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The geography of technological innovation systems - The case of forest-based biofuels in a Swedish region

Muhammad Arfan *, Karl Hillman

Department of Building Engineering, Energy Systems, and Sustainability Science, University of Gävle, SE-801 76 Gävle, Sweden

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ABSTRACT

Geographical proximity exerts a substantial influence on structural evolution, developmental trajectory, and pace of sociotechnical system growth. This study explores this aspect within the context of the development of forest biomass-based biofuel technology, employing a Technological Innovation System (TIS) framework with the lens of geographical proximity utilization of system components. The research employed a combination of document analysis and interviews with key system stakeholders as data collection methods. The analysis reveals that the close geographical proximity of the system components and technologies, encompassing both technical aspects and sectors, did not result in synergetic effects, in contrast to prior TIS research findings. Rather than fostering collaboration, it has engendered a competitive dynamic, partially driven by actors vying for knowledge leads and funding from both regional and national agencies. Consequently, the potential benefits of geographical proximity of system components remain largely untapped. In light of these results, this study offers practical recommendations for exploiting untapped opportunities, advocating for more strategic use of geographical proximity to foster system technology development and enhance its role in national TIS development. This case study enriches sustainability transition literature by providing valuable insights into the role of geographical proximity in innovation processes.

1. Introduction

The transition towards renewable energy goes beyond climate-mitigation motives and encompasses security-of-supply concerns and rural economic development. Related to this transition, many studies have highlighted the potential for increased use of biomass in, for instance, the electricity (Lönnqvist et al., 2017; Thunman et al., 2018) and transport sectors (Hellsmark et al., 2016). Based on the flexible intake of forest residues and/or other lignocellulosic raw materials, biomass conversion technologies permit the production of copious quantities of bulk products, such as biofuels, and high-value products, such as biochemicals (Thunman et al., 2018; Vähä-Savo et al., 2014).

Advanced biofuel production technologies can often be integrated into the existing industrial infrastructure (e.g., the forest industry or chemical process industries). Such integration can increase synergies with energy and material flows, and contribute to knowledge regarding processes, organization, and byproducts (Börjesson et al., 2013; Hillman et al., 2011; Nanda et al., 2015). The commercial-scale development, diffusion, and deployment of biomass-based fuels, chemicals, and other products also hold potential for the renewal of mature process industries, such as fossil refineries, by creating opportunities for new businesses through innovative value chains and products (Geels, 2005).

However, the development and diffusion of renewable energy technologies, such as forest biomass-based transport fuel technologies, are driven not only by capital and natural resource accumulation, but also by innovative capacity, policies allowing entrepreneurship, and innovation systems (IS) that encourage innovative environments (Karltorp, 2014). The geographical proximity of actors, learning networks, and institutions plays an important role in driving innovation and knowledge spillover (Li et al., 2022; Obschonka et al., 2023). Regional innovation systems, characterized by strong networks among key actors, active knowledge sharing, and collaborative initiatives, tend to be more innovative (Asheim & Coenen, 2005; Cooke, 2005). Thus, for the effective adoption of domestic renewable energy technologies, it is imperative to understand the localized aspects of both national and global renewable energy innovation systems. This understanding is pivotal for shaping country-specific transition strategies and advancing future technological development (Li et al., 2022).

To analyze the dynamics of innovation systems with the goal of informing policies and strategies for enhancing innovation systems and technology development and diffusion, the literature incorporates a

* Corresponding author. Department of Building Engineering, Energy Systems and Sustainability Science, University of Gävle, Gävle SE-80176, Sweden.
E-mail address: Muhammad.Arfan@hig.se (M. Arfan).

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Abbreviations

BSC	Biofuels Supply Chain
BTG	Biotechnology Group
CTO	Crude Tall Oil
CHP	Combined Heat and Power
EU	European Union
IS	Innovation Systems
R	Recommendations
R&D	Research and Development
SA	Subsystem Activities
SEPA	Swedish Environmental Protection Agency
SMEs	Small and Medium Sized Enterprises
TIS	Technological Innovation System

range of interconnected and partially overlapping concepts and frameworks. These include the Global Innovation System (GIS), National Innovation System (NIS), Regional Innovation System (RIS), and Technological Innovation System (TIS) (Coenen & Díaz López, 2010; Markard et al., 2012).

The technological innovation system (TIS) framework is often described as appropriate for analyzing the development and diffusion processes of green energy technologies (Bergek et al., 2015; Binz et al., 2014; Truffer, 2015). However, the TIS literature partially analyzes the role of geographical proximity of innovation system components and their utilization in the development and diffusion of technologies (Coenen, 2015; Strambach & Pflitsch, 2020). However, understanding the localized aspects of national renewable energy innovation systems is pivotal for shaping place-specific transition strategies and advancing future technology development (Li et al., 2022). This is particularly essential when the study aims to provide policy support for increased local benefits with the evolution and diffusion of specific technologies (Bach et al., 2020; Muscio, 2006).

In this context, Swedish wind power TIS and ethanol TIS are interesting cases. In the formative phase, Swedish wind power TIS failed to utilize the geographic proximity of actors (i.e., national firms) between the 1980s and the 1990s. The structure consisted only of farmers and economic associations; thus, the investment subsidies launched in the 1990s by the Swedish government were utilized almost exclusively by Danish companies (Bergek, Jacobsson, & Sandén, 2008). Thus, the TIS structural growth created benefits in other geographic locations. In contrast, in the case of Swedish ethanol TIS, the early structure of the TIS successfully utilized the geographical proximity of the actors. In particular, the inclusion of politically powerful actors such as agricultural industry organizations and the vehicle manufacturer Saab Automobile AB generated strong advocacy through coalitions, which resulted in institutional alignment and TIS development (Bergek, Jacobsson, & Sandén, 2008). This points to the potential that the utilization of geographical proximity of TIS structural elements could not only enhance the TIS's ability to grow but also increase the local benefits of technology diffusion.

To contribute to the significant knowledge gap highlighted above, this study offers an extensive examination of the geographical proximity of structural elements and their utilization within the innovation system for renewable energy technology. This includes an analysis of artefacts, actors, networks, and institutions, along with the mechanisms that guide the utilization of proximity in the advancement and diffusion of forest biomass-based biofuel technologies within a specific geographic region, as demonstrated by the case of Gävleborg. This study intends to uncover insights that can inform regional policymaking. Our emphasis is on fostering technology development that not only enhances local economic benefits, but also contributes to the advancement of national Technological Innovation Systems (TIS), particularly in the context of forest-based biofuels. This study seeks to answer the following research questions.

1. What are the regional artefacts, actors, networks, and institutions of Swedish TIS for forest-based biofuels?
2. How has the geographical proximity of artefacts, actors, networks, and institutions been utilized and be utilize to enhance the regional biomass to biofuel technology development and its contribution to Swedish forest-based biofuel TIS key processes?

The Gävleborg region is an interesting case from the perspective of biomass as a resource, forest industry, and forest biomass-based biofuel production and technology development. It is located in central Sweden with approximately 1.6 million hectares of forestland (Statistics Sweden, 2017). In this region, there are four pulp and paper mills and seven sawmills with advanced state-of-the-art wood processing technologies. The regional forest industry is nationally and globally recognized from the perspective of supplying high-quality timber, pulp, and paper products (Länsstyrelsen Gävleborg, 2019; Norell, 2019).

