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Industrial Symbiosis Networks in Greece: Utilising the Power of Blockchain-based B2B Marketplaces

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Abstract
The proliferation of industrialisation and its environmental consequences over the last decades dictates the need for transitioning to a 'Circular Economy' (CE) business model with a view to balancing manufacturers' economic prosperity and environmental sustainability. Business models based on 'Industrial Symbiosis Networks' (ISNs), within which traditionally independent industries continually exchange energy, materials and by-products, with no or minimum waste produced, have the potential to proceed in this direction. However, due to various cultural, organisational and managerial barriers, their state of development in Greece, similar to rest of the world, is very low. That is exactly where this article sets its objectives, aiming to alleviate these barriers and contribute in establishing cross-sectoral synergies by introducing an innovative business model, supported by an exchange platform in the form of a blockchain-based B2B digital marketplace. The proposed business model will detail a plan for creating symbiotic relationships among manufacturing companies in Greece and will be supported by a blockchain-based marketplace, which will enable material, by-product and energy exchanges in a reliable and secure way. Blockchain will act both as an exchange platform and a trust mechanism, since its decentralised nature, which is manifested in all its capabilities i.e. smart contracts or tokenisation will increase the business model's reliability and facilitate its adoption and market penetration. The successful implementation of the proposed business model will bring about a multifaceted positive impact ranging from its contribution to exceeding the current state-of-the-art in the intersection of environmental science and information technology, to benefiting society and economy through fostering sustainable regional development.

Keywords: *Blockchain, B2B Marketplaces, Circular Business Model, Industrial Ecology, Industrial Symbiosis Networks, Industry 4.0*

JEL Classifications: *Q57*

1. Introduction

The proliferation of industrialisation over the last decades has undoubtedly led to environmental degradation, while casting a long shadow over manufacturing companies, failing to efficiently conform to waste prevention policies and capture the financial and social benefits of a more circular and sustainable manufacturing practice [1], [2]. At the same time, the ever-increasing population dictates the continuous evolution of businesses' manufacturing processes, in order for them to accommodate growing customer needs and ultimately flourish in today's constantly shifting competitive landscape [3]. Unfortunately, these business achievements come, all too often, to the detriment of the environment, rendering industrial activity responsible for a plethora of adverse effects, including waste generation, harmful Greenhouse Gas (GHG) emissions and depletion of natural resources [4]. As a matter of fact, in Greece, waste resulting from such activities is predicted to amount to 18.074 tons in 2020, while GHG emissions exceeded 7 megatons (Mt) in 2017 [5]. To add insult to injury, Greece's voracious consumption levels are so unsustainable that it would need to grow four times its current acreage to meet consumers' future needs, which indisputably aggravates resource depletion, land use and global warming. It is beyond the shadow of doubt that industrial systems cannot be sustained for long, when natural materials become scarce and waste to nature exceeds its carrying capacity, i.e. the ability with which nature can decompose waste within a given time and space.

Under these circumstances, the need to ensure manufacturers' environmental compliance without compromising their resource supply and undisrupted production, and hence their economic benefits, is of paramount importance. In view of the intrinsic mechanics of the conventional linear economy, which rely on a wasteful 'take, make and dispose' flow [6], the need for transition to a sustainable Circular Economy (CE) business and manufacturing model emerges as a viable and imperative solution for achieving a better balance and harmony between economic prosperity and environmental sustainability. Environmental practices such as the 6Rs, i.e. 'reduce, reuse recycle, repair, rethink and refuse', fully encapsulate the essence of CE by promoting closed-loop flows, which optimise material cycles, maximise resource efficiency and reduce environmental impacts [7]. In this direction, Industrial Ecology (IE) has been widely considered for over two decades, as an immensely useful framework for facilitating and guiding this transition towards circular and sustainable manufacturing [8]. This is accomplished by investigating the hypothesis that an industrial system can be viewed as an ecosystem constantly trying to avoid waste, reintroducing waste as a resource and preserving the value of a product as long as possible [9].

