An e-marketplace system for efficient, sustainable rural logistics and mobility, based on cyber-physical contracts

Enhancing rural infrastructure by connecting stakeholders on a privacy-focused web platform

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Abstract: Due to demographical changes and urbanisation, rural areas often lack sufficient transportation and mobility infrastructure compared to urban regions. As a result, residents feel more socially excluded and need to travel longer distances to access basic goods and services with private car use as the only viable option. This situation is a significant driver of carbon emissions among rural populations. In this paper, we present an e-marketplace system, that aims to help in reducing the number of trips by connecting regional stakeholders and using local resources more efficiently. Our approach focuses on self-organising communities while following high standards of privacy and security. We use cyber-physical contracts within a decentralised network for communication between users and show how this network of services can be represented on a web platform for everyone to access and participate.

Keywords: Webapp, Cyber-Physical Contracts, Rural Development, Logistics, Mobility, Self-Organisation

1 Introduction

In the past decades, the globalisation of supply and value chains, demographic changes and a trend towards urbanisation have taken a toll on rural areas all over the world [LBG19; SG15]. In Germany, we see these demographic changes in the form of a general decline in population and an ageing in rural areas, due to migration to cities, especially among younger people [GP15; Bu23; Sa14; BRT19]. This development leads to a gap between metropolitan and rural regions in terms of infrastructure and access to basic goods and services [Te21]. In rural areas, there is a decreasing offer of jobs, cultural and social facilities, food retailers, medical care and education, as suppliers, for example supermarkets and discounters, agglomerate in towns and cities with higher population and demand [Bu23; NK21; Bo16] or are being supplemented by large online marketplaces [An23].

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As a result, residents of smaller villages feel generally more socially excluded [OCE11] and need to travel longer distances to meet their needs. Since public transport is also lacking in most rural areas [Bu23], the vast majority of people rely on private cars, which pose the most commonly used mode of transportation [NK18; NK21; Bu23]. It has been found that this situation is a significant driver of carbon emissions and increases the carbon footprint of rural populations [SG15; GM18]. Although we are focusing our research on the situation in Germany, we can observe these trends and problems all across the world [LBG19; SG15; Te21; Ve12; BI19].

In order to contribute to the solution of this problem, we introduce an e-marketplace system, tailored to rural communities. Our goal is to reduce transportation emissions by creating a more efficient and sustainable value and supply chain in these regions through a novel approach. Existing and capable providers of goods and transportation often fail to deliver these to remote areas, due to low demand and economical reasons [Bo16]. Therefore, we consider decentralised self-organisation and a more condensed supply chain to be a viable solution. Our e-marketplace system connects regional stakeholders and users with each other, in order to utilize and promote existing potentials and resources in rural communities. We aim to incentivise people to share trips or to combine deliveries, leisure trips and commutes to reduce the overall private car use, consequently leading to a decrease in emissions. Also, when goods and services are consumed closely to where they are produced, this effect can be additionally amplified. Technically, we set high standards for security and privacy in our system, so we used a novel alternative to smart contracts, called cyber-physical contracts, for communication [CD20, CSD21]. Finally, the e-marketplace was developed as a progressive webapp to ensure a broad accessibility and usability. In the following sections, we introduce related work, describe our system architecture and the implementation of the e-marketplace.

2 Related Work

Cyber-physical contracts represent an alternative to conventional smart contract systems, focusing on decentralisation, privacy in online communication, freedom of speech, and transparency for digital interactions. By using transparent contract templates, written in natural language, users can digitize generic processes without programming experience. Every piece of information exchanged during contract execution is protected through encryption. Both manual and automated contract processes are supported, without the use of Blockchain or cryptocurrencies. The concept of cyber-physical contracts was published in [CD20]. Furthermore, the reference implementation Fides, that we are using, was made open source and published in [CSD21]. The work in [CWD22] enhanced the implementation to enable participation in digital contracts via LoRaWAN in regions without internet connectivity. An independent legal opinion in [SBM23] also confirmed,

that cyber-physical contracts can be legally binding and affirmed their greater legal security compared to conventional smart contract systems.