In this region, the drive to reduce waste and use local bioresources for transportation fuels is flourishing, with waste streams, especially those originating from the local forest industry, emerging as pivotal resources (Länsstyrelsen Gävleborg, 2019). A recent review article (Ranjbari et al., 2022) sheds light on the technological advancements and significance of effectively managing biomass and organic waste within the framework of a circular economy. These findings highlight the urgent need for further research in this field.

Technological developments in utilizing biomass for biofuels in the region are characterized by four thermo-chemical and biological technologies intended to produce bio-oil for renewable transport fuels (e.g., biodiesel and biogasoline) based on sawdust from the timber industry, lignin from pulp residue, and black liquor from the paper industry. These activities make the regional forest-based biofuel technological system an extremely interesting case in which upholds technology variety sharing the same upstream resource (forest biomass) and downstream product (biodiesel and biogasoline for transport), experiencing structural (actors, networks, and institutions) overlap in regional and national geographic contexts.

The remainder of this paper is organized as follows. The methodology section introduces the analytical approach used, followed by an illustration of the data collection and analysis strategies. In the results section, the research questions are answered by describing the technological directionality of the subsystem, utilization of the geographical proximity of structural components, and subsystem development. This section also highlights situations where the geographical proximity of subsystem structural components has contributed to the national TIS key processes and identifies areas where further utilization of geographical proximity could enhance the contribution of the subsystem. In the Discussion section, we critically analyze the validity of the applied approach and the results of this case study. The section ends with a brief discussion of the practical implications and limitations of this study, and recommendations for future work. Finally, the paper concludes the study and points out possible directions for future research.

2. Methodology

TIS has often been described as appropriate for analyzing the development of emerging green energy technologies (Andersson et al., 2018; Bergek, 2015). This is commonly defined as a sociotechnical system that focuses on the development, diffusion, and use of a particular technology (Bergek, Jacobsson, Carlsson et al., 2008; Hekkert & Negro, 2009). The structure of a TIS can be defined in different ways (Bergek, Jacobsson, Carlsson et al., 2008), but in this study, artefacts, actors, networks, and institutions are considered the fundamental structural components (Table 1). Actors in a TIS work in an institutionalized environment and create networks, resulting in TIS development and technology diffusion. To examine the pace of technology development and diffusion, a set of seven key processes (Appendix Table 2) is generally used (Hekkert & Negro, 2009), where the analysis revolves around essential innovation

Table 1
Description of the TIS structural components.

Structural components	Description
Artefacts	Physical objects that constitute or enable technological developments (i.e., complementary technologies, testing infrastructure) as well as codified knowledge such as scientific papers (Andersson et al., 2018).
Actors	Firms along the technology value chain, universities, research institutes, public bodies, non-governmental firms, and standards organizations (Bergek, Jacobsson, & Sandén, 2008).
Networks	Could be of two types, political and learning. Political networks aim to implement a political agenda to drive innovation to politically motivated pathways. Learning networks aim for knowledge creation and diffusion, and influence perceptions of what is possible and desirable, guiding specific investment decisions (Jacobsson & Karltorp, 2013).
Institutions	Refers to policy and regulatory aspects as well as to norms, cognition, and culture that structure human interaction and decide the value base in society, influencing the decision of the value chain firms and other actors (Jacobsson & Karltorp, 2013). Institutions have a key role in the evolution of TIS and firms compete to gain influence over institutions through cooperation and manipulation (Bergek, Jacobsson, Carlsson et al., 2008).

resources, such as knowledge, financial capital, and processes that describe innovation and development.

In this paper, an adapted version of the TIS framework (Fig. 1) presented by (Bergek, Jacobsson, Carlsson et al., 2008) is operationalized. In the conceptual framework (Fig. 1), the national TIS is the Swedish TIS of forest-based transport fuels (S), consisting of several subsystems (G1-Gn) defined as the structural components located within a specific subnational region. The thick arrow from subsystem (G1) to key processes (F) represents the effects of the subsystem dynamics on key national TIS processes. The arrow from the reference TIS structure (S) to the key processes (F) symbolizes the effects of changes in subsystem structures on the national TIS structure. The arrow from key processes (F) back to structure (S) indicates the feedback loop (i.e., the entrance of new firms and the formation of new institutions and networks) in response to an increased or decreased contribution of the subsystem structures (G1-Gn).

2.1. Data collection approach

A combined approach of document analysis and interviews with regional industries, including SMEs and public authorities, is used. Data were collected mainly from interviews with 15 key actors representing the forest industry, knowledge-generating firms, and government institutes, conducted in the period 2019–2021 (see Appendix Table 1). Each interview lasted one–two hours, either face-to-face or via Zoom (depending on accessibility). Project and/or business development managers were interviewed. The interviews were semi-structured and used a technique called 'responsive interviewing,' as proposed by (Herbert & Irene, 2005). This approach relies heavily on interpretive constructionist philosophy, mixed with some critical theory, and then shaped by the practical needs of conducting interviews (Herbert J.& Irene S., 2005).

Interviews were preferred over questionnaires, because some questions required elaboration from the actors involved. The interview questions were divided into three types: main, follow-up, and probes. The main questions focus on the research problem (i.e., what, why, and how?) and remains on the target by addressing the research question. Follow-up and probe questions were asked to ensure that we pursued depth, detail, vividness, richness, and nuances. One to two respondents represented each participating organization.

Interview summaries were written and information was coded into different categories based on related subject areas, as suggested by Voss et al. (2002). The categorization was based on: (i) the role of the case company (technology developer/adopter); (ii) the internal and external motivations; (iii) the role of networks and networking organizations; and (iv) influencing factors. This helped evaluate how the geographical proximity of the subsystem components influenced the technology development processes. To validate and reduce bias, we triangulated the interview information using document analysis, including media archives, industry reports, company materials, information from public agencies, and previous research on the focus subject.

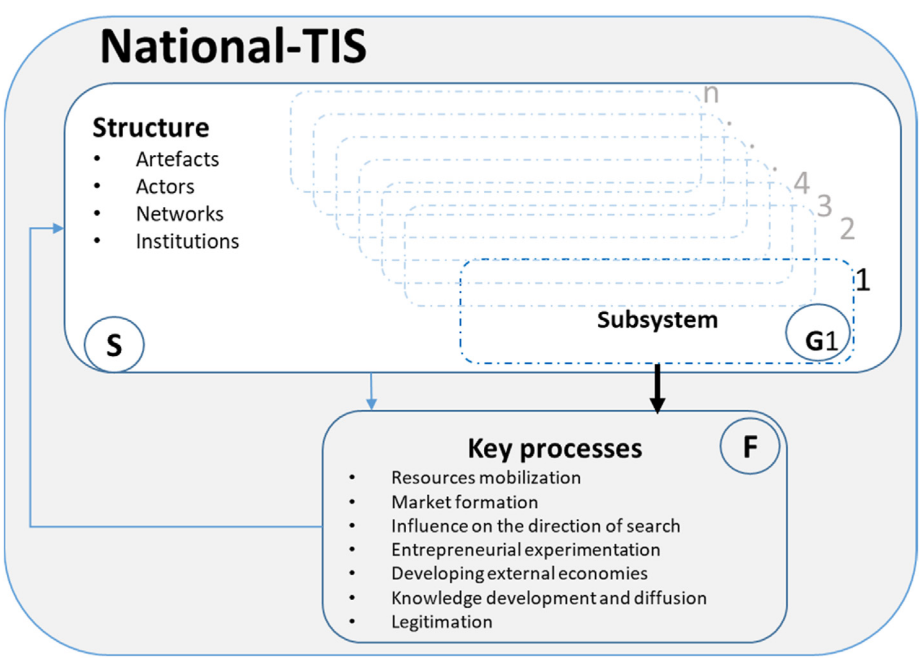

Fig. 1. Conceptual Framework. The national TIS is the Swedish TIS for forest-based transport fuels, whereas the subsystems represent the structural components at the subnational (regional) level.

