Collaboration and Power in Sweden's Bioeconomy Innovation System

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Through innovation, sustainability transitions decide over future states of socio-technological systems. Consequently, many transitions are arenas of contestation where actors try to exert power to realize their favored transition outcome. Power in transitions remain an underdeveloped aspect in literature and not least because of demanding measurements of power. This paper contributes to this debate with a parsimonious operationalization of power through collaboration networks. Using literature-based innovation output data covering significant innovations in Sweden from 1970 - 2021, the most powerful actors in Sweden's forest-based bioeconomy innovation system are identified. While conceptually broad, the bioeconomy aims to replace economic systems based on the consumption of fossil-fuels with a more sustainable system based on biological materials, resource efficiency and circularity. Intra and inter-sectoral collaboration is frequently highlighted as a necessity for this transition, yet results show that the actor network of commercialized innovation remains highly fragmented. While diverse in their origin, the most powerful actors all possess a broad innovation portfolio with low shares of innovation activity falling within the forest-based bioeconomy. This entrenchment in current fossil-fuel regimes raises questions as to their bioeconomy transition ambitions.

1 Introduction

Sustainability transitions are a radical shifts from socio-technical systems incompatible with ecological boundaries to systems which fulfill societal functions within those boundaries (Köhler et al., 2019). Transitions are complex, marred with uncertainty, and often require that solutions are identified on normative grounds opening them up for contestation over outcomes and pathways (Wanzenböck et al., 2020). Socio-technical systems consist of different actors who produce, diffuse and use technologies (Geels, 2004; Geels & Schot, 2007). As part of socio-technical systems, policy makers, citizens, firms, innovators and other stakeholders have agency to create, reproduce and shape institutions over time (Borrás & Edler, 2014). Consequently, policy advice frequently mentions the importance of decentralized governance of transitions through facilitating diverse and creative forms of cooperation between actors

(Kuhlmann & Rip, 2018). However, this raises questions regarding the politics of governance (Avelino et al., 2016; Roberts et al., 2018) and power to decide and influence sustainability transitions (Avelino & Wittmayer, 2016).

In addition to governance, collaboration has another important task. Too strong, or too weak collaboration between actors involved in the production of technological change can cause network failures of inefficiency or lock-ins (Weber & Rohracher, 2012). Especially where sustainability transition require radical change across multiple sectors – which is typically the case (Köhler et al., 2019) – the need for collaboration is emphasized. This paper focuses on one such transition: the bioeconomy, an imagined new economy built on the sustainable use of biomass as fuel and production material instead of fossil resources (Bauer et al., 2018; Bennich et al., 2018).

By analysing 50 years of significant commercialized innovations in Sweden, this paper unpacks the network of collaborative innovation producers in the Swedish forest-bioeconomy and addresses two research questions. First, how collaborative is the innovation system which is expected to generate the technological change needed for a transition to a forest-based bioeconomy? Building on Avelino and Rotman's (2009) theoretical framework of power in transitions, collaborations are used to operationalize a measure of actor's power to answer the second research question: which innovation system actors exercise most power?

Based on data about collaborations and innovation outputs of individual firms from a unique literature-based innovation output database of Swedish innovation (Sjöö et al., 2014), I find that on average firms collaborate less within the forest-based bioeconomy than in the overall innovation system. The collaboration network in the bioeconomy is additionally heavily fragmented, forming many small clusters of isolated collaboration. The most powerful actors are some of the largest Swedish firms and research universities. Although heavily involved in collaborations within the bioeconomy, the majority of their innovation output occurs in non-bioeconomy areas.

2 Background and Theoretical Framework

This background section turns to transition studies and innovation systems as popular frameworks to analyze novel economic phenomena such as the bioeconomy, reviews previous literature on innovation networks in the bioeconomy, and introduces the theoretical framework of Avelino and Rotmans (2009, 2011) to investigate power in transitions.

2.1 Transition Studies and Innovation Systems

A transition is a radical shift in socio-technical systems (Köhler et al., 2019). The notion of socio-technical systems expands systems involved in the production of innovation to include the diffusion and usage of technologies to fulfill societal functions (Köhler et al., 2019). From the start, transition research attempted to account for the dynamics between consistency and change in socio-technical systems (Köhler et al., 2019). One of the core frameworks in transitions, the multi-level perspective (Geels et al., 2004; Geels & Schot, 2007; Smith et al., 2010), conceptualized transitions as processes involving pressures from macro level "landscape" events and new entrants into the system "niches" onto the incumbents who establish the status quo "regime" and resist change (Geels, 2014; Szabo, 2022). A second major influence, which places more weight on aspects of change rather than stability is literature on innovation systems, particularly technological innovation systems (Bergek et al., 2015; Hekkert et al., 2007; Souzanchi Kashani & Roshani, 2019). In both, interactions between diverse actors play a central role. In the innovation systems literature, networks of different actors are important system builders which enable the system to fulfill its functions (Hekkert et al., 2007; Musiolik et al., 2012). In the multi-level perspective, while regime actors are viewed to form a core alliance (Geels, 2014), interactions and relations between actors can be explicitly adversarial, as is the case when a regime is confronted with radical innovation pressure generated by niche actors (Geels, 2014; Geels & Schot, 2007). However, it is important to note that regime and niche interactions need not be hostile and can also take on collaborative forms (e.g., Yang et al., 2022).

2.2 Networks and Power in the Transition to a Bioeconomy

Networks also feature large in transition to a bioeconomy. They are expected to provide additionality in innovation inputs and outputs (Graf & Broekel, 2020), as well as behavioral additionality such as collective learning, and increased innovation output (Söderholm & Bergquist, 2012), as well as build the innovation system (Musiolik et al., 2012). In the case of Swedish pulp and paper mills collaborations between industry and governmental actors played an important role in greening production processes through stimulating knowledge and technology development (Bergquist & Söderholm, 2011), the result were more persistent improvements in the sector's environmental impact reduction than from policy compliance alone (Söderholm & Bergquist, 2012). Consequently, bioeconomy strategies frequently explicitly target collaboration initiatives (Meyer, 2017).

Behavior and network strucutre coevolve, for example through preferential attachment processes, where well connected actors gain increasingly more ties over time (Barabási & Albert, 1999). In innovation networks such processess have been explained through increased visibility and more diverse portfolios of large firms (Broekel & Hartog, 2013), and larger firms having more capacity, through more resources and more employees, to engage in collaboration (Tether, 2002), which further makes them more attractive to possible collaborators (Nooteboom et al., 2007).

While innovation collaborations in Sweden so far do not point towards strong intersectoral activities (Bauer et al., 2018; Chaminade & Bayuo, preprint), networks build trust between actors as members tend to form ties with actors they have previously collaborated with or are indirectly connected to (Bauer et al., 2018). Although the network of biorefineries analyzed by Bauer et al. (2018) was not dominated by few centrally placed actors, the discourse network in Sweden is (Holmgren et al., 2022).

These actors are strong proponents of production intensification (Fischer et al., 2020), and a resource based bioeconomy that centers on the substituion of fossil inputs in the economy with biobased ones (Bugge et al., 2016; Vivien et al., 2019). Conflicting narratives (Bauer, 2018) express contested visions of future bioeconomies with different underpinning sustainabilty assumptions (D'Amato et al., 2017; Dieken et al., 2021; Vivien et al., 2019). Research and innovation agendas, however, tend to align with goals of eco-modernization and productivity increases (Allain et al., 2022; Holmgren et al., 2022).