There are some similar works and projects that rather focus on single aspects of our system, for example "Smart Emma"[2], "Regiothek"[3] or [SW22] also aim to connect local suppliers or mobility on a web platform. Self-organisation and crowd logistics in rural areas are researched in works such as [Fi20] or [Gr24]. To the best of our knowledge, there is no similar approach that combines decentralisation, social self-organisation and privacy through cyber-physical contracts to connect actors on a web-based e-marketplace in a rural scenario.

3 System architecture

The foundation of our system architecture is Fides and its proposed distributed network. The idea is, that a group of people (e.g. a community, a village or a whole region) is able to self-organise by setting up their own network and letting interested parties participate. Thus, secure communication between users via private, decentralised cyber-physical contracts is enforced. Following the protocol [CD20; CSD21], when someone wants to offer a service to the community, this can be represented by a template, published in the network and identified by its hash. Fides offers no tool to search for templates within the network, due to privacy reasons, so the e-marketplace acts as a searchable catalogue of services and demand. This architecture is visualised in Fig. 1.

[2] https://www.efre.nrw.de/daten-fakten/gute-praxisbeispiele/smart-emma-frische-produkte-online-bestellen/ (28.06.24)
[3] https://www.regiothek.de/ (28.06.24)

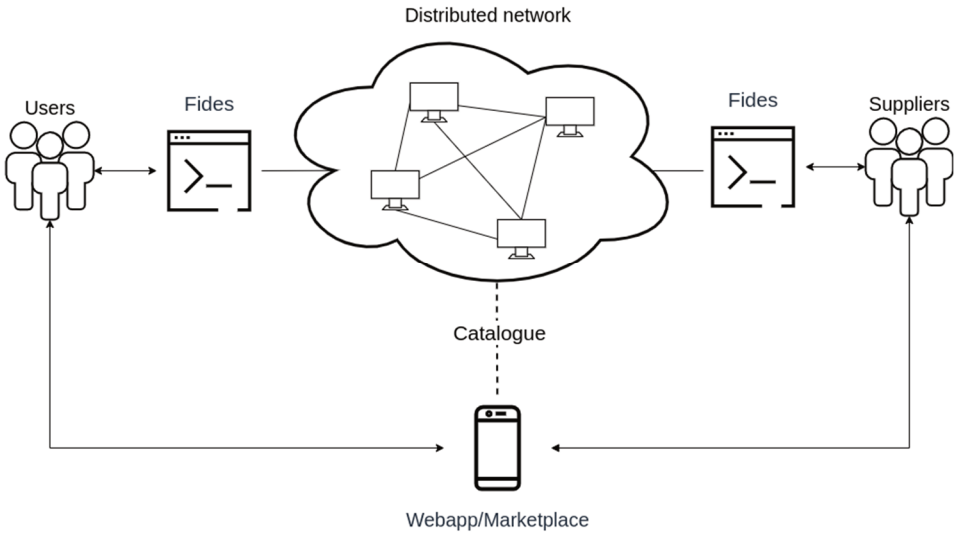


Fig. 1: Conceptual architecture

In summary, when a supplier wants to offer a service, they need to go through two steps: (1) publish a template in the network and (2) add a corresponding entry on the e-marketplace, to make it public for other users to find it. Users who want to make use of this service, search for the needed identifiers on the e-marketplace, join the network and start communicating privately with the supplier via Fides.

We chose to separate our system into these two parts due to privacy concerns. While the catalogue of services in the network can be accessed publicly on the e-marketplace, all communication between users stays private. This also prevents that sensitive data are accumulated on the e-marketplace, as a centralised entity, and create a single point of failure. Also, no participant gains an advantage by operating the web platform, so this can even be outsourced to external, commercial operators without the risk of private data exploitation.

4 Implementation

The e-marketplace has been implemented as a modular webapp, that consists of a frontend (Javascript, React), a backend (Python, Flask) and a recommendation engine (Python). Communication between front and back is conducted via a REST-API and authenticated with JSON Web Tokens. The modular approach allows the backend to be accessed on its own, for example, if users want to automate the process of publishing services. The frontend was developed responsive, so the app can also be used on mobile devices. For

storage, we used a SQLite Database, which can be upgraded to a more sophisticated solution when the application is being deployed to a production environment.

The landing page of the app and the search function can be seen in Fig. 2. The system handles two different entities called services (“Mobile Services”) and posts (“Anfragen”).