The use of patents and scientific publications was not suitable for this case study because of their limited geographical scope, few actors, and incomplete value chains. For media archives, news articles (news articles and press releases) published in five different web media channels were used. The selection criteria were designed to include media channels that cover the following.

a. General and local events/news
b. Political and social issues
c. Bioenergy-specific developments
d. National presence

Only web articles were used to ensure access to all relevant information and avoid repetition. The keyword language was Swedish (Appendix Table 3, given in parentheses), because the media articles were in Swedish. We used the Retriever database (Retriever, 2020). The research was restricted to activities related to forest biomass for transport fuel production and related technologies (i.e., gasification, pyrolysis, torrefaction, hydrogenation, and biological). In total, 246 news media articles published between January 2010 and April 2021 were found to be relevant (see Appendix Table 3) with keywords in combination with the names of the Gävleborg municipalities.

Detailed content analysis was conducted to triangulate the interview information and identify regional and national actors, activity types, and networks. This helped to validate the interview information. Based on our document analysis and interview data, it was identified that the actors contribute to subsystem development to varying degrees, which is used as a basis for the qualitative analysis of the proximity and utilization of the subsystem structural component (Table 2). The scale was high, intermediate, low, and unclear. High is assigned where relevant structural component proximity was analyzed as sufficient for the development of the technology structure, and utilization was assumed high where most relevant actors were involved, and the technology was supported by subsystem institutions in terms of financial capital and regulations. An intermediate is used when some relevant actors are not involved, the technology has low institutional support, and the structure lacks networking organization. In contrast, low is used where most of the relevant actors are not involved and the structure is struggling for institutional support and network building. Unclear is used in cases with insufficient information.

3. Results

Technological directionality underscores the fact that technological innovation is not a completely random or open-ended process. Instead, they follow specific trajectories or paths, influenced by existing technologies, scientific research, and various contextual factors. Four distinct technology routes were employed, all sharing the same primary resources (forest biomass) and producing similar end-products (biodiesel and biogasoline for transportation). These routes exhibit a structural overlap, particularly from the perspective of institutional and industrial business networks. These technologies can be broadly categorized as thermochemical and biological processes. In this section, we delve into each technology route individually, elucidating how each structure originated and evolved, and focusing on actor entries and network formation. Fig. 2 provides an overview of the overall achievements and patterns of the subsystem technologies.

3.1. Thermochemical technologies

3.1.1. Pyrolysis

In 2015, Setra Gävle, a subsidiary of the Setra Group and significant contributor to Sweden's wood industry, examined the potential of utilizing sawdust and wood chips for bio-oil production through pyrolysis. This idea evolved through internal discussions involving experts from various fields within the Setra Group, and in collaboration with bioliquid, a Dutch company specializing in fast pyrolysis technology for converting sustainable biomass residues into bio-oil.

In 2015–2016, Setra, in partnership with Pöyry Sweden AB, conducted a preliminary study that demonstrated the feasibility of constructing a pyrolysis plant integrated with a sawmill and an adjacent CHP (Combined Heat and Power) plant in Gävle. This study served as the foundation for a grant application to Klimatklivet, which resulted in an investment support of 177 MSEK for the construction of a pilot facility in 2017. Obtaining an environmental permit in October 2018 further

Table 2
An overview of the subsystem technology structural components' proximity potential and their utilization.

Technology	Pyrolysis		Lignin		CTO		Biological	
Components	Proximity	Utilization	Proximity	Utilization	Proximity	Utilization	Proximity	Utilization
Artefacts	+++	+	+++	++	++	+	++	0
Actors	+++	+	+++	+	++	0	+++	0
Networks	++	+	+++	+	+++	+	++	0
Institutions	+++	++	++	+	++	0	0	0

Scale; High (+++), intermediate (++), low (+), unclear (0).

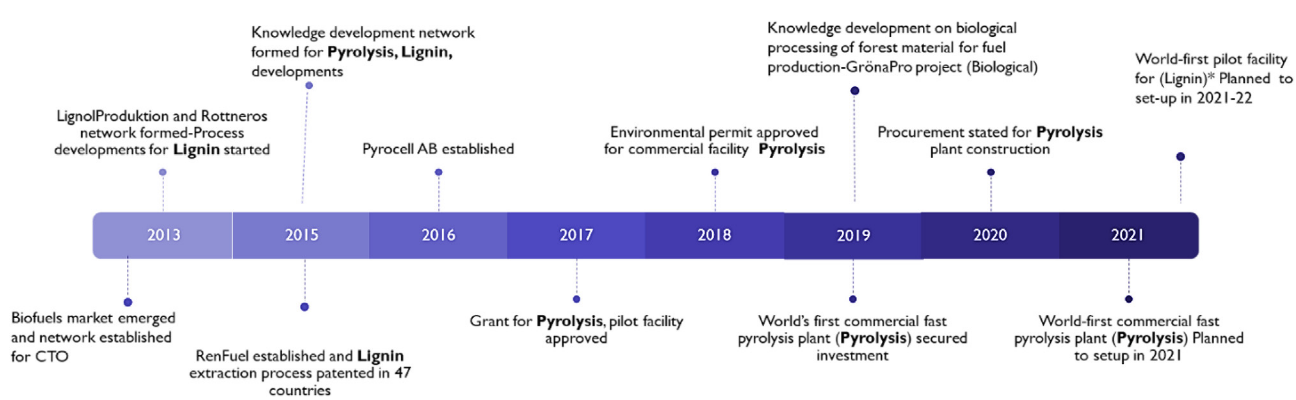

Fig. 2. Timeline of the important activities that contributed to the development of the TIS subsystem structure. Boxes that do not include a description of the technology cover all technologies. (Lignin)* = Facility construction is planned but not in the region.

solidified the project's alignment with the formal and informal institutional requirements.

In 2016, Setra and Preem entered a collaboration agreement, leading to the formation of a new company named Pyrocell AB. In the spring of 2019, Setra and Preem invested in the construction of a pyrolysis plant in Gävle. Procurement began in 2020 and the facility was inaugurated at Setra's sawmill Kastet in Gävle in the spring of 2021, with production beginning in August 2021. This groundbreaking facility represents the world's inaugural commercial establishment of its kind, dedicated to innovative pyrolysis technologies. At this facility, pyrolysis oil is derived from forest industry residues, specifically sawdust.

The facility's anticipated output is in the range of 25,000 to 30,000 tons of pyrolysis oil annually, which is equivalent to the yearly diesel consumption of 15,000 passenger cars in Sweden. Once refined through Preem's Lysekil refinery, this valuable resource is transformed into biofuels, including biogasoline and biodiesel. With ambitious plans to amplify pyrolysis oil production and envisage the installation of additional units both within the region and across Sweden, this project has the potential to pave the way for a sustainable future.

Furthermore, Norrsundet Slamförädling AB, an innovative small-scale company, joined this subsystem with the unique concept of biochar production through the microwave pyrolysis of wood. Notably, this process yields bio-oil as a byproduct, which is estimated to constitute approximately 30% of the biomass used. This bio-oil is poised to be shipped alongside pyrolysis oil to Preem's refinery for the further production of transport fuels. While the technology remains in the pilot-testing phase, the entry of this firm augments the subsystem structure with fresh knowledge and an expanded network.

