NGI ONTO CHAIN

Blockchain
for the Next
Generation
Internet

D6.5 ONTOCHAIN RECOMMENDATIONS

31/08/2023

NGI ONTOCHAIN

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D6.5 ONTOCHAIN POLICY RECOMMENDATIONS: A ROADMAP FOR A HUMAN-CENTRIC AND TRUSTED INTERNET

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ABSTRACT	This deliverable provides a set of future research directions for semantic blockchain based ecosystems and a set of policy recommendations based on the experience and lessons learned from each of the ONTOCHAIN phases, with the help and support of the ONTOCHAIN community built around the project. If blockchain-enabled markets are to mature, policy makers and businesses must create the rules together. Regulators should provide guiding principles to attract

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private-sector investors, ensure consumer protection and citizens' rights, and provide safeguards against anticompetitive practices. ONTOCHAIN partners believe that ONTOCHAIN policy recommendations will prove to be of great value for regulators to provide such guiding principles.

KEYWORDS trust, policy semantic blockchain, DLT

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2	UNIVERZA V LJUBLJANI	UL	SI
3	IEXEC BLOCKCHAIN TECH	IEXEC	FR
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5	ATHENS UNIVERSITY OF ECONOMICS AND BUSINESS - RESEARCH CENTER	AUEB	EL
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EXECUTIVE SUMMARY

Policy makers are tasked with solidifying Europe's position as a leader in blockchain innovation and adoption, while upholding fundamental values such as privacy, participation, and diversity. This is a challenging undertaking, but ONTOCHAIN aims to make it easier by assisting policy makers and regulators in understanding the issues, developing solutions, and working in collaboration with the broader blockchain community. The objective of this deliverable is to gather a set of policy recommendations based on the lessons learned from each phase of the ONTOCHAIN project, with input from the ONTOCHAIN community.

To mature blockchain-enabled markets, policy makers and businesses must work together to establish rules. Regulators can offer guiding principles to attract private-sector investors, protect consumers and citizens' rights, and prevent anticompetitive practices. ONTOCHAIN's partners believe that the policy recommendations developed throughout the project will be of significant value to regulators seeking to establish such principles.

This deliverable defines the shared domain of the Semantic Web and Blockchain and identifies the essential building blocks necessary for creating trust in the Next Generation Internet. We analyse the challenges and security concerns of the Semantic Web, as well as the scalability and interoperability challenges of Blockchain, and provide a comprehensive review. We also present an in-depth survey of the research challenges associated with integrating Semantic Web and Blockchain, along with recommendations for future research directions. Ultimately, our goal is to offer the best possible policy recommendations for the development of a new approach, technology, and protocols for trustworthy content handling and information exchange, contributing to a more trustworthy Next Generation Internet.

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ABBREVIATIONS

IP	Internet Protocol
TCP	Transmission Control Protocol
NGI	Next Generation Internet
SW	Semantic Web
GDPR	General Data Protection Regulation
DLT	Decentralized Ledger Technology
OCS	Outermost Spiral
OWL	Web Ontology Language
DL	Description Logic
WNM	Word Nonlinear Matching
PPWNM	Privacy-Preserving Word Nonlinear Matching
NLP	Natural Language Processing
RDF	Resource Description Framework
URIs	Uniform Resource Identifiers
PoW	Proof-of-Work
PoS	Proof-of-Stake
BFT	Byzantine Fault Tolerance
DAG	Directed Acyclic Graph
SCP	Stellar Consensus Protocol
UUIDs	Universally Unique Identifiers
AI	Artificial Intelligence
IoT	Internet of Things
DGs	European Commission Directorates-General
FCA	Conduct Authority

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1 INTRODUCTION

ONTOCHAIN aims to revolutionize the internet landscape by establishing a robust and adaptable multi-layer technology framework. By leveraging the NGI (Next Generation Internet) and blockchain ecosystems, ONTOCHAIN envisions the implementation of a diverse range of cutting-edge real-world solutions. These include trustworthy web and social media platforms, reliable crowdsensing systems, secure service orchestration, decentralized online social networks, and more. By harnessing multiple ledger technologies, ONTOCHAIN empowers practitioners to tackle the numerous challenges of the Next Generation Internet effectively.

ONTOCHAIN's use-cases will be developed on different protocols and interactions between various blockchain frameworks, ensuring seamless inter-service process cooperation while shielding users from the underlying complexities. The proposed blockchain-based framework exhibits enhanced performance and scalability by integrating diverse business logics, access methods, and governance models. Additionally, it provides scalable solutions to facilitate secure and transparent content and information exchange, as well as seamless service interoperability.

As a fundamental building block of the NGI, the ONTOCHAIN technology framework embodies the principles of openness, decentralization, inclusiveness, and privacy protection. By returning control to end-users, it empowers them to actively participate in democratic, transparent, and trustworthy decision-making mechanisms. ONTOCHAIN's vision is to contribute to the development of a more human-centric internet that aligns with these core values and ensures that users can fully benefit from a reliable and transparent online environment.

This deliverable provides an overview of the latest trends and challenges in Semantic Web (SW) and Blockchain technologies. We present a systematic review of the literature on the integration of SW into Blockchain and identify the most recent policy recommendations for the integration of semantic data and Blockchain. The primary objective of this deliverable is to investigate knowledge management, focusing on achieving high-quality data during their management and exchange and provide recommendations for future project development.

One of the most important objectives of ONTOCHAIN is to design and disseminate insights set out by the members of Expert Groups, finding the synergies between SW and Blockchain technologies.

Hence, we explore several techniques that have been utilized to implement real-world applications by leveraging Blockchain and SW-based technologies. The final objective is to provide to the European communities with recommendations on key challenges for the integration of SW and Blockchain, enabling high-quality data management and exchange.

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To prepare this document we utilize our knowledge and outcomes of the third-party projects funded through ONTOCHAIN Open Call 1 (OC1), Open Call 2 (OC2) and Open Call 3 (OC3)

The remainder of this deliverable is structured as follows:

- Section 2 provides an overview of the project, its objectives, technological aspects, and the methodology employed.
- Section 3 outlines the lessons learned from our collaborative work on the ONTOCHAIN project, including insights gained from third-party funding.
- Section 4 delves into the challenges faced for the integration of two innovative technologies, SW and Blockchain, and offers insights into future development and integration requirements.
- Section 5 discusses the policy recommendations necessary to establish a framework centred around human needs.
- Section 6 offers insights and recommendations stemming from the ONTOCHAIN community and International Advisory Board findings regarding legal aspects and potential stakeholders to promote wider adoption of Blockchain technologies.
- Section 7 concludes this deliverable.

2 PROJECT OVERVIEW

In this section we provide the objectives, technologies, methodology and business model applied during our ONTOCHAIN project.

2.1 ONTOCHAIN OBJECTIVES & MILESTONES

In recent years, we have observed an increase of Internet-based marketplaces that facilitate the connection between asset owners or service providers and potential consumers. These platforms enable owners to leverage the unused capacity of their assets, while consumers can access services from their peers at a lower cost or even for free, as compared to traditional commercial providers. Examples of such marketplaces include Airbnb, Uber, and others. These economic ecosystems that

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emerge from these marketplaces are commonly referred to as "peer economies" or "sharing economies," as coined by The Economist in 2013[1].

Simultaneously, the advent of cryptocurrencies and smart contracts has ushered in a new era of distributed application ecosystems, exemplified by platforms like Ethereum[2], Hyperledger Fabric[3], NEO[4], Stellar, Waves[5], and more. These ecosystems offer a ground for deploying innovative services with low barriers to entry, thanks to a decentralized infrastructure and secure transaction management. With the added benefits of anonymous transactions, sizable user communities, and a decentralized bottom-up nature that facilitates user adoption, these ecosystems hold significant economic potential.

This current era is characterized by the token economy of distributed apps, which works in harmony with peer economies. Within this landscape, novel business models emerge where a portion of the value generated by distributed apps is allocated back to the distributed blockchain community as remuneration for their computational resource contributions. While the token economy focuses on incentivizing participation and value creation, companies and organizations still require a foundation of trust. They need mechanisms to understand their user base, verify identities, manage digital assets, and exercise control over trust issuance within their ecosystem.

To maximize the market impact of the evolving economic landscape, ONTOCHAIN aims to:

1. **Enable trustworthy transactions of services and content**: ONTOCHAIN will spearhead the development of innovative decentralized reputation models. These models will enhance transparency by uncovering the hidden quality and type of service providers or services themselves, as well as verifying the credibility of data sources.
2. **Enable trustworthy and traceable content handling**: ONTOCHAIN recognizes the importance of secure and traceable content handling. Authorized parties will have the capability to process data in accordance with the privacy policies defined by the respective data owners. By implementing robust mechanisms, ONTOCHAIN will ensure that content remains tamper-proof and verifiable throughout its lifecycle. This will enhance trust among participants, assuring them that data is handled in a responsible and compliant manner.