Actors in the Swedish bioeconomy actively use networks as ways to exercise power in the discourse, best summarized by a participant quoted Holmgren et al. (2022, p. 52) who, talking about Swedens national and regional forest programs, whose explicit aim is to provide a arena for exchange and broad dialogue on forests in a sustainable society, remarked, "It didn't become a meeting place for major issues around the role of the forest, diversity, environmental actors and so on… They simply weren't there. It was those who wanted to make new biofuels and build a lot more in wood". Fischer et al. (2020) have called this consensus creation through exclusion. Visibility and plurality come together in these instances to allow actors who already possess the ability to mobilize resources to exercise this ability as power over the innovation system and hence the transition to a bioeconomy.

2.3 Theoretical Framework to Study Power in Transitions

Transitions involve normative questions over desired outcomes and, therefore, are contested between Yet, analyzing power in transitions is more difficult than looking at the elements and actors involved in discourse. Paying more attention to power in sustainability transitions has been frequently called for and remains an underexplored phenomenon in transition studies (Köhler et al., 2019). Power is a highly contested concept in social sciences with deep divides between scholarly communities (Avelino & Rotmans, 2011).

Avelino and Rotmans (2009) adress this short coming and develop a framework that explicitly includes innovation and transformation as types of power. Their definition of power, "… the capacity of actors to mobilze resources to achieve a certain goal" (p. 550), highlights three important aspects. First, that power is an ability of actors rather than systems, second that resources must be mobilized, to, third, achieve certain goals. The ability of actors to mobilize resources, based on Parsons (1963) and Arendt (1970), is built on consensus between actors as a necessary condition for power. However, unlike Parsons (1963) and Arendt (1970), where power means concerted resource mobilization to achieve collective goals, Avelino and Rotmans (2009) allowed for actors to mobilize resources for self-interested goals.

For Avelino and Rotmans (2009) resources are persons, assets, materials as well as human, mental, monetary and natural forms of captial. Importantly, these forms of capital include factors needed for innovation, both embodied in humans as mental resources such as ideas, beliefs, concepts and information, but also embbeded in technology, such as apparatuses, infrastructures or products (Avelino & Rotmans, 2009, 2011). While resources themselves are inherently power neutral, their mobilization turns them into exercise of power. Avelino and Rotmans (2009, 2011) distinguished between five types of power exercise. Destructive power – the ability to render exisiting resources unusable – and innovative power – the ability to create or discover new resources, are distributive types of power. The exercise of these power types needs to be visible and hence involve more than one actor. The distribution of resources can be influenced through constitutive power – the establishment of institutions and structures to distribute a resource – and transformative power – redistributing existing resources as well as their subsititution with novel resources. Lastly, systemic power is defined as, "… the 'combined' capacity of actors to mobilize resources for the survival of a societal system, i.e. a particular continent, region, nation, sector, industry or business" (p. 553).

All types of power are important to achieve a transition from one system state to another. Even seemingly opposing types of power, such as innovative and destructive exercises of power, play an important role in innovation processes. At one stage, for example, the focus of actors might lay on resource mobilization towards accessing new types of resources, such as new processes or products, while at the diffusion stage, the focus might shift more towards ensuring that the innovations replace the status quo (cf. Schumpeter & Elliott, 2012).

To understand transformative change, it is of central interest to understand which actors can exercise the power to initiate, steer, and conclude a transition. To this end, Avelino (2011) introduced a horizontal typology of power relations (further elaborations in Avelino & Rotmans, 2009, 2011; Avelino & Wittmayer, 2016). Between actors A and B can exists three different power types: power over, more / less power, and different kinds of power. These power types can manfiest in three different ways: mutual dependence, one-sided dependence, independence. Table 1 summarizes the different outcomes of the combinations between power relations and manifestations.

Table 1: Typology of Power Relations (Avelino, 2011, p. 75).

Relation Type	Manifestation of Power Relations		
Power Over	**Dependence** A and B depend on each other, they have power over one another	**One-Sided Dependence** A depends on B, B has power over A	**Independence** A and B do not depend on each other, no power over the other
More / Less Power	**Cooperation** A exercises more power than B, but collective goals	**Competition** A exercises more power than B, but mutually exclusive goals	**Co-existence** A exercises more power than B, independent co-existent goals

Table 1: Typology of Power Relations (Avelino, 2011, p. 75).

Relation Type	Manifestation of Power Relations		
Different Power	**Synergy** A and B exercise enabling and mutually supporting power	**Antagonism** A and B exercise opposing powers	**Neutrality** Power exercises do not affect one another

Avelino and Rotmans (2011) cautioned not to equate actor A having more power than actor B with B being powerless compared to A. To illustrate this they use the example of a large incumbent actor, who mobilizes more resources than a small entrepreneur. While A exercises more power than B due to their ability to mobilize resources on a larger scale, B can exercise different types of power, for example, by innovating and gaining access to new types of resources.

For actors in the transition to a bioeconomy this entails important consequences. The innovation system active in the forest based bioeconomy aims to exercise transformative power to replace an incumbent system based on different types of resources, namely those centered on a fossil basis. To achieve this, the actors have to exercise innovative types of power aimed at the creation of new resources, or new ways to access exisiting resources, for some actors this includes the exercise of destructive power to convert forests into usable biomass, which leads to power contestation between actors within the forest bioeconomy innovation system. Different actor coalitions therefore exercise constitutive power to establish their desired vision of how a bioeconomy uses resources obtained from forest ecosystems. Naturally, actors employ a large number of strategies, which Avelino & Rotmans (2011) defined as methods for resource mobilization such as formalization, lobbying, networking, experimenting, protesting etc. At the same time as these negotiation processes about the nature of the future bioeconomy unfold, a successful transition away from existing socio-technical systems build on fossil resources is required regardless. Drawing once more on Arendt (1970), Avelino and Rotmans (2011) identified the importance of visibility for innovative power, as, in their words, "[a] new idea or tool is powerless if it is not visible" (p. 799). Visibility is only achieved if an action is observed by someone and hence requires plurality of actors (Avelino & Rotmans, 2011).

3 Data and Methods

Previous research into bioeconomy networks has examined discourse coalition networks (Holmgren et al., 2020), or for innovation networks, data have been collected from co-signed R&D funding applications (e.g., Bauer et al., 2017; Broekel & Bednarz, 2018; Graf & Broekel, 2020), or citation networks in bibliographies (Gould et al., 2023) or patents (e.g., Abbasiharofteh & Broekel, 2021; Barragán-Ocaña et al., 2023). While these data are wide spread, they focus on input (R&D) or throughput (articles and patents) measures of the innovation process. These measures, however, are limited in that they are either too broad capturing activities that do not result in innovation, or miss out on innovation developed without external funding, not discussed in scientific literature first or protected through other means than intellectual property rights (Kleinknecht et al., 2002; Wydra, 2020).