3.1.2. Lignin for fuel

Since 2013, Preem and LignolProduktion AB (a research-based company rooted in Uppsala University and the originator of the lignin-to-lignin-oil concept) has embarked on a collaborative journey to develop the process of extracting lignin from pulp residue to produce liquid transport fuels. This collaboration not only enriched their knowledge base, but also catalyzed the formation of a new network in 2015. This network included key players, such as Rottneros, LignolProduktion AB, Preem, and RenFuel (holders of patents related to lignin oil processing), united in their goal of deploying this technology through the establishment of a lignin extraction facility.

In 2016, an exhaustive pre-study was conducted in collaboration with Preem, exploring the feasibility of constructing the world's inaugural commercial-scale lignin extraction plant at Rottneros' pulp production facility in Vallvik, Söderhamn. Preem provided substantial financial and market support and this project entailed intensive research. Stakeholders RenFuel, Vallvik, and Preem pooled their resources, including grants from the EU and Swedish national institutions, into this endeavor. The envisioned plant aimed to annually produce 25,000–30,000 m^3 of lignin annually, which would then be processed into lignin oil at the facility. The resulting lignin oil was slated for transportation to Preem's biorefineries, where it was planned to be transformed into gasoline, biodiesel, and other valuable chemicals.

However, in 2019, the project was temporarily halted, primarily because of the substantial investment costs and uncertainty surrounding the future market demand for lignin. Although a comprehensive description of the challenges remains undisclosed, certain techno-economic hurdles have emerged. Notably, achieving lignin extraction without disrupting pulp production posed a significant challenge, as did meeting RenFuel's specific lignin purity requirements, including molecular weight distribution and water removal (30–40%) before conversion into lignin oil. To be financially viable, the lignin extraction plant required a certain level of black liquor production either at the mill or within the geographical scope of the subsystem. The Vallvik mill did not meet these threshold limits, and the other nearby mills were not integrated into the collaborative structure. Consequently, the subsystem encountered difficulties in technology diffusion and temporarily deferred the project while exploring alternative locations with higher black liquor availability.

3.1.3. Crude tall oil (CTO)

Crude tall oil (CTO), a valuable by-product of the sulphate pulping process employed in pulp production, holds immense promise as transport fuel. In this subsystem, BillerudKorsnäs, Iggesund (part of the Holmen Group), and Rottneros operate advanced, fully integrated pulp, paper, and paperboard mills. To harness the potential of the CTO generated in these mills, it is transported to the Sunpine refinery in Piteå and the Kraton chemical facility in Sandarne. Sunpine plays a pivotal role in processing CTO to produce tall oil, diesel, and gasoline, which, in turn, are refined into transport fuels by Preem. On the other hand, Kraton utilizes CTO to produce environmentally friendly green chemicals.

Despite these actors forming a purely business-oriented network, the absence of a local facility to fully exploit this geographically accessible resource poses a constraint on realizing its complete potential. The future evolution of CTO for transport-fuel applications is contingent upon factors such as fossil-fuel prices and institutional support. In essence, the network of participants involved in the production and utilization of CTO represents a substantial opportunity to enhance local benefits and foster economic growth.

3.2. Biological

In 2019, the subsystem actor Colabitoil AB, in collaboration with Mid Sweden University and the University of Gävle, initiated the GrönaPro project. This endeavor aimed to develop a groundbreaking technology capable of processing wood biomass, primarily wood fiber sourced from the pulp industry, using microorganisms for biodiesel production. At this stage, the technology was in its experimental lab phase, and concurrent research focused on assessing environmental and energy balance implications.

The versatility of this technology extends to the utilization of various biomass sources, potentially encompassing any type of biomass for biodiesel production. However, waste fiber derived from the pulp and paper industries has been identified as the most suitable feedstock, given its current lack of alternative uses. Nevertheless, the adaptability of the technology allows for the incorporation of other biomass types, such as wood chips, sawdust, wheat straw, and more, if required for large-scale production facilities in the future.

3.3. The subsystem development and geographical proximity utilization

This section elaborates on the proximity potential of the subsystem structural components in each technological route, assessing the extent to which this potential has been harnessed and the potential contributions to the national TIS key processes (Appendix Table 2). Table 2 provides an overview of the proximity potential of the subsystem's structural components concerning the subsystem technologies and their level of utilization. The scale utilized, ranging from high to intermediate, low, and unclear, is defined in the methodology section.

In summary, our analysis shows that both business and private networks play pivotal roles in the emergence of a subsystem's technology structures and the utilization of its structural components. In the case of pyrolysis and lignin, the proximity potential of the structural components was exceptionally good. However, their utilization has been analyzed as low. Conversely, in the case of the CTO, the proximity potential of the structural components has been evaluated as an intermediate. Interestingly, in this technology design, the utilization of artefacts and networks' proximity potential was exceptionally low, while in the case of biological technology, the utilization of actors and institutional potential remained unclear.

From a subsystem perspective, it becomes apparent that despite the high geographical proximity potential of actors and networking organizations such as BiodrivMitt, Industry organizations (Företagarna), the environmental forum Gävleborg (Miljöforum Gävleborg), and fossil-free Gävleborg, this potential has not been effectively utilized. The reasons for this are discussed in the following subsection.

3.3.1. Artefacts

Our research, comprising interview data and document analysis, revealed that the subsystem within the forest industry, encompassing sawmills, pulp, and paper, boasts a robust competence base. This competence stems from both the engineering knowledge and experience acquired through wood processing and other related industrial and business activities. This subsystem possesses a significant untapped potential in terms of wood biomass to produce renewable transport fuels. Approximately 79% of the land area within the geographical scope of the subsystem is covered by forests; concurrently, the geographically proximate forest industry generates substantial quantities of biomass residues. These residues, including sawdust, wood chips, black liquor, and CTO, have been empirically proven to be suitable for producing renewable transport fuels, such as biodiesel and biogasoline.

Furthermore, the subsystem benefits from favorable infrastructure proximity. Subsystem technologies have the potential for seamless integration with existing forest industry infrastructure, district heating systems, and distribution networks. For example, lignin oil production technology aligns exceptionally well with the existing black liquor utilization process at Vallvik, a pulp-production facility located in Söderhamn. This synergy underscores the promising possibilities for efficient and sustainable utilization of resources and infrastructure within the subsystem.

In the case of pyrolysis technology, there has been partial but successful utilization of high artefactual proximity. The proximity of feedstock (sawdust), combined with industry actors' tacit and engineering knowledge, as well as the existing sawmill infrastructure, played a significant role in the technology's rapid development and diffusion. However, the optimal potential of artefactual proximity was not harnessed because several other geographically proximate sawmills were not integrated into the technology structure. Nevertheless, this partial utilization resulted in the operational launch of a pyrolysis oil production facility in September 2021.

In contrast, in the case of lignin technology, the utilization of artefactual proximity was initially particularly good during the emerging and formative phases. Proximate physical artefacts, including R&D labs, black liquor plants, and the possibility of integrating lignin technology with the existing pulping process, played a pivotal role in the development of the technology, culminating in the setup of a test facility. This utilization generated valuable new knowledge regarding the use of black liquor for high-value products such as lignin oil, which could benefit the subsystem industry and society as technology diffused.

However, for further advancement of the technology structure, artefactual proximity, such as proximate pulp and paper industry resources in terms of knowledge and material resources (black liquor and technology infrastructure), was not well utilized. This shortcoming has led to the failure to establish a commercial facility despite the availability of financial resources.