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[1] https://www.economist.com/leaders/2013/03/09/the-rise-of-the-sharing-economy
[2] https://ethereum.org/en/
[3] https://www.hyperledger.org/projects/fabric
[4] https://neo.org/
[5] https://waves.tech/

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3. **Build an economically sustainable ecosystem** where the total value generated surpasses the operational costs, including electricity consumption. To achieve this, ONTOCHAIN focuses on fair sharing of the generated value among resource contributors and providing appropriate incentives to the user community.

By implementing a fair value distribution mechanism, ONTOCHAIN ensures that users who contribute resources are rewarded proportionally. This not only sustains the user community but also empowers them both economically and socially. Economically, users can access goods and services at a lower cost, enhancing their own well-being. Socially, ONTOCHAIN enables users to be more active and engaged within their local networks, fostering social interactions, and strengthening social capital.

Sharing economies facilitated by ONTOCHAIN also contribute to social capital by allowing individuals to leverage their own skills, thereby improving the overall well-being of their local communities. Through open application-protocol APIs, ONTOCHAIN provides various functionalities such as ontology representation, decentralized identity verification, market mechanisms, privacy-aware and secure data exchange, and incentive mechanisms. These APIs, along with gateway APIs for interledger integration, enhance interoperability and expand the reach of ONTOCHAIN's benefits.

2.2 TECHNOLOGIES & APPROACHES AND METHODOLOGY

ONTOCHAIN's ecosystem is very articulated as it includes a variety of services and applications. With decentralization and technologies like Linked Data, Ontologies, Formal Proofs, and Blockchain, together with our third parties' projects it delivers innovative solutions for openness, inclusiveness, privacy protection, and giving control back to end-users. By empowering individuals and society with data ownership, ONTOCHAIN fosters trust, transparency, and accountability while enabling efficient data management and decision-making. Its potential impact is transformative, reshaping the digital landscape with user-centricity and data sovereignty.

ONTOCHAIN followed a multi-layer approach as shown in Figure 1 to enable various next-generation real-world solutions, including trustworthy web and social media, crowdsensing, service orchestration, and decentralized social networks. As the framework evolves, practitioners may utilize multiple ledger technologies to implement different solutions, accommodating the diverse needs and complexities of ONTOCHAIN applications.

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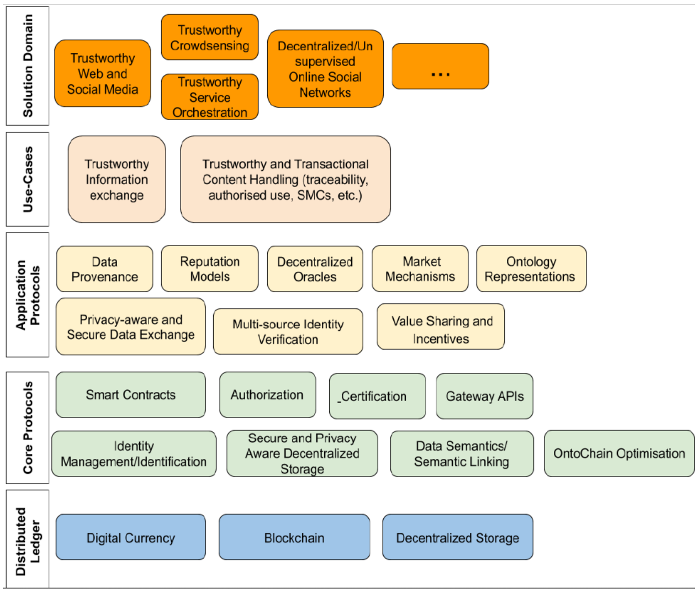

FIGURE 1: ONTOCHAIN ARCHITECTURE AND CONCEPT

ONTOCHAIN employs a modular approach for scalability, openness, and high performance. Each layer builds upon the functionality of the lower layers. At the Solution Domain layer, various next-generation applications address internet challenges. They rely on the combined functionality of the Application Protocols layer, which in turn builds upon core blockchain-based services at the Core Protocols layer. The Core Protocols use basic distributed ledger functionality, such as Blockchain and Digital Currency. This layered structure ensures efficient development and deployment of ONTOCHAIN's solutions.

ONTOCHAIN aims to support cross-collaboration in the conceptualization, development, experimentation, and integration of new Blockchain technologies that aim to preserve the integrity and reliability of information and content on the internet. For this reason, ONTOCHAIN aims to build a strong community and cover all the blocks defined in the above architecture, by organizing three open calls. In each open call we defined several topics and collaborated with diverse teams and projects around the Europe. The detailed information and dissemination activities related to the open calls can be found in this document (https://ontochain.ngi.eu/sites/default/files/deliverables/D7.8-Yearly-communication-report.pdf).

Overall, the purpose of the open calls was to:

- Attract a large number of Blockchain & DLTs technology researchers, startups, and SMEs.

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- Act as brokerage between Blockchain & DLTs stakeholders to build innovative concepts and applications.
- Build upon existing tools.
- Leverage the development of new research fields and product/service applications.
- Implement and reconsolidate ONTOCHAIN's new business models.
- Ensure that potential market barriers are removed through validated demonstrations.

ONTOCHAIN is uniquely positioned to enable and foster trust in internet information exchange and content with blockchain. The proposed implementation process for each call and the selection of the applicants is shown in the Figure 2. Most of the work for the duration of the propagation and diversification phase is allocated in WP2, WP3 and WP4. In Figure 2 propagation and diversification is represented in Research and development/teste and scaling/sustainability phases. Three open calls were organised to attract the most talented and knowledgeable innovation third parties to contribute to ONTOCHAIN.

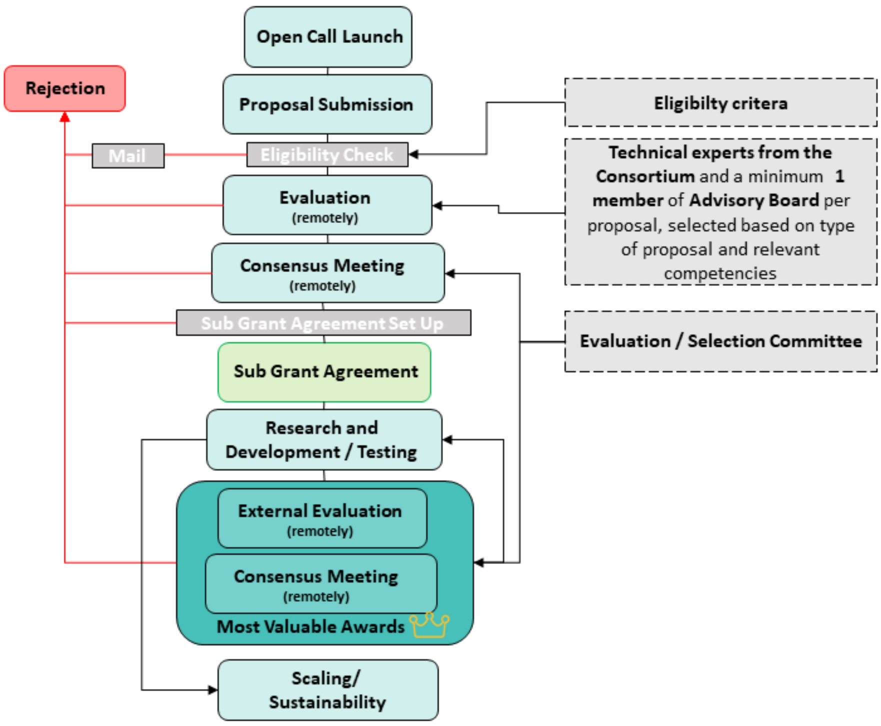

FIGURE 2: OPEN CALL PROCESS AND METHODOLOGY

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After we organized three open calls, and selected the sub projects in each open call, the latest status and the blocks covered are shown in the Figure 3. This figure shows the names, logos of funded sub projects for each open call and the layer they address.

FIGURE 3: ONTOCHAIN LATEST STATUS AND FUNDED PROJECTS

2.3 METHODOLOGY

For contributing new ideas and engaging various stakeholders to the ONTOCHAIN project an agile and efficient Open Call Management Strategy that includes community engagement and growth to create the ONTOCHAIN ecosystem has been created.

The ONTOCHAIN methodology followed the spiral model, as each step builds upon the previous one. By gathering of requirements at the beginning of each step, based on the previous step, designing the logical, architectural, final design and analysing and mitigating risks at each step with finally building prototypes, solutions, and applications at every iteration, the ONTOCHAIN methodology is both agile, in terms of being flexible and resistant to changes in direction, and good for mission critical projects, in terms of risk identification and mitigation.