3.1 Collaborations in Swedish Literature-Based Innovation Output Data

A measure that can capture innovation output is the literature-based innovation output method (Kleinknecht & Reijnen, 1993; van der Panne, 2007). For Sweden, a database constructed with this method, exists: the SWINNO database. Data for the SWINNO is gathered by collecting and reading trade journal articles for mentions of innovations commercialized by, or with participation of, Swedish organizations (Kander et al., 2019; Sjöö et al., 2014). The trade journals are independent and aim to inform specialized as well as interested the interested general audience about technological developments. In the most recent release, the database contains just below 5000 innovations from 1970 to 2021. Because the source articles mention not only actors who commercialized an innovation, but also those involved in their development, a collaboration networks can be created (Chaminade & Bayuo, preprint; Taalbi, 2017). Because journal editors chose which innovations to report on, the included innovations can be viewed as signifcant technological changes instead of minor reconfigurations or improvements (Kander et al., 2019; Sjöö et al., 2014). Additionally, unlike patents producers of innovations cannot control if their innovation is discussed in one of the trade journals, leading to a high share of innovations captured that were never patented (Taalbi, 2022). This entails two benefits for the analysis of power in this paper. First, because companies cannot control if their innovation is covered or not, they cannot conceal their activities within the innovation system. Second, because of the independent nature of the trade journals, they must maintain an audience by capturing their attention. Both of these aspects ensure that new ideas or tools become visible and hence powerful as per Avelino and Rotmans (2011).

3.2 Network Construction

In a first step, I identify innovations that relate to the forest bioeconomy based on key sectors producing and using forest-related goods and services as well as keywords describing the bioeconomy value chain (Wolfslehner et al., 2016). The list of sectors and keywords is reproduced in the appendix Table 4. After removing false positives, 786 innovations are identified as originating in or being used by Sweden's forest-based bioeconomy. 122 of these innovations are the result of a collaboration between at least two actors.

I proceed to construct undirected collaboration networks, $G(N, L)$, for these innovations. A collaboration network G consists of nodes N, representing named entities and links L, representing collaborations between distinct nodes. In the network, a node refers to a unique named entity involved in at least one innovation. This means that for some statistics, such as the average number of collaborations per year, or the total number of innovating actors, nodes which did not collaborate at any point are included. Henceforth, these individual innovators are referred to as isolated nodes. Each link contains information about the year of the collaboration and a unique identifier that can be used to link the collaboration to a specific innovation. I use the collaboration time stamps to create four subperiods, two periods of growth and two periods of decline between 1970 and the last available year in the data, based on trends in the overall output of the Swedish innovation system (cf., Figure 1 f). 1970 to the first peak in 1983 characterizes a period of output growth, followed by a decline until the trough in 1990. Growth from 1991 to 2008 and new decline from 2009 onwards complete the periods.

A crucial issue when working with company data is the level of aggregation. In SWINNO, entities involved in the innovation are recorded as they are mentioned in the source. For small companies or individuals this poses no issues. However, for companies that are part of a larger corporation, locating the innovation comes with a potential measurement error. While it is possible to aggregate subsidiary companies into parent companies, not all articles mention specific susbidiaries. In these cases the innovation is recorded as originating from the parent company. Work in progress aims to link SWINNO organzations with organizational register data, to construct a multi-plex network of innovation collaboration and ownership links. A related issue emerges from the temporal span of this research. Between 1970 and 2021 some companies, universities and other organizations have changed owners, names, or both. The ongoing work of retrieving and linking data aims to also adress this limitation.

The main analysis of this paper uses a manual aggregation obtained from consolidation of name varieties, well-known name changes and aggregation into major corporate groups [1]. Similar aggregations were used by Hylmö and Taalbi (2024) and Taalbi (2023). As this data has some limitations, such as not accounting for temporary reversals of company mergers, I provide key figures and statistics for a dissaggregated specification in the appendix (Section 7).

I calculate network dynamics using python, especially using the packages networkx (Hagberg et al., 2008) and polars (Vink et al., 2024). Code for the analysis is available at github.

3.3 Operationalization of Power Measure

I use these collaboration networks to operationalize a measure for power of the same kind in transitions. While relationships, such as collaborations on innovation projects, are not power themselves, they become involved in the exercise of power. Relationships in the context of innovation collaboration, however, are also the mobilization of (another) actors resources. Avelino and Rotmans (2009, 2011) stressed that there is no inherent hierarchy to these resources. These resources include highly visible artefacts of socio-technical systems, for example, machinery, patents, or financial capital, but also less visible resources such as human capital and tacit knowledge. It is therefore not possible for actor A to know for

[1] I thank Josef Taalbi for providing the data for this aggregation.

certain which resources another actor B possesses.

The theoretical framework predicts that actors who have exercise the same type of power and share a collective goal will cooperate to achieve said goal (Table 1). Collaborating in the production of innovation, is one manner by which A can learn about and, more importantly, access the resources of B. Being able to engage in and sustain collaborations, therefore, is an exercise of power. However, an individual collaboration observed in the data cannot discern between the different relation types. Whether the collaboration occurred because the actors depended on each other, or because they mobilized different types of resources, in other words, exercised different types of power, cannot be separated without knowing the reasons for the collaboration.

Neither can a single collaboration reveal which of the involved actors mobilized more resources, thereby exercising more power. But collaboration is also costly (Tether, 2002). At the very least actors involved in a collaboration incur the opportunity cost of not collaborating with someone else. This allows to identify which actors possess more / less power within a collaboration network. The more collaborations an actor engages in, the more power they exercise. At the node level, this can be easily measured using the degree of a node. The degree of a node is the number of links connecting it to other nodes in the network. The higher the degree of a node, the more collaborations it was involved in that resulted in a commercialized innovation. It indicates how successful a node is in mobilizing resources and hence how powerful it s.

4 Results

The results first turn to the development of the entire network over time and the innovation output of the forest-based bioeconomy before turning to the structure of the bioeconomy collaboration network and the most powerful nodes therein.

4.1 Network and Output Dynamics

Table 2 contains key summary statistics for the total study period and each periodization therein. Density is a measure of the connectedness of the network, calculated as the ratio of links in the network to the maximum number of possible links. For the bioeconomy, network densitities are consistently low and the total densitiy is only 0.01. This indicates a very sparse network with few links between nodes. For the number of nodes in Table 2, isolated nodes were ommitted, meaning in total 231 nodes were involved in at least one collaboration. A total of 196 links between nodes were created. The periods of growth (1970-1983 and 1991-2008) saw more individual nodes and more collaborations the periods of output decline. This is further corroborated by the trends in Figure 1.

Table 2: Summary of Aggregated Network

Network	Nodes	Links	Average Degree	Density
1970-1983	87	64	1.47	0.02
1984-1990	52	40	1.54	0.03
1991-2008	78	65	1.67	0.02
2009-2021	35	27	1.54	0.05
Total	231	196	1.70	0.01

Figure 1 plots the development of average degree, nodes in the collaboration network and innovation output over time for the bioeconomy network and for all collaborations in the database. Isolated nodes were inlcuded in the data, to more accurately capture how network and output dynamics interact. While the overall innovation output featured two peaks (1983 and 2008), this pattern was less pronounced in the forest bioeconomy. Innovation output dropped sharply in the 1980s from a peak of 31 in 1976, to an average of 12 innovations commercialized per year between 1990 and 2015. The average degree, including isolated nodes, for the bioeconomy over the entire period was 0.50 while for the entire Swedish innovation it was 0.57. While the number of nodes in the total Swedish innovation system recovered from the decline in between 1980 and 1990 (Figure 1 d), the bioeconomy was not able to return to its previous peak of active nodes (Figure 1 a). Similarly, the while total innovation output started to recover in the 1990s (Figure 1 f), the bioeconomy did not (Figure 1 c).