In the case of CTO technology, even though there is a high geographical proximity of artefacts, including industry competence, knowledge, and enabling infrastructure, these have not been utilized. The present structure and network for the CTO were purely business-oriented (Fig. 3), with the CTO being traded among network actors for their individual business needs. This network may not be considered part of the subsystem structure. Finally, in the biological route, the proximity of resources (pulp industry fiber waste) is good because of the presence of four large pulp and paper industries. However, the extent to which artefactual proximity is utilized remains unclear as this technology is still in its emerging phase.

3.3.2. Actors and networks

The subsystem has high geographical proximity to the actors and networks. It boasts several networking organizations, seven sawmills, four pulp and paper industries with cutting-edge production technologies, and active business and learning networks at both national and international levels. Universities and technology parks contribute to this rich ecosystem. However, despite this high proximity, none of the technology structures within the subsystem effectively leveraged these resources.

Each technology structure has remained limited to only two or three actors, with one or two belonging to the subsystem's geographical area, while the others are national or international (Fig. 3). For instance, in the case of pyrolysis, Setra was the sole actor from the subsystem geography, connected to national (Preem) and international (BtGbiofuels) actors. Other proximate actors, such as the six sawmills, the Forest Industry Association, BiodrivMitt, and Svebio, were not integrated into the

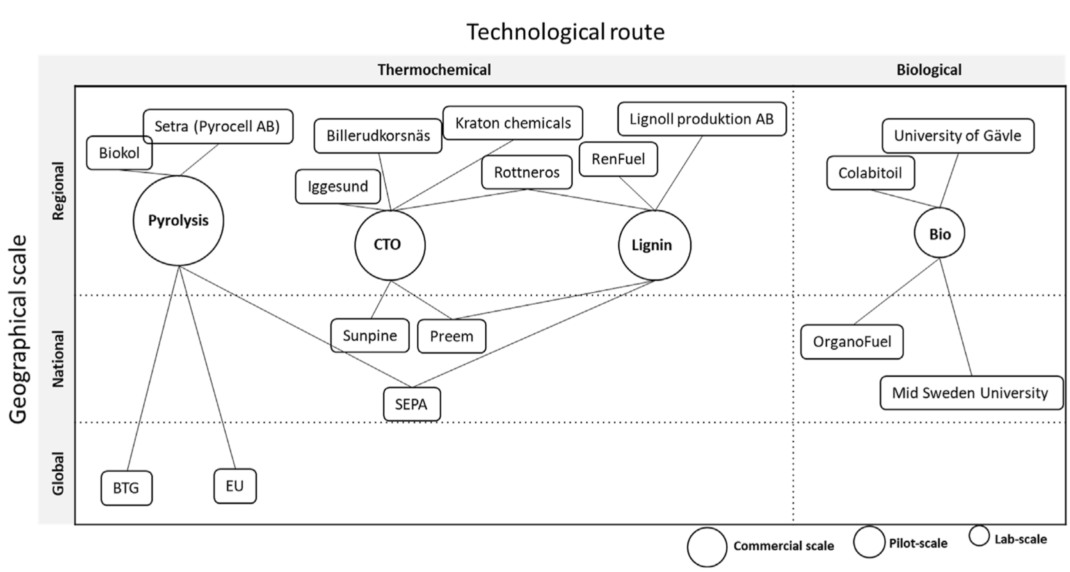

Fig. 3. Topology of subsystem actors and networks (i.e., learning and business networks). The Swedish Environmental Protection Agency (SEPA) and the European Union (EU) are funding agencies, whereas BTG Bioliquids are technology developers and operational service providers. Commercial scale refers to a large-scale industrial plant that produces production on a commercial basis, whereas the pilot scale refers to a facility built to test and develop products or processes. Lab scale refers to the technology state under development, where different feedstocks and operating conditions are tested.

technology structure. The interview data indicated that these proximate actors were not well informed about the technology development process, which hindered their participation.

A comparable situation emerged in the case of lignin technology, where the other three geographically proximate pulp and paper industries (Holmen Group, BillerudKorsnäs, and StoraEnso), networking organizations, and knowledge-generating firms could not become part of the structure. The limited utilization of actors and network proximity can be attributed to several factors, including differences in companies' sustainability strategies, some major actors' skepticism about the future market for forest-based biofuels, high investment costs, and low level of cooperation (due to competition or knowledge protection). The actors also pointed out the perceived inadequacy of networking organizations in facilitating collaboration.

However, the limited established structures (actors and networks) of pyrolysis and lignin technologies have effectively utilized network resources, including knowledge, competence, infrastructure, and business networks, to advocate for these technologies. This has resulted in their legitimation, as evidenced by the acquisition of environmental permits and securing of the necessary financial resources for pilot facilities through both private and public funding sources.

From the perspective of these technologies, this subsystem has partially contributed to several key national TIS processes. These contributions encompass knowledge development and diffusion, legitimation, research direction, and positive externalities, as the initial research and pilot facilities function as testbeds. The experiences gained from these technologies hold significant value for further development and diffusion of the national TIS.

3.3.3. Institutions

The subsystem has a high geographical proximity in terms of favorable regulations and public acceptance. There are dedicated environmental management departments and experts at both the regional and municipal levels. Cooperation among regional municipalities and industries was also assessed as good. These regional and municipal environmental managers play a vital role in promoting environmentally friendly technologies, particularly green energy technologies, by providing support to encourage initiatives that not only promote sustainability, but also maximize local economic benefits.

Our analysis of the interview data revealed that public institutional alignment with subsystem technologies was strong, both at the municipal and regional levels. This alignment is reflected in the regional sustainability strategy, which sets ambitious targets to increase the use of renewable fuels. By 2025, the strategy aims for 40% of all fuel consumption to come from renewable sources, focusing on locally produced renewable fuels (Länsstyrelsen Gävleborg, 2019). Furthermore, social acceptance and market regulations have been supportive, with several prominent regional transport companies and industries already adopting renewable fuels, such as HVO and biodiesel. Additionally, multiple renewable fuel stations are in operation, demonstrating readiness in the market for such fuels.

However, despite the high geographical proximity of institutions and favorable conditions, the utilization of these resources has been limited. Its primary use has been to obtain environmental permits for pilot-scale facilities. The reasons for this underutilization remain unclear, as the interviewees were unable to provide a clear answer. One point mentioned by municipal and regional authority representatives is the perceived high risk associated with investments as they are accountable for public funds and need to exercise caution in financial matters.

3.4. Contribution to the national TIS key processes

The analysis of the subsystem's structure and development highlights instances in which its structural components have made valuable contributions to national TIS key processes. Additionally, it identifies opportunities for further development that can enhance its contribution (Fig. 4).

For instance, the partially utilized potential of regional forest industry residues (sawdust, lignin, and CTO) for bio-oil production (SA1) and the associated industry networks (SA2) have contributed to national TIS key processes, particularly *resource mobilization (F1)* and *knowledge development and diffusion (F2)*, especially in the case of the pyrolysis technology route. The lignin extraction project in Gävle is another example of a first-of-its-kind technology in Sweden, and the presence of national TIS actors within the subsystem (Fig. 3) suggests knowledge spillover.

