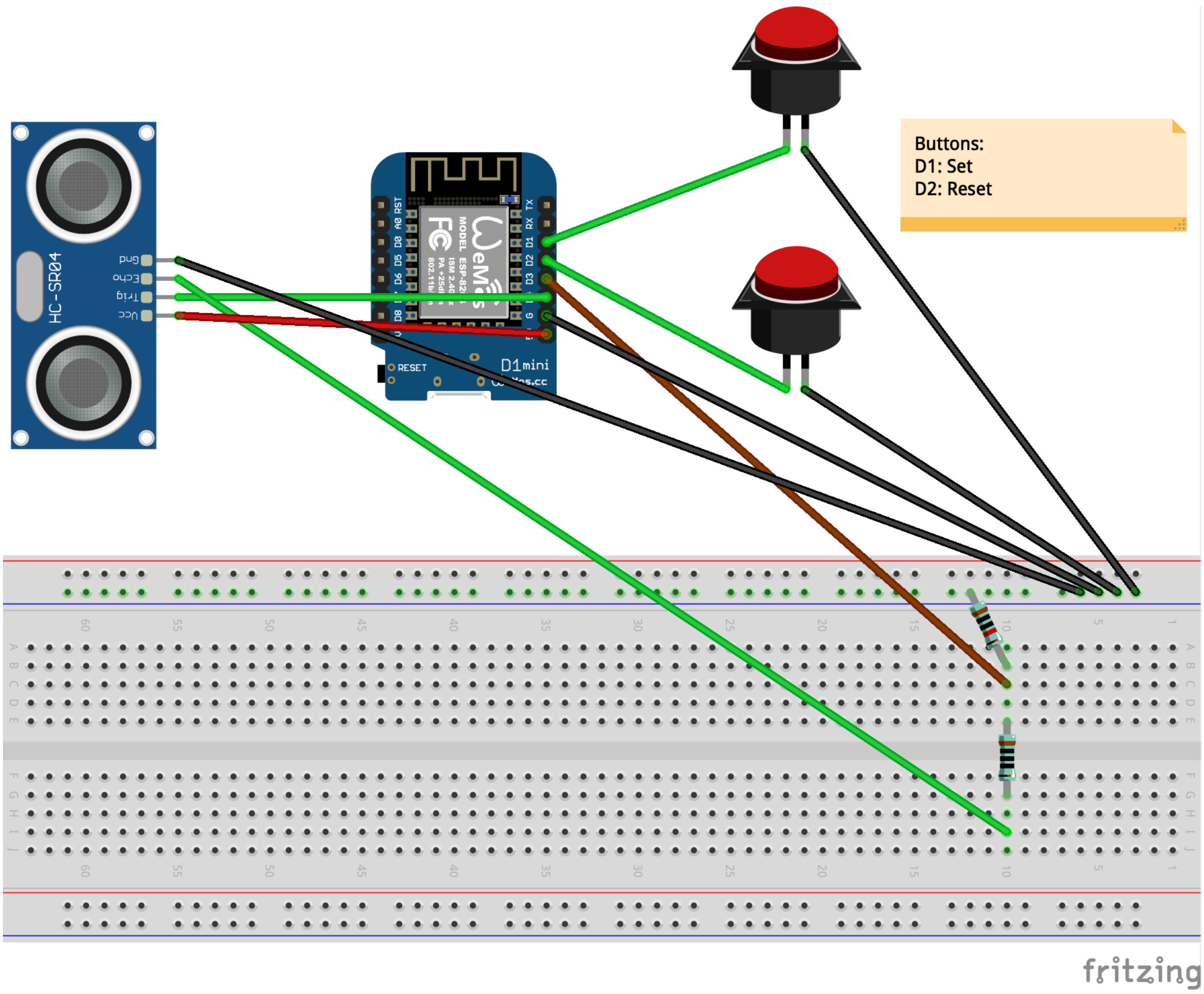

Figure 3.5: *Schematic view of the IoT device. A Wemos D1 mini board is connected to a ultrasonic module HC-SR04 and two buttons: the "set" button is connected via D1 port, while the "reset" button uses D2 port. The lower resistor is* $100\ \Omega \pm 1\%$*, while the higher one is* $10k\ \Omega \pm 2\%$.

The second functionality is to send the results on the blockchain. This is done by using a RESTful API. In a real environment, the IoT device would "wake up" once per month to calculate the used oil and it would publish it on the blockchain by perform a request to the blockchain in an automated fashion.