4.2 Structure of the Forest Bioeconomy Innovation Network

I now turn to the structure of the forest bioeconomy innovation network. The low network density of Table 2 already suggested a sparse network. Plotting the network reveals that, in addition to being sparse, the bioeconomy was also highly fragmented across and within all periods (Figure 2). Individual components were generally small, containing at most 13 nodes. Figure 3 plots the degree distribution of the bioeconomy network. Most nodes were involved in only one collaboration, with only one additional node. One node had 8 links, while less than 10 nodes had more than 4 links.

Although collaboration within the bioeconomy is the focus of this paper, actors within the bioeconomy are also embedded within the overall innovation system in Sweden. Figure 4 plots the bioeconomy embedded in the network of all collaborations found in the database. Links representing an innovation belonging to the bioeconomy are colored green. It appears that, while some links connected to the giant component present in the total Swedish innovation network, a notable amount of dedicated bioeconomy clustered existed outside of that component. The extent to which the bioeconomy played a role in building the total innovation system is beyond the scope of this paper, but can be explored in the future.

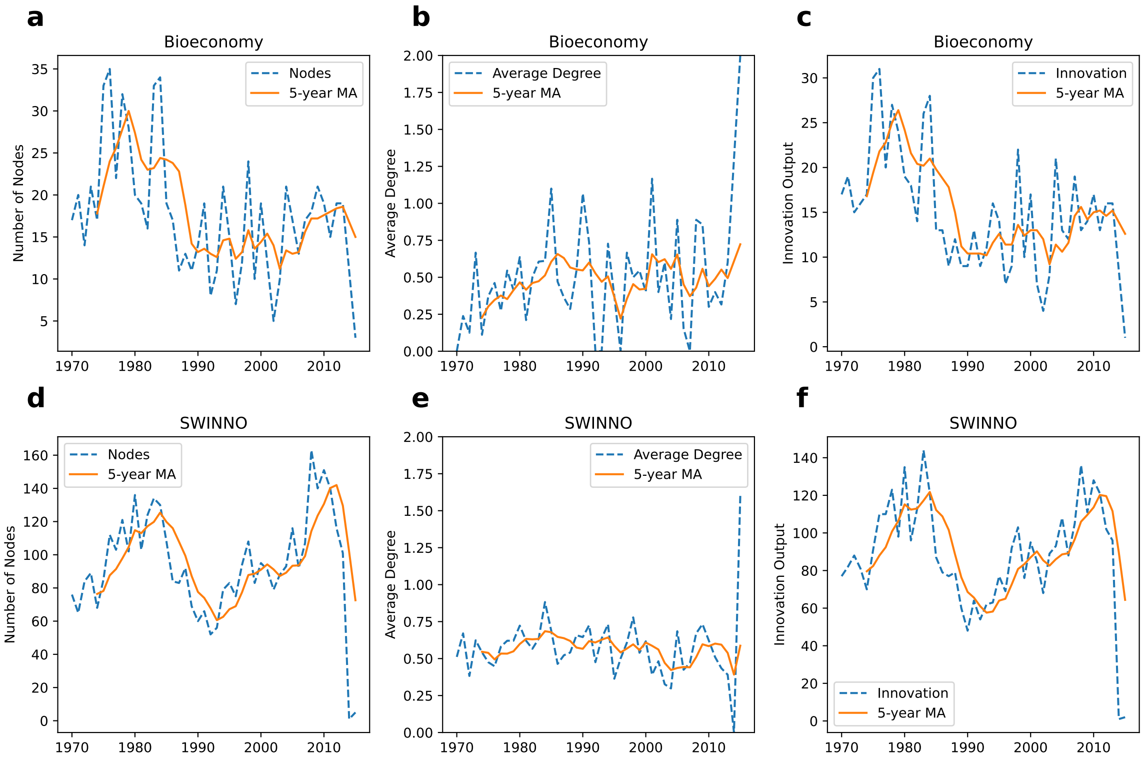

Figure 1: Plot of Nodes, Average Degree and Innovation Output Over Time for Bioeconomy Innovations and SWINNO Innovations.

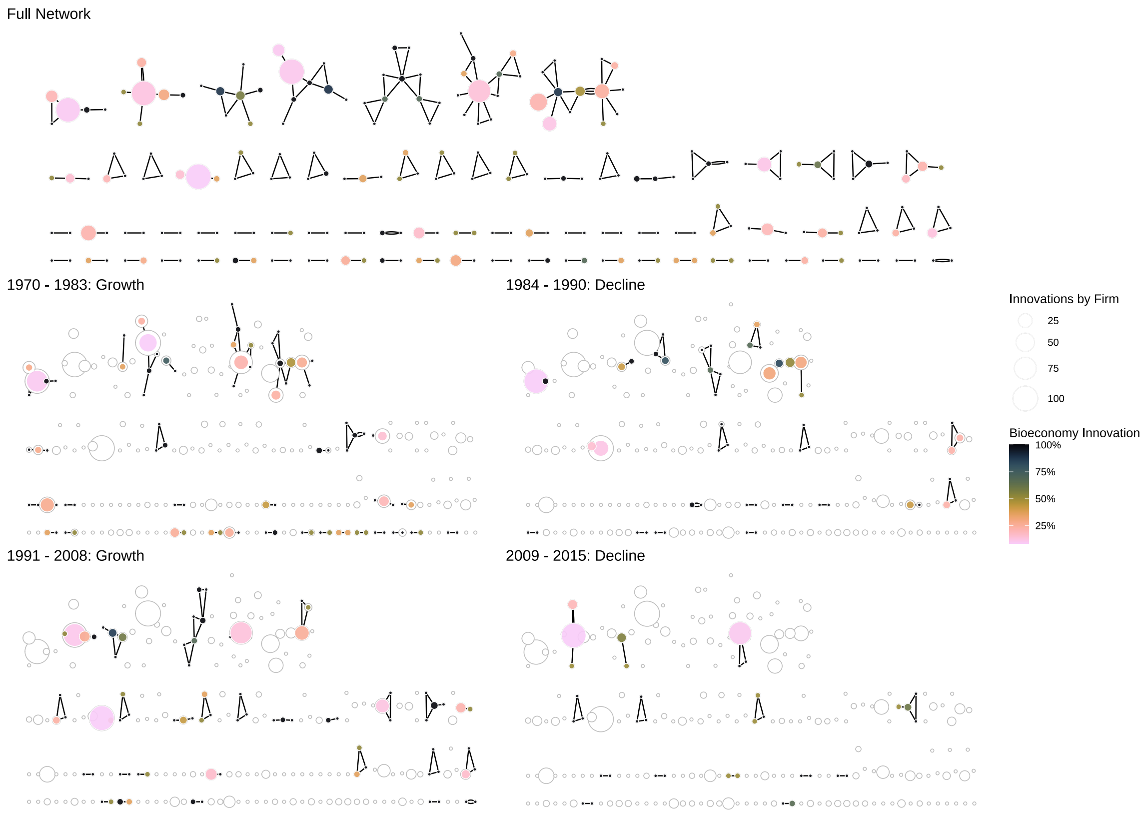

Figure 2: Network of bioeconomy collaboration over time. Gray circles indicate final network. Sizes of individual nodes correspond with cumulated total innovation until end of the depicted period. Fill color shows a company's share of innovation within the bioeconomy compared to its total innovation in SWINNO data.