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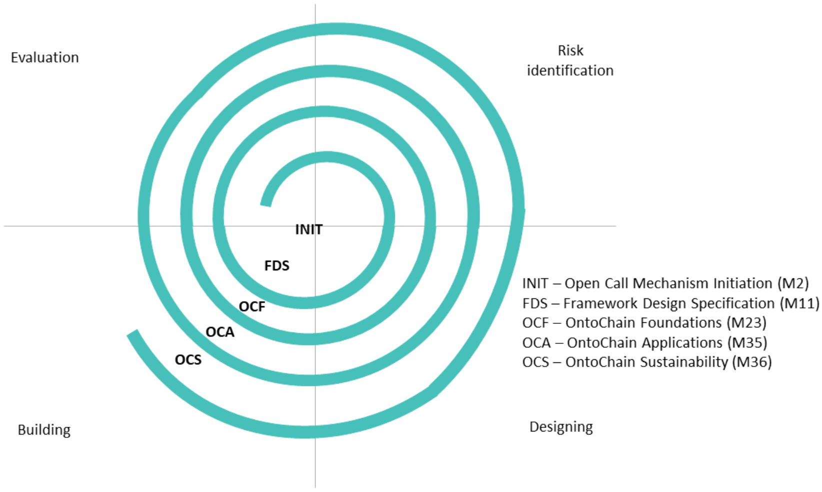

FIGURE 4: ONTOCHAIN FOLLOWS THE SPIRAL MODEL

Figure 4 depicts the ONTOCHAIN methodology, with the outermost spiral (OCS) encapsulating not only the sustainability model, but also business opportunities, impact creation and assessment, a roadmap for a trusted human-centric internet as well as ONTOCHAIN exploitation.

2.4 SUSTAINABILITY MODEL METHODOLOGY BUSINESS MODELS

Our sustainability approach involves a structured process that commences with the initial group of proposers, extends to all applicants who have shown interest in our calls, and ultimately encompasses the identified end-user communities. The ONTOCHAIN project showcased innovative business models as part of the ongoing research and innovation activities. These included the following business models: Subscription to High Quality Information, Outcome Based, Secure Asset-Sharing, Trusted Multi-Party Service Provisioning, "Razor Blade," Raw, Secure and Trusted IoT Data Monetisation, Pay-Per-Usage, and similar. Monetisation possibilities could spread from traditional revenue models to Blockchain based revenue models, including the possibility to provide services and move resources and assets from one ledger to another. This will create a new business ecosystem with the participation of potentially many new individuals and organisations. The partner company IEXEC[6]

[6] https://iex.ec/

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that already operates a marketplace for computing resources available on Blockchain with their innovative coins provided additional guidance in the process of achieving sustainability for the project outcomes.

3 LESSONS LEARNED

In this section we explain the lesson learned during the project while trying to build a complex ecosystem combining Semantic Web (SW) and Decentralized Ledger Technologies (DLT). We will go through each challenge that we faced during our journey and what were the measurements taken to address these challenges.

3.1 TECHNOLOGY CHALLENGES

The key point of ONTOCHAIN is to suitably federate blockchain and semantic technologies to overcome the following technology challenges.

1. *Decentralisation of heterogeneous components*: ONTOCHAIN leveraged techniques, algorithms, and software from different fields (e.g., knowledge representation, storage and querying, Machine Learning, data analytics) and integrated them in a unique decentralized ontology framework. In addition to the effort of adapting their interfaces and semantics, porting each heterogeneous component to run efficiently and safely in a decentralized way, connected to a blockchain, required specific adaptations.

To address the challenge of decentralization of heterogeneous components, ONTOCHAIN implemented several strategies:

- *Adaptation of interfaces and semantics*: The team focused on adapting the interfaces and semantics of the heterogeneous components to ensure compatibility and seamless integration within the decentralized ontology framework. This involved mapping the functionalities and data representations of each component to align with the requirements of the blockchain-based system.

- *Efficient and safe decentralization*: The ONTOCHAIN project made specific adaptations to ensure that each heterogeneous component could operate efficiently and securely within the decentralized environment connected to the blockchain. This included optimizing the performance of the components and implementing security measures to protect the integrity and confidentiality of the data and transactions.

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- *Collaboration and expertise*: The project leveraged the diverse expertise and knowledge of its team members and collaborators from different fields, including knowledge representation, storage and querying, machine learning, and data analytics. This collaborative approach enabled the efficient integration and adaptation of heterogeneous components, drawing on the specialized knowledge of experts in each respective area.
- *Continuous evaluation and improvement*: Throughout each phase, ONTOCHAIN continuously evaluated the performance and effectiveness of the decentralized framework and its integrated components. This allowed for iterative improvements and refinements to address any challenges or limitations encountered during the decentralization process.
- In Open Call 3 (OC3) of ONTOCHAIN selected the subproject BabelFish, which focused on building a service catalogue that describes and registers all existing ONTOCHAIN services and applications. By selecting this project, ONTOCHAIN aims to tackle the challenge of adapting interfaces, semantics, and efficient porting of heterogeneous components in a decentralized manner connected to the blockchain.

By employing these strategies, ONTOCHAIN aimed to overcome the challenge of decentralizing heterogeneous components, ensuring their compatibility, efficiency, and safety within the decentralized ontology framework connected to the blockchain.

Adapting diverse existing systems to function securely in a decentralized manner interfaced with a blockchain entails specific modifications beyond transforming their interfaces and semantics. Effective blockchain solutions necessitate integration with external technologies and data sources[7]. For enterprises, coordinating and sharing information across entities is impeded by heterogeneous data formats[8]. Recently, supply chain data has been migrated to blockchains in order to facilitate collaboration in low-trust environments. However, this induces scalability issues when spanning inter-organizational supply chain workflows. Researchers must construct comprehensive domain ontologies on blockchain networks by leveraging their capabilities[9]. This requires applying blockchain to ontology management and utilizing blockchain infrastructure for open knowledge graphs[10].

2. ***Fast pace of innovation in blockchains****:* the technologies that enabled ONTOCHAIN are evolving so quickly, that many design choices may become obsolete before the end of the project. We are determined to make ONTOCHAIN sustainable by adopting a flexible approach, which translates into a set of

[7] https://oro.open.ac.uk/57436/
[8] https://ieeexplore.ieee.org/abstract/document/9592395
[9] https://dl.acm.org/doi/abs/10.1145/3404709.3404769
[10] https://direct.mit.edu/dint/article/3/2/205/101024/OpenKG-Chain-A-Blockchain-Infrastructure-for-Open

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guidelines for sub-projects. The most important guideline given to all technical sub-projects was to produce two different results: a proof of concept that can be integrated into the ONTOCHAIN prototype, and a generic design that can be reused outside of the project.

To address the challenge of the fast pace of innovation in blockchains technology within the ONTOCHAIN project, the following strategies were implemented:

- *Continuous monitoring and adaptation*: ONTOCHAIN actively monitored the evolving landscape of blockchain technologies and stayed updated with the latest advancements. This allowed the project to adapt and incorporate new innovations and design choices as they emerged. Regular evaluations and assessments were conducted to ensure that the project remains aligned with the most relevant and efficient technologies.
- *Agile development approach:* By Adopting an agile development approach enabled ONTOCHAIN to be flexible and responsive to changing requirements and emerging technologies. By breaking down the project into smaller iterations and frequent feedback loops, the team quickly adapted and incorporated new design choices. This approach allowed for iterative development and integration of proof-of-concept implementations based on the latest technologies.
- *Collaboration and partnerships*: Engaged with International Advisory Board, external blockchain experts, research institutions, and industry partners provided valuable insights and access to the latest advancements. Collaborative efforts helped ONTOCHAIN stay at the forefront of blockchain innovation, exchanging knowledge, and leveraging expertise to address design obsolescence. This collaboration also facilitated the development of generic designs that can be reused outside of the project, ensuring long-term sustainability and impact beyond the project's duration.

By adopting these strategies, ONTOCHAIN navigated the fast pace of innovation in blockchains and ensured the sustainability of the project. Flexibility, agility, collaboration, and adherence to standards allowed ONTOCHAIN to integrate the latest technologies, produce proof of concept implementations, and develop reusable designs that have value beyond the project's lifespan.

3. *Open and flexible design*: Sub-projects had to make numerous trade-offs, e.g., between the granularity and how much data is stored on-chain vs. performance, that may evolve as future blockchain protocols emerge. Keeping these trade-offs documented and adaptable helped ONTOCHAIN make contributions interoperable and sustainable.

To address the challenges of open and flexible design within the ONTOCHAIN project, the following approaches were implemented:

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- *Documentation and transparency*: It is crucial to document the trade-offs and design decisions made during the development of sub-projects. Each open call sub-projects delivered 4 deliverables where they described in detail all the aspects and decisions that were taken during the development process. This documentation included the rationale behind the chosen trade-offs, the considerations for performance, data storage, and other relevant factors. By maintaining transparent documentation, ONTOCHAIN ensured that the design choices were well-documented and accessible to the project team and stakeholders. This transparency facilitates understanding, collaboration, and future adaptability.
- *Modularity and flexibility:* The ONTOCHAIN project adopted a modular approach, where different components and functionalities were developed independently and combined or interchanged as needed. By designing components with flexibility in mind, the project can be easily adapted to future blockchain protocols or emerging technologies. This modularity enabled the project to update or replace specific components without disrupting the entire system, making it more adaptable to future changes.