The research presented in this article focuses on Industrial Symbiosis (IS), a concept which dates back in 1997 coined from the successful case of the Kalundborg recycling network in the northern part of Sjaelland in Denmark [10]. Since then the term has become established within the field of IE and also within the business community and policy makers. IS in essence, aspires to form interorganisational networks, termed Industrial Symbiosis Networks (ISNs), emulating the symbiotic functioning of ecological systems, within which traditionally independent industries continually exchange energy, materials and by-products, with no or minimum waste produced [11]. These networks traditionally exploit geographical proximity and manage to bring about a twofold advantage over traditional industrial systems. First, they manage to improve resource efficiency by transforming waste streams into new valuable resources, which are thereafter used in other processes. In that way, ISNs prolong the economic useful life of materials, which have exhausted their physical and/or functional service life and would otherwise be disposed of. Second, the production of waste, GHG emissions and subsequently the environmental footprint of collaborating industries is significantly reduced [4].

However, despite its merits, the practical implementation of ISNs is currently lacking the expansion the underlying concept of IS deserves. There are many reasons for this hampered performance. First of all, participating in an ISN is an investment and as such financial barriers and investment-inherent risks have to be overcome in order to proceed in such a decision. Still, these barriers being hard in nature can be easily quantified and in most cases the decision to proceed in the development or participation in an ISN would be favorable, since the benefits of creating a demand-supply network of processed by-products are significant [12]. Alas, as literature proves, there is a variety of cultural, organisational and managerial factors negatively affecting decision making on forming or participating in an ISN, as shown in Figure 1.

Greece is not an exception when it comes to the application of IS concepts in industry and manufacturing systems. The state of ISN development is very low and Industrial Symbiosis, as a concept, is not well acknowledged among stakeholders, policy makers and regional authorities [13]. Therefore, in light of Greece's environmental status quo, peaked consumption profile and resource scarcity, the adaptation of the ISN paradigm by the Greek industries seems like an imperative. That is exactly where this research sets its vision, objectives and aspirations aiming to contribute in alleviating the aforementioned barriers by introducing an innovative Circular Business model for ISNs in Greece supported by open-source blockchain technology, which seems a perfect fit for tackling major obstacles of ISN development and operations, such as trust, information sharing, compatibility, misalignment and limited management awareness and insights.

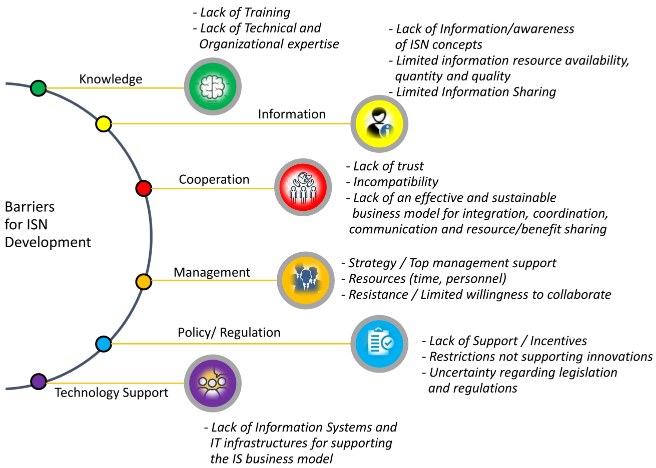

Figure 1: A Taxonomy of barriers for ISN development

2. Challenges

Our initial review of available literature and the current perception of industry and policy makers as expressed in white papers and regulatory documents supports – with little or no dispute – the argument that Circular Economy and specifically Industrial Symbiosis Networks have the potential to support the sustainable, environmentally responsible and 'clean' growth and development of industrial manufacturing systems. Nonetheless, the development of ISNs globally and the number of cases where the ISN model has become prevalent is still lagging, with most of the cases referring to the establishment of eco-industrial parks [14], [15]. The main reasons behind that situation are summarised in the barriers of Figure 1, which are hindering ISN development and therefore, in essence, outline the framework of challenges this article aims to address. Indeed, the proposed business model aims to a) provide the impetus needed to tackle these obstacles of ISN development by raising awareness and providing them with a viable circular business model and a roadmap with guidelines for its implementation, b) support Greek manufacturing companies to examine ways to build a knowledge base of material/by-products and waste exchanges and to further study and rethink their business processes in order to facilitate the establishment of synergies across companies of the same or different industries and c) support the development and operation of closed-loop material/by-products and waste exchanges within and across industrial ecosystems supported by an open source, low-cost and reliable information technology infrastructure.

