The role of digital platforms in the transition to symbiotic and “smart communities”

Le rôle des plateformes numériques dans la transition vers des communautés symbiotiques et intelligentes

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ABSTRACT. The global decline in resources and raw materials, challenges in waste management, and the rise in greenhouse gas concentrations are driving companies to seek more sustainable and symbiotic business models. Digital platforms, as hubs for information and data flows, play a key role in coordinating symbiotic production and service systems. Industrial symbiosis (IS) represents one such business model, where the exchange of waste, by-products, or other resources between firms and local organizations generates new forms of competitive advantage.

Despite growing awareness of the role of information technologies and digital platforms in advancing sustainability, research on these digital sharing platforms as enablers of symbiotic networks remains in its early stages. This paper seeks to address this gap by examining the role of digital platforms in transitioning local ecosystems into symbiotic and “smart” communities. The study employs a systematic review of existing literature alongside a case study. The paper is structured into three major sections, followed by conclusions and implication.

KEYWORDS. digital platforms, symbiotic business model, industrial symbiosis, smart and sustainable communities.

1. Introduction: conceptual and methodological framework.

1.1. *Research design and methodology*

Economic growth has become the undisputed goal of the world's economies. However, growth also leads to greater demand for raw materials, as well as significant amounts of energy being released into the environment. According to the World Economic Forum (2023), the modern industrial sector is responsible for 30% of global CO2 emissions. Furthermore, according to European environmental authorities (European Environmental Agency, 2024), around 50% of the effects of chemical substances emitted in Europe originate from just a few countries, including Germany, the United Kingdom, Poland, Spain, and Italy. Moreover, the global depletion of resources and raw materials challenges waste management and forces companies to search for more sustainable and circular business models. According to the OECD report on “Global Material Resources Outlook to 2060”, the material intensity of the global economy is projected to decline rapidly over the next decade, at an average rate of 1.3% per year, whereas the production and consumption are shifting towards emerging and developing economies, which have higher material intensity on average. In response to these challenges, businesses are increasingly adopting collaborative practices that involve sharing resources, by-products, and energy with one another. This approach aligns closely with the concept of industrial symbiosis or symbiotic networks, where companies work together to create mutually beneficial exchanges, turning waste and by-products into valuable inputs for other businesses. The idea of symbiotic networks lays within the field of Industrial Ecology, and is closely related to the concepts of circular economy (CE) and Ecological Modernization Theory (EMT). It was widely recognized and popularized by Frosch and Gallopoulos (1989), who introduced the idea of creating closed-loop industrial systems that function similarly to natural ecosystems, where the waste products of one process become inputs for another. This concept of resource efficiency and interconnectedness aligns with the works of Benedict et al. (2018) and Yeo et al. (2019), which reflect ecological modernization as a synergy between people and technology, including the integration of digital technologies, to foster sustainable and circular industrial practices. The latter aligns with the principles of “smart

communities", which use digital technologies to optimize resource management, promote collaboration, and enhance sustainability in urban environments. In the past years, a vast literature on the industrial symbiosis and symbiotic business models and their tools has been published by for example Domenech et al. (2019), Lawal et al. (2021), Azevedo et al. (2020), Lawal et al. (2021), Islam (2016), Golev et al. (2015), Kirchherr et. al. (2017), Kincaid and Overcash (2001), Chertow (2008), Rombi (2015).Ce paragraphe est un paragraphe classique. Each author brings unique perspectives to industrial symbiosis. Yet, the knowledge on circular and symbiotic networks formation, in particular with the role of digital technologies in supporting circular and smart communities has not been in-depth investigated, accept for Lawal et al. (2021). The authors emphasize the role of digital platforms in facilitating industrial symbiosis, arguing that the increasing digitization is key to the future of symbiotic business models. For them platforms can help overcome traditional barriers like geographical limitations, information asymmetries, and lack of coordination. This contradicts with Domenech et al. (2019) and Kirchherr et al. (2017), who argue that for the evolution of industrial symbiosis in terms of its scale and complexity, the governance and regulative structures are of the key importance. Kincaid and Overcash (2001) focus on large-scale applications, while Chertow (2008) stresses the importance of smaller firms and informal networks, highlighting a key divergence in the literature regarding the scalability of industrial symbiosis, with only one common emphasis on the need for infrastructure-intensive solutions.

Other studies, like Varriale et al (2024), Di Vaio et al. (2020) and Giordano et al. (2023) explore the role of individual technologies, such as IT, artificial intelligence (AI) and blockchain technologies in achieving the sustainability goals and support industrial symbiosis indirectly by enhancing resource efficiency and reducing waste . Yet other authors, like Kluczek et al. (2023) and Holzinger et al. (2023)emphasize the importance of application of specific digital technologies in the management of biotechnology, agriculture, food and supply chain industries. Still, the study of digital sharing platforms, particularly from a circular economy perspective, is just emerging. Among the notable works are the contributions to the subject related discussion are the papers of such authors as van Capelleveen et al. (2018), Aid et al. (2015) ; Angelis-Dimakis et al., 2021; Benedict et al. 2018; Kerdlap et al. 2019; Schwanholz and Leipold, 2020 and Yeo et al., 2019). These authors have contributed to understanding how digital platforms can enhance collaboration, efficiency, and overall effectiveness of circular process. Digital platforms facilitate industrial symbiosis by connecting companies that have by-products or waste materials with those that can use them, building circular and smart communities, facilitating physical meetings and discussions among local companies), sharing infrastructure, developing trust and commitment for the long-term partnerships. The application of digital platforms in the symbiotic community concept requires further understanding with regard to the realization of the above benefits and existing barriers. This paper aims to fill the literature gap by examining the role of digital platforms as enablers of transitioning to smart and symbiotic communities. For the purpose of this study 'symbiotic community' has been defined as a natural ecosystem in which different local stakeholders promote more efficient use of resources, by engaging in exchanging resources and minimizing waste generation, reducing pollution and improving overall competitive advantage of industrial sights. This definition is inspired by the biological study of "symbiosis" by Margulis (1991), where the process of one organism living inside the another was crucial for the evolvement of all biological structures. Moreover, for Margulis it is symbiosis, rather than competition has been the driving force behind evolutionary innovation and new forms of life. For the purpose of this study a 'smart community' refers to a community that integrates digital technologies, and data-driven solutions to improve the sustainability, and optimize resource management (energy consumption, waste management or transportation). This definition was formed based on the studies by Nam and Pardo (2011), who defined "smart community" as a system that integrates technology, data analytics, and governance to improve social, economic, and environmental outcomes, and Alawadhi et al. (2012) who highlighted the role of digital technologies and data management in enhancing efficiency in areas such as waste management, energy, and transportation. The study seeks to address the question - how do digital platforms, designed for resource sharing and partnerships matching, facilitate the transition toward smart and symbiotic communities?