By implementing these approaches, ONTOCHAIN effectively addressed the challenges of open and flexible design. Transparent documentation, modularity, continuous evaluation, and collaboration contributed to the adaptability and sustainability of the project. This ensured that trade-offs can be revised, new protocols can be incorporated, and the project can evolve in response to emerging technologies and changing requirements.

As blockchain technology changes rapidly, the innovator must make the balance between granularity and how much data is kept on-chain vs. performance, which may change as future blockchain protocols emerge. Blockchain's underlying data storage and structure have some key limitations. The block data structure is inefficient and complex for many applications[11]. Blockchain lacks configurable processes for information hiding and custom data structures [12]. Improved data models are needed to clearly convey connections and knowledge[13]. Formal standards for querying blockchain data storage are essential[14]. Processing files on the blockchain requires integrating file storage with knowledge graph traceability[15]. Combining knowledge management and reasoning technologies with blockchain can enhance data representation capabilities[16]. Current electronic recruiting systems mainly store

[11] https://ieeexplore.ieee.org/abstract/document/9359029
[12] https://link.springer.com/chapter/10.1007/978-3-030-82153-1_41
[13] https://scholarspace.manoa.hawaii.edu/items/ba814a7f-5d29-45a4-b27f-a67f69f0b2ba
[14] https://dl.acm.org/doi/fullHtml/10.1145/3184558.3191554
[15] https://www.sciencedirect.com/science/article/pii/S0306457321000534
[16] http://www.inass.org/2021/2021063004.pdf

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candidate contact details. However, recruiting could benefit from combining blockchain and science & technology to add capabilities[17].

4. *Formal logic proofs*: Another technological challenge was about how to transparently derive a new truth out of several known truths according to a set of rules. Various languages such as the OASIS Web Ontology Language (OWL) exist to express formal logic. OWL comes in three expressivity levels, known as species: Lite, Description Logic (DL) and Full. While formal rules are quick to compute in Lite, and more time consuming in DL, the Full specie cannot use formal proofs as the reasoning program may cycle indefinitely as proven by the already mentioned Kurt Gödel's theorems[18]. There may, however, exist ways to design specific Smart Contracts that would implement first order logic directly on the blockchain.

To address the challenges of formal logic proofs within the ONTOCHAIN project, the following approaches were implemented:

- *Utilize expressive yet computationally efficient languages*: While the Full species of OWL may not be suitable for implementing formal logic proofs directly on the blockchain due to potential infinite cycles, the Lite and Description Logic (DL) species can still offer expressive capabilities. By leveraging these languages, ONTOCHAIN can represent formal rules and logic in a computationally efficient manner. Careful consideration was given to selecting the appropriate species of OWL that strikes a balance between expressivity and computational efficiency. ONTOCHAIN subprojects have used standards defined by W3C consortium., and they have developed or extended ontologies in different domains such as real estate, supply chain, LNG, and copyright management.
- *Design specialized Smart Contracts*: Instead of relying on general-purpose Smart Contracts, specific Smart Contracts can be designed to implement first-order logic directly on the blockchain. These specialized contracts can include predefined rules, logical operators, and reasoning mechanisms to derive new truths from known truths. By tailoring the Smart Contracts to the specific requirements of formal logic, ONTOCHAIN ensured transparent and verifiable reasoning on the blockchain.
- *Stay updated on research advancements*: The field of formal logic and blockchain is constantly evolving, with ongoing research and advancements. ONTOCHAIN actively stayed updated on the latest research in the field, attend conferences, and engage with the academic and research community. This enabled the project to

[17] https://scholarspace.manoa.hawaii.edu/items/ba814a7f-5d29-45a4-b27f-a67f69f0b2ba
[18] https://www.taylorfrancis.com/chapters/edit/10.4324/9780203407769-6/kurt-g%C3%B6del-solomon-feferman

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leverage new techniques, tools, or breakthroughs that may address the challenges more effectively.

By adopting these approaches, ONTOCHAIN tackled the challenges related to formal logic proofs. Leveraging expressive languages, designing specialized Smart Contracts, collaborating with experts, conducting thorough testing, and staying updated on research advancements contribute to the development of transparent and verifiable logic reasoning mechanisms within the ONTOCHAIN framework.

3.2 STRATEGIES AND PRACTICES THAT CAN BE APPLIED TO FUTURE PROJECTS

Based on the experience we gained from the ONTOCHAIN project, in this section we provide some advice and recommendations for future projects working in a similar direction:

1. *Embrace modularity and flexibility*: Adopt a modular and flexible approach in the design and implementation of the project. This allows for easier adaptation to evolving technologies and changing requirements. By decoupling components and making them interchangeable, future projects can quickly integrate new advancements and adapt to emerging blockchain protocols.
2. *Document trade-offs and design choices*: Maintain thorough documentation of the trade-offs and design choices made throughout the project. This includes documenting the rationale behind each decision, the corresponding considerations, and the implications for future developments. This documentation will serve as a valuable resource for future projects to understand the reasoning behind certain design choices and to guide their own decision-making process.
3. *Foster interoperability and standardization*: Promote interoperability and standardization within the project. Adopt existing standards and protocols where applicable and contribute to the development of new standards if needed. This will facilitate the integration of components from different projects and ensure compatibility with other systems and platforms in the future.
4. *Continuously monitor technological advancements*: Stay updated on the latest technological advancements in blockchain, formal logic, and related fields. Monitor research publications, attend conferences and workshops, and engage with the broader community. This awareness will help future projects to leverage new tools, techniques, and methodologies to address emerging challenges and take advantage of cutting-edge technologies.

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5. *Foster collaboration and knowledge sharing*: Encourage collaboration and knowledge sharing among project teams, as well as with external stakeholders, such as academic institutions, industry experts, and open-source communities. Collaborative efforts can lead to cross-pollination of ideas, sharing of best practices, and collective problem-solving. Establish platforms or forums for ongoing communication and collaboration to foster a vibrant community around the project's domain.

6. *Prioritize testing, verification, and validation*: Place a strong emphasis on rigorous testing, verification, and validation of the developed solutions. Establish comprehensive test suites, conduct thorough functional and performance testing, and engage in formal verification methods where applicable. Robust testing practices ensure the reliability, correctness, and security of the project's outcomes.

7. *Consider the broader societal impact*: Consider the broader societal impact of the project's outcomes. Consider the ethical, legal, and social implications of the deployed technologies and solutions. Engage with relevant stakeholders, regulatory bodies, and policymakers to address potential concerns and ensure alignment with societal values and goals.

By following these advice and recommendations, future projects in this direction can build upon the successes and lessons learned from the ONTOCHAIN project. This will enable them to further advance the field, contribute to the development of innovative solutions, and drive the adoption of decentralized technologies for trustworthy information exchange and content handling.

4 SEMANTIC BLOCKCHAIN CHALLENGES AND INTEGRATION PROSPECTIVES – ONTOCHAIN VIEW

In this section we will provide our experience and gathered knowledge regarding the integration of blockchain and SW technologies. Furthermore, we will try to answer the following questions:

- What are the main challenge areas addressed by combining Blockchain and SW?
- What are the main advantages, disadvantages, and limitations of combining both technologies?
- What are the main technical approaches to combine Blockchain and SW?
- What is future research directions on that combine Blockchain and SW?

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4.1 MAIN CHALLENGES

The main challenge is interoperability between data sources, which occurs in all areas (supply chain, IoT, e-health). Another main topic is data storage and retrieval, which is not occurring in all areas (copyright management, content creation, social media) but forms the biggest part of the published research. Side themes, which are occurring only in one area, are GDPR compliance, and provenance and traceability. Interoperability between data sources is seen in all areas. Blockchain data needs to integrate with other types of data on other technology stacks. Due to the large number of external data sources, blockchain must process different types of data. Blockchain needs interacting with other technologies and disclose their data. For organizations, the heterogeneous nature of data and need for sharing makes the process of collaboration between organizations more complicated. Sharing business data across independent enterprises is crucial. Supply chain and associated data are moving to blockchain to enable inter-organizational processes in networks with low trust which provides a scaling issue for blockchain. SW organizations need evolving domain ontologies globally by using blockchain as a platform relying on its features and capabilities, applying knowledge blockchain to ontology and using blockchain infrastructure for open knowledge graphs.

The second main challenge is data storage and retrieval, which we divide it into three sub-challenges: search, security and improving blockchain data structures. For the first sub-challenge, a secure search on the blockchain platform is required for reliable and accurate results. For example, there are discrepancies when searching for keywords through blockchain-encrypted data. The security sub-challenge appears in organizations: blockchain can tackle security threats and provide data integrity. This can be used to decentralise healthcare data operations and to make healthcare data transparent and immutable. In ONTOCHAIN the funded sub-project TrussiHealth addresses the challenges of transferring health data in a secure manner and controlled by data owner.