Lack of management knowledge and awareness of ISN concepts, mechanisms and benefits is a key challenge to overcome when attempting to identify potential synergistic opportunities. Absorptive capacity, i.e. the ability to 'recognise the value of new, external information, assimilate it, and apply it to commercial ends' [16], succinctly captures the capabilities needed for knowledge transfers to translate into financial incentives. The proposed business model will be aligned to the need for enhanced absorptive capacity of stakeholders and effectively address it by creating mechanisms to educate potential stakeholders and enhance their understanding of IS concepts, technical and organisational aspects of symbiosis, rules of participation, expected benefits and their sharing mechanisms. As for information sharing between potential participants, it is obvious that lack of it can create conflicts leading to reduced intention and willingness for resource sharing. The proposed research addresses this challenge by establishing a means of coordination of information flows pertaining to resources' origin, availability, quantity and quality. Emboldening exchanges of such knowledge is capable of increasing the cognitive proximity and understanding of each other's business, thus leading to improved selection capabilities and utilisation of resources to the furthest extent possible. Another dissuasive factor against ISN development is the lack of compatibility, which can result from different company sizes, management culture or even more operational reasons such as old and long-standing contracts. The proposed research addresses this challenge by establishing direct information exchanges and knowledge base access, in order to enhance visibility even for smaller companies and transparency regarding available resources and production outputs (waste/by-products) for all the companies participating in the ecosystem. This approach will eventually eliminate the unfamiliarity with one another's business and lead to the creation of synergies between industries and their manufacturing systems.

An additional fundamental challenge ISN development is faced with is the lack of support, i.e. deficiencies in policies, outdated regulations and restrictive definitions of waste, by-products and industries' potential involvement in their usage. Again, the proposed business model, through its successful operation, will be able to contribute, in the long run, to the identification and specification of required legislation and regulations on all scales, including companies, industries, supply chains and beyond, to support IS applications. Last but not least, although the introduction of the proposed business model might point the way towards legislative changes, its influence on current management practices and decision-making in organisations will probably be ponderous. It is only through its success and expansion over time that the proposed business model will be able to shift companies' focus towards reshaping actual strategies to examine the lack of training, expertise and resourcing of time and personnel under the lens of organisational ISN-oriented change.

Intentionally we left for last the challenge of trust, which according to literature is the most prominent between challenges, since most potential participants have no experience of a symbiotic relationship and no cooperative mechanisms of this nature in place, thus they are hesitant to adopt an ISN business model. Indeed, building a trusted IS ecosystem is of paramount importance and overcoming common obstacles, such as competitive attitudes or corporate 'social isolation' is a vital prerequisite for forming viable, long lasting and functional synergies. To deal with this difficult challenge and also provide the necessary technology support (see Figure 1) for the proposed circular business model to work efficiently, we introduce an innovative B2B (Business-to-Business) marketplace based on blockchain technology, which will be described in detail in the next section. Truth is that there are numerous research efforts studying the potential of Blockchain in greening supply chains or applying Circular Economy business models, but to our best knowledge, current literature lacks any research efforts dealing with ISN, supported by Blockchain-based marketplaces. If one had to pinpoint a research fairly resembling the one presented in this article, this would pinpoint the work of Nallapaneni & Chopra [17]. The authors study the energy flows in Networks of Firms resulting in an Industrial Symbiosis-based Multi Energy System (IS-MES). They claim that the actual implementation of such an IS-MES is vulnerable to cascading failures emerging from one firm in the network, which makes them inherently resilient. To counter this resilience challenge, they propose the use of the Blockchain-based Online Information Sharing (BOIS) platform, where a firm-to-firm (F2F) IS relationship establishment mechanism following the IS principles is possible through the blockchain-based smart contracts. In essence, the potential of blockchain to support environmental sustainability, according to [18], comes down to one key feature: its ability to provide a verifiable record of who exchanges what with whom and therefore who has what at a given time. Many of the challenges for how we manage natural resources and maintain ecosystem services arise because of a lack of trust and confidence in the rules governing exchange and possession.

