Digitalization of the Value Chain Pig Production - Discussion of Novel Approaches and Application of Self-Sovereign Identity

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Abstract:

Livestock management is adapting to consumer demands with the aid of Precision Livestock Farming and innovative technologies like blockchain and Self Sovereign Identity. In this paper, we raise the question if Self Sovereign Identity (SSI) can be leveraged for creating decentralized digital identities, particularly in pig production, by discussing three proposals towards SSI adoption in the value chain pig production. We discuss employing Sovrin's thing controller approach followed by a proposal for pig representation through Verifiable Credential (VC) or dynamic Non-Fungible Token. Scalability (in terms of the number of wallets or number of VCs) and ownership transfer (along with underlying transaction costs) emerge as critical challenges, while general feasibility is given from a high-level perspective. However, based on the potential towards enhanced transparency and traceability, we argue to pursue further empirical research while highlighting a research direction towards the decision support for choosing a proper SSI framework.

Keywords: Self Sovereign Identity; Blockchain; Decentralized Identities; Pig Production

1 Introduction - Precision Livestock Farming and the Value Chain Pig Production

Modern livestock systems dramatically increased worldwide livestock production, meeting the growing demand for livestock products [Ha17]. Nevertheless, the current livestock production will have to undergo significant changes to tackle the increasing demand for food on the one hand and the threat of food insecurity on the other [Ha17]. Especially the potential

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food insecurities lead to a growing interest in Food Supply Chain (FSC) information by end consumers [Gf13], [Kr21].

Within livestock management, the so-called Precision Livestock Farming (PLF) can support traceability throughout the FSC with the potential to enable end consumers to validate food safety, at least to some degree [Be14]. In general, PLF describes the real-time management of livestock based on continuous, automated data collection in the barn [Be17]. Thus, it poses the potential to contribute to the welfare and health of the respective animals while also improving efficiency and sustainability [Be14]. However, the applicability of PLF, for example, in pig production, especially in Europe, is at an early stage [VB17]. Looking at the value chain pig production, depicted in figure 1, a set of dedicated actors along various stages of pig production can be identified. This includes the production and utilization of

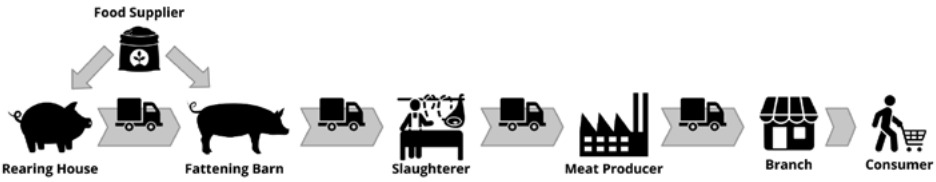

Fig. 1: Pig Production at High Level. Source: Own depiction

plant-based animal feed, the complete cycle of pig farming (from breeding and rearing to fattening), and the subsequent steps of transportation, slaughter, butchering, and processing. Additionally, it involves the crucial aspects of trade and consumption of the produced pork products. Further, note that additional stakeholders, for example, farm veterinarians, breeding consultants, professional associations, quality assurance and certification bodies, and regulatory authorities, can join the value chain. In the context of pig production, PLF focuses mainly on the cycle of pig farming by enhancing the traditional measurements (e.g. temperature or humidity) with direct measures focused on single animals using sensors, growth monitors, cameras or microphones [VB17], [Ma17].

Nevertheless there is also the concern that PLF data will be manipulated or not adequately communicated [Kr21], raising the questions of how to share the relevant data in a secure and tamper-proof way to enhance transparency and traceability in the FSC. In general, increased food choices and complexity in supply chains are unsettling consumers and could damage trust [De21]. Furthermore, considering the value chain pig production, PLF data currently is most beneficial for actors within the cycle of pig farming even though it could also add benefits to other actors along the value chain. These potential benefits are not yet investigated, highlighting a possible new area of research topics orbiting around the questions on how to make the gathered PLF data usable throughout the entire value chain of pig production.