The study addresses the four major research hypotheses: 1) Digital platforms correspond to the theoretical principles and political objectives of the symbiotic and smart communities; 2) Digital platforms allow to overcome the barriers to the and symbiotic community networks; 3) The major impact of digital platforms on the symbiotic networks reveals itself in their potential in rising symbiotic awareness and user-driven collaborative and resource sharing networks formation; 4) Digital platforms produce a range of externalities (both beneficial and potentially adverse) that impact the development of symbiotic and 'smart communities.'The methodology of this study is composed of a literature search based on a review of the selected subject literature and evaluation of existing case study of Kalundborg region in Denmark and the results of previous studies from the following databases were chosen: Science Direct, Scopus, and Web of Science. The case study analysis of the Kalundborg region is significant because it exemplifies the practical model of circular community and highlights how digital platforms can complement the resource sharing and collaboration efforts, rise the circular awareness, and enhance accelerating the transition to circular and "smart communities." These databases were selected due to their comprehensive coverage of peer-reviewed research in the fields of sustainability, digital innovation, and circular economy. A set of relevant keywords and phrases were applied to capture the intersection of digital platforms, circular economy, smart communities, and resource sharing. These included terms such as "digital platforms," "circular economy," "smart communities," "resource exchange," and "industrial symbiosis." The project required the systematic literature review (SLR) to identify, select, and analyze the articles. To maintain focus on high-quality, peer-reviewed literature, only articles published in the last ten years were included, with few exceptions of earlier editions if their contribution was significant.

The paper consists of four major sections, followed by conclusions and implications, structured as follows. The first section begins with a literature review to discuss the link between digital technologies, knowledge management and the transition to a circular and smart economy practices. The next section explores the role of digital platforms in enabling companies and organizations to quickly access and utilize information. It discusses the role of digital platforms and the related drivers and barriers in enhancing circular and symbiotic resource exchanges, referring to the examples of concrete digital platforms. The third section focuses on the specific case study of Kalundborg region (Denmark) to demonstrate its symbiotic model, and the role of digital platforms in it. Last but not least, it proposes business and policy recommendations on how to develop digital platforms to promote sustainability.

1.2. *The conceptual framework of “smart” and “symbiotic” community*

The industrial symbiosis (IS), circular economy (CE) hubs and collaborative consumption networks are the most popular models and approaches to forming and implementing symbiotic communities (Klewitz and Hansen, 2014; Álvarez Portas and Ruiz-Puente, 2017; European Commission, 2020). Smart community is a type of as social innovation processes to achieve sustainable and inclusive urban development of city-communities. Both concepts of "smart" and "symbiotic" communities are mutually reinforcing, with each contributing to the advancement of the other. Smart community uses technology and data to enhance the efficiency, connectivity, and overall quality of life within the community. It leverages advanced technologies and data-driven approaches to enhance economic performance, efficiency, and innovation (Curry et. al, 2021). It also integrates digital tools to optimize processes and decision-making in various economic sectors. Smart technologies often support symbiotic networks by providing sharing platforms and tools for efficient resource management, whereas circular and symbiotic technologies leverage smart technologies to enhance their sustainability and efficiency (Lee et al., 2023). Both align with and incorporate principles of the sharing economy (SE).

The discovery of symbiotic business model as a circular model of reducing of the energy consumption has, became a breakthrough in the field of industrial ecology and an important tool for the European Green Deal (EGD), which is the EU’s growth plan for a climate-neutral Europe by 2050 (European Environmental Agency, 2024). A symbiotic business model refers to a collaborative,

interdependent relationship between firms or entities that creates mutual value, often aligning with the concepts of shared value (Porter & Kramer, 2011) and resource co-creation (Teece, 2010).

World-renowned expert in the field IS Marian Chertow (2000) considers that the advantages of IS networks lie in the possibility of sharing underutilized assets (such as machines, vehicles, infrastructures, personnel, expertise, storage space) among firms or other stakeholders, as well as in the use of one's residual outputs (such as materials, by-products, energy or waste) as raw materials for the production processes of other firms or stakeholders. These symbiotic relationships between local stakeholders mimic the natural environment, creating what is called an industrial ecosystem in industrial ecology. In the traditional industrial process, companies use raw materials as inputs for their production processes. The production of the main product often generates surpluses, which can be materials, energy, heat, and water (which are not further valorised throughout the process) that the company needs to manage.

Hence, the IS model enabled efficient use of resources and waste reduction through collaborative practices. In many cases its been reinforced by the establishment of CE hubs, which rise up circular awareness and support sharing practices in the local communities (such as repair, reuse, and recycling). The CE hubs may also be facilitated by various community sharing platforms for materials and tools, and cover such areas as energy, agriculture, industry, infrastructure, environment, transportation, finance and development (European Green Deal, EC, 2024).

Digital technologies can help energy, food, mobility and community buildings systems to become more efficient, by enhancing symbiotic interfirm networks and cross-organisational cooperation in the exchange of resource, knowledge, information, and expertise.

2. Digital technologies as enablers of symbiotic networks - a resource-based view

Golev et al. (2020), Henriques et al. (2020) and Islam (2016) have identified several barriers and drivers to IS networks. The first group of barriers includes technological, economic, regulatory (laws and regulations), and financial barriers, whereas the second one includes factors such as a lack of information, lack of trust between organizations, risk and uncertainty, and lack of commitment to sustainable development. Meanwhile, the driving force includes a system of formal incentives encouraging and facilitating the IS implementation for communities, companies, and other entities (e.g., government programs). Government projects may not have long-lasting impact on circular transition processes and may hinder policy coherence, if policymakers, businesses and citizens lack awareness of what the circular economy and IS model entails (Ddiba et al., 2020; OECD Urban studies, 2021).

According to Kirchherr et al. (2017) and Vermunt et al. (2019) one of the barriers to the transition to circular business models is the information and knowledge gap. Therefore, information and communication technologies (ICT) and their related systems, such as digital platforms, may play a key role as enabler and accelerators of circular transition and IS partnerships. As Grant et al. (2010) and Maqbool et al. (2018) point out that orchestrating or enabling inter-IS cooperation maybe a challenging task, which is often supported by social networks. Digital platforms are technology-based business models that connect and promote valuable social interactions between the various stakeholders involved. As hubs for information flows, digital platforms constitute the main coordination centers for production and services systems. They enable the procedures that facilitate relationships between consumers, enterprises, and other local stakeholders, enabling the reuse, repair, refining or recycling of raw materials and products (Figure 1).

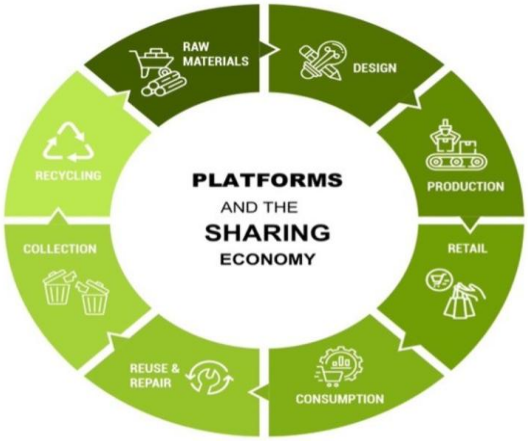

Figure 1. *Digital platforms and symbiotic (resource sharing) platforms*
Source: www.vibemarketingeastcoast.co.za

Digital platforms, such as online market places, social networking applications, knowledge repositories, help monitor and track the availability, quality, and location of material and energy flows (Figure 2). Platforms launched by governments, companies, and NGOs play complementary roles in promoting industrial symbiosis through digital technologies. Government-driven platforms typically focus on regulatory compliance, sustainability goals, and transparency, ensuring alignment with national or regional objectives (Alawadhi et al., 2012). Companies-led platforms, like Kalundborg Symbiosis Platform[1] optimize business operations by enhancing resource-sharing and tracking material and energy flows, improving waste management efficiency (Golev et al., 2015). NGO and community-driven platforms, like Kalundborg Symb-DK[2] foster collaboration, knowledge sharing, and resource exchange among SMEs and local communities. Together, these stakeholders create and maintain platforms tailored to specific needs, enabling more coordinated and effective industrial symbiosis management.