Finally, we present the specifications of our IoT device, named Olga. The board is a Wemos D1 mini, connected with two buttons and a ultrasonic module HC-SR04. The connections are shown on Figure 3.5. An Arduino is connected with the sensor using two resistors: the lower one is a $100\ \Omega \pm 1\%$ resistor while the second one is $10k\ \Omega \pm 2\%$ resistor. Furthermore, thanks to the pull-up support of the Wemos board, we didn't need any resistor for the button.

As soon as the board is started and the sensor is located in the correct position (during our demonstration we used a beer tower filled with water and coffee), the initial volume must be reset by pressing the "reset button" (in Figure 3.5 it is the one connected to port D2). Then, upon pressing the "set button" (the one connected to port D1), the oil consumed is calculated

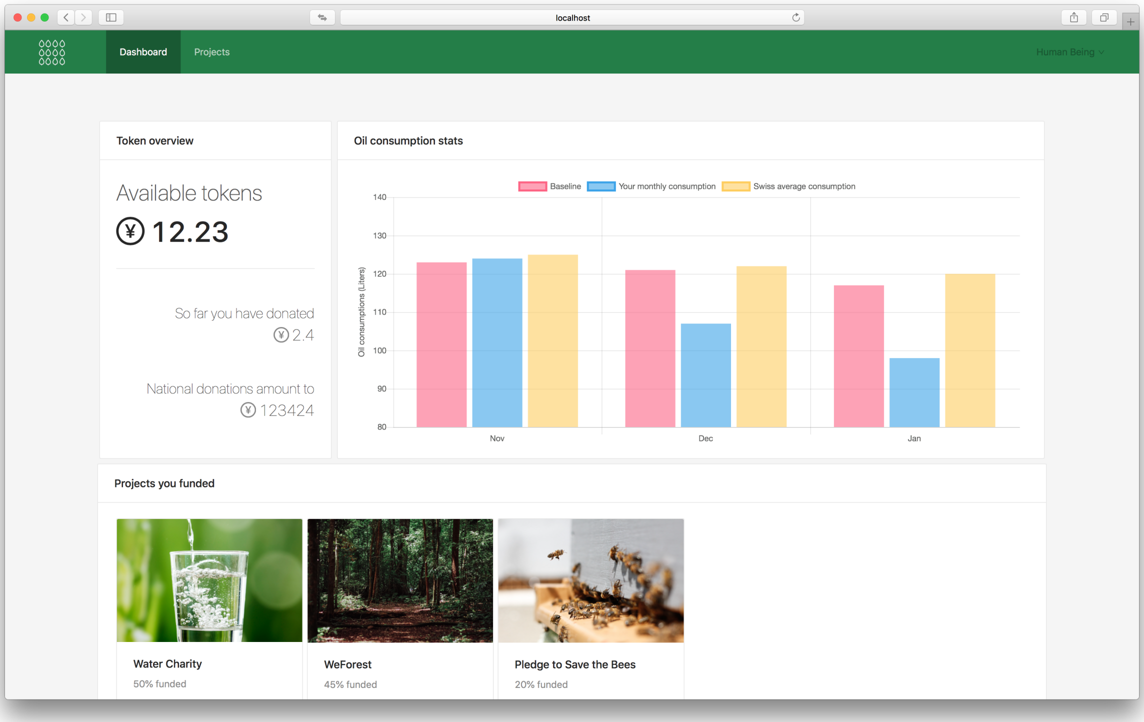

Figure 3.6: *Dashboard of the web app. The information of an example user are shown; mainly, information about tokens in the top-left box, statistics about consumption in the top-right box and projects founded by the user in the bottom box.*

and sent to a blockchain.

To conclude the specifications, we used different libraries to integrate the ultrasonic sensor and the WiFi card (integrated in the board) with the Arduino board. For the ultrasonic sensor we used `arduino-lib-hc-sr04`[7] library, while for the WiFi and the HTTP requests we used the official `ESP8266` libraries[8]; namely `ESP8266WiFi`, `ESP8266WiFiMulti`, `ESP8266HTTPClient`.

3.4 Web app

Our group decided to create a web app so that householders can see the status of the projects they founded, the amount of tokens each member has and to discover new projects to spend tokens on. Furthermore, thanks to personalized charts, each user can compare its monthly consumption to the national average and the baseline. This feature should spur a sort of race between participants so that the consumption get lower and lower every month.