Also, for supply chains, the combination of blockchain and SW allows storing larger files while keeping the security and transparency provided by blockchain. The sub-challenge improving blockchain data structures can be recognised in blockchain area. Blockchain's data storage structure is not efficient, and the block data structure is complex. Blockchain structures are missing hiding configuration processes and missing the ability to create custom structures. Developed data models are urgently needed to make clear connections and knowledge. An official querying and data storage about blockchain is essential. Processing files in blockchain requires file storage using Knowledge Graph traceability. Representation capability of data can be boosted through integration of knowledge management and reasoning technologies with blockchain.

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The side challenge GDPR compliance appears in the blockchain area. For data protection in legislation organizations, it is difficult to maintain GDPR compliant in real time when the volume of shared data grows to exascale levels. A GDPR knowledge graph has been integrated with blockchain to have an audit log of every operation and the corresponding GDPR policy that permits the operation[19]. Another side challenge, provenance and traceability, occurs in the supply chain area. One of the supply chain major concerns is defining the source of information. Several food manufacturing systems present food traceability systems that suffer from a low level of readability, scalability, and data accuracy. Blockchain can facilitate ontologies to be used for much improved supply chain provenance as metadata and SW enabled ontologies to be applied for knowledge provenance. For example, many systems of blockchain and SW are proposed for supply chain management and provenance tracking[20].

4.2 ADVANTAGES, DISADVANTAGES AND LIMITATIONS

Regarding blockchain technology, the advantages achieved by the combination of blockchain, and SW are improved interoperability, improved search, improved security, and traceability, more efficient blockchain deployment, and use of SW tools. Searching for information in DL will be improved, search property will be more accurate and will use domain specific terms across multiple ledgers with improved power, usability and blockchain scope and services. Furthermore, searching will achieve higher accuracy for ranked results[21]. Data can also be simply linked to other sources of information using SW approaches. It is possible now to connect domain-specific data from sources external to the chain, for example linking blockchain Open Badge information with other Linked Data resources. Interoperability will be simpler and complex domains will become easier to deal with[22]. Furthermore, interoperability can be used in privacy-preserving applications, such as privacy preserving image retrieval. Additionally, facilitating blockchain powered knowledge graph construction schemes greatly simplify the building of new blockchain systems. The ability to manage multiple blockchains for different domain specific knowledge graphs also becomes easier. Faster and more robust, trustful, and reliable services can be achieved[23]. Users of blockchain can work with standard tools developed in the domain of SW like SPARQL for querying, Linked Data mechanisms for accessing the nodes of the graph's reasons for ontologies and many others, while benefiting from blockchain

[19] https://ieeexplore.ieee.org/abstract/document/9123033
[20] https://onlinelibrary.wiley.com/doi/abs/10.1002/isaf.1424
[21] https://publikationen.bibliothek.kit.edu/1000127040
[22] https://link.springer.com/chapter/10.1007/978-3-030-82153-1_41
[23] https://www.sciencedirect.com/science/article/pii/S2096720921000440

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mechanisms in their capacity to guarantee data reliance. Storing the process file of building a knowledge graph into blockchain ensures their security and traceability. For example, process files of a certain period, which may store reasoning error or security issues, can then be obtained from the chain on demand[24].

In terms of organizations, the benefits accomplished are enhanced services, improved privacy, higher accuracy, increased productivity, improved security. Advanced knowledge management mechanisms can provide reliable service exchange and reliable content handling. Other benefits are to systematically improve temporal delay, data inconsistency, and lack of trust issues, to aid maintaining the scenarios where the user will always have access to their data as well as the ability to track it. This empowers consumers while ensuring their privacy and decent service quality[25]. Furthermore, blockchain with SW can overcome security challenges, improve data integrity, and transform the transacting process in a decentralised, transparent, and immutable manner. For example, HealthOnt[26] supports the selection of blockchain by security experts when designing healthcare applications. It encodes traditional healthcare applications' information security into a blockchain-based system development that can be extended, reused, or integrated with other security ontologies. Considering the advantages in supply chain industry, highly secure access to immutable supply chain data can be provided. Provenance can be evaluated even when no party claims ownership over all supply-chain data. In addition to improving data representation capability, transparency and traceability is enhanced by its ability to query all systems in the supply chain network. For example, a shared understanding between humans and IoT in a blockchain-based pharmaceutical supply chain can be enabled. In addition, scalability and data sovereignty problems of blockchain can be addressed with off-chain semantic data modelling.

The advantages for SW industry are, that automatic ontology validation and evaluation technique are enhanced. Knowledge, experiences, improvements and conflicts are quantifiable and measurable. The universal ontology process can be automated with increasing resilience and improving cross-domain collaboration. Advantages of using an ontology management system based on combining blockchain and SW include data loss protection, data restoration, change tracking, and automatic consistency checking.

[24] https://link.springer.com/chapter/10.1007/978-3-030-57881-7_29
[25] https://ieeexplore.ieee.org/abstract/document/9592395
[26] https://content.iospress.com/articles/informatica/infor486

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4.3 TECHNICAL PERSPECTIVE

The primary obstacle faced by the technologies within the blockchain domain revolves around storage solutions, notably encompassing challenges in both file storage and data storage. In addition, there are less frequently explored technological aspects such as data indexing and data matching. Enhancing the utility of related data and its connection to pertinent external sources is significantly heightened through the creation of an index for blockchain using smart contracts to symbolize Open Badges. This index encompasses contracts, accounts, and data tied to their external semantics, thereby vastly improving the capacity for utilization. In the context of blockchain search capabilities, a secure methodology has been devised to transform the Word Nonlinear Matching (WNM) problem into a privacy-preserving word nonlinear matching (PPWNM) problem. This technique serves to assess the likeness between a query and a document. Through the application of similarity metrics, encrypted documents are ranked, yielding precise outcomes.

The procedure for constructing a knowledge graph from process files involves initial preprocessing via a distributed file system. This preliminary step bolsters storage efficiency and resource conservation. Subsequently, the treated files find their place within the blockchain network to ensure utmost security and integrity. By merging the power of blockchain and a distributed file storage system, the process guarantees secure file storage and rapid access during knowledge graph creation.

Leveraging the ONTOCHAIN funded sub project GraphChain[27] architecture in tandem with Ethereum blockchain yields the possibility of establishing a distributed graph data storage mechanism, augmenting the storage capacity of blockchain. Furthermore, an additional service layer can be introduced. This layer incorporates data graphs, logical reasoning, and foundational inference rules to effectively address advanced prerequisites concerning intricate data models within the blockchain realm.

With regard to organizations, ONTOCHAIN as a semantically enhanced ecosystem is built to allow the creation of secure distributed applications. Blockchain, ontology, and heuristic rules collectively form the foundational infrastructure for facilitating the exchange of business data among autonomous enterprises. A tangible illustration lies in the domain of Data Protection Regulation, where policies are enacted through the utilization of SW, Natural Language Processing (NLP), and Text Mining techniques.

Within the supply chain sector, a novel methodology is gaining prominence, where an ontology-driven blockchain technology modelling approach is harnessed, leveraging informal or semi-formal ontologies[28]. This approach presents an avenue for

[27] https://ontochain.ngi.eu/content/graphchain
[28] https://jit.ndhu.edu.tw/article/view/2608

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bolstering the interpretability of blockchain through ontology integration. Notably, off-chain data finds representation in Resource Description Framework (RDF) format and is conveniently accessible through a RESTful manner, often referred to as Linked Data. The core of this approach involves the storage of merely hashes, Uniform Resource Identifiers (URIs), and links on the blockchain. These elements serve as the means for verifying off-chain data. Verification is facilitated by employing a query strategy centred around link traversal, all executed through smart contracts[29].

In the realm of SW, a significant stride is being taken. By housing explicit knowledge within a decentralized blockchain, a profound comprehension of the model's concept is realized. Furthermore, this arrangement paves the way for establishing a framework that delegates model operations to diverse identities. This strategic setup is instrumental in the SW industry, bringing about innovative possibilities for decentralized and collaborative model management[30].

Since blockchain networks are distributed, creating a new record in the chain requires mechanisms to prevent data and system state inconsistencies. Therefore, various consensus mechanisms like proof-of-work (PoW), proof-of-stake (PoS), Byzantine Fault Tolerance (BFT), and similar are used for creating new blocks in the blockchain network. These mechanisms check if the block added to the network is done as part of majority-decision judgments.

In essence, blockchain technology aims to replace the need for a centralized database and traditional setup with an autonomous access-control mechanism. Blockchains incorporate consensus algorithms, distributed ledgers, timestamps, Merkle trees, and digital cryptography keys and algorithms to build a decentralized, immutable, traceable, and secure network. Combined with various modern technologies like IoT, cloud computing, and data mining, blockchains can provide more trustworthy and secure services[31].