Furthermore, the partial utilization of regional social and institutional legitimacy (SA5, SA6) regarding the use of forest biomass for high-value products (e.g., biodiesel and biogasoline) has strengthened national TIS

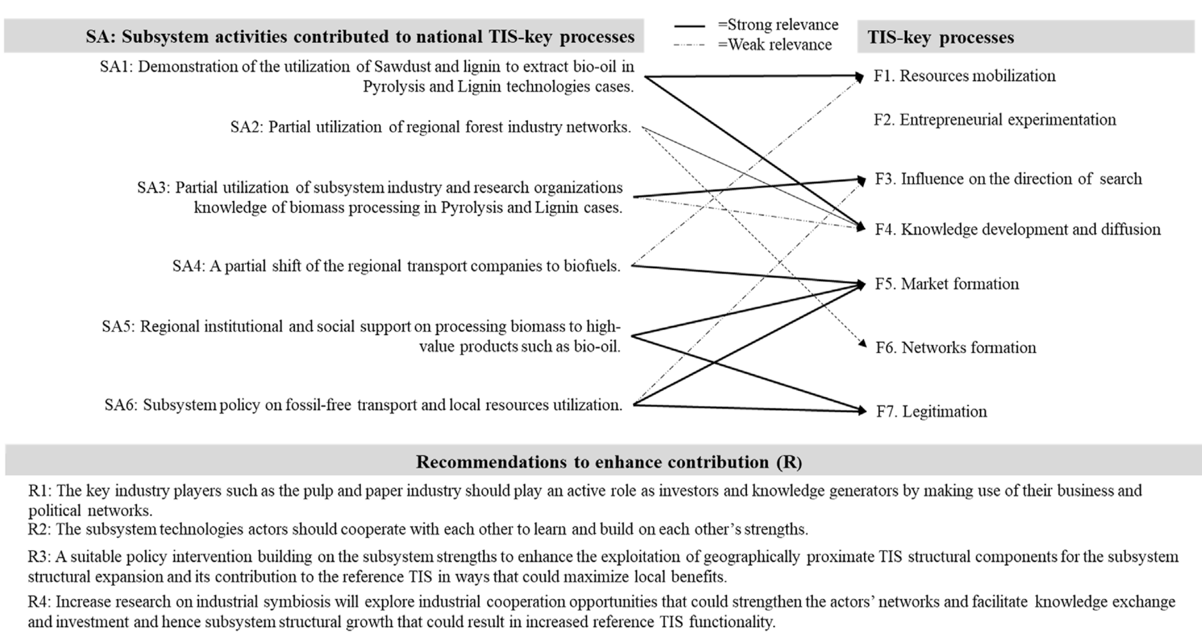

Fig. 4. Overall analysis summary of the case study: The arrows from the SA column to TIS-key processes indicate the potential contributions of the subsystem to the directed function.

key processes related to market formation (F5) and legitimation (F7). Some national actors have expressed an interest in replicating similar projects in other Swedish regions.

Moreover, the analysis highlights various opportunities for cooperation between the subsystem and the national TIS structure for mutual growth and benefits (Fig. 4). The subsystem actors can contribute to national TIS development by sharing their experiences and opening their technology pilot facilities for national TIS actors to learn through experiments (R1, R2). Conversely, the subsystem structure can utilize the national TIS structure for knowledge and capital resources needed to upscale regionally focused technologies, particularly in the cases of Lignin, Pyrolysis, and CTO, given the national TIS's history of green energy technology development and diverse competencies.

Additionally, the subsystem's technology structures can establish inter-subsystem technologies and cross-boundary learning networks (R1, R2, and R3). This has the potential to enhance its contribution to national TIS key processes related to resource mobilization (F1), knowledge development and diffusion (F4), and market formation (F5). Mutual learning and problem-sharing networks among these actors can facilitate the generation of innovative ideas and knowledge (R2). Utilizing regional sustainable resource management policies (R3) and networking organizations (R5) could further enhance the subsystems' contributions to national TIS key processes, including entrepreneurial experimentation (F2), knowledge development and diffusion (F4), and legitimation (F7).

Suitable policy and networking organizations' interventions (R3, R4, R5) can be immensely helpful in establishing networks between the subsystem and national TIS actors. The bridge could not only facilitate knowledge exchange (F2) and the effective use of geographically restricted resources to develop subsystem technologies, but also financial capital generation (F1), which was one of the major challenges for the subsystem structure in its further development.

However, it is important to note that the knowledge gained during the development of these technologies is still largely confined to the subsystem structure. The national-level actors involved in renewable energy technologies were not part of the subsystem structure (Fig. 3). To further leverage the potential of inter-subsystem technologies and cross-boundary learning networks, it is crucial to share knowledge and experience beyond the subsystem structure. This can lead to even more significant contributions to the national TIS key processes, which is in line with the findings of Karltorp (2014).

4. Discussion

Subsystem technology structures have evolved with the shared objective of increasing the utilization of forest biomass for biofuel production. These structures exhibit an overlap in their core structural components, encompassing artefacts, actors, networks, and institutions. At present, the technologies are in the early stages of development, characterized by a noteworthy challenge – namely, intense competition among technology stakeholders for leadership in knowledge acquisition, securing public funding, and access to bioresources. This competitive landscape can, in part, be attributed to the underutilization of the geographic proximity of the system's components, particularly actors and institutions. In addition to emphasizing the significance of suitable long-term national and regional policies for the effective use of bioresources, a recommendation that has been frequently underscored in previous studies (Ammenberg et al., 2018; Scott et al., 2018)–a strategy aimed at fostering collaboration among system actors and institutions–holds the promise of mitigating various challenges arising from this competitive environment.

The underutilization of the geographical proximity of actors and institutions may also be attributed to a limited network connection among actors within the subsystem, encompassing the forest industry, associated entities, and public institutes (Fig. 3). This phenomenon can be ascribed, in part, to the inadequacy of economic support and knowledge, particularly in the context of CTO and Lignin. This is consistent with previous research findings (Bridge et al., 2013; Maassen, 2012). Networking organizations, such as BiodrivMitt and forest industry associations, whose role has not been admitted by the system actors, can play a crucial role in fostering connections and collaborations within the subsystem and national TIS stakeholders.

Notably, the close geographical proximity of the subsystem technologies is expected to be synergistic, as previously established (Usai et al., 2017). Nonetheless, in our specific case, the pronounced geographical proximity of regional biomass-to-fuel technologies, both in terms of technical aspects and sectors, yielded unexpected adverse consequences. Instead of promoting collaboration, it has given rise to a competitive dynamic partly stemming from actors competing for funding from both regional and national agencies. In the case of pyrolysis technology, the study discerns a favorable assessment regarding the partial exploitation of geographical proximity, particularly concerning artefacts (such as the sawmill and CHP plant) and institutions. This utilization has nurtured the establishment of a resilient and tightly knit network among technology stakeholders and local institutions. This network, along with the actors' political affiliations, has played a pivotal role in facilitating their access to public funding, a crucial factor contributing to the progression of technologies from the pilot phase to full-scale commercialization environments (Karltorp, 2014).

Nevertheless, the enduring security of feedstock supply has been identified as a crucial determinant for the growth of a TIS and the diffusion of technology (Zahraee et al., 2020). In this regard, the case of tidal kite TIS is particularly relevant (Andersson et al., 2018). The tidal kite TIS emerged in Sweden, but its expansion has transpired in other regions of Europe, primarily because Sweden lacks the necessary water tides (Andersson et al., 2018). In our case, the lignin and CTO technologies encountered similar issues. The primary factors contributing to the limited dynamics of lignin and CTO technology structures in leveraging the geographical proximity of actors and institutions are rooted in considerable uncertainty regarding the long-term security of feedstock supply, pricing dynamics, and the market for lignin oil. These uncertainties have posed significant obstacles to the sustained growth and commercialization of these technologies, in agreement with previous studies (Andersson et al., 2018; Zahraee et al., 2020).