A potential answer could be the usage of blockchain technology, as it has already been proposed by [Kr21] to leverage it's potential to enhance traceability and transparency through being decentralized and tamper-resistant [XWS19]. The benefits of applying blockchain

to the area of livestock-based products was analyzed within a systematic literature by [KTA22] where they "[..]found that while blockchain technology is potentially sustainable and worthy of applications, there remain various limitations and complications toward adoption, such as the low awareness among stakeholders, the weak sector-wide coordination, and the lack of capacity in primary suppliers."[KTA22]. This shows that similar to PLF systems, the adoption of blockchain-based systems is in its infancy. But first approaches towards adopting blockchain-based systems to enhance traceability, for example, for the pig supply chain as presented by [Yu20], are researched. However, novel approaches targeting potentially every participant within the value chain of pig production emerge. For example, the novel idea to apply SSI systems to enhance privacy and data sovereignty, especially when exchanging data or providing specific certifications and standards. In [CTM21], for example, a SSI-based system to enhance access and verifiability for certification regarding food and related processes is proposed.

As shown, multiple research threads exist targeting the introduction of novel technologies to the value chain pig production. In this paper, we raise the question if and how those research threads could be combined to enhance the overall transparency and traceability within the value chain pig production. To do so, we focus on the possible benefits of introducing SSI for digital pig identities, aiming to lay the foundation to connect collected PLF data to a decentralized digital identity of the respective animal. Thus, we aim to discuss the following research questions: *Can SSI be leveraged for representing decentralized digital identities for pigs, laying the foundation for connecting PLF data with digital pig identities?*

2 Self-Sovereign Identity

On a conceptual level, SSI is a novel approach towards Identity and Access Management (IAM). It can be considered as a specific expression of decentralized identity with a focus on self-sovereignty [CT21]. While in centralized or federated IAM systems, the user data is stored and managed *for* the user, in SSI the users' data is stored and managed *by* the user, highlighting the significant difference between the different models. Thus, data sovereignty for the user over their data is enabled, representing the fundamental principle of SSI [SC22], [Al16]. Nevertheless, note that, as SSI itself is a considerably young approach, there is not yet an exact definition for the term [CT21] and SSI as well as decentralized identity are often used interchangeably while still posing differences [Se21]

Within an SSI-based system, three main roles exist, namely *Issuer*, *Holder* and *Verifier*. The issuer creates a VC attesting certain attributes of a subject, which is usually a human but can also be an organization, thing or animal, and transfers it to the holder while storing key information on a verifiable data registry; usually, a blockchain [Se21] [Ab22]. The term VC usually refers to the definition within the standardization by the W3C and will also be used in this context within this paper. The holder is an entity that requests VCs from an issuer and holds them in a digital wallet as well as presenting VCs as Verifiable Presentations (VPs) to a verifier [Ab22]. Note that the holder is not necessarily the subject [Ab22]. The verifier is

an entity that requests certain claims of a subject to verify them [Ab22], usually in order to evaluate if the holder is authorized for a certain service, leveraging the verifiable data registry. As [Se21] point out, current SSI approaches focus mainly on the human as holder and subject, but it should also be evaluated if and how these approaches and concepts could also be applied to non-humans, such as things or animals. Thus, in the following section, we will contribute towards the latter by discussing potential areas of leveraging SSI to create digital identities for pigs.

3 Proposals towards using Decentralized Digital Identities in Pig Production

Even though the following proposals are discussed on a relatively high level, we like to point out that, when applying SSI or any Distributed Ledger Technology (DLT)-based system, questions concerning key management must be considered since assets, funds, or identity ownership are depending on the private key [Me18], [Pa21], [SGS21]. Usually, wallets are used for key management and are either software wallets (dfurther distinguished as warm hot or cold wallets) or hardware wallets [SGS21], [RZ19]. [Pa21]. Given the importance of proper and secure key management, it is an active research field on its own, and the authors would like to refer keen readers to the work of [SNA19] and [RZ19] that stands exemplary for approaches described a practical key recovery model for software-based wallets and a backup approach for hardware wallets respectively.

3.1 Proposal One: Pigs as (Sovereign) Identity Holders

Within this approach, we propose that for each pig a respective entity/decentralized identity is created by means of SSI connected to a digital wallet. This wallet contains all the information about the pig's identity, including characteristics, relationships, and authorizations. As animals, in our case pigs, are to be considered as non-sovereign within the context of SSI, we consider them as *dependent entities* [NJ22], meaning the identity owner must have full control over the key materials for each animal. One potential approach towards the management of such dependent entities is discussed by [Ab19]. They describe the concept of a *thing controller* within the context of the *Sovrin Network* with the aim to control "something that is by its nature incapable of self-sovereignty." [Ab19], also defining dependent Sovrin identities [NJ21]. Assuming that a respective wallet is created and managed for each pig, the dedicated information concerning the respective animal (e.g. vaccination, food supplements etc.) can be created as VCs and added to the respective wallet, potentially creating a digital shadow of each animal. As described in section 1, PLF can support collecting automated data concerning the respective animal. Note that next to Sovrin, *uPort* emerged as a system providing SSI [NJ20] even though it split up into *serto* and *Veramo*. However, they pushed the adoption of Decentralized Identifier (DID) and decentralized identity within the Ethereum ecosystem by defining, for example, the