By 2023, according to VibeMarketing corporation, the global value of the circular economy is at approximately 410 billion USD, with platforms accounting for around 25% of this sum. As company predicts, by 2030, the CE will be worth 1.5 trillion USD, with circular platforms making up nearly 60% of that value[3].

Information sharing is one of the models that reinforce symbiotic awareness and resource sharing and exchange via platforms (improving the valorisation of waste, increasing resource efficiency and reducing environmental impact) (Schwanholz and Leipold, 2020). Information and data exchange enables companies to find partners quickly and easily, to establish partnerships and build up symbiotic networks (Kerdlap et al., 2019; Van Capelleveen et al., 2018).

The section below explains in more details the types of digital platforms and their potential role in fostering symbiotic partnerships.

3. Digital technologies as enablers of IS networks- a user-based view

The pushing forward the symbiotic agenda in the industrial networks of companies may be a subject of sustainable consumption, the contribution of the end users and their circular awareness. This drives the companies` interest into promoting the economy of services (rent out or lease its products), instead of production and sales of new products (Herold and Prokop, 2023; Heiskanen and Jalas, 2003; Kumar et. al., 2022). Heiskanen and Jalas (2003) provide the evidence on the role of services (like repair,

1 www.symbiosis.dk
2 www.symb.dk
3 www.vibemarketingeastcoast.co.za

maintenance, or rental services) in a radical eco-efficiency improvements and greater eco-efficiency compared to traditional product-based approaches. Digital platforms promote symbiotic practices and encourage end users to adopt more sustainable behaviours. They facilitate the exchange, rental, or sharing of goods and services between individuals or businesses. Here are some notable examples of platforms, which could be grouped as: recycling platforms, sustainability platforms, and sharing economy learning platforms. The first group includes such platforms as iRecycle (the US)[4] and Recycle CoachCanada[5]) .The second group may include food-sharing apps like Olio and Too Good To Go platforms. Olio is a food-sharing app that connects users with excess food to those who need it. Finally, the third group of user awareness platforms is a group of sharing economy learning platforms dedicated to disseminate and haring economy news, resources, and guides. They offer articles, case studies, and toolkits for understanding and implementing sharing economy practices and examples of successful sharing economy models. The examples of these platforms include: Shareable[6]), Collaborative Consumption[7], University of Edinburgh – Sharing Economy Lab[8], Sustainable Living Lab[9], Skillshare[10]. These platforms provide valuable educational resources and tools to learn about symbiotic networks and sharing economy, helping individuals and organizations integrate these principles into their practices and daily lives.

3.1. *Online marketplaces databases*

Online marketplace platforms such as crowdsourcing platforms can also be viewed through the lens of a two-sided marketplace symbiotic network model. Online marketplace platforms also allow households to share idle or underutilized resources (Sundararajan, 2016). In fact, expanding capabilities to launch and scale industry-wide symbiotic and sharing economy solutions is often a part of the formal strategies of these platforms (e.g., Amazon Climate Pledge). In the context of symbiotic collaboration, this type of platforms includes, but is not limited to, the sharing of waste, overstock inventory, raw materials, excess warehousing, office space, human resources, machinery, and equipment. Such possibilities enable business and other stakeholders to participate in symbiotic networks, optimizing their resources and facilitating exchange of waste between companies. However, to date, there are not many platforms offering specific B2B services for sharing waste, inventory or other resource. The Table 1 presents the overview of the selected resource sharing digital platforms promoting symbiotic communities. One such platform is the European FLOOW2.com platform, established in 2012. It is a B2B platform for businesses and (healthcare) organizations to exchange equipment, services, facilities as well as knowledge and skills. In 2016, the platform added the resources, waste and materials, enabling businesses to share residual flows and materials within (local) governments and businesses. In 2018, FLOOW2[11] had 35 000 users. Another example is the Canadian-based B2B online marketplace platform BizBiz Share[12]. Founded in 2015, it is the largest business resource marketplace in North America. Users of this sharing platform can buy, sell, and rent resources and assets. By 2021, the platform had over 2,000 members (Shanks, 2021).

There are also a growing number of publicly initiated digital platforms that aime to promote symbiotic networks dedicated to the efficient matching of materials/services between different businesses, leading to new ideas through the development of symbiotic B2B models. Quite a few of them were funded by EU regional and cross-border schemes (like INTERREG or Horizon 2020), i.e.,

4 https://irecycle.com
5 https://recyclecoach.com
6 www.shareable.net
7 www.collaborativeconsumption.com
8 www.sharingeconomy.ed.ac.uk
9 www.sustainablelivinglab.org
10 www.skillshare.com
11 www.floow2.com
12 www.bizbizshare.com

the SWAN digital Water Waste platform[13] , Circular SYMBIOSIS platform[14] , Looplocal network[15] , M3P[16] (Material Match Making Platform) or ECO3 bio-IS[17].

Type of platform	Actors	Activity
Platforms between (local) governments and businesses (FLOOW2 – 35 users,(www.floow2.com). Canadian-based B2B BizBizShare (bizbizshare.com	BTB	Sharing waste, inventory, raw materials, excess warehousing, office space, human resources, machinery and equipment
Publicly EU Initiated platforms: SWAN digital water waste platform (swan-interreg.com); Circular SYMBIOSIS platform (circularsymbiosis.com); Looplocal network (energy-cities.eu), M3P (Material Match Making Platform (www.lifem3p.eu) or ECO-3 bio IS (eco3.fi).	G2B, B2B	Resource and material sharing
Business platforms: RecycleNation, IRecycle, TrashOut, recycle Coach, Waste No Food, Too Good To Go, EcoCharge, Litteratti, Enevo or Good on You. Governmental platforms: Waste Sorting Guide in Shanghai (Waste Sorting Shanghai app)	B2B, B2C, C2C, G2C	Waste management platforms; waste management user friendly webs
Knowledge repositories: GreenPolicyPLatform (www.greenpolicyplatform.org), Stonly (www.stonly.com), Green Growth Knowledge Platform (greengrowthknowledge.com), World Bank Group Green Knowledge Platform (www.ndcpartership.org).	B2B, G2B, B2C	Knowledge and information sharing
Social media: LinkedIn, Facebook Instagram, Twitter	B2B, B2C, C2C	Spreading environmental awareness to the largest audience possible
Online marketplaces databases: EC21, Elance, and eBay; Amazon Mechanical Turk; Facebook Marketplace.	B2B, B2C, C2C	Sharing idle or underused resources; spread environmental awareness (Amazon Climate Pledge)
Sharing infrastructure platforms: Uber, Airbnb	B2B, B2C	Sharing transportation mean

Tableau 1. *Selected resource sharing digital platforms involving various stakeholders**
Source : own elaboration based on the official websites of the above platforms.