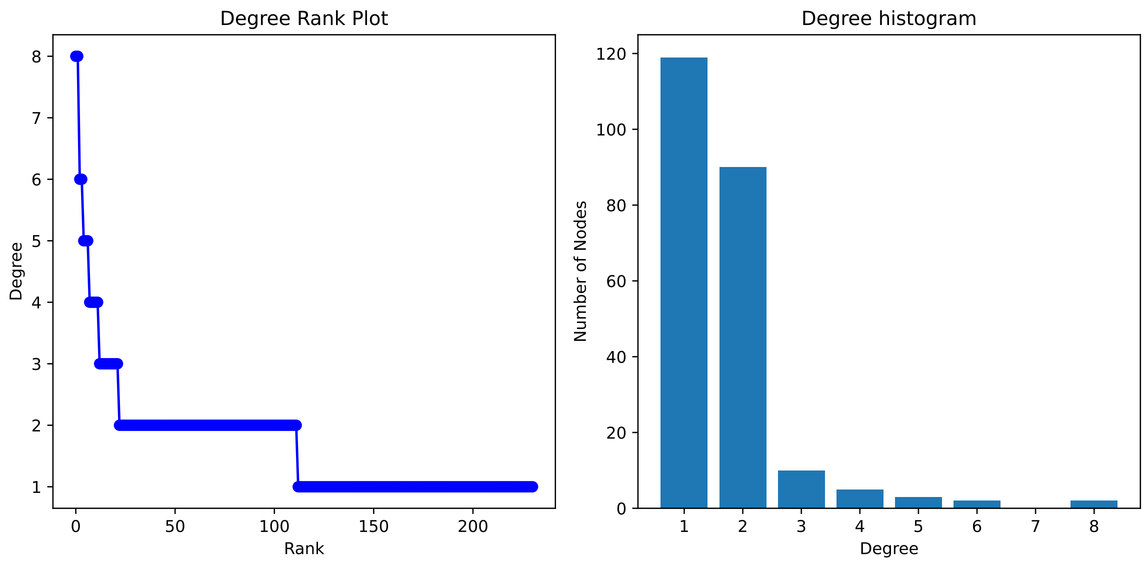

Figure 3: Degree Distribution of Bioeconomy Collaborations Over the Total Period (1970 - 2015)

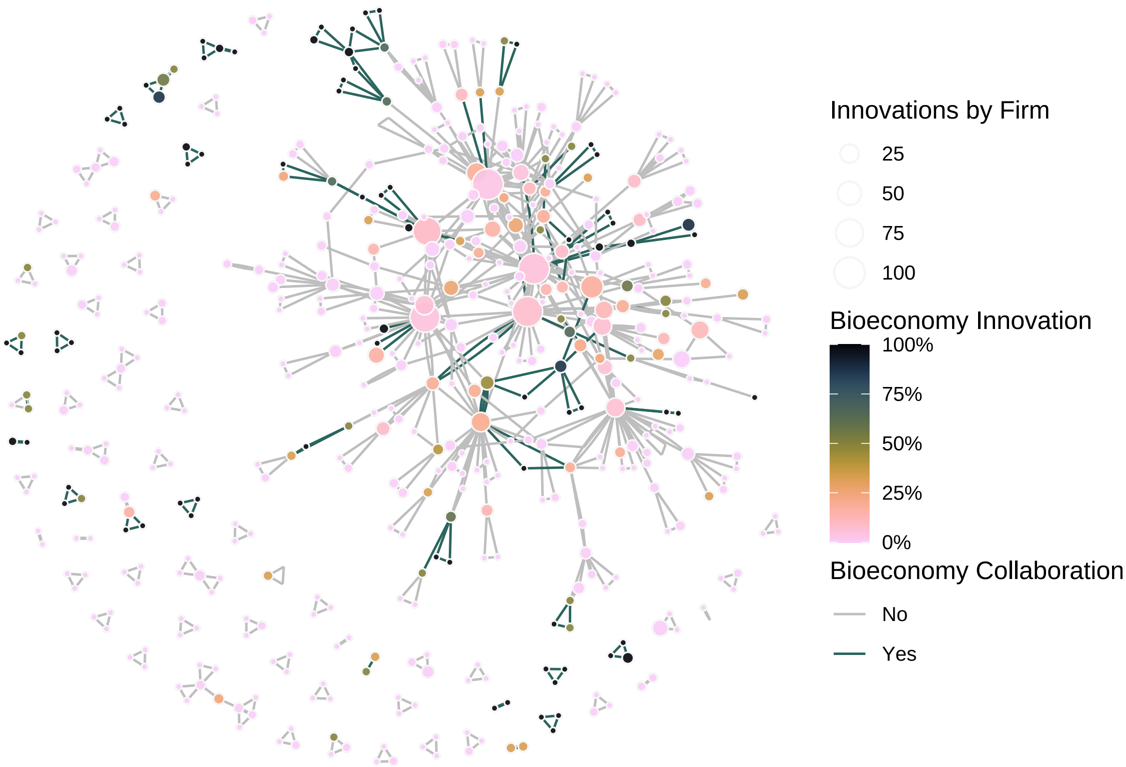

Figure 4: Network of all innovation in database. For better clarity, only nodes with more than 1 collaboration are shown. Sizes of individual nodes correspond with cumulated total innovation. Fill color shows a company's share of innovation within the bioeconomy compared to its total innovation in SWINNO data. Collaborations resulting in a bioeconomy innovation are highlighted in color.

4.2.1 Most Connected Nodes

Using the exclusively bieoconomy network, the top ten nodes based on total degree are presented in Table 3. Volvo was the most collaborative node, with a total degree of 8. It was collaborated in every period, except from 1984 to 1990. Its most active period was from 1970 to 1983 when it collaborated 5 times with other nodes. Six degrees each had Chalmers, Trätek and Sunds; none of which occurred in the last observed period. The only node that collaborated at least once in each period was EKA, a chemical producer. With Arbetarskyddsstyrelsen, Domänverket, Statens Utvecklingsfond, and Banverket, four public sector actors were among the 10 most collaborative nodes. The total share of innovations commercialized within the bioeconomy by these nodes ranged between 8% and 100%.

Table 3: The 10 Most Connected Nodes

		Degree				
		Total	1970 - 1983	1984 - 1990	1991 - 2008	2009 - Final
Node	Bioeconomy					
Volvo	10%	8	5	0	1	2
Chalmers	21%	6	3	2	2	0
Sunds	88%	6	5	1	0	0
Trätek	100%	6	0	2	4	0
EKA	56%	5	1	1	2	1
Arbetarskyddsstyrelsen	67%	4	2	2	0	0
ABB	8%	4	0	0	2	2
Domänverket	100%	4	2	2	0	0
Statens Utvecklingsfond	67%	4	0	4	0	0
Banverket	67%	4	0	0	4	0

Table 3 points to inconsinstent collaboration patterns in the bioeconomy. Figure 5 plots the cumulative bioeconomy and total innovation output for each of the top ten nodes. Companies with high shares in the bioeconomy have mostly not been active for the entire study period. The four public sector nodes were active for only a few years each. For those nodes which commercialized innovations over more years, two types of innovation experience can be identified. First, nodes such as Sunds, EKA, and Trätek, were specialized in the bioeconomy, producing few, if any, innovations outside of the bioeconomy. Others, such as Volvo, Chalmers and ABB were more diversified in their innovation activity. Apparent is the divergence between innovations within the bioeconomy and the total count of innovations commercialized by these actors.