Moreover, this study also makes a significant contribution to innovation theories, particularly within the realm of the 'geography of TIS,' by investigating and analyzing the crucial role of geographical proximity and the mechanisms governing its utilization in the development of sociotechnical systems. This research underscores the paramount significance of comprehending how the geographical proximity of structural elements influences the dynamics and progression of a sociotechnical system. As mentioned in the introduction, it is often overlooked in TIS research (Hansen & Coenen, 2015; Markard et al., 2012). The findings of this case study highlight that the utilization of geographical proximity of TIS structural components leaves a distinctive imprint on the development of the subsystem and its contribution to the national TIS key processes.

In Addition, *resource mobilization*, *knowledge development and diffusion*, and *network formation* have been identified as the most influential TIS key processes (Asheim & Coenen, 2005; Usai et al., 2017), particularly in the national TIS context. The findings of this case study affirm that these processes also have a significant influence at the subsystem level. For instance, in the pyrolysis and lignin technology cases, the mobilization of internal financial and human resources by companies such as Rottneros and Setra played a decisive role in initiating the technology's development. These emerging structures have attracted both national and international actors, leading to increased investment, knowledge dissemination, and the establishment of pilot facilities. This culminated in the decision to deploy pyrolysis technology on a commercial scale in the region, while the future development of lignin technology is likely to occur elsewhere in Sweden.

Collaboration and knowledge sharing among actors involved in cross-sector Technological Innovation Systems (TISs) are of paramount importance for the cross-border diffusion of green energy technologies and the generation of new knowledge (Li et al., 2022; Usai et al., 2017). The evaluation of this case study demonstrates that the subsystem technology structures encounter similar challenges, which can, in part, be attributed to the underutilization of actors and institutional proximity. This research underscores the paramount importance of *collaboration and networking* among various actors within the forest biomass-based transport fuel technological system, in line with a previous study. Regional policymakers and industry leaders can play a pivotal role in promoting collaboration among the forest industry, public institutes, and networking organizations. By fostering strong and steady networks, these collaborations can facilitate the exchange of knowledge, mobilization of financial resources, and human capital. In turn, this can significantly contribute to the growth and dissemination of subsystem technologies. Collaborative efforts can bridge gaps, harness synergies, and drive innovation in the sector, thereby advancing the entire forest biomass-based biofuel TIS.

Furthermore, regional policymakers can utilize the insights gleaned from this research to design effective *policy interventions* that propel the forest biomass-based biofuel sector forward. Strategically crafted policy interventions must harness the strengths of subsystems and improve the utilization of geographically proximate structural components. Such policies may include providing incentives for research and development initiatives, offering subsidies to support technology deployment, or eliminating regulatory barriers that impede the commercialization of these innovative technologies. By creating an enabling environment, policymakers can catalyze the growth of forest biomass-based biofuels and bolster the broader bioeconomy.

Furthermore, our analysis suggests that regional policies should actively promote collaboration between the forest and biofuel technology sectors, facilitating resource pooling and investment in the advancement of subsystem technologies. Such cooperation can result in increased efficiency, innovation, and sustainability, consistent with Mirata (2004). The concept of industrial symbiosis can play a pivotal role in the efficient utilization of local bioresources and optimization of production processes, thereby enhancing the growth and competitiveness of the subsystem.

Furthermore, this study's findings indicate that the development of subsystem technologies can yield significant local economic benefits. Regional governments and development agencies should consider supporting these technologies as integral components of broader economic development strategies. This support can take various forms, including providing financial assistance for pilot projects and infrastructure development, fostering workforce training programs to meet the specialized needs of the sector, and promoting the integration of biofuel technologies into regional energy and transportation systems. By aligning *regional economic development* goals with the growth of the subsystem, policymakers can create a win-win scenario for both local communities and the forest biomass-based biofuel industry.

This case study has certain limitations that warrant careful consideration when attempting to generalize the findings. First, its narrow geographic focus on a specific small region raises questions regarding the applicability of its conclusions to larger and more intricate technological innovation systems. Furthermore, heavy reliance on qualitative data obtained through interviews may introduce subjectivity and potential bias into the analysis. The absence of quantitative data limits our ability to draw precise and statistically significant conclusions.

Additionally, this study primarily examines technologies in their nascent or formative stages, potentially overlooking insights into the dynamics of mature technologies or those in later stages of commercialization. The single-case study design, while providing in-depth insights, lacks the comparative perspective offered by multi-case studies. Furthermore, the potential for long-term shifts in forest ecosystems is not considered in this analysis.

Moreover, several studies have found that the knowledge dynamics of renewable energy technologies are affected by technology-specific characteristics (Binz & Truffer, 2017; Stephan et al., 2019). Thus, it might be misleading if these case study results are accounted for in countries or regions with large differentiations (Li et al., 2022; Petralia et al., 2017).

5. Conclusions

The subsystem comprises four technology routes: three thermochemical routes and one biological route. These technologies are at various levels of development, which can be partly attributed to their ability to utilize the geographical proximity of the structural components of the system. The partial utilization of the subsystem's artefacts and institutions has played a crucial role in the overall structural growth and technological development of the subsystem. However, the competition of the system actors in securing knowledge leads, access to bioresources, and public funding has hampered the overall subsystem's structural growth. This can partially be attributed to the lack of network among the subsystem technologies' actors and the poor beliefs of a few subsystem actors, such as the pulp and paper industry and public institutes, in successful business cases for the commercialization of the technologies.

The analysis suggests that key industries within the subsystem, such as the pulp and paper sector, should actively invest in R&D to fulfil knowledge needs by leveraging their business and political networks. To promote growth, technology actors within the subsystem must collaborate and build on each other's strengths. Appropriate policy interventions are necessary to ensure that the subsystem development leads to local benefits. These interventions should leverage the strengths of the subsystems to improve the utilization of geographically proximate TIS structural components, thereby contributing to the reference TIS. Networking organizations can serve as a bridge between the reference TIS and the subsystem structures, including actors not yet part of the subsystem structure, whose roles have yet to be explicitly recognized.

In summary, the insights derived from this research provide a valuable foundation for policymakers, industry leaders, and researchers dedicated to advancing forest biomass-based biofuel technology. To harness the potential of this innovative sector and foster sustainable growth in the biofuels industry, it is imperative that stakeholders prioritize collaboration, implement targeted policies, advocate for industrial symbiosis, facilitate knowledge sharing, and commit to ongoing research.

Despite certain limitations in data acquisition and the use of a small system as a case study, this study shows that analyzing a subsystem's development and its potential contribution to the national TIS key processes with the lens of geographical proximity of structural components can yield important insights. Some of these insights may be overlooked with TIS analysis using key processes, particularly at a large system level, such as the EU and national TIS levels. Therefore, a key lesson for TIS analysts is to be mindful of the role and effect of the structural components' geographical proximity context conditions in TIS case studies.

Future research in the current context should emphasize a comprehensive exploration of the socio-techno-economic factors contributing to the underutilization of actors and institutional proximity within the existing subsystem structure. Furthermore, there is a pressing need to expand the scope of analysis by simultaneously examining more than two subsystems to unveil their mutual interdependencies and contributions to the broader development of the national Technological Innovation System (TIS). It is important to acknowledge that such an endeavor can substantially increase the analytical complexity and pose methodological challenges.

In addition, future studies must also consider the inclusion of comprehensive sustainability assessments, utilizing tools such as life cycle assessment and exergy analysis. Notably, this study lacks an evaluation of the sustainability dimensions of the investigated technological systems, which is a paramount parameter for the successful integration of green energy technologies (Aghbashlo et al., 2021).