* B2B: Business to Business transactions or interactions between business entities; B2C: Business to Consumer transactions or interactions conducted between a business and individual consumers; C2C: Consumer to Consumer - Transactions or interactions conducted between individual consumers, often facilitated by a third-party platform (e.g., online marketplaces); G2B: Government to Business - Interactions or transactions conducted between government agencies and businesses; C2G: Consumer to Government - Interactions or transactions conducted between individual consumers and government entities.

The SWAN digital Solid Waste reuse Platform for the Balkans, established in 2014, covers Greece, Albania, Bulgaria and Cyprus regions. It promotes solid waste reuse among industrial solid waste producers and potential solid waste re-users. The platform includes detailed information on more than 500 industrial plants from four countries (Angelis-Dimakis et. al. 2021).

Circular SYMBIOSIS platform dedicated to developing B2B models on the Bioeconomy (Greece and Macedonia); Looplocal network (Sweden, Denmark), established in 2011, provides a tool to compare IS data and estimate regional material and energy flows (on a facility level) to identify potential IS networks; The ECO3 bio-IS (Kolmenkulma eco-industrial park) Tampere Region,

13 swan-interreg.com
14 www.circularsymbiosis.com
15 www.energy-cities.eu/project/lifeloop
16 www.lifem3p.eu
17 www.eco3.fi

Finland), launched in 2014, facilitates and creates opportunities for IS projects testing (new products and materials). M3P (Material Match Making Platform) started in 2016 as a toolkit to help turn the waste of one industry into secondary raw materials for another. It covers Italy (Lombardy), Belgium (Flanders), Greece (Western Macedonia) and Spain (Asturias).

Some of the waste management user-friendly apps available in 2024 include RecycleNation, iRecycle, TrashOut, Recycle Coach, Waste No Food, Too Good To Go, EcoCharge, Litterati, Enevo or Good On You. These are B2B, B2C and C2C platforms that inform participants about resource sharing and recycling in their local area as well as raise awareness of responsible waste management.

Publicly funded and facilitated resource and material sharing platforms between businesses and organizations in the EU, i.e. Circular SYMBIOSIS platform or Material Match Making Platform, promote sustainability through sharing economy principles in G2B interaction model.

In a broader way, IS partnerships may also incorporate the sharing of infrastructure, such as pipelines, energy, water, by-products and other materials and resources; such resource sharing platforms (e.g., Uber, Airbnb) and a marketplace platform (e.g., Facebook Marketplace) could be seen as the IS enabler.

3.2. *Social network platforms*

To successfully accelerate the transition to smart and symbiotic community model , integrated commitment from all stakeholders is a needed. Therefore, social media platforms such as LinkedIn, Facebook, Twitter or Instagram can be increasingly useful for raising environmental awareness within the business communities (business-to-business B2B) and consumer communities (consumer-to-business C2B) to the largest audience possible. Studies by Amicarelli et al. (2022) and Recuero-Virto and Valilla-Arróspide (2022) show that the C2B relationships have been empowered by social media platforms, creating a large amount of online data, which can be transformed into knowledge about people's environmental needs, expectations, feedback or experiences.

Policy makers and governmental agencies may accelerate the smart and symbiotic networks formation by scaling up actions among communities and their stakeholders. The government-to-consumer (G2C) digital model refers to the process by which government agencies provide products or services directly to consumers through the Internet, i.e., social platforms. As for 2023, there were 4.76 billion social media users worldwide, just under 60% of the total global population (Digital 2023 report). LinkedIn is an important virtual place peer to peer connections within the industry. In the year 2023, the platform had over 830 million members globally, with approximately 31% of visitors coming from the US. The platform was responsible for 80% of B2B leads from social media (LinkedIn Statistics, 2023). The Digital 2023 report revealed that most people have multiple social media accounts. For example, more than 80% of LinkedIn users also used Facebook (86.6%), WhatsApp (80.4%), and Instagram (82.6%).

3.3. *Knowledge repositories*

A knowledge repository is an online database that systematically captures, organizes and categorizes knowledge-based information. These private, public or non-profit platforms offer an expert knowledge (in the form of global reports, case studies, guidance notes and learning products) that identify and address major knowledge gaps on the latest IS technologies, IS theory and practice. Some samples of such platforms include Green PolicyPlatform[18], Stonly[19], Green Growth Knowledge Platform[20] , World

18 www.greenpolicyplatform.org
19 www.stonly.com
20 www.greengrowthknowledge.org

Bank Green Growth Knowledge Platform[21], Green Industry Platform[22], European Cluster Collaboration Platform[23].

4. Potential positive externalities of digital platforms to symbiotic and smart communities

Digital platforms can facilitate the identification of potential synergies and interactions between firms, consumers and other stakeholders by supporting the exchange of (real-time) information, matching and sharing resources of buyers and suppliers. Moreover, BizBiz Share example shows that company's employee motivation to engage is much higher when working on the projects that matter for their communities (Shanks, 2021). More importantly, as digital technology companies, platforms providers use very few physical resources, require fewer financial resources and are therefore very cost-effective. Digital platforms build a sense of community by connecting like-minded individuals who are passionate about environmental conservation.

However, the successful adoption of digital platforms depends on the level of openness and trust in the platform among potential users and providers (Gawer, 2014; Parker et al., 2016). Many specialized symbiotic platforms fail as they are unable to pass from the initiation phase to the growth phase. These platforms usually struggle with a 'chicken-and-egg' problem, where there is a mismatch between participants on the platform. In order to maintain positive environmental effects from digital platforms, more participants (users and providers) must join the platform. The more participants there as, the more willing others are to join them. This is a common market barrier to the diffusion of any network or platform. Therefore, raising environmental awareness campaigns in local communities and matching supply and demand on platforms can prevent these negative network effects (Wirtz et al., 2019).

4.1. *Potential negative externalities of digital platforms to sustainable and "smart communities"*

Although digital platforms align with the theoretical principles of IS model (enabling resource efficiency, cost savings and additional turnover) and the policy objectives of the European Green Deal (2020) such as transform the EU into a modern, resource-efficient and competitive economy, there are also potential negative externalities of digital platforms for the environment. Even though stimulating symbiotic resource sharing, they cause potential rebound effects and increase total CO2 emissions, such as the lower cost of car-sharing services compared to public transport may increase travel frequency (Font Vivanco et al., 2015; Tussyadiah and Pesonen, 2016). The growth in the implementation of IoT technologies is also leading to more intense use of fossil technologies in order supply energy for IoT production lines.

Moreover, the development of knowledge repositories platforms relies heavily on data centers and cloud computing, which require significant amounts of energy. Although some data centers are moving toward renewable energy, many still rely on non-renewable sources, contributing to greenhouse gas emissions. The environmental footprint of the data centers supporting cloud-based waste management systems may counteract with the sustainability gains from the waste sorting process. Moreover, the use of smart devices and sensors for waste sorting and collection, leads to increased electronic waste (Konietzko et al., 2019; Ning and Khuntia, 2022; Hamzaoui et al., 2024). As Konietzko et al. (2019) point out, platform providers collect increasing amounts of data, and this information must be stored in servers that should ideally be powered by renewable energy but unfortunately often are not. Finally, from a regulatory point of view, platforms may lead to a loss of tax revenues for governments (e.g., with Airbnb) (Zervas et al., 2017), however local governments have a significant interest in increasing asset sharing among users (Zervas et al., 2017; Shanks, 2021).