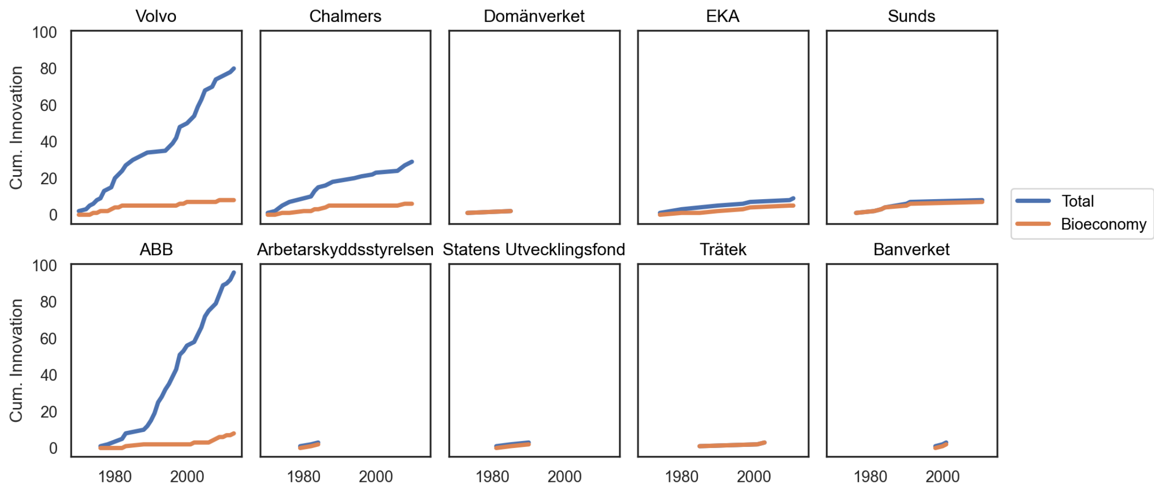

Figure 5: Innovation Experience of 10 Most Connected Actors

5 Discussion

The innovation system commercializing innovation for and in the Swedish forest bioeconomy suffers from fragmentation. Collaboration within bioeconomy system happens in separated clusters, although the some members of these clusters are well established in the national innovation system. Based on the average degree, the extent to which actors within the bioeconomy tend to collaborate does not differ from collaborations in the total innovation system. The bioeconomy is also comprised of diverse actors, including public, private and research actors. However, the number of nodes in the bioeconomy and their output have declined after a period of high activity in the 1970s and 1980s. A similar trend cannot be identified for the overall innovation system, suggesting that the decline in innovation output can be traced to a decline in innovators within the bioeconomy.

This picture is reinforced by the innovation activity of the most powerful actors. Of the ten most powerful actors, measured by their degree, are some of Sweden's largest private sector firms, namely Volvo and ABB. With Chalmers University one of Swedens largest research universities is among the most powerful actors in the innovation system underpinning the bioeconomy transition. This is not surprising as large firms are more visible as possible collaboration partners (Broekel & Hartog, 2013) and have higher capacity to maintain many collaborations (Tether, 2002). This, is firmly in line with the theoretical framework on power in transitions (Avelino & Rotmans, 2009, 2011).

Turning to the shares of bioeconomy innovation commercialized relative to the total output of these organizations reveals that they fall between 8 and 21 percent. Considering the size of these companies and the range of their activities this could be considered a substantial amount of their innovation portfolio. However, the trends in Figure 5 caution against an overly optimistic interpretation. For the largest nodes in terms of innovation output, the bioeconomy appears to play an lesser role than innovation in other areas.

In terms of the transition to a bioeconomy, this research points to the importance of incumbents of a fossil based economy in the bioeconomy innovation system. For transitions this raises further questions regarding the interplay of incumbent and niche actors. Beyond resisting change outright by influencing insitutions (Geels, 2014; Szabo, 2022), incumbents might be active contributers and collaborate among themselves and with niche actors; while at the same time focusing their innovation production efforts elsewhere. While it cannot be said that the incumbents have withdrawn from the bioeconomy over time, it appears that the bioeconomy is not at the center of their efforts to produce technological change.

5.1 Policy Implications

Some implications for innovation system policy and transition governance can be dervied from this study. First, while stimulating the formation of innovation networks remains an important task to facilitate innovation system functions, collaboration is also deeply tied to the exercise of power. For the governance of transition this implies that special attention has to be paid as to which actors to support when stimulating the formation of technology producer networks.

5.2 Limitations

However, the extent of technology producers power needs to be contextualized in two substantial ways. First, although I present a parsimonious measure of more / less power, it should not be confused as a measure of power in general. As Avelino and Rotmans (2009, 2011) deliberated in great detail, actors can exercise different types of power to shift power relations between actors (Avelino & Wittmayer, 2016).

Second, this study only examined power within the network of innovation producers. Other actors in socio-technical systems exercise power within transitions, for example, by mobilizing resources to diffuse or utilize technology. These actors are not captured by the data used here.

The data suffers from additional limitations. While sources mention if two or more actors collaborate, the data does not reveal when one acting entity is a collaborative effort itself. For example, oil companies and forest industry companies have formed Joint Ventures to explore commercial biorefinery. Innovations commercialized by such Joint Ventures are only captured as single actor efforts in the database. Additionally, it is possible for nodes to mobilize more resources in the production of innovation than anyone else within the innovation system, without collaborating. Using measures of innovation output alone does not allow to exclude this possibility.

While these actors would thus exercise more power than other technology producers, the two other conditions, visibility and plurality, are met to a lesser degree in the case of an isolated innovation effort. Second, it can likely be assumed that a company capable of mobilizing resources at this scale would collaborate in other areas, even if this occurred for economic reasons alone.

6 Conclusion

Based on the theoretical framework of Avelino and Rotmans (2009, 2011), collaborations between innovation producers can be used to measure which actors have more / less power. In Sweden, the most powerful actors are a diverse mix of private, public and research actors. However, the innovation activities of the most powerful actors point to the forest-based bioeconomy falling behind other areas in terms of innovation outputs. Despite the importance of, and political support for collaboration, the network of innovation producers in Sweden is highly fragmented and has not been able to recover from a decline in active producers in the middle of the 1980s.