ERC-1056, describing a lightweight identity concept for Ethereum [BT18]. This poses a different approach as a *claim registry model* is used where claims are also stored as reference on-chain, while in the approaches that follow the W3C specification, the blockchain is used as a *identifier registry model* [Mü18].

Potential Challenges: While dependent entities are a general thing to be considered within SSI approaches, the concept of a thing controller is only given in the context of the Sovrin system. Thus, the technology selection is limited to Sovrin and its provided Software Development Kits (SDKs)in order to apply the thing controller concept. This raises the question if the desired principles of SSI, such as portability and interoperability, as defined by [Al16], could be fulfilled. Furthermore, it is not yet discussed if the amount of identities that must be issued, is manageable within the system, posing questions to the scaleability of such system. This is also directly connected to the before-mentioned general challenges of key management, as the amount of key materials to be managed is equivalent to the number of pigs that must be represented. However, note that animal-related data should be stored off-chain (e.g., within the wallets) to avoid potential transaction costs. Also, consider that within the value chain, the pigs are sold and thus the transition from one stage to another (e.g., from the nursery to the finishing barn), changing the owner. Such change of ownership must also be applied to the digital identity of the respective pig, e.g. the wallets or their copies must also change hands. This is challenging, as within the SSI framework, the focus lies on *presentation* of data and information instead of transferring ownership, highlighting another vital discussion and potential research question.

3.2 Proposal 2: Pigs as Verifiable Credential

Another proposal, next to considering the pig as a dependent entity, is the representation of a pig as a VC. Representing pigs as VCs would dramatically decrease the amount of key materials required while increasing the amount of VCs to be managed within a single wallet. Since the usage of VCs within the context of SSI is a well-known and used concept, it is supported by multiple platform. Thus, the portability requirement is secured as no specific systems must be used. As subject value within the VC could be the respective Radio-Frequency Identification (RFID) be used or a specific DID. To gather automated data for each individual animal, the PLF system can provide support, as outlined in chapter 1. The holder of these VCs would be the respective actor, e.g. the farmer. What remains to be researched is the question of data exchange. As VCs are, within the context of the W3C standard, used to derive VPs to present certain claims and their proofs, it is currently not designed to *transfer* said credential. Applying this to the value chain pig production raises the question if, for example, a VP proofing the proper treatment of pigs is sufficient throughout the value chain or if, for example, also the ownership of the VC must be transferred throughout the value chain.

Potential Challenges: Considering the ownership perspective, a similar problem as in the first proposal arises, i.e. the transfer of the pig throughout the value chain also requires

the changing of ownership of the digital identity of the respective pig. Considering a VC approach, it remains unclear if and how the ownership of a VC might be changed. In the active W3C standard for VCs this is not considered, but in the current working draft for VCs (as of August 2023), a transfer is recognized as a potential use case, though the editors stated that this is something that will not be standardized via the W3C [SLC23] Furthermore, updating of the VC might be required, e.g. to track the medical history of the animal, thus requiring the VC to be updateable, which is currently only limited via a *refreshService* [SLC22]. Like the first proposals, the scaleability must be analyzed as each holder must manage a large set of VC. Thus it becomes essential to evaluate the feasibility of utilizing existing systems like Hyperledger Indy or determine the viability of building a custom solution. Within the scientific literature, first research has been published, investigating existing (commercial) SSI solutions, e.g. [No21], which can be used as a starting point.

3.3 Proposal 3: Pigs as dynamic Non-Fungible Token

As shown in the first two proposals, the transfer of ownership of the respective animal's digital identity is a challenge. Within the concept of tokenization, transfer of ownership is a central feature. Thus we pick up the idea proposed by [KJW23], to analyze the possibility of Non-Fungible Token (NFT)-based identities by discussing the before mentioned SSI-based approaches in combination with tokenized pig identities. Generally, a token refers to digital representations of physical goods or assets [Su21] created and managed on a blockchain or distributed ledger. While a static NFT is characterized by its immutability, meaning that its attributes are fixed and cannot be altered once they are recorded on the blockchain, dynamic NFTs have the capability to adapt and change based on specific conditions. In Ethereum, for example, NFTs are defined by the ERC-721 standard and are extended towards multiple token types and additional features by the ERC-1155 standard It allows a single smart contract to manage multiple token types, each with its customizable attributes, metadata, and supply, while enabling a constant change of the dynamic NFTs data [SB22].