21 www.ndcpartnership.org
22 www.greenindustryplatform.org
23 www.clustercollaboration.eu

4.2. *Drivers and barriers to the application of digital platforms in symbiotic and smart communities*

Adams et al (2016) were one of the first authors to mention the use of new technology in sustainable oriented innovation context. The study of Rodríguez-Espíndola et al. (2022) developed this idea further on. Their findings suggest that the adoption of digital platforms can have impact on sustainable oriented innovation only if it is preceded by a change in the organizational mindset fostered by the integration of symbiotic or sharing economy principlesWhen organizations start applying those principles, they also start realizing the greater potential of digital platforms to support sustainable oriented innovation. Digital platforms facilitate the creation of sustainable and symbiotic models/practices in the communities. They promote the sharing, reuse and recycling of products and materials, enable the development of sustainable products and services, enhance transparency and traceability, foster collaboration among stakeholders. As a result, the symbiotic awareness in the whole community rises. A growing number of companies, especially in the waste management sector, are applying IoT technologies in order to contribute to more efficient waste management. For example, the research of Voca and Ribic (2020) show that 84% of citizens are willing to participate in bio-waste separation and recycling, which could be facilitated by digital technologies (smart waste management). Just a couple of decades back CE concepts were yet not fully recognized or implemented (Voca and Ribic, 2020).

Digital technologies offer useful solutions to improve communication, coordination and management of stakeholder activities and processes. For example, over 85% of corporate users say that Slack has improved their communication[24]. In the peer reviewed study The study by Anders (2016), the author describes Slack as a platform supporting social collaboration practices, more efficient knowledge sharing and real-time problem-solving within teams (i.e. it encourages both task-focused discussions and spontaneous interactions).

Among the biggest barriers to the application of digital platforms in sustainable and "smart communities" are insufficient digital readiness, lack of environmental awareness, low social and public trust, focus on short-term solutions and profit maximisation, low stakeholder commitment to sustainability and lack of well-defined policies and standards that can create uncertainty and hinder adoption (Rupeika-Apoga and Petrovska, 2022)According to the European Commission (2023), some 77% of higher education students have at least basic digital skills, while only 35% of those aged 55-74 and 29% of retirees have at least basic digital skills, with the gap between rural and urban areas even wider - only 46% of individuals in rural areas have at least basic digital skills in comparison to the urban areas where this share is 61% (Digital Economy and Society Index, 2022).

5. Kalundborg – a pioneer in smart and symbiotic industrial community

One scientific reference for one of the oldest organically evolving symbiotic community models is Kalundborg industrial park, located in Kalundborg, a town on the west coast of Zealand (Sjælland) in Denmark, with the population of around 16,000 residents. The foundation of Kalundborg's IS model began in 1961, when a novel project was initiated to use surface water from Lake Tisso for a new oil refinery. This marked the start of a collaborative effort among local industries to optimize resource usage. By the 1980s, various local industries had effectively self-organized into a collaborative network, which allowed companies to exchange their resources and by-products. In the early case study on the Kalundborg, Jacobsen (2006) discusses several barriers to building symbiotic networks in the region, which included lack of information and awareness regarding the potential benefits of IS, lack of trust in forming symbiotic networks, and cultural and behavioural factors, such as lack of willingness to engage in collaborative sharing and circular initiatives. In later studies, Benedict et al. (2018) and Yeo et al. (2019) claimed that the circular user practices and awareness, synergy between people and technology, clear vision of networks stakeholders, along with the information flows

24 https://www.selecthub.com/p/collaboration-software-tools/slack.

supporting companies in the search for by-products and services, were among the key conditions for the successful implementation of IS initiatives in the Kalunborg region. Hence, the IS in Kalundborg is not merely a static achievement but an evolving process shaped by strong community networks, environmental awareness, and social capital. Over the past sixty years, these elements have fostered collaborative relationships among diverse industries, enabling the efficient sharing of resources and the development of innovative solutions to environmental challenges. Hence, in order to understand the Kalunborg`s path towards its smart and symbiotic community model, two approaches to IS must be distinguished. The first one refers to a socio-economic system built around the sharing of resources and services, whereas the second one puts its focus on creating closed-loop systems where waste or by-products are reused or recycled within an industrial or ecological system – IS model. Both share similarities in promoting resource efficiency and sustainability, and contribute to sustainability by optimizing resource use and promoting reuse. Both, the sharing economy and the IS model mutually reinforced one another. The Figures 2 and 3 demonstrate these interlinkages.

Figure 2 depicts a summarized model of the material flows of inputs - raw materials and surpluses (wastes and by-products), as well as the possible destinations of surpluses – 1) disposal, 2) recovery/recycling, and 3) intra-IS (the surplus is valorised internally within the company) or inter-IS (the surplus is valorised externally by another company) practices[25].

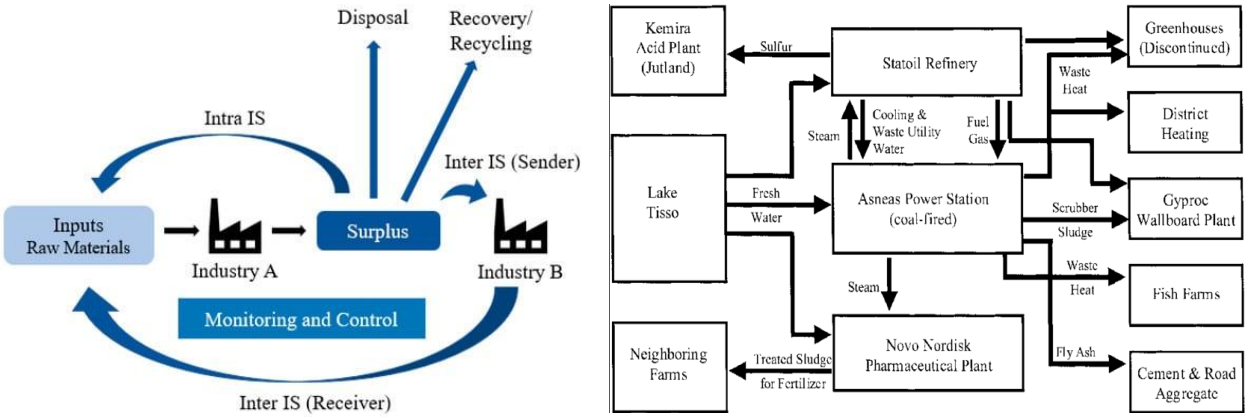

Figure 2. *General model of resource (materials, waste, and surplus resources, like water and energy) sharing and the example of Kalunborg**

* The symbiosis networks is made up of 6 companies: a power station, two major chemical companies, a plaster board manufacturer, a soil remediation company, a refinery and the municipality of Kalundborg.