In the proposed business model, blockchain acts both as an exchange platform and as a trust mechanism. Traditionally, a B2B marketplace relies on an intermediary (market owner) who brings together multiple buyers and sellers to facilitate transactions. Because trust is fundamental for valued relationships in B2B markets, this entity acts as a Trusted Third Party (TTP), which safeguards against fraud and the misuse of trust among market participants. Additionally, the TTP keeps the electronic registry of the transactions, ensures its integrity and depends on the banking payment system for settling registered transactions. For these services, the TTP charges transaction fees covering its operating expenditures. However, because the TTP controls the infrastructure, information flow and the processes governing the marketplace, trust issues are raised. Blockchain eliminates this issue by its trustless definition, since there is no central authority dominating the market. Record keeping and data-sharing in the ISN ecosystem will be kept in a digital ledger, visible to all authorised members only, since the blockchain will be permissioned, thus enhancing transparency and traceability, while at the same time protecting sensitive information from unauthorised parties. Naturally the level of shared information, especially as sensitive as sustainability information, could be a point of conflict and tension and it is something that will be researched in the context of the proposed research. Finally, regarding the trust issues raised by the inherent reliability and security capacity of the B2B blockchain marketplace, up to now few are the cases of failures and attacks to such systems. Still, since the technology is yet at its infancy, the research will put specific emphasis on security aspects. Regardless, by definition blockchains share information in highly secure and reliable cryptographic modes, a fact which when coupled with the inherent technology characteristics of immutability, consensus and distributed ledgers, enhances the trustworthiness of information and lessens the probability of its falsification, fraud or corruption.

3. System Architecture

According to [19], there is an immense need for a web of knowledge to facilitate the establishment of physical exchanges of resources among diverse organisations. Furthermore, the definition by [20] further clarifies that the exchanges must be novel and that IS requires the integration of the following features in order to be successful and have a significant impact in science and society, i.e. a) a functional web of knowledge, b) a network of diverse organisations, c) novel sourcing of inputs, d) value-added destinations of non-product outputs (and further end-life products), e) improved business and technical processes, f) a collective approach of a system as a whole and, finally, g) a justified definition of the boundary of the industrial ecosystem (material-based, product-based, geographic-based). Exhaustive scrutiny of the CE and IS's current state-of–the-art testifies, to the best of our knowledge, that such efforts do not exist.

As already mentioned, forging IS partnerships between Greek manufacturing companies, has thus far been inadequate [13] for them to fully reap the benefits of IS – a fact, highlighting our proposal's inherently innovative character. Therefore, the proposed research puts special emphasis on bridging technological advance and market application, while attuned to the triptych of balancing and maximising environmental, economic and societal values. The proposed business model combined with the development of the blockchain B2B marketplace platform will actively serve this purpose by stimulating cross-sectoral connections, enabling material flow compatibilities and leading to the formation of industrial synergies. In the epicentre of the article's innovation lies the notion of third-generation marketplaces, i.e. decentralised B2B exchanges. The term 'exchange' refers to traditional price-setting mechanisms including auctions. In essence, the proposed marketplace will utilise blockchain technology for waste/by-product trade digitisation, enabling multiple participants to collaborate and transact using shared views of the system's knowledge base for selecting suppliers and products (waste or by-product type and quantity) and current transactional information including shipping details and expected delivery dates.

The marketplace will incorporate a private Payment system for Ecosystem Services (PES) and a Smart Execution of Transaction (SET) capability, based on decentralised applications running on the blockchain platform, i.e. Smart Contracts. Specifically, each participant of the ISN ecosystem will be able to browse the knowledge base for identifying available products (waste or by-products) they wish to acquire and then proceed in closing a predetermined available smart contract embedding codified business logic, rules and terms hard-coded using a programming language such as C++, JavaScript or Java. The contracts will be fully transparent, verifiable and permanently written into the marketplace's blockchain. This SET capability is of great importance for the financial viability of the ecosystem, since the design and operation of the contracts can be achieved at minimal cost, several orders of magnitude lower than the costs of operating computer servers and personnel as in traditional marketplaces. Moreover, the marginal cost of developing a new contract or replacing a redundant one with an improved newer version, as in the case of a change in contractual terms, is expected to be equally low. Finally, as mentioned earlier, one has to note the importance of SET for building trust among participants in the ecosystem, since all transaction processes on decentralised B2B exchanges will be self-executed and the transmission of information, product ownership and value will take place in a fully autonomous fashion without a central authority policing, monitoring and potential influencing the integrity of fair transactions.