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Appendix

Using producer / user codes

Table 4: Key Sectors Used in Query

SNI Code	Description
02	Forestry and related services
20	Wood and wood product manufacturing except furniture

SNI Code	Description
21	Pulp, paper and paper product manufacturing
36	Furniture manufacturing; other manufacturing

Table 5: Swedish Keywords used in Query: `WHERE description LIKE %keyword% OR ...`

Swedish	English
virke	timber
cellulos	cellulose
lignin	lignin
spån	chip
bark	bark
levulinsyra	levulinic acid
furfural	furfural
svarttjära	black tar
svartlut	black liquor
växtbas	plant-based
ved	wood
trä	timber
skog	forest
biobränsle	biofuel
biologiskt	biological
nedbrytbar	biodegradable
papper	paper
pappret	cardboard
karton	carton
lyocell	lyocell
tencel	Tencel (brand of lyocell)

7 Disaggregated Network Specification

Table 6: Summary of Aggregated Network

Network	Nodes	Links	Average Degree	Density
1970-1983	94	75	1.60	0.02
1984-1990	63	68	2.16	0.03
1991-2008	97	100	2.06	0.02
2009-2021	85	116	2.73	0.03
Total	318	359	2.26	0.01

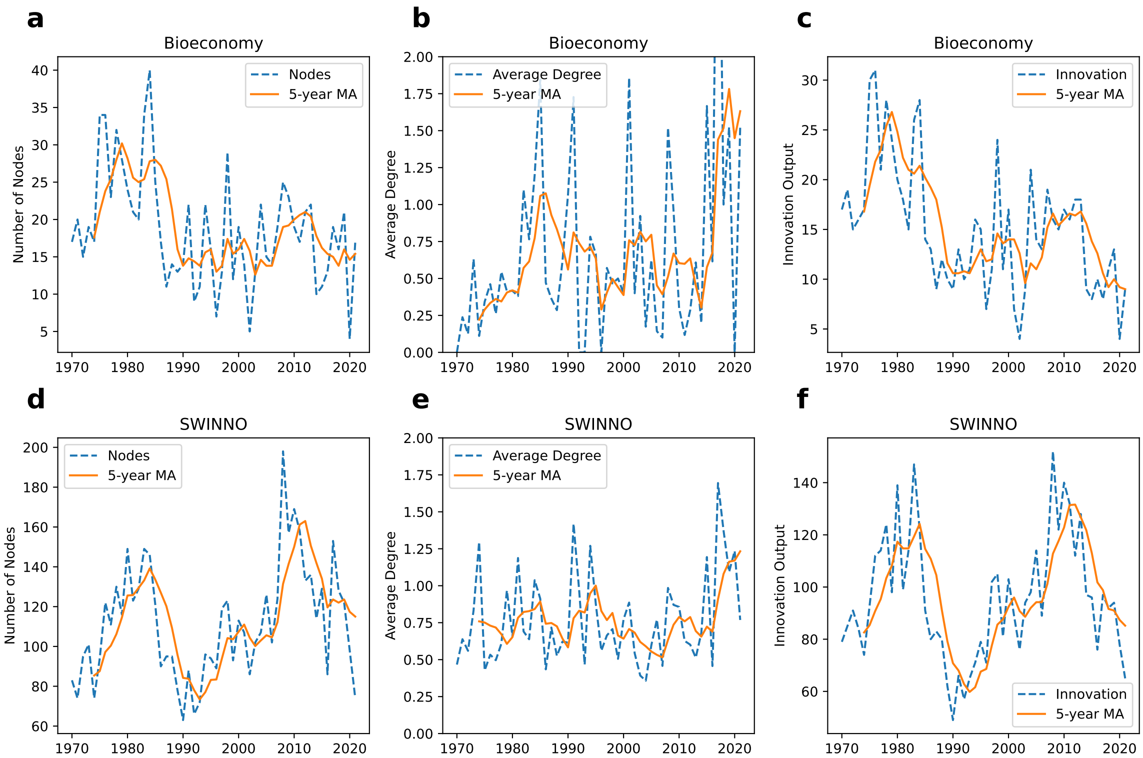

Figure 6: Plot of Nodes, Average Degree and Innovation Output Over Time for Bioeconomy Innovations and SWINNO Innovations.

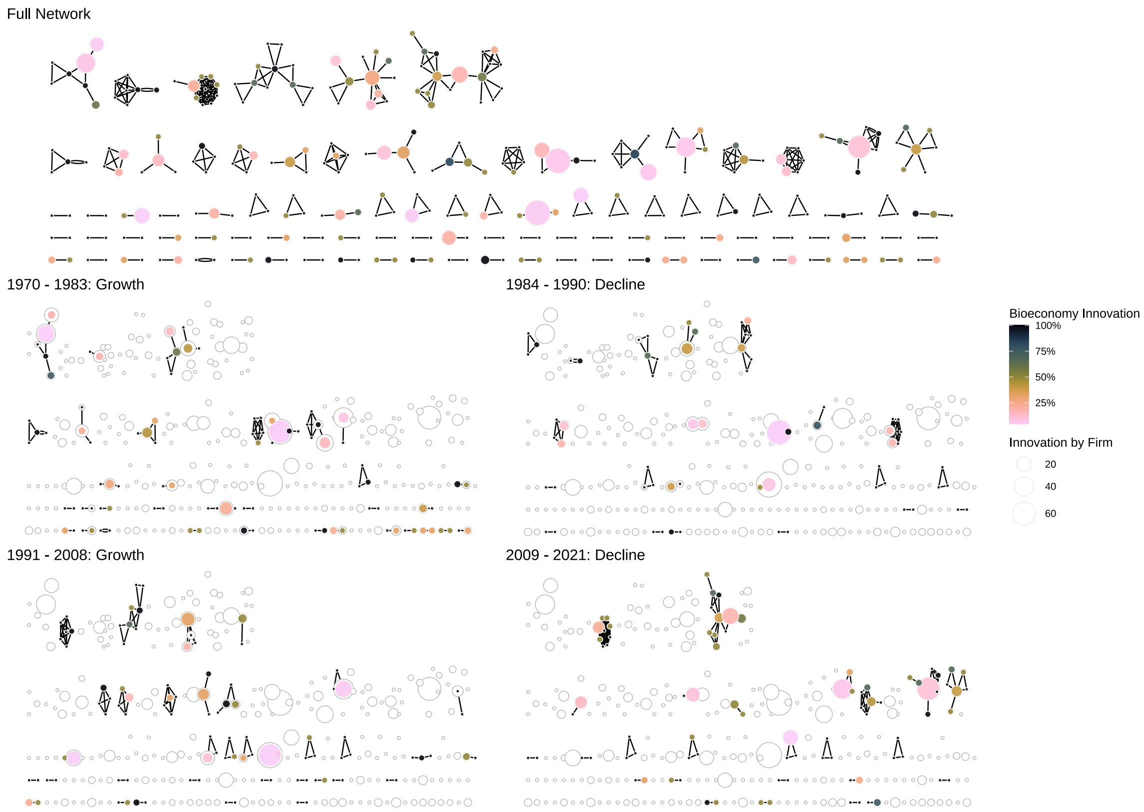

Figure 7: Network of bioeconomy collaboration over time. Gray circles indicate final network. Sizes of individual nodes correspond with cumulated total innovation until end of the depicted period. Fill color shows a company's share of innovation within the bioeconomy compared to its total innovation in SWINNO data.