The web app is connected to the blockchain by using the RESTful API served by the Hyperledger Fabric server. Upon login, the main page, called dashboard, is served and shows all the

[7] `https://github.com/Martinsos/arduino-lib-hc-sr04`, accessed 24.04.2019
[8] `https://github.com/esp8266/Arduino/tree/master/libraries`, accessed 24.04.2019

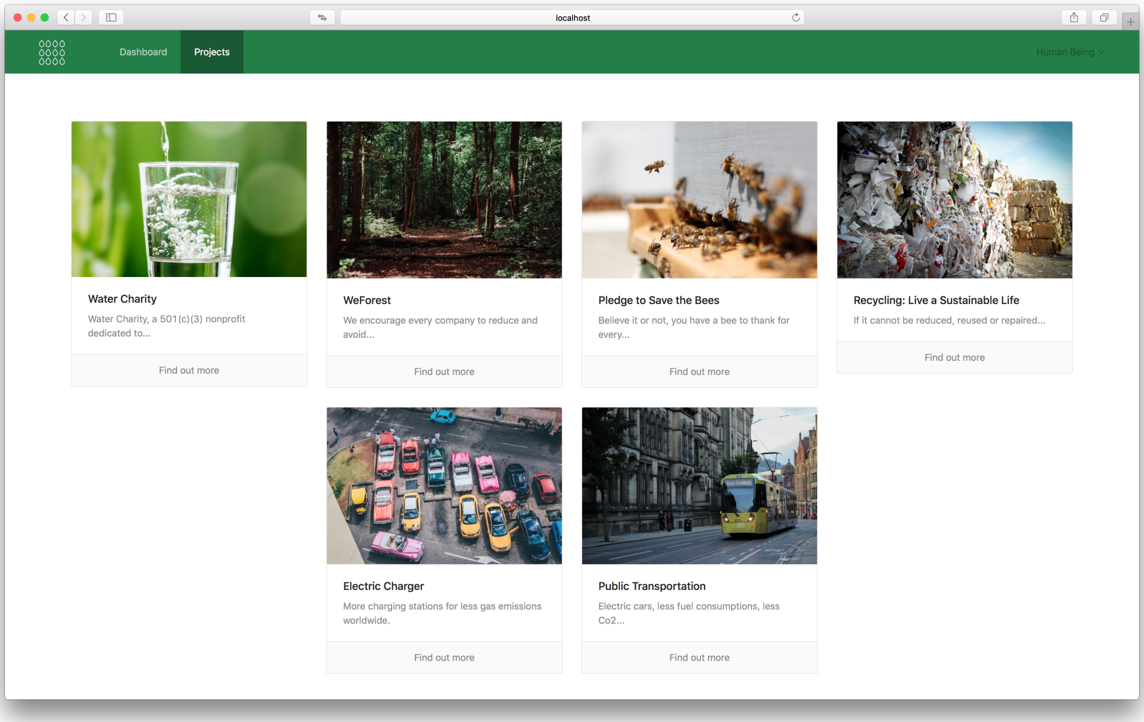

Figure 3.7: *Project descriptions. The page contains all the projects that can be founded and, by clicking a project, it is possible to see the corresponding project description*

information of the logged user, mainly the amount of credit he has, some comparison between his consumption versus the baseline and the national average and, finally, the list of projects that he founded. Figure 3.6 shows how the dashboard looks like. The second main page is the one showing the list of projects that can be founded and the relative descriptions. From this page, an interested user can donate his tokens to the project he prefers. Furthermore, from the project description it is also possible to see the tokens already donated and the final goal to start the development. Figure 3.7 shows the graphic of the page that lists all the projects currently available.

From a technical prospective, the web app has been created by using Angular 7.2.4[9] and developed under the official style guidelines[10].

3.5 Discussion & Future Work

In the previous Sections, we described our solution for the "SwissEnergy challenge". First, we discuss general aspects of the system design and pose questions that need to be answered for real-world implementation. In a second step, we state some of the technical limitations of the current implementation and future work related to it.