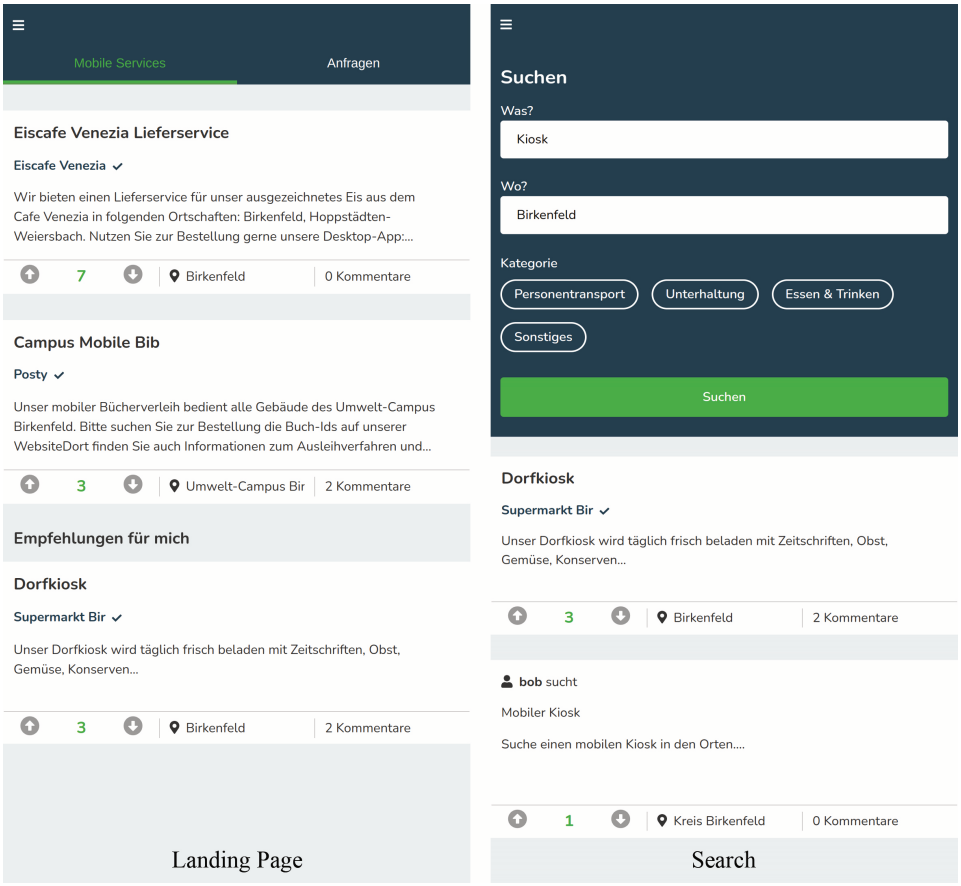
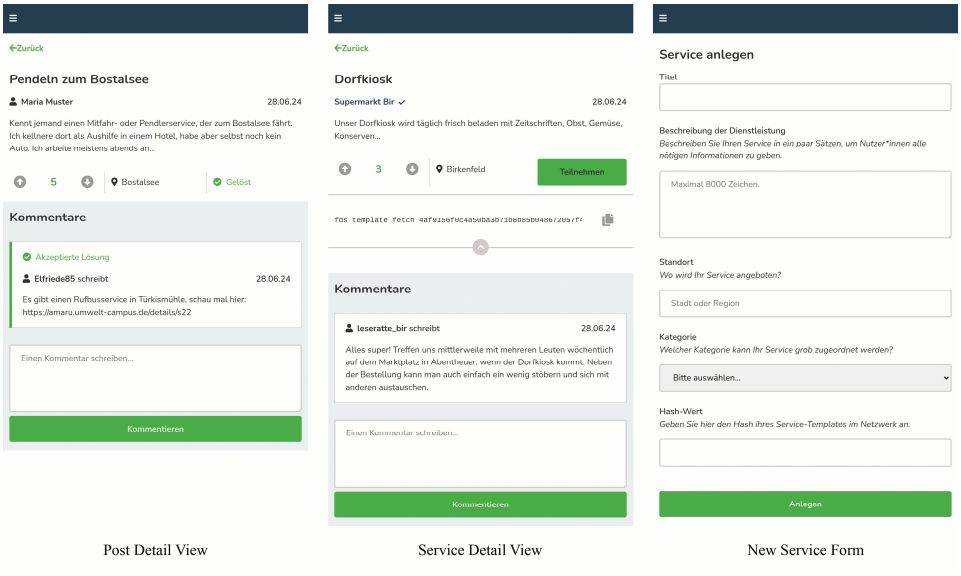