Author contributions

M. Arfan. Conceptualization, Investigation; Methodology; Data curation, formal analysis, writing–original draft. Karl Hillman: Supervision; conceptualization; review & editing. All the authors have read and agreed to the published version of the manuscript.

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Data availability statement

Not applicable.

Declaration of competing interest

The authors declare no conflicts of interest.

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Appendix

Appendix Table 1
Interviewed actors (firms/organizations).

Company/organization	Description and interviewees
Pyrocell AB, Setra Group	Setra is one of the biggest wood industries in Sweden, producing around 10% of the sawn wood products in Sweden and is one of the big players in the Gävleborg region. Pyrocell, a company that is co-owned by Setra and Preem, built a plant to produce pyrolysis oil at Setra's sawmill Kastet in Gävle. Respondent: Pontus Friberg (Chairman of the Board of Pyrocell AB)
Billerudkorsnäs AB	A pulp and paper mill in Gävle produces roughly 700,000 tons of pulp per year. The main products are liquid packaging board and white top liners. The pulp is obtained chemically through the sulphate process in which black liquor, containing the lignin, is separated from the fibre. Linda Wit (Director Corporate Technology & Investment)
Iggesund, Holmen group	The pulp and paper mill in Iggesund, owned by Holmen Group. It produces around 375,000 tons of solid bleached board (SBB) each year. At the plant, CTO is extracted from the black liquor. The production of CTO at Iggesund is somewhere around 14,000–15,000 tons per year. A part of the produced CTO is sold to Kraton chemicals, earlier to Sunpine. Johan Granås (Sustainability Communications Manager) and Jonas Bergström (Service Development Manager)
Rottneros (Pulp & Packaging)	Vallvik, owned by Rottneros, is a pulp mill that produces pulp with the sulphate process. The CTO from Vallvik is of higher quality since Vallvik doesn't use any deciduous trees, which gives a lower "tall oil" quality compared with conifers. Vallvik sells a small portion of CTO to Kraton. The company has planned to construct a lignin extraction to lignin oil production facility at the mill in cooperation with RenFuel. Kasper Skuthälla (Marketing and Business Development Director)
Colabitoil	The company has a pilot plant, with a capacity of around 1500m3/year, to produce HVO at Norrsundet (40 km from Gävle) and is distributing HVO produced by Neste. The technology developed by the company is adaptable to wood biomass as raw material. The company has collaboration with OrganoFuel (research-based company situated at Sundsvall) and plans to build a production plant for biogasoline and bio-jet fuel from ethanol. Magnus Nyfjäll (VD/CEO)
Preem	The largest fuel company in Sweden, with a refining capacity of more than 18 million m^3 of crude oil a year. The company sells both fossil and renewable gasoline, diesel, and heating oils in Sweden with a nationwide service network of 570 fuel stations for private and commercial traffic. Respondent: Mattias Backmark (SVP Investor Relations & Project Financing).
Stora Enso	An international firm that develops and produces solutions based on wood and biomass for a range of industries and applications. The company has several pulp, paper, and packaging facilities in Sweden. In Gävleborg, the company has a pulp mill at Skutskär, paper mill Kvarnsveden and sawmill in Ljusne. Roxana Barbieru (Business Development Director, Regenerated Cellulose and MFC Biomaterials)
ELE Trävaru AB	The company manufactures short lengths of lumber in pine and spruce. The sawmill has a capacity of 45,000 m^3 of sawn and trimmed lumber with 16 employees. Respondents: Helena Vahlund (CEO), Maria Rylander (Managing Director)
BiodrivMitt	A network organization for companies in Gävleborg and Dalarna with an interest in sustainable business operations. In part, the organization works to ensure that policies, instruments, and regulations create the conditions for profitable commercial production and the use of sustainable fuels. Respondent: Claes Rosengren (Chairman)
F3center	F3 a Swedish Knowledge Center for Renewable Transportation Fuels is a national forum for collaboration between industry, academia, research institutes and authorities engaged in sustainable fuel production and use. Ingrid Nyström (Senior advisor)
Region Gävleborg	A public organization, where the regional council is the highest decision-making body. The organization is responsible for areas that contribute to regional development. The main areas of management and responsibility are public health and health care, infrastructure and public transport, skills and education issues, business development, international co-operation, and culture. Respondents: Anna Backlin (strategist, infrastructure, and social planning), Berit Löfgren (Head of Department of Rural Development)
Svebio (Swedish bioenergy association)	Svebio is a non-profit environmental organization for companies and individuals. It works for the development of models for the production and use of bioenergy in an economically and environmentally optimal way, nationally and internationally. Tomas Ekbom (Program director, BioDriv)

Appendix Table 2
TIS key processes (functions). The authors own description based on (Bergek, Jacobsson, Carlsson et al., 2008; Hekkert et al., 2007).

Functions	Description
F1. Resource mobilization	A process activating public and non-public actors' interest in financing technology R&D and innovative projects, complementary infrastructure development and generation of skilled labour.
F2. Market formation	The process of strengthening the factors driving market formation through regulatory change, social acceptance, investment in technology development & diffusion.
F3. Influence on the direction of search	The incentives for organizations and actors to enter the technological field. These incentives may stem from vision, expectations of growth potential, policy instruments, technical bottlenecks, etc.

(*continued on next page*)

Appendix Table 2 (*continued*)

Functions	Description
F4. Entrepreneurial experimentation	The process of knowing the types of experimental activities performed by the TIS actors and knowledge gained (e.g., testing of new raw materials, technology process, product applications, and markets).
F5. Formation of social capital	A process of network formation through the entrance of new firms, academia, and government organizations. Delivering specialized service and flow of information and knowledge spillover.
F6. Knowledge development and diffusion	The breadth and depth of the knowledge base. How was that knowledge developed, diffused, and combined in the TIS?
F7. Legitimation	The process of gaining acceptance of new knowledge, technology, and product use. Supportive regulations backed by strong drivers and motivations (i.e., climate change, sustainable energy supply, energy security) from relevant institutions.

Appendix Table 3
Number of media news articles published in selected media channels with their respective keywords. The period is January 2010–April 2021

Media Keywords	Dagens Nyheter[a]	Gefle Dagblad[b] (premium)	Arbetarbladet[c]	Bioenergi[d]	Cision Wire Sweden[e]
Biomass (Biomassa)	4	7	4	3	5
Renewable fuels (Biodrivmedel)	4	6	4	9	24
Forest-based biofuels (Skog drivmedel)		1	3	1	4
Tall-oil (Tallolja)		4	2	2	4
Sawdust (Sågspån)		12	15	9	14
Pyrolysis oil (Pyrolysolja)		3	3	5	14
Hydrogenated vegetable oil (HVO)	5	16	16	4	39

Notes to the Table.
[a] Dagens Nyheter is a daily newspaper in Sweden. It is published in Stockholm and aspires to full national and international coverage.
[b] Gefle Dagblad, GD, is a daily newspaper that covers the municipalities in Gästrikland and is available as a paper newspaper, e-newspaper, site, app, in newsletters and social media.
[c]Arbetarbladet is a daily newspaper that covers Gästrikland and Norduppland (strongest in Sandviken, Hofors, Ockelbo, and Norduppland) and is available as a paper newspaper, e-newspaper, site, app, newsletters, and social media.
[d] The magazine aims to reflect on what is happening in the field of bioenergy by examining and highlighting people, companies, and events with a focus on Sweden and the Nordic countries.
[e] It is a news portal where companies and organizations publish their news globally. The news was written and published by the respective company or organization.

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