Each one of the transactions in the marketplace will be validated and recorded in the blockchain registry upon the payment of the supplier of waste/by-product. For that reason, the marketplace will use a private PES functionality materialising the exchange of waste, by-products and materials through a transparent and immutable way, monetised and translated into tokens. The traditional energy-intensive Proof-of-Work (PoW) consensus algorithm will be replaced by a new 'Proof-of-Contract' method (PoC), which will be based on the main principles of the Proof-of-Stake (PoS) concensus mechanism. Instead of having miners (PoW) or validators/forgers (PoS), in the proposed concensus mechanism, the ecosystem will use the concept of 'Closers', i.e. members of the blockchain with a high credibility score In the proposed research, credibility is measured as a weighted sum of three factors, the number of 'closed' contracts, the number of parties participating in these contracts and the sum of tokens exchanged in these contracts. In that way, the major security concern of PoS concensus mechanisms, i.e. the party owning more than 51% of the ecosystem's token value can manipulate transactions, is significantly ameliorated. As the authors in [21] argue, while in the PoS one needs to store enough tokens to dominate the ecosystem, in the suggested hybrid consensus-reaching approach using credibility score, one needs to use enough tokens in order to make contracts. Since storing and using tokens are opposite ideas, it is harder to increase both of them, and its harder to manipulate the ecosystem.

The successful execution of the transaction will release – as a reward – the number of tokens hard-coded in the smart contract. It is reasonable, that the exchanges in the ecosystem are not necessarily reciprocal, meaning that a company might have materials, by-products or waste to offer without needing to receive any in exchange, or vice versa. This will undoubtedly contribute to the accumulation of unutilised tokens within the network. To address this eventuality, the ecosystem will explore the options offered by an Initial Coin Offering and the token's participation in an established exchange, such as Coinbase.

The high-level architecture of the proposed Blockchain-based marketplace is presented in Figure 2. It has three access points, depending on the user type (project, business stakeholders supply-side and business stakeholders demand-side) attempting to enter the ecosystem and all users have to be registered before using the marketplace functionalities. The architecture is segmented in five integrated functional areas, i.e. Identity and Access Management (IAM), Database and Knowledge Management (DKM), Ledger Management (LM), Smart Execution of Transactions (SET) and Payment for Ecosystem Services (PES). Each functional area includes a set of blocks, each one providing a specific set of ecosystem functionalities, for example the Query Execution Manager (QEM) is a functional block of the Database and Knowledge Management area and is responsible for both scheduling query execution and directing queries to the appropriate tables inside the system's knowledge base. The QEM enhances response, decreases processing times and delivers data to users in appropriate formats.

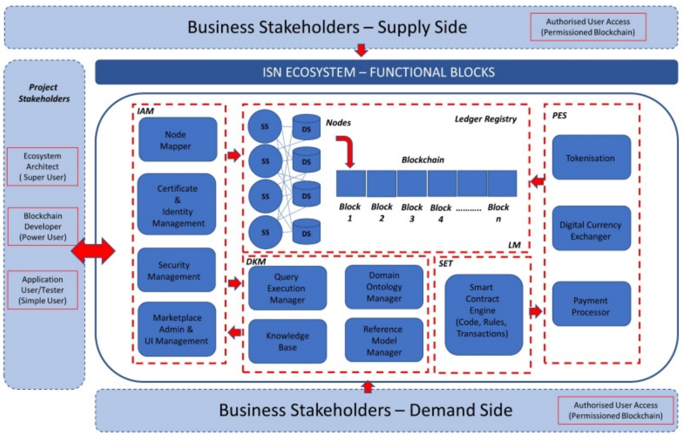

Figure 2: Functional Blocks of the Proposed System

The Blockchain-based marketplace will be the epicenter of the proposed business model, which will take advantage of its functionalities in order to secure its flawless and undisrupted operation, while creating a trusted collaborative environment for all the participants of the ecosystem.

4. Expected Impact

Industrial Symbiosis (IS) and the formation of interorganisational networks operating on a symbiotic nature can play a significant role in the global efforts for industrial sustainability and manufacturing compliance with Circular Economy principles. And the stakes for such a strategy, management, corporate culture and organisational change are far from insignificant. Actually, according to [22], the application of Circular Economy principles in all sectors and industries will benefit Europe environmentally and socially, while having the potential to generate a net economic benefit of EURO 1,8 trillion by 2030, resulting in over 1 million new jobs across the EU by 2030. The proposed reserach provides a set of targeted solutions and services for enhancing and supporting all the above success factors for an ISN to flourish and create significant scientific, social and potentially financial impact.

The research presented in this article is expected to have a strong socio-economic impact, since the adoption of its results can potentially lead to the emergence of novel ISNs in the Greek periphery and enhance regional development, by enabling existing and new industries, as well as communities, to access more competitively priced resource inputs and reduce their waste management and emission control costs. More resource inputs will be transformed into marketable products, which further enhances resource productivity and provides economic benefits. Moreover, in some cases the adoption of the proposed business model will bring new processing or transfer needs, which will in turn stimulate new business development and employment. Finally, the success of the proposed research can ignite a series of improvements to regional eco-innovation capabilities, with profound implications for more sustainable regional development.