As an alternative to blockchain scalability issues, the IOTA system[32] utilizes a Directed Acyclic Graph (DAG) structure called the Tangle. Unlike blockchain networks where transactions are grouped into blocks and validated by miners, the Tangle enables a stream of individual transactions to form a network. In the Tangle, each new transaction confirms two previous ones, creating a web-like structure. This unique

[29] https://publikationen.bibliothek.kit.edu/1000127040
[30] https://www.unifr.ch/inf/digits/en/assets/public/files/research/papers/Applying_the_Concept_of_Knowledge_Blockchains_to_Ontologies_CAMERA_READY.pdfhttps://www.unifr.ch/inf/digits/en/assets/public/files/research/papers/Applying_the_Concept_of_Knowledge_Blockchains_to_Ontologies_CAMERA_READY.pdf
[31] https://www.sciencedirect.com/science/article/pii/S0167739X19316280
[32] http://cryptoverze.s3.us-east-2.amazonaws.com/wp-content/uploads/2018/11/10012054/IOTA-MIOTA-Whitepaper.pdf

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approach eliminates the need for miners and allows parallel processing of transactions, potentially improving scalability and reducing fees.

Blockchain systems typically use consensus mechanisms like PoW or PoS to agree on the ledger's state. In contrast, IOTA initially used a Coordinator to confirm transactions and secure the network. However, the project has been working towards a decentralized model called Coordicide, aiming to remove the coordinator entirely and adopt a more trustless consensus mechanism.

Security is vital in any DLT system. While blockchain's PoW and PoS mechanisms secure the network, they remain susceptible to 51% attacks or specific vulnerabilities. IOTA's consensus model and absence of miners offer different security dynamics, relying on transaction numbers and network activity.

Blockchain's scalability is limited by block sizes and time, leading to network congestion as user and transaction numbers increase. In contrast, IOTA's Tangle facilitates parallel processing and avoids miners, presenting a potential solution for improved scalability and accommodating higher transaction volumes[33].

IOTA has found applications in various sectors, including supply chain[34] , identity validation[35], smart city[36], and IoT[37]. The choice between these systems depends on specific use case requirements and constraints.

4.4 FUTURE DIRECTIONS

Blockchain enables the implementation of immutable transaction logic in a "trustless" decentralized infrastructure upon distributed agreements. It might be combined with several modern technologies, such as IoT, cloud computing, and data mining as a decentralized infrastructure. As a result of our survey, we can underline that many applications in several domains, apart from crypto finance, are using blockchain as a trustworthy ecosystem for storing and keeping track of transactions. SW protocols provide an ability to capture the context semantics of data, services, products, and processes, which may all play a role in various transactions. Hence, it makes a great deal of sense to enrich our transactions with meaningful and trusted data. Moreover, it makes a great deal of sense to enrich the SW with verifiable proofs, starting from zero-knowledge to full-proofs that may enhance our trust in the information provided. Several initiatives have been proposed that combine

[33] https://ieeexplore.ieee.org/abstract/document/9243366
[34] https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3717389
[35] https://ieeexplore.ieee.org/abstract/document/9241693
[36] https://www.sciencedirect.com/science/article/pii/S1084804518303473
[37] https://www.mdpi.com/1424-8220/21/13/4354

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blockchains and SW and, many of them, have already integrated parts from both technological spheres.

Within the SW landscape, a comprehensive exploration is warranted concerning the Stellar Consensus Protocol (SCP) along with its constituent sub-protocols: the nomination protocol, the ballot protocol, and the hybrid consensus algorithm[38]. Of particular interest is the evaluation of data structures to ascertain the most suitable option for representing ontologies within the context of blockchain technology.

It's worth noting that the application of Universally Unique Identifiers (UUIDs) might not be the optimal solution for ontologies, despite their advantages in terms of decentralized and independent element creation[39]. The SW domain offers additional avenues for investigation, including the assessment of performance challenges stemming from intricate knowledge identification on the blockchain. Furthermore, the decentralized storage of knowledge graphs and the formulation of trainable incentive models for knowledge crowdsourcing emerge as pertinent areas for exploration[40].

During the ONTOCHAIN project, we have been closely tracking the latest trends in SW and blockchain technologies. In this section wee explained the benefits that SW can offer to blockchain and vice versa. In addition, we focused on the challenges of integrating these two innovative technologies. ONTOCHAIN funded projects have successfully combined the SW and blockchain to address different problems in various areas such as supply chain (DKG, BabelFish, OTCnLNG, Caps-CO, RecheckGreenBox), e-Health (TrussiHealth, Carechain), copyright management (CopyrightLY), and IoT (Desmo-LD, ADOS).

Currently, the Internet faces serious challenges, such as centralization of power, unknown or unverifiable provenance of information, anonymity, unreliable identities, privacy-aware data exchange, and no fair rewards for good quality. We believe that these challenges can be tackled by a suitable integration enabling SW technologies, such as Linked Data, Ontologies, RDF, and OWL with blockchain. However, in order for the integration of SW with blockchain to become a competitive solution to existing (centralized) technologies and offer more trustworthy, decentralized services for the users, more systematic work on this matter has to be done in the future. Scalability, computational performance, representation of metadata on-chain or off-chain, cross-chain semantic and syntactic interoperability, greenness, and adoption issues still need to be addressed.

[38] https://dl.acm.org/doi/abs/10.1145/3404709.3404769

[39] https://www.unifr.ch/inf/digits/en/assets/public/files/research/papers/Applying_the_Concept_of_Knowledge_Blockchains_to_Ontologies_CAMERA_READY.pdf

[40] https://direct.mit.edu/dint/article/3/2/205/101024/OpenKG-Chain-A-Blockchain-Infrastructure-for-Open

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Overall, towards a more human-centered and trustworthy Internet and a new (personal, proprietary, corporate) data market, one should advance and successfully integrate blockchain and SW technologies. Our major endeavour to this extent is to continue development of the ONTOCHAIN software ecosystem, which represents a rich portfolio of novel technologies to improve our trust in the data, products, and services.

5 POLICY RECOMMENDATIONS

In the ever-evolving landscape of blockchain technology, the critical intersection of policy and innovation necessitates a thorough exploration of effective policy recommendations. As ONTOCHAIN continues to pave the way for enhanced data sharing, security, and interoperability, it becomes imperative to delineate policies that align with these advancements. This section delves into the intricate realm of policy recommendations within the ONTOCHAIN framework, aiming to elucidate strategies that ensure the responsible and sustainable integration of blockchain and ontology technologies. By addressing the multifaceted considerations of governance, privacy, and regulatory harmonization, this section seeks to establish a comprehensive foundation for the prudent implementation and operation of the ONTOCHAIN ecosystem.

5.1 POLICY RECOMMENDATIONS FOR FOSTERING A HUMAN-CENTRIC AND TRUSTED INTERNET ENVIRONMENT.

In this section we provide some policy recommendations for future projects to build human-centric services.

- *Privacy Protection and Data Ownership:* Implement policies that prioritize individuals' privacy rights and ensure transparent and informed consent for data collection and usage. Empower individuals with greater control over their personal data and establish mechanisms for data portability and erasure. Encourage organizations to adopt privacy-by-design principles and promote the development of privacy-enhancing technologies.
- *Cybersecurity and Data Breach Prevention:* Enact comprehensive cybersecurity policies to protect individuals, businesses, and critical infrastructure from cyber threats. Foster collaboration between public and private sectors to share threat intelligence, best practices, and resources. Encourage the adoption of robust

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security measures, such as encryption and multi-factor authentication, and promote cybersecurity awareness and education programs.

- *Digital Inclusion and Accessibility:* Promote policies that bridge the digital divide and ensure equal access to digital technologies and services. Develop initiatives to provide affordable internet connectivity, digital skills training, and accessibility accommodations for persons with disabilities. Encourage the development of inclusive and user-friendly digital interfaces and services.
- *Trust and Transparency in Artificial Intelligence:* Establish policies to govern the development and deployment of Artificial Intelligence (AI) systems. Promote ethical AI principles, including fairness, transparency, accountability, and human oversight. Encourage the adoption of explainable AI algorithms and mechanisms for auditing and validating AI systems. Foster interdisciplinary research and collaboration to address the social and ethical implications of AI technologies.
- *Digital Literacy and Media Literacy:* Implement policies to promote digital literacy and media literacy skills among individuals of all ages. Develop educational programs that teach critical thinking, online safety, and responsible digital citizenship. Foster partnerships between educational institutions, civil society organizations, and technology companies to enhance digital literacy efforts.
- *Consumer Protection and E-Commerce Regulations:* Enact regulations that protect consumers in the digital marketplace. Establish clear guidelines for online transactions, product quality, pricing transparency, and dispute resolution mechanisms. Ensure adequate enforcement of consumer protection laws and foster cooperation between regulatory bodies and online platforms to address fraudulent and deceptive practices.
- *Open Data and Interoperability*: Encourage the adoption of open data principles and promote interoperability among digital systems and platforms. Establish policies that enable the sharing, reuse, and integration of data across different domains and sectors. Support initiatives for open standards, data sharing agreements, and data portability to foster innovation and collaboration.
- *Ethical Use of Emerging Technologies:* Develop policies and regulatory frameworks that address the ethical implications of emerging technologies, such as blockchain, Internet of Things (IoT), and virtual reality. Ensure that these technologies are deployed in a manner that respects privacy, human rights, and societal values. Promote public dialogue and engagement to shape the ethical guidelines and governance frameworks for emerging technologies.
- *International Cooperation and Multistakeholder Engagement:* Foster international cooperation and collaboration to address global challenges in the digital space. Engage with stakeholders from governments, civil society, academia, and industry in multistakeholder processes to develop inclusive and

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effective policy solutions. Promote the exchange of best practices, knowledge sharing, and capacity building initiatives across borders.