Thus, each pig could be assigned a dynamic NFT at the beginning of its journey through the value chain. The dynamic NFT should contain essential information about the pig, such as its origin, breed, health records, vaccination history, and any other relevant data. A PLF system, as described in chapter 1, can facilitate the automatic generation of relevant data. At each step of the pig's journey, the dynamic NFT data can be altered based on specific external conditions, for example, a medical condition. This flexibility enables dynamic NFTs to capture and reflect the dynamic nature of the underlying assets or processes they represent [SB22], which could be utilized to represent the different properties of pigs throughout the value chain as well as the change of ownership, making it more flexible than, for example, the in subsection 3.2 discussed approach leveraging VCs.

Challenges: In comparison to static NFTs, dynamic NFTs are less secure because the metadata is changeable [SB22]. The information in the NFT should be appropriately controlled and encrypted to protect sensitive data. In dynamic NFTs, using multiple metadata

files introduces complexities in the verification process, making it more challenging to ensure authenticity and accuracy. In addition, updating the metadata involves more transaction costs [SB22]. This can be a deal breaker for adoption, for example, for the farmers, as the profit margin is already tight. However, even though ERC-1155 is Etehreum based, other L2 chains (e.g. Polygon or Ronin) adopted such functionality as well [GM23], enabling potential cost savings. Nevertheless, as dynamic NFTs are still in their infancy [SB22], no proper analysis and calculation considering costs are available, highlighting the need for further research in this direction.

4 Conclusion and Future Work

Since end consumers have a growing interest in the FSC, the applicability of novel technologies such PLF, blockchain or SSI emerge, tackling these new requirements while also enhancing traceability and transparency within the value chain pig production. However, as especially SSI is in its infancy considering adoption outside of credentials tailored towards humans, we raised the research questions *Can SSI be leveraged for representing digital identities for pigs, connecting gathered PLF data to a pig specific digital identity?*.

To ignite the first spark for possible future research, we described three proposals to represent pigs and their data and information based on PLF data as digital identities, leveraging SSI and dynamic NFTs. We emphasized that key management is crucial in every blockchain- or SSI based system. Within the first proposal, we discussed the possibility of considering each pig as a dependent entity, leveraging the thing controller approach provided by the Sovrin system. Sovrin is, to the best of the authors' knowledge, currently the only system that provides such an approach despite the concept of dependent entities being a general one. Second, we discussed the representation of each pig as a VC, reducing the required key material and management compared to the first proposal. Nevertheless, this approach raises the question of scalability regarding the ability of respective wallets to handle a large amount of VCs. Both approaches fall short when considering the requirement to transfer the ownership of the digital identities of the respective pigs in the event of selling the pigs to the next actor in the value chain since within SSI, a transfer of ownership is not yet considered. This might change, as the W3C recognized in the current draft for the VC model 2.0. the use case for transferring of VCs [SLC23]. Taking the question concerning the transfer of ownership as motivation, we discussed the possibility of leveraging dynamic NFTs to represent the respective pig as a third proposal, posing the advantage of leveraging existing infrastructure regarding tokenization and transfer of ownership. Within this approach, especially the potential transaction costs must be further analyzed, as the profit margin within the value chain pig production is already tight. Furthermore, another approach, leveraging existing Ethereum functionality for identities such as the ERC-1056 in which the change of ownership is already defined [BT18] could be further evaluated in terms of applicability.

After the brief discussion of these three proposals, we can not answer the stated research questions definitely. We think that creating digital identities for each animal poses benefits, especially considering traceability and transparency. However, as our brief discussion already showed, several open questions must be analyzed and finally answered by empirical research. Thus, we aim to continue the research, following the principles of design science research [HC10] along with case studies within the value chain pig production to fully explore the potential of using decentralized digital identities in pig production. But we also see challenges in properly selecting an SSI based system or framework due to the different approaches, technologies and terminology. Therefore, we identify missing decision support (for example, via flowcharts or decision trees) as another research opportunity within decentralized digital identities.

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