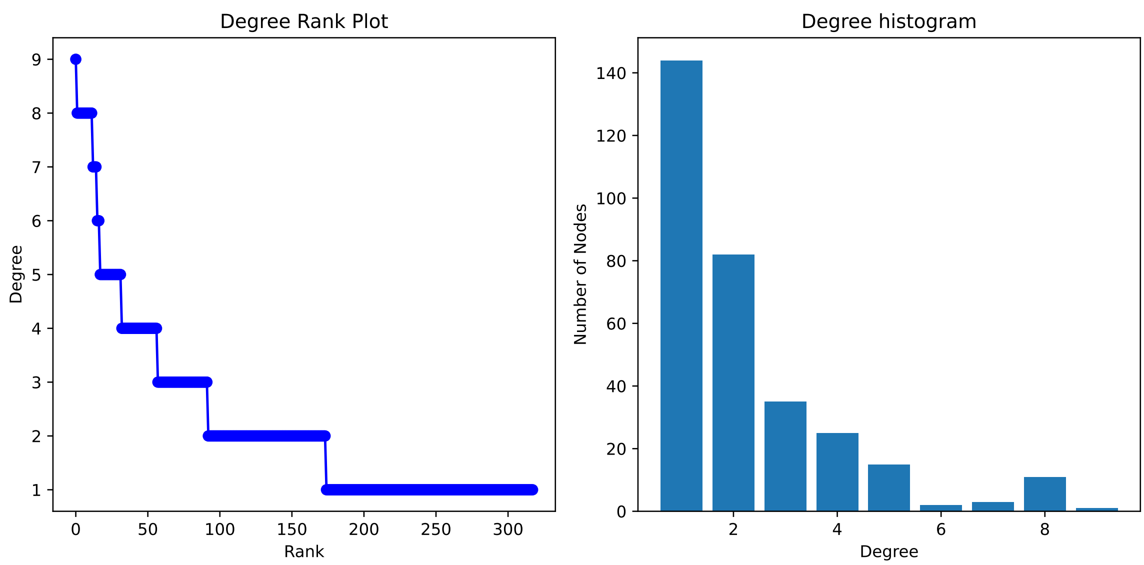

Figure 8: Degree Distribution of Bioeconomy Collaborations Over the Total Period (1970 - 2021)

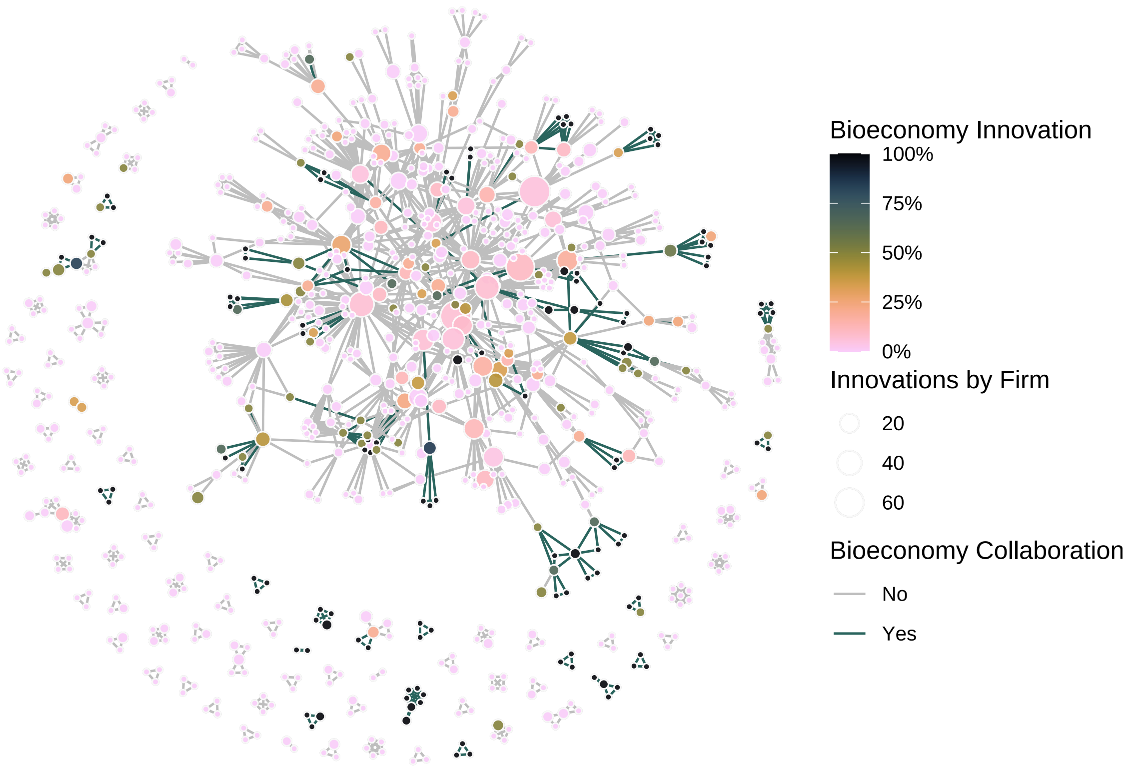

Figure 9: Network of all innovation in database. For better clarity, only nodes with more than 1 collaboration are shown. Sizes of individual nodes correspond with cumulated total innovation. Fill color shows a company's share of innovation within the bioeconomy compared to its total innovation in SWINNO data. Collaborations resulting in a bioeconomy innovation are highlighted in color.

Table 7: The 10 Most Connected Nodes

		Degree				
		Total	1970 - 1983	1984 - 1990	1991 - 2008	2009 - Final
Node	Bioeconomy					
Boliden	23%	9	1	0	0	8
Ragn-Sells	50%	8	0	0	0	8
Ecoloop	100%	8	0	0	0	8
MTC	100%	8	0	0	0	8
Processum	100%	8	0	0	0	8
Swerock	50%	8	0	0	0	8
Ramböll	100%	8	0	0	0	8
Naturvårdsverket	50%	8	0	0	0	8
SGU	50%	8	0	0	0	8
Chalmers	27%	8	3	2	3	0

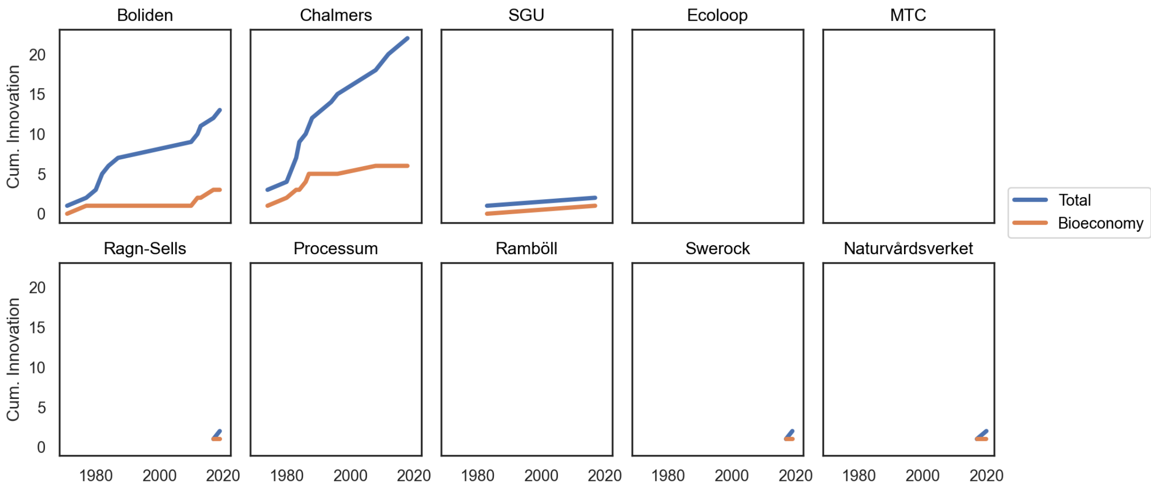

Figure 10: Innovation Experience of 10 Most Connected Actors