The IS networks researchers of Kalundborg distinguish five types of transactions: 1) exchange of material and waste flows; 2) exchange and cascading of water; 3) cascading of energy (maximizing of energy efficiency with heating and cooling, as well as smart building infrastructure) and 4) exchange of technical and operational knowledge. While the first three types of content denote a tangible component, the exchange of knowledge refers to an intangible exchange of know-how, potentially leading to innovation (emergence of an eco-innovation dynamics) (den Hond, 2000). To further enhance these efforts, the integration of digital solutions played a crucial role in managing and optimizing these transactions. Digital platforms enable real-time monitoring, data sharing, and coordination across various sectors, ensuring that the exchange of water, energy, and materials is streamlined and efficient. The Figure 3 shows that building smart and symbiotic community requires the solid foundation of basic digital structures. The specific digital solutions and platforms are applied across (A type of networks), and within (B type of networks) the Kalundborg`s green sectors. There are also platforms combining both types of networks.

25 https://www.cyclifier.org/project/kalundborg-symbiosis.

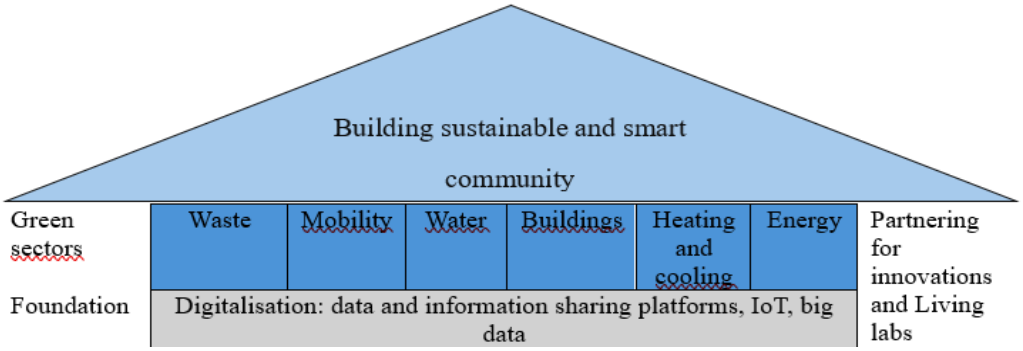

Figure 3. *Framework for smart and symbiotic community based on the case of Kalundborg*
Source: own elaboration based on Smart Cities, 2019.

In case of the A type of networks, the digital platforms allow to optimize energy usage, manage waste, and track water consumption across all the green sectors in Kalundborg (from waste, mobility, water, buildings, heating and colling to the renewable energy). These digital platforms have broad application covering multiple sectors or areas. Some examples includes the Kalundborg Symbiosis Platform[26], Kalundborg Municipality's Water Management System[27], Kalundborg Energy systems[28] or Kalundborg Municipality Digital Citizen Portal[29]. Kalundborg Symbiosis Platform connects various industries and sectors to promote the reuse of the waste heat from industries (in the district heating systems). It allows to recycle the water between companies reducing the overall water usage, and shares energy resources in order to optimize energy consumption across businesses. Kalundborg Symbiosis Platform uses internal data and information sharing platform to manage the IS networks across different industries, stakeholders and their resources. Table 2 provides an overview of the key stakeholders involved in the Kalundborg Symbiosis Platform, highlighting their respective sectors, roles within the symbiosis, and key contributions to the collaborative resource-sharing network.

26 https://www.symbiosis.dk
27 https://www.kalfor.dk
28 https://www.kalfor.dk; https://en.energinet.dk
29 www.borger.dk

Stakeholder	Sector	Role in the symbiosis	Key contributions
Novo Nordisk	Pharmaceutical	Producer of pharmaceutical products; shares waste heat and recycles wastewater	Supplies waste heat to the district heating system; shares treated wastewater with other industries.
Novozymes	Biotech	Producer of enzymes and microorganisms; exchanges residual biomass and water	Supplies surplus heat and wastewater; uses recycled water in production processes
Kalundborg Municipality	Public Administration	Facilitator of infrastructure development for district heating and wastewater management	Provides regulatory support and manages the district heating system.
Statoil (now Equinor)	Energy (Oil Refining)	Supplies waste heat and sulfur by-products for use in the symbiosis network.	Provides residual heat to the district heating system; shares sulfur for local production of sulfuric acid.
Asnæs Power Station	Energy (Coal/Power)	Generates power and supplies steam, heat, and gypsum to other stakeholders.	Provides waste heat for district heating; supplies fly ash for cement production.
Gyproc	Building Materials	Producer of gypsum boards; utilizes by-products from other industries.	Uses gypsum from Asnæs Power Station; contributes to the recycling loop for construction materials.
Kalundborg Water Supply	Utilities (Water)	Manages water treatment and recycling infrastructure for the symbiosis.	Supplies treated water; helps reduce overall water usage in industrial processes.
Municipal Wastewater Plant	Utilities (Wastewater)	Treats and recycles industrial wastewater for reuse in production and cooling.	Recycles and supplies treated wastewater to industrial participants.
Avista Oil Denmark	Recycling	Recycles used oil and shares by-products with other participants in the symbiosis network.	Provides clean base oils for reuse; minimizes hazardous waste.
Dong Energy (now Ørsted)	Renewable Energy	Generates and supplies renewable energy, waste heat, and CO2 for various industrial processes.	Promotes sustainable energy integration into the symbiosis network.

Table 3. *Stakeholders of Kalundborg Symbiosis Platform*
Source: based on the websites: www.symbiosis.dk and www.kalundborg.dk

The Kalundborg Municipality`s Digital Citizen Portal enables public engagement and interaction between the local government and its residents making city administration more transparent and responsive to the issues like potholes, streetlight outages, or waste collection problems. The Digital Citizen Portal itself might not be directly a part of IS model, but it facilitates IS in Kalundborg by enabling collaboration between industries, the local government, and citizens, by sharing data, resources, and information more efficiently the Platform supports resource optimization, waste reduction, and energy sharing.

The B type of symbiotic networks cover platforms which enhance symbiotic partnerships within the particular Kalundborg green sectors, supporting the resource efficiency, environmental responsibility, and the reuse and recycling of materials, water, and energy. Such platforms include Public Transport

Planner Platform[30], Farm Management software application[31], Smart Waste Collection Platform (Renovation App[32]), Sustainable Waste Solution[33], and Tech-Platform for circular waste management[34].

The Clever (EV Charging Network) and Rejseplanen (Public Transport Planner) Platform embraces smart mobility and traffic management to enhance transportation efficiency. Some specific tools include smart grid EV charging stations, public transport apps and real-time traffic updates all contributing to greater resource efficiency. Through data sharing, resource optimization, and collaboration the Platform shares the spirit of interconnectedness and resource optimization seen in symbiotic networks.

The Farm Management software platform helps farmers streamline daily operations, improve resource efficiency, and make data-driven decisions. The platform enhances food production and soil efficiency, while reducing environmental impact. Its use allows farmers to monitor soil conditions, crop health, and weather patterns in real-time to optimize resource usage such as water and fertilizers. It applies IoT sensors, automated irrigation systems and drones and is seen as key enabler of IS, contributing to the region's goals of resource optimization, waste reduction, and sustainability. By integrating data and promoting collaboration between farms, the platform can enhance food production efficiency. AgriWebb is widely used in Denmark and other countries for its ability to manage large-scale farm operations digitally.

The Kalundborg Municipality Smart Waste Collection System Platform has implemented smart waste management systems that use sensors in waste bins to monitor fill levels and optimize waste collection routes. This reduces unnecessary truck trips, saves energy, and helps to keep the city cleaner. A Smart Waste Collection System in Kalundborg operated by the municipality can indeed be considered a part of the IS model, especially when it integrates with the larger network of industries and circular economy initiatives in the region. The data-driven nature of the system optimizes waste management, facilitates the reuse of materials and energy, and promotes sustainability. The platform can contribute to resource efficiency and waste reduction—core principles of IS model.

Finally, the Tech-Platform for circular waste management facilitates waste reduction for organisations and features waste streams supported by regional partners (Denmark, Netherlands, Germany): logistics, processing, manufacturing and consultancies. It aims to save as much waste as possible and accelerate the transition towards a circular economy.

Moreover, the Kalundborg case study shows that the successful implementation of IS initiatives is highly related to stakeholder’s partnerships, especially companies, and requires close cooperation among businesses in unrelated industries, which are located in close geographical proximity (clusters) (Benedict et al., 2018; Yeo et al., 2019). The symbiotic partnerships in Kalundborg are developed through the so called “Living labs”, where smart technology solutions are developed and tested in a user-centred way (Figure 3).

The networking platforms that promote these symbiotic networks, both across and within green industries, i.e. A and B types combined, in a both formal and informal ways include such examples as Biotech City[35] and the Symb-DK[36] platforms. Through the process of co-creation, concepts are developed in real life, allowing citizens, public institutions and private actors to contribute to development and exploration of new technological solutions (Figure 4).

30 https://www.rejseplanen.dk
31 www.AgriWebb.org
32 www.affald.dk
33 https://www.argo.dk
34 https://www.seenons.com
35 www.biotekbyen.dk
36 www.symb.dk

The Biotech City is a collaborative innovation platform focusing on biotech, sustainability, and green technology initiatives. The platform is dedicated to sharing the latest news, updates, and developments related to the activities and initiatives taking place at Kalundborg community, especially those related to sustainable biotech, green tech, and the circular economy (e.g. Tech Talk events).

The Symb-DK web-based platform allows users, such as companies, NGOs representatives, researchers or municipalities, to register, log in, and manage their profiles and resource exchanges. The platform plays a critical role in connecting all stakeholders and facilitates communication, collaboration, and resource (data and information) exchange across sectors on new technologies for industrial symbiosis, waste management, and resource efficiency, advocating policy frameworks, and ensure the environmental compliance of symbiosis projects. The participating NGOs or public organizations representatives help raise awareness about IS and sustainability practices, offering credibility and public support for Symb-DK's initiatives. Investors have opportunities to discuss the potential funding for companies that are engaged in sustainable and circular economy initiatives (that could further increase long-term benefits in resource efficiency and waste reduction). The initiatives such as SYMB Sunday Brunch or Book clubs, create an open forum for both the international and Danish citizens and their families, who live, work or study in Kalundborg to propose challenges or address needs related to funding, technology development, support for a local initiatives or other innovative solutions.

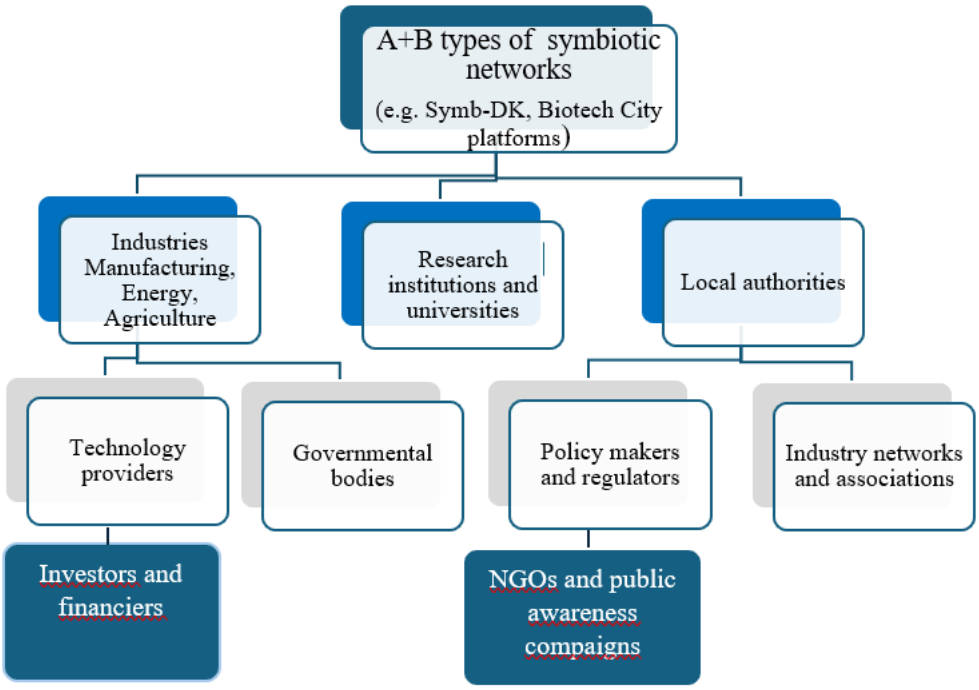

Figure 4. *Simplified representation of interlinkages between major group of stakeholders in the Symb-DK platform*

Source: own elaboration based on www.symb.dk and www.biotekbyen.dk.

The Kalundborg case shows that building smart community requires not only a sustainability political agenda but also a robust digital infrastructure for managing sustainable ways of communication, services and resource sharing, rising symbiotic awareness and social community engagement for disseminating symbiotic practices).

Even though knowledge and information transfer were not considered in the study by Domenech et al. (2011) on Kalundborg Symbiosis networks, the authors concluded that knowledge in the IS network was originated from a single actor, however the communication protocols within the IS network made it likely to be disseminated across the entire network, leading to innovation and know-how transfer. As a result, the region soon has turned to the "sustainability hub", with many initiatives such the

Kalundborg Circular Economy Hub, Kalundborg Sustainability Fair, Community Gardens ad Urban Farming Projects, and Green Business Incubator. These initiatives served as a collaborative space for businesses, residents, and community organizations to share knowledge, resources, and ideas related to sustainability and sharing economy - rising symbiotic community awareness.

The region's approach to resource efficiency, collaborative governance, and economic benefits demonstrates how "smart community" principles can be effectively applied to create a more sustainable and resilient urban environment. Kalundborg is also considered a smart community due to its successful integration of IS, sustainability practices, and advanced technologies (Smart specialisation platform, 2023). As the major tool to build the smart community, Kalundborg has developed the IS model, which significantly reduced waste, enhanced resource sharing and introduced a closed-loop system to minimize waste and maximize the use of resources; implemented innovative environmental practices, such as using bioenergy and optimizing water usage, which further supported region`s sustainability goals.