Fig. 2: Landing page and search function

A service is provided by a supplier and corresponds to a published template in the network. Posts are mapping needs and demands of the community to the app and their detail page is shown in Fig. 3. A registered user can ask for a service or propose a new one. Other users can comment these requests, for example by suggesting an already existing service or linking suppliers to draw their attention. The original poster is able to mark a comment as an accepted solution, when it solved the problem to his liking.



Post Detail View | Service Detail View | New Service Form

Fig. 3: Post and service detail views and form for creating a new service

To underline the idea of communal self-organisation, the platform offers even more social features. The comment function works for both services and posts, in order to incite discourse. Furthermore, there is a rating system, so users can give simple feedback in the form of up- and downvotes. These user inputs are furtherly processed by the recommendation engine, which calculates possibly interesting services for each user, based on their past interactions, and integrates its results into the list on the landing page ("Empfehlungen für mich"). Services and Posts are therefore assigned to categories, which also enhance the search function, as can be seen in Fig. 2. Users can generally search for name, categories and location and the result contains services and posts. More available metadata is depicted in Fig. 3, in the form for creating a new service. Besides title, description, location and category, suppliers also need to enter the template hash, that identifies the service in the Fides network. The e-marketplace features an interface to Fides, so if it runs within the network or has access to it, the template hash can automatically be checked for authenticity and correct ownership. Suppliers are required to give their Fides public key upon signing up in the webapp. The public key is then compared to the owner of the template. This ensures that every service on the e-marketplace is really existing and was published to the community in the network. The check mark, next to the suppliers name, indicates that this user has verified their public key with the operators of the marketplace.

After creating, the service detail view (Fig. 3) shows users the entered information, including the template hash. If a user wants to book the service, they have to click the

button “Teilnehmen”, and run the given command in Fides, which will import the template from the network. All further actions like creating a contract and communication between the two parties are then handled in Fides.

5 Discussion and Outlook

Our e-marketplace system is presenting a possible concept to enhance sustainable development and logistical infrastructure in rural regions from a technical point of view. By connecting regional stakeholders in a privacy-focused way and thereby improving the efficiency of transportation and logistics, we are certain that the amount of trips can be reduced and thus, emissions can be saved. At this point, the applicability of our concept and its real impact on sustainability can only be assumed and derived from related studies, since this is a novel approach and the field of research on mobility and emissions is still open, especially in rural areas. We see a need for further research and tailored case studies, that consider the numerous influencing factors, such as demography, e-mobility, routing optimisation, existence of capable suppliers and profitable business models. We are also aware, that the usability of our system is uncommon, due to the split between Fides and the e-marketplace as a catalogue, and that operating a network and communication requires users that are tech-savvy and willing to adopt to novel concepts of self-organisation and infrastructure. The demographic structure of rural regions is partly limiting the number of such users, since many lack the resources or expertise to engage with decentralised apps or run Python applications like Fides. Still, our concept allows engagement of businesses or companies that are technologically proficient, without abandoning the privacy of private participants. Anyway, we chose this architecture for our system as a first proof-of-concept and to set a strong focus on security and privacy.

We are currently working on addressing the mentioned issues and supporting our claims on sustainability in the project “GreenTwin”[4], where we follow a more holistic approach. There, we are running a digital twin to simulate supply and demand, work with real suppliers and conduct surveys regarding user applicability. Also, we consider the different means of transport and perform actual emission calculations [Ba24]. For all of that, we are using this e-marketplace system as a foundation to extend and improve. Additionally, our future work will focus on a web-based implementation for cyber-physical contracts to broaden accessibility. While this choice presents security challenges and susceptibility to other kinds of attacks, it significantly enhances usability as it requires only a standard web browser, thus further democratizing access to our concept.

[4] https://www.umwelt-campus.de/birkenfeld-institute-of-technology/projekte/bmuv-gefoerdertes-projekt-greentwin (28.06.24)

Following our general idea, the e-marketplace has been published open source under the MIT license for everyone to use.[5]

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