These are the policy recommendations that ONTOCHAIN project suggests and by addressing key areas such as privacy, cybersecurity, content moderation, digital inclusion, AI ethics, consumer protection, open data, and international cooperation. Implementing these policies can help create an internet ecosystem that prioritizes user empowerment, trust, and respect for individual rights, while promoting Impact

6 HARNESSING THE OUTCOMES OF ONTOCHAIN ON BLOCKCHAIN AND DISTRIBUTED LEDGER TECHNOLOGIES FOR POLICY DEVELOPMENT

Blockchain and Distributed Ledger Technologies (DLTs) hold great potential for enhancing trust, traceability, and security in various sectors. The ONTOCHAIN initiative, under the Next Generation Internet (NGI) aims to support theoretical and applied research in this field. This policy brief highlights how to extract the outcomes of such projects and engage relevant stakeholders to shape policy recommendations for the European Commission.

First, in order to engage stakeholders effectively, it may be worth considering employing the following approaches:

- Form thematic working groups or consortia consisting of representatives from relevant stakeholders to facilitate focused discussions and collaborative efforts.
- Organize conferences, webinars, and workshops tailored to specific sectors or policy areas, inviting stakeholders to share their expertise and insights.
- Develop strategic partnerships with key industry players and organizations to leverage their resources, networks, and expertise in support of ONTOCHAIN objectives.
- Facilitate internships, secondments, or temporary placements for experts from stakeholder organizations to work on ONTOCHAIN-related projects, fostering knowledge exchange and cross-sector collaboration.
- Launch targeted public awareness campaigns to raise the visibility of ONTOCHAIN's objectives and outcomes, highlighting the benefits of blockchain and DLTs for different sectors and end users.

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Also, taking into account:

- Specific policy workshops and roundtables - Organizing workshops and roundtables with stakeholders to discuss research outcomes, share best practices, and draft policy recommendations.
- Knowledge sharing platforms - Creating an online platform to disseminate research findings, share resources, and facilitate discussions among stakeholders.
- White papers and policy briefs - Publishing white papers and policy briefs to summarize research outcomes and offer evidence-based recommendations to policymakers.
- Public consultations - Conduct public consultations to gather input from a wider range of stakeholders and ensure policies are developed in a transparent and inclusive manner.

In general terms, a raw list of *Stakeholders to engage* should include:

1. European Commission Directorates-General (DGs)
    - DG CNECT (Communications Networks, Content & Technology)
    - DG GROW (Internal Market, Industry, Entrepreneurship & SMEs)
    - DG RTD (Research & Innovation)
    - DG SANTE (Health & Food Safety)
    - DG ENV (Environment)
    - DG MOVE (Mobility & Transport)
    - DG EAC (Education & Culture)
    - DG CLIMA (Climate Action)

Engaging with relevant DGs to align research outcomes with policy priorities and facilitate cross sectoral collaboration.

2. Members of the European Parliament (MEPs)
    - ITRE (Committee on Industry, Research & Energy)
    - IMCO (Committee on the Internal Market & Consumer Protection)

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- ENVI (Committee on Environment, Public Health & Food Safety)
- TRAN (Committee on Transport & Tourism)
- CULT (Committee on Culture & Education)
- JURI (Committee on Legal Affairs)
- FISC (Subcommittee on Tax Matters)

Engaging with MEPs in relevant committees (e.g., ITRE and IMCO) and interest groups, to advocate for policy changes informed by the research outcomes.

3. European Union Agencies
    - European Union Intellectual Property Office (EUIPO)
    - European Union Agency for Cybersecurity (ENISA)
    - European Data Protection Supervisor (EDPS)
    - European Medicines Agency (EMA)
    - European Agency for the operational management of large-scale IT systems in the area of freedom, security and justice (eu-LISA)
4. National policymakers and regulators
    - National Ministries responsible for technology, industry, research, health, environment, mobility, and education
    - National Data Protection Authorities (DPAs)
    - National Cybersecurity Authorities
    - National Intellectual Property Offices
    - Collaborating with national representatives from Member States to ensure the harmonization of policies across the EU.
5. Industry partners and innovators
    - Large enterprises, SMEs, and startups operating in relevant sectors.
    - Technology providers and blockchain/DLT developers
    - Industry-specific associations and networks
    - Research institutions and universities

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Fostering partnerships with businesses, high-tech companies, and academic institutions to accelerate technology adoption and market readiness.

6. International organizations
   - International Telecommunication Union (ITU)
   - World Intellectual Property Organization (WIPO)
   - World Health Organization (WHO)
   - United Nations Development Programme (UNDP)
7. Non-governmental organizations (NGOs)
   - NGOs focused on digital rights, data privacy, transparency, and decentralization.
   - Think tanks and policy research institutes.
8. Citizen and end-user representatives
   - Consumer associations and advocacy groups
   - Privacy and data protection activists

Furthermore, specific examples and recommendations that may be considered include:

1. Health sector: promoting the development of a secure and interoperable Health Data Space, leveraging blockchain technology to ensure data privacy and traceability.
2. Energy and sustainability: supporting the integration of blockchain-based solutions for decentralized energy markets, enabling transparent and secure energy trading among prosumers.
3. Public services: encouraging Member States to adopt blockchain-based solutions for e-government services, such as digital identity, land registries, and voting systems, to enhance transparency and reduce bureaucracy.
4. Industry 4.0: fostering the development of blockchain-enabled supply chain management solutions to ensure traceability, quality assurance, and secure data exchange among stakeholders.

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Anyway, when defining policy briefs for the European Commission, it is essential to avoid certain bottlenecks to ensure their effectiveness and relevance. Some key bottlenecks to avoid include:

1. Differences in regulatory frameworks across countries: consider the diverse legal and regulatory environments within EU Member States. Align recommendations with existing EU legislation and directives, while considering national variations to ensure harmonization and facilitate implementation.

2. Lack of stakeholder engagement: inadequate engagement with relevant stakeholders can lead to policy recommendations that fail to address real-world challenges or gain support. Establish open communication channels and collaboration opportunities with stakeholders across academia, industry, government, and civil society to ensure policy briefs are grounded in practical experience.

3. Insufficient evidence base: policy recommendations should be based on solid research and empirical evidence. Ensure that policy briefs draw upon the latest findings from European-funded projects and other relevant studies to provide a robust foundation for decision-making.

4. Overlooking cross-sectoral impacts: Blockchain and DLTs have implications across multiple sectors. Examine the potential cross-sectoral consequences of policy recommendations to avoid unintended consequences and ensure a comprehensive approach.

5. Overemphasis on technical aspects: while technical details are crucial, it is essential to balance them with policy and socio-economic considerations. Frame policy briefs in a way that is accessible to non-experts, focusing on broader benefits and challenges rather than specific technical components.

6. Limited scalability and transferability: develop policy recommendations that are scalable and transferable across different EU Member States and sectors. Avoid overly narrow or context specific recommendations that may hinder widespread adoption.

7. Short-term focus: policy briefs should consider both short-term and long-term implications, as blockchain and DLTs are rapidly evolving fields. Strike a balance between addressing immediate challenges and laying the groundwork for future development and innovation.

8. Ignoring ethical and social considerations: address ethical and social concerns, such as data privacy, digital inclusion, and equitable access to technology, to ensure that policy recommendations are aligned with European values and contribute to sustainable development.

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9. Inadequate monitoring and evaluation mechanisms: establish clear indicators and metrics for measuring the impact of policy recommendations. This will enable ongoing assessment and refinement of policies to ensure their continued relevance and effectiveness.

By addressing these bottlenecks, policy briefs can better support the European Commission's objectives and contribute to the development of a robust, sustainable, and inclusive European digital ecosystem.

The outcomes of ONTOCHAIN can significantly contribute to shaping policy recommendations for the European Commission. Engaging with relevant stakeholders, sharing knowledge, and adopting best practices can ensure that policy development is informed by cutting-edge research, accelerating the deployment of blockchain and DLTs across various sectors.