The implementation of the IS model in the Kalundborg industrial region reduced annual CO2 emissions by 275,000 tons, saved €80 million, and improved the profitability of many companies by resolving their dependence on natural resources (Rombi, 2015). For individual companies, it also meant a reduction of transaction costs and maximization of their economic benefits, while for the whole society and local community, it contributed to improve service delivery, economic development, and reducing environmental footprint. The success of Kalundborg have turned researchers` attention toward understanding what factors drive the greater expansion of symbiotic practices. Based on the current study, one could conclude that Kalundborg`s symbiotic awareness among both suppliers and users has been cultivated through research and education, partnerships for innovation, community engagement, and the integration of digital technology and community policies.

6. Conclusions and policy implications

In relation to four key hypotheses regarding the role of digital platforms in fostering circular and symbiotic community networks, the study assessed both their alignment with theoretical principles of the concept of "smart communities" as well as their potential externalities.

With regard to hypothesis 1: Digital platforms correspond to the theoretical principles and political objectives of the symbiotic and smart communities - the study confirms that digital platforms align with the theoretical and political objectives of symbiotic and smart communities by facilitating the development of social tools and systems designed for IS partnerships. These platforms contribute to enhancing stakeholder engagement, information exchange, and resource orchestration, which are key to smart and circular community development. The case study of the Kalundborg region exemplifies this alignment through the reduction of social and cultural barriers in fostering symbiotic networks (across and within green sectors).

Referring to hypothesis 2: Digital platforms allow to overcome the barriers to the symbiotic community networks - the study provides evidence that digital platforms help in overcoming social and cultural barriers by connecting various stakeholders and enabling valuable social interactions. These platforms promote the exchange of resources and enhance trust within communities, which is essential for building resilient symbiotic networks. The Kalundborg case highlights how these platforms reduce barriers by fostering circular awareness and trust building (providing centralized and transparent access to resources and services plays a significant role strengthens this process).

Concerning the hypothesis 3: The major impact of digital platforms on the symbiotic networks reveals itself in their potential in raising symbiotic awareness and user-driven symbiotic networks formation - the study notes that digital platforms increase circular awareness and facilitate the creation of user-driven networks, which contribute to the formation of symbiotic networks. Although the direct

measurement of impact may be limited, the observed outcomes in regions like Kalundborg indicate a significant influence through the development of symbiotic ecosystems and fostering open cultures.

Finally, with relation to hypothesis 4: Digital platforms produce a range of externalities (both beneficial and potentially adverse) that impact the development of sustainable, symbiotic and 'smart' communities - the study identifies both positive and negative externalities associated with digital platforms. On the positive externalities side, they enhance resource efficiency and promote circularity; however, potential negative externalities include energy consumption, digital divide, and safety issues. These risks necessitate ongoing technological improvements and policies aimed at addressing these challenges, particularly through public funding and the development of supportive frameworks to mitigate adverse impacts.

The Kalundborg symbiotic community model exemplifies several key theories surrounding the role of digital technologies in supporting circular and smart communities, particularly in the context of industrial symbiosis. While the role of digital technologies has been underexplored in literature—except for works like Lawal et al. (2021), which highlight digital platforms as essential to facilitating industrial symbiosis—the Kalundborg case proves this theory by demonstrating how the integration of digital tools can enable the efficient exchange of resources and foster collaboration among companies. The Kalundborg Municipality Digital Citizen Portal, for instance, is a clear example of how a digital platform can facilitate industrial symbiosis by overcoming traditional barriers such as geographical limitations, information asymmetries, and lack of coordination. Through this platform, businesses in Kalundborg can share resources, by-products, and waste, significantly enhancing the efficiency and sustainability of their operations. Furthermore, the Kalundborg case provides a practical example of how institutional and regulatory structures—emphasized by Domenech et al. (2019) and Kirchherr et al. (2017)—are crucial for the success of industrial symbiosis. Kalundborg's success is underpinned not only by the use of digital tools but also by strong governance and regulatory frameworks that ensure cooperation and long-term partnerships among companies. This convergence of digital tools and governance structures illustrates demonstrate how both are necessary for scaling up industrial symbiosis and creating sustainable business models. The case also aligns with the findings of Kincaid and Overcash (2001), who focus on large-scale applications, by showing how an industrial symbiosis network can evolve from a small-scale initiative into a large-scale, interconnected system. This development supports the view of Chertow (2008), who emphasizes the importance of smaller firms and informal networks in the scaling of industrial symbiosis, as Kalundborg’s network includes both large corporations and smaller enterprises. The shared infrastructure and mutual trust, built upon the process of co-creation and open social platforms, further support the idea that successful industrial symbiosis can thrive on a combination of formal governance and informal, trust-based networks. In addition, Kalundborg’s success reflects the potential of digital technologies, as explored by authors such as Varriale et al. (2024), Di Vaio et al. (2020), and Giordano et al. (2023), to enhance resource efficiency, reduce waste, and support sustainability. The use of digital platforms not only facilitates material exchanges but also fosters the creation of smart, circular communities by connecting businesses that can exchange by-products and waste, sharing infrastructure, and enhancing overall collaboration and transparency. Thus, the Kalundborg case can certainly enrich the existing literature by demonstrating how digital platforms, governance structures, and collaborative networks can work together to facilitate large-scale industrial symbiosis, offering valuable insights for future research on digital sharing platforms in circular economies. The successful integration of digital tools into the symbiotic framework Kalundborg can serve as a model for other regions seeking to adopt similar practices in their pursuit of a more sustainable and smart economy. Moreover, the quality of such platforms tools is constantly being improved with new advancements in Big Data and AI technologies - delivering faster and more accurate matching of interested parties). The growing number of such platforms suggests that the lack of information and trust are becoming a less predominant barriers to the formation of symbiotic partnerships. The subject literature supports the conclusion that favourable to smart and symbiotic socio-economic ecosystems, facilitated by digital platforms, encourages greater

participation by individual companies, industrial organizations, local authorities or university labs, in IS initiatives.

For the policy implications, the public funding and national programs must restructure the IS funding for businesses, by focusing more on promoting various tools raising social (community) environmental awareness rather than on IS projects. Public investments must further improve digital readiness of user communities (to adopt digital solutions to shift to a climate-neutral, and more resilient communities). Governments can also offer subsidies and grants to academic institutions and private R&D firms in order to boost publicly available innovations and transformative technologies in renewable energy, waste management, carbon capture and energy efficiency. Last but not least, development of digital platforms for perspective IS projects requires the process of identifying synergies, assessing the benefits and challenges associated with digital platforms for the environment, eliminating existing barriers and fostering follow-up steps of existing platforms (after the funding period).

More in-depth study is needed to assess the broader impact of the above digital platforms on resource sharing and the development of symbiotic and smart communities. The future study should focus on understanding how these platforms influence collaborative behaviours, optimize resource utilization, and foster long-term sustainability within interconnected networks. Additionally, a closer examination of the operational dynamics and outcomes of these digital systems will provide valuable insights into their role in enhancing community engagement, and facilitating more efficient exchanges between stakeholders. The latter shortages highlights the limitations of the present study, which, while contributing to some insights, does not fully address these complex aspects of digital platform integration and their long-term implications for symbiotic and smart communities formations.

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