[9] `https://angular.io/`, accessed 24.04.2019
[10] `https://angular.io/guide/styleguide`, accessed 24.04.2019

Discussion points related to the systems design are:

1. The success of such an opt-in system is strongly related to the adoption of people using and participating in the solution. Is the introduced incentive design strong enough to engage people so that they take action?
2. Assuming the opt-in system is working, the funding pool needs to be sustainable without creating direct revenue streams from the users towards it. Is the assumption of external funding opportunities such as governmental tax funds or funds from third-parties justified?
3. If point 1. and 2. are not given, would a forced participation from governmental side solve it? In that case one could introduce penalties being above average in CO_2 consumption that fund the projects. How would citizens react to such a system?
4. Assuming the system works and households become more efficient over time, how does the system stay attractive?
5. Implementing such a system is not free. Who finances the initial development of the decentralized application? Who runs and pays for the servers later on?
6. Is the system only for households or also for industry? Would they participate in the same system or have a separate one with different baselines and incentives?
7. Who decides on which projects can be funded? In theory, there could be a second system in place, so that users below the baseline can also propose new projects. But if users can propose them, who checks the feasibility and appropriate budget? Furthermore, funding opportunities are limited. How to decide which projects have priority? Token curated registries (TCR)[11] for decentralized, user-based voting could be a topic of future investigation to solve that issue.
8. At the moment, the baseline is assumed to be fixed for all regions and time-spans. However, in reality the baseline is strongly dependent on geographic location (e.g. mountain regions are colder and need more energy) and seasonality (e.g. if the baseline is calculated on a yearly average, during wintertime most probably everyone would emit more CO_2 due to heating). A more dynamic and fair calculation of the baseline should be investigated for all regions, ideally also on a monthly basis.
9. We only measure in our solution the CO_2 emissions from oil heating systems. In the future, the solution should include all major CO_2 emission sources, such as electricity, gas, water, mobility, ...
10. The privacy needs should be thoroughly investigated. At the moment, each household has its own ID, and a normalized CO_2 consumption is only referenced with this ID every month. So, no name and absolute CO_2 emission is written into the blockchain. Also, real-time data of energy usage is not shared. Is this enough privacy protection? On the one hand, transparency on CO_2 emissions reinforces the incentive to change due to competition. On the other hand, this data might still be misused. More advanced privacy methods should be investigated if they are compatible with the system, such as differential

[11] see `https://hackernoon.com/token-curated-registry-tcr-design-patterns-4de6d18efa15`, accessed 08.04.2019

privacy[12], saving only hashed[13] values in the ledger, or others.

11. It needs to be decided who will run the different nodes of the blockchain in the future to ensure enough decentralization. Only the government? Also different communities, cities, or organizations?

The presented implementation still needs a lot of work to improve and finish its full functionality. The most important next working steps are:

1. Connecting the web-application to the RESTful server of the blockchain.
2. Defining access control and permissions of the blockchain. Currently, all users can create all assets and perform all transactions.
3. Extending the functionality of the system for more CO_2 emission sources. This involves adding additional sensors and additional features in the web app benefiting the users. The blockchain back-end should be adjusted with more endpoints and a more dynamic baseline calculation.

[12]see `https://en.wikipedia.org/wiki/Differential_privacy`, accessed 08.04.2019
[13]see `https://en.wikipedia.org/wiki/Cryptographic_hash_function`, accessed 08.04.2019

Conclusion

In this report we introduced and described *aDappter*, our solution to the "SwissEnergy Challenge" at the BETH2019 hackathon (see Section 1.3). We believe that our system is able to satisfy both criteria of the challenge by tracking and storing CO_2 data of households over time, as well as introducing an incentive system that allows users without any intermediary to benefit from their savings through reinvestment in sustainable projects. Our solution consists of three main parts. The core component and back-end of the application is the Hyperledger Fabric blockchain (see Section 3.2). It stores the CO_2 history and enforces the logic of our solution through smart contracts. If the CO_2 emissions are below the baseline, tokens are emitted to the respective household, which can be used to fund sustainable projects. The second core component is the IoT sensors (see Section 3.3), which measure the oil level of heating systems in households and send the data to the RESTful server of the back-end. Using sensors for this task ensures full automation of the process. We successfully demonstrated this functionality with our demonstrator Olga. The third and last component is the web app (see Section 3.4), which allows users to interact with the system by accessing the RESTful server of the back-end. They can track and compare their emissions with their neighbourhood, the canton, and Swiss average consumption. Furthermore, they manage and spend their tokens for the available sustainable projects. Overall, we believe that our solution aDappter represents a good starting point for a real-world implementation.

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