One last key concept is the following: Reconciling policy briefs for regulatory frameworks with the fast-paced, innovative nature of the blockchain environment requires adopting flexible and adaptive approaches. Below are some suggestions and specific examples to bridge the gap between traditional policymaking and the dynamic blockchain ecosystem:

- Regulatory sandboxes: establishing regulatory sandboxes, where startups and innovators can test their blockchain solutions in a controlled environment without facing full regulatory compliance. This approach allows regulators to better understand the technology, identify potential risks, and develop appropriate regulations while fostering innovation. For example, the UK's Financial

- Conduct Authority (FCA) operates a successful regulatory sandbox that has facilitated the testing of various blockchain-based solutions.

- Co-creation of policies: encouraging co-creation of policies by involving blockchain stakeholders such as startups, developers, and researchers in the policymaking process. This collaborative approach ensures that policies address the needs and challenges faced by the blockchain community, promote innovation, and remain up to date with technological advancements.

- Innovation hubs: establishing innovation hubs or dedicated support centers that provide guidance to blockchain stakeholders on navigating the regulatory landscape. These hubs can offer expert advice, networking opportunities, and resources to help innovators comply with relevant regulations while developing their blockchain solutions. An example is the European Blockchain Partnership, which aims to build a European Blockchain Services Infrastructure (EBSI) and serves as a collaborative platform for blockchain stakeholders.

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- Agile regulation: adopting an agile regulatory approach that is responsive to rapid technological changes in the blockchain environment. This includes updating regulations as needed, adopting principles-based regulation that focuses on high-level objectives rather than prescriptive rules, and using regulatory pilots to test and iterate policy interventions.
- Education and capacity building: enhancing the capacity of policymakers and regulators to understand blockchain technology by providing training, workshops, and knowledge exchange opportunities. This will enable them to make more informed decisions and develop policies that effectively address the unique challenges and opportunities presented by blockchain and DLTs.
- Cross-border collaboration: fostering cross-border collaboration among regulators and policymakers to harmonize regulatory frameworks and facilitate the development of common standards and best practices. This can be achieved through initiatives like the European Blockchain Observatory and Forum, which aims to promote European cooperation and knowledge sharing in the blockchain space.
- Public-private partnerships: encouraging public-private partnerships (PPPs) to jointly develop and implement blockchain solutions in sectors such as healthcare, public services, and energy. PPPs can help bridge the gap between traditional regulatory frameworks and the innovative nature of the blockchain environment by enabling collaboration, knowledge sharing, and joint risk management.

A list of real-world examples of policy briefs related to blockchain:

Country: European Union

Year: 2020

Goal: Promoting the development of blockchain technology in the EU

Provider: European Parliamentary Research Service (EPRS)

Title: "Blockchain and the General Data Protection Regulation: Can distributed ledgers be squared with European data protection law?"

Link: https://www.europarl.europa.eu/RegData/etudes/STUD/2019/634445/EPRS_STU(2019)634445_EN.pdf

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The EPRS policy brief examines the compatibility between blockchain technology and the General Data Protection Regulation (GDPR), providing recommendations to reconcile distributed ledger systems with European data protection law.

Country: United States

Year: 2019

Goal: Understand blockchain's potential impact on public sector services

Provider: IBM Center for The Business of Government

Title: "The Impact of Blockchain for Government: Insights on Identity, Payments, and Supply Chain"

Link: https://www.businessofgovernment.org/sites/default/files/The%20Impact%20of%20Blockchain%20for%20Government.pdf

The IBM Centre's policy brief explores the potential impact of blockchain technology on government services, focusing on identity management, payment systems, and supply chain transparency.

Country: Canada

Year: 2018

Goal: Examine potential applications of blockchain technology in intellectual property administration

Provider: Canadian Intellectual Property Office (CIPO)

Title: "CIPO Blockchain Policy Brief"

Link: https://smit.vub.ac.be/policy-brief-55-how-can-blockchain-impact-public-values-a-playing-field-analysis

The CIPO Blockchain Policy Brief discusses the possible applications of blockchain technology in intellectual property administration, addressing challenges and opportunities in the IP landscape.

Country: United Kingdom

Year: 2016

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Goal: Investigate the applications and implications of distributed ledger technology

Provider: UK Government Office for Science

Title: "Distributed Ledger Technology: Beyond Blockchain"

Link:
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/492972/gs-16-1-distributed-ledger-technology.pdf

The UK Government Office for Science's policy brief delves into distributed ledger technology beyond blockchain, investigating various applications and implications of the technology across multiple sectors.

Country: Australia

Year: 2020

Goal: Explore the potential of blockchain technology to support digital trust and regulatory compliance

Provider: Australian Government Department of Industry, Innovation and Science

Title: "National Blockchain Roadmap"

Link: https://apo.org.au/sites/default/files/resource-files/2020-02/apo-nid276541.pdf

The National Blockchain Roadmap outlines Australia's strategic plan to harness blockchain technology for digital trust and regulatory compliance, guiding the country's growth and adoption of the technology.

These policy briefs and reports highlight the increasing attention that governments and organizations around the world are giving to blockchain technology and its potential applications across various sectors.

Each of these documents presents insights, recommendations, and strategies to advance the adoption of blockchain technology while addressing the challenges and risks it poses.

By adopting these strategies, policymakers can develop more agile and responsive regulatory frameworks that support innovation in the blockchain ecosystem while addressing risks and ensuring the protection of citizens and consumers.

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We recommend that policymakers consider the potential benefits of building a human-centric ecosystem based on Decentralized/Blockchain and semantic web technologies. Our project aims to create such an ecosystem, and we believe that these technologies can be used to create a more efficient and effective system that prioritizes the needs of individuals and communities.

To support the development of such an ecosystem, we recommend that policymakers:

- Encourage research and development into decentralized and semantic web technologies, with a focus on developing platforms that are user-friendly and accessible to a wide range of individuals and communities.
- Explore ways to incentivize the development and adoption of decentralized platforms, such as tax breaks or other financial incentives for companies that invest in these technologies.
- Promote education and awareness about the potential benefits of decentralized and semantic web technologies, both for developers and end-users.
- Work to establish standards and best practices for adopting decentralized and semantic web technologies, with a focus on ensuring the security and privacy of user data.
- Collaborate with industry leaders and experts to identify and address any potential challenges or barriers to the development and adoption of decentralized and semantic web technologies.

By taking these steps, policymakers can help create an environment that fosters innovation and supports the development of a human-centric ecosystem that is built on decentralized and semantic web technologies. This, in turn, can lead to a more efficient, effective, and equitable system that prioritizes the needs of individuals and communities.

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7 CONCLUSION

In conclusion, the ONTOCHAIN project has been a significant endeavour in building a human-centric and trusted internet. Throughout this journey, we have encountered challenges, made important discoveries, and developed recommendations that hold great significance for the future of digital ecosystems.

KEY FINDINGS:

Our project's journey has illuminated several key findings:

1. Technology Challenges: We have identified technology challenges that must be addressed to realize the potential of semantic blockchain. These challenges include scalability, interoperability, and security concerns.
2. Best Practices: Through our experiences, we have uncovered valuable strategies and practices that can be applied to future projects in this domain. These lessons learned will guide future endeavours toward success.
3. Semantic Blockchain Potential: We have explored the vast potential of semantic blockchain, recognizing its advantages, disadvantages, and limitations. This technology offers enhanced data management, transparency, and trust, but it also comes with complexities that demand careful consideration.

RECOMMENDATIONS:

Based on our findings, we put forth recommendations aimed at fostering a human-centric and trusted internet environment. These recommendations span both technological and policy dimensions, emphasizing:

Policy Recommendations: We propose policy measures to establish a regulatory framework that safeguards user privacy, data security, and trust while promoting innovation and collaboration.

Technological Innovation: We encourage continued research and innovation in blockchain and distributed ledger technologies, focusing on addressing challenges and realizing the full potential of semantic blockchain.

SIGNIFICANCE:

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The significance of our work lies in its potential to shape the future of the internet. By prioritizing human values and trust, we aim to create an online environment that empowers individuals and organizations while ensuring the security and integrity of digital transactions. Our work lays the foundation for a more inclusive, transparent, and reliable digital world.

CONTINUED RESEARCH AND POLICY DEVELOPMENT:

The journey does not end here. We emphasize the importance of continued research, innovation, and policy development in this domain. As technology evolves, must of our strategies and regulations should also evolve. The ONTOCHAIN project serves as a catalyst for ongoing efforts to enhance the internet's human-centric and trusted nature.

In closing, we express our gratitude to all who have contributed to the ONTOCHAIN project. Together, we have embarked on a mission to reshape the digital landscape, and with unwavering dedication. We shall continue to pave the way towards a more secure, trustworthy, and human-centric internet.

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