Essentially, the adoption of research results can provide an important competitive advantage for the traditional Greek industries that have been affected by the global economic downturn and industrial restructuration taking place in Europe and worldwide, and in addition protect them from the forthcoming new wave of economic crisis as an aftershock of the COVID-19 pandemic. Creating symbiotic relationships and adopting new, innovative and sustainable business models that take advantage of otherwise unused industrial flows may be a partial solution to disrupted supply chains as a result of natural disasters.

As for individual organisations participating in an ISN network and adopting the proposed business model, the impacts are numerous and multifaceted. First of all, IS exchanges can potentially generate significant cost savings, by reducing the cost of waste management and purchasing of raw materials while at the same time reaping benefits from the sale of by-products or the reuse and recycle of waste materials. Other, more difficult to assess, economic opportunities are related to the strengthening of the environmental position of the company and enhancing its Corporate Social Responsibility (CSR) profile, which can be translated as a tangible competitive advantage leading to the increase of the company's customer base. Furthermore, adopting a strong environmental commitment and a pro-active attitude towards the introduction of further environmental improvements will build a moral high stand for both management and employees, which in turn contributes to strengthening the company commitment, by providing resources on a continuous basis to invest in environmental improvements, thus benefiting the environment and the community as a whole.

Finally, one should not overlook the benefits of adopting the proposed business model in management and cooperation culture of participating companies. Although as displayed in Figure 1, the absence of communication and cooperation is one of the main obstacles for the development of environmental ISN initiatives, by embracing the proposed business model companies are expected to take positive steps to improve communication with other agents at the intra-organisational level. Furthermore, the progressive integration of the environmental variable in the process of decision-making of companies and its growing relevance in strategic terms, will provide an excellent opportunity for the further development of IS and collaboration projects once the environmental gains of such a strategy are fully recognised.

5. Conclusions

In order to address the challenges inherent to implementing blockchain-based solutions and overcome the well-known obstacles of ISN development as shown in Figure 1, the research proposed in this article will proceed in a set of action steps, presented in Figure 3. These steps are in line with the European Commission's ambitious Circular Economy Action Plan [23] and Agenda of Sustainable Development adopted by all United Nations Member States in 2015 and more specifically, Sustainable Development Goal (SDG) 12 under the heading of 'Responsible Consumption and Production'. Among other targets, SDG 12 seeks to substantially reduce waste generation through prevention, reduction, reuse and recycling and encourage companies to adopt sustainable practices and integrate sustainability information into their reporting cycle, with the aim of achieving sustainable management and resource efficiency by 2030 [24].

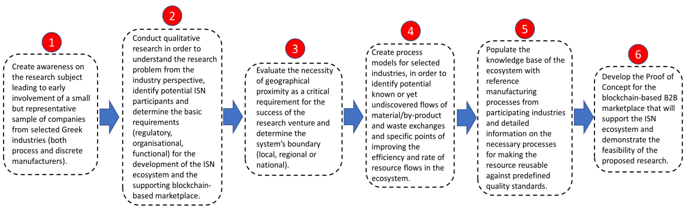

Figure 3: Research Action Steps

Finally, the research proposed in this article has unavoidable limitations, propagated mostly by the barriers of ISN development presented in Figure 1, with the most prominent ones being the lack of technical expertise by potential participants and the uncertainty regarding legislation and regulations in support of ISN initiatives and blockchain adoption in specific regions. In terms of technical implementation, the proposed research is again limited by 'soft' issues that may arise during the initiation phase, such as the persisting lack of trust in the technology, which most of the times comes as a result of its inherent complexity leading decision makers to a deficient understanding of underlying concepts and mechanisms. To that end, the lack of blockchain standards further impedes the research efforts for blockchain technology adoption and signing off of similar research projects. In order to mitigate the effects of lack of trust in the technology, the proposed research aims to develop and disseminate right from the start, a proposed business plan for creating symbiotic relationships supported by two white papers, the first detailing a roadmap for potential business stakeholders and the second including guidelines and suggestions towards ISN policy makers and regulatory bodies. The early identification of limitations or enablers of the in effect – at the time of the study – legislative and regulatory framework can be of great significance, especially when it comes to attract investors and influencing initial participants.

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Not applicable.

Author's contribution:
I am the sole author of this paper

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