What Shade of Green is the Swedish Forest Bioeconomy Transition?

Measuring Directionality Through Innovation

Jonas Kreutzer

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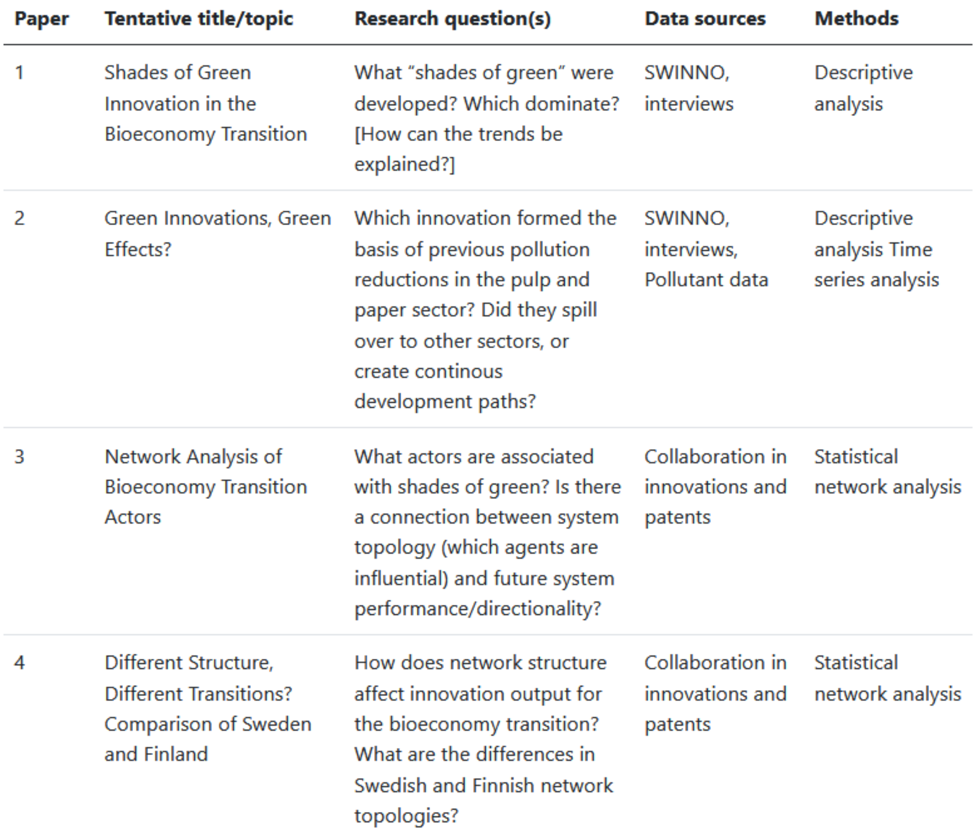
Overview



Paper	Tentative title/topic	Research question(s)	Data sources	Methods
1	Shades of Green Innovation in the Bioeconomy Transition	What “shades of green” were developed? Which dominate? [How can the trends be explained?]	SWINNO, interviews	Descriptive analysis
2	Green Innovations, Green Effects?	Which innovation formed the basis of previous pollution reductions in the pulp and paper sector? Did they spill over to other sectors, or create continous development paths?	SWINNO, interviews, Pollutant data	Descriptive analysis Time series analysis
3	Network Analysis of Bioeconomy Transition Actors	What actors are associated with shades of green? Is there a connection between system topology (which agents are influential) and future system performance/directionality?	Collaboration in innovations and patents	Statistical network analysis
4	Different Structure, Different Transitions? Comparison of Sweden and Finland	How does network structure affect innovation output for the bioeconomy transition? What are the differences in Swedish and Finnish network topologies?	Collaboration in innovations and patents	Statistical network analysis

Innovation policy has recognized that addressing the pressing social and ecological issues we are facing requires intentional and concerted action (Schot & Steinmueller, 2018). Transformative change is needed to ensure that our societies and economies provide for current and future needs without overstepping the limits of our planet. Such change requires reflection, demand-articulation, the coordination of policy and directionality (Schot & Steinmueller, 2018).

However, sustainability transitions are wicked problems lacking clear solutions. Worse, solutions often require trade-offs. A sector in which the need to balance goals becomes highly evident are those based on forests. Forests themselves represent intricate ecosystems, needed to a number of ecological disasters such as climate change, biodiversity collapse and degradation of geochemical cycles. Yet, they also provide biomass on which hopes to make other sectors more environmentally friendly hinge. An emerging bioeconomy is poised to increase the pressure and cause a trilemma between for Baltic forests (Högbom et al., 2021).

Due to their high economic, ecological, and socio-cultural value, the debate around forests and acceptable pathways for the development of related sectors (Weber & Rohracher, 2012) is extremely contested (Holmgren et al., 2022). While conflict is a necessary part of guiding the direction of a transition (Schot & Steinmueller, 2018), it makes it difficult to acquire an accurate picture of the direction in which a transformation unfolds.

Research Aim

Viewing innovation as embedded ideas (Dosi, 1982), this project aims to use a unique database of significant innovation to measure past and current directions in the transformation to a forest bioeconomy in Sweden.

Directionality is at the heart of the transformation process, yet measuring it remains elusive and thus prohibits intervention based on data rather than opinions. This PhD project will look at the direction taken by forest actors in the past, and their interactions to provide insights relevant for guiding the transformation of a sustainable bioeconomy in Sweden.

Background

Planetary Stewardship

Humanity's success in adapting to the physical environment puts this very success at risk. We have begun to alter the self-regulating cycles which have provided the stable conditions under which modern societies were able to emerge (Steffen et al., 2011). Our impact on the Earth System is so severe that it threatens to irreversibly changing the state of the Earth System (Steffen et al., 2018). The term Earth System refers to an integrated systems view of earth compromising physical, chemical, biological and human components, and their complex and dynamic interactions (Steffen et al., 2020).

Stability in the Earth System is upheld through regulating biophysical processes (Steffen et al., 2015). They indicate a safe operating space for humanity and reflect early warnings that a system state changing threshold might soon be reached (Steffen et al., 2015). Climate change, stratospheric ozone depletion, ocean acidification, atmospheric aerosol loading, land-system change, freshwater use, biochemical flows, biosphere integrity, and novel entities, these are the planetary boundaries. Since the 1950s, in a period dubbed the Great Acceleration, pressure on the planetary boundaries has increased dramatically (Steffen et al., 2011). Two of these boundaries are capable of changing earth system states by themselves: climate change and biosphere integrity (Steffen et al., 2015).

Forests Hightlight Tradeoffs Inherent in Stewardship

Ensuring that planetary boundaries are not transgressed, requires that humanity becomes the steward of our planet (Steffen et al., 2011). Stewardship must include managing Earth's systems at their various levels in a sustainable manner. Ecosystems, are functional units formed by dynamic and complex interactions between their parts (Millennium Ecosystem Assessment, 2005). Like the Earth System at large, ecosystems provide services on which every living being on this planet depends on (Millennium Ecosystem Assessment, 2005). Ecosystem services are the benefits ecosystems provide to people and are categorized into four main categories: 1. supporting services, 2. cultural services, 3. regulating services, and 4. provisional services (Millennium Ecosystem Assessment, 2005, p. 40).

Intervening in an ecosystem is often characterized by trade-offs between different services. Increased provision of wood mass, for example, might limit the extent to which a forest can regulate the water cycle (Himes et al., 2020). Additionally, trade-offs exist also between ecosystems, for example, a more intensely used plantation forest might prevent land-use intensity changes in agricultural or natural forest ecosystems (Himes et al., 2020). For Nordic forests, these trade-offs result in what Högbom et al. (2021) call a trilemma: how to balance biodiversity, climate change mitigation services and increased demand for forest biomass?

Making decisions about these trade-offs is complicated as many services lack easy measures (Millennium Ecosystem Assessment, 2005). Some services, such as the provision of materials, on the other hand are easily evaluated. With 80% of Swedish forests subjected to commercial forestry, provisional services are an important factor of the Swedish economy. Genetic and ornamental resources, biochemicals and inputs to (natural) medicines, fresh water, food, fiber and fuel had a total production value of 21.4 billion SEK (2.4 % of GNP) (Hansen & Malmaeus, 2016, p. 5). It is important to keep in mind that ease of measuring service values does automatically make these services necessarily more valuable.

New use-cases for forest biomass will increase the pressure on land covered by forests. For example, in a recent paper, Mishra et al. (2022) argue that it would be possible to house 90% of the new urban population by 2100 in wood based buildings. This would save 106 Gt of additional CO_2, but increase demand for plantation and natural forest timber. Figure 1 shows that the standing timber volume in Sweden has steadily increased since 1960. And still, meeting these goals with the available land, without compromising other ecosystem services is challenging. The economic, social and conservation demand for forests in Sweden has been estimated to be 2 to 4 times the currently available land area (Svensson, Neumann, et al., 2020). This pressure is especially pronounced in Northern Sweden where competing interests increase the pressure on forest and society (Svensson et al., 2012). Northern Sweden, along with areas in Finland and Russia, is home to Europe's last remaining intact forest landscape and high in ecological value (Svensson, Bubnicki, et al., 2020).

Bioeconomy, Bioeconomics – Different Concepts, Different Visions

An idea which is bound to increase the pressure and trade-offs between different ecosystem services is the bioeconomy. In recent years the concept has gained relevance among policymakers, practitioners and researchers. The term bioeconomy refers broadly to an economy which uses bio-based inputs instead of fossil based ones. Connected to this are hopes of increased

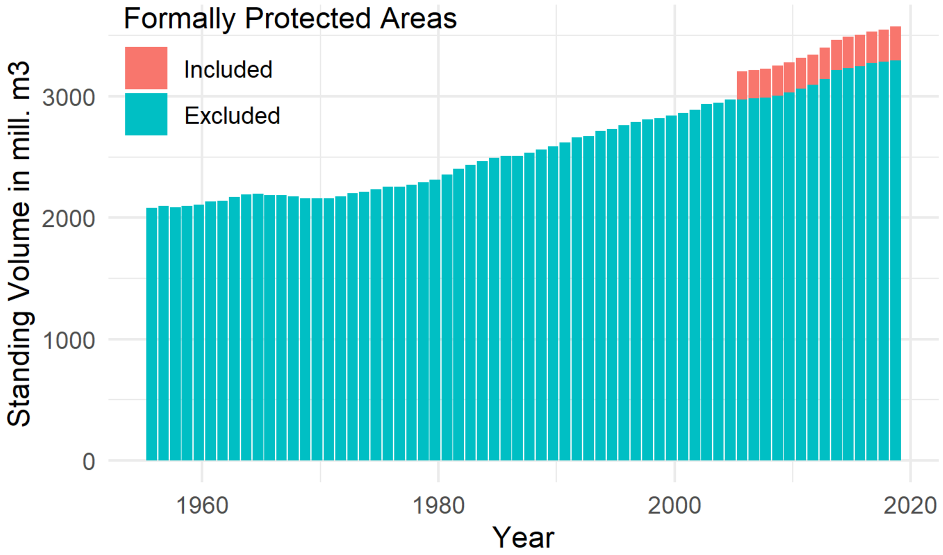


Figure 1: Standing volume of Swedish forests form 1960-2020. Data from The Swedish National Forest Inventory, Swedish University of Agricultural Sciences (2022).

resource efficiency and renewability. In a report commissioned by the Swedish Government, the *Swedish Research and Innovation Strategy for a Bio-Based Economy.* (2012) defines a vision of a Swedish bioeconomy based on two central pillars. It is to be an economy based on,

> [a] sustainable production of biomass to enable increased use within a number of different sectors of society. The objective is to reduce climate effects and the use of fossil-based raw materials.

With,

> [a]n increased added value for biomass materials, concomitant with a reduction in energy consumption and recovery of nutrients and energy as additional end products. The objective is to optimize the value and contribution of ecosystem services to the economy. (p. 9).

These pillars reflect the two most influential visions the bioeconomy concept. Notions of a bio-technology and bio-resource oriented bioeconomy are widespread and dominate discourse at various levels (Dieken et al., 2021). Despite – or perhaps because of – the bioeconomy lacking a strong definition, it is used to refer to different concepts, with different aims and objectives, foci, normative assumptions and hence implications for society and environment (Bugge et al., 2016).

The bio-technology vision focuses on economic growth and job provision through the application of bio-technology (Bugge et al., 2016). Science driven innovation features prominently in this vision, with collaborations between research institutions in academia and industry taking on an important role (Bugge et al., 2016). Vivien et al. (2019) present a review of the concept showing that the focus on science as an absolute motor of change also shaped policy recommendations, driven especially by the OECD, towards increasing the speed and diffusion of innovation through partnerships between new start-ups and establish pharmaceutical companies. As a policy narrative this vision was particularly potent and widespread at the turn of the 21st century. According to them, the intellectual heritage of Schumpeter and Kontradieff play an important role in this vision. Technological breakthroughs are poised to solve economic and ecological challenges, for example through genetic engineering. Consequently, this vision has a weak sustainability notion, viewing sustainability challenges as temporary and nature as substitutable given sufficient research and knowledge creation (Vivien et al., 2019).

In more recent years, visions of a bio-resource bioeconomy have taken over as the leading narrative. Unlike the bio-technology vision, this conceptualization does not only focus on economic growth and job creation, but attempts to include ecological sustainability challenges (Bugge et al., 2016). Biological resources, not technologies, form the basis of a new economy. In essence, there are two ways in which bio-resources are poised to replace fossil resources: as substitution, e.g., bio-fuels replacing fossil fuels, and as high value added products, e.g., Cross-laminated Timber used as a concrete alternative in construction (Vivien et al., 2019). To substitute fossil resources requires significant efforts in innovation. In contrast to the bio-technology vision, however, innovation is not confined to scientific advances from a narrow biochemical and pharmaceutical field. Instead, new and old actors are required to collaborate between and beyond established sectors (Bugge et al., 2016). Although sustainability plays a more important role in this vision of the bioeconomy, this vision is considered an example of weak sustainability (D'Amato et al., 2017; Vivien et al., 2019). The reason is the focus of substitution and high biomass demands. The consumption of raw materials may even increase, not only for bio-based, but also for fossil-based resources (Asada et al., 2020).

The exact role played by forests in a bioeconomy transition depends on the desired vision (Kleinschmit et al., 2014). There is no doubt that the Swedish vision places high demands on forests as primary providers of the required biomass. Both in the strategy formulated in

Swedish Research and Innovation Strategy for a Bio-Based Economy. (2012) and in public discourse, a small, well-connected group of actors center the bio-resource vision as legitimate and desirable (Holmgren et al., 2022). The result is a forest sector which operates under a "more of everything" paradigm (Beland Lindahl et al., 2015).

Innovation for a Bioeconomy

Apart from the substitution of fossil resources through bio-based resources, a central narrative used in the Swedish transition is that, "[t]echnological innovation is key to a greener future" (Holmgren et al., 2022, p. 42). According to Jankovský et al. (2021) four types of innovation are central for a forest based bioeconomy:

1. Substitute Products,
2. New (bio-based) Processes,
3. New (bio-based) Products,
4. New Behavior.

Currently, most research into bioeconomy innovation relies on patent data or qualitative case studies (e.g., Bennich et al., 2021; Jander & Grundmann, 2019). Unfortunately, these approaches are not without their flaws. Focusing on patents could overestimate the importance of the bio-technology vision, whose science oriented innovation approach is driven by patents (Bugge et al., 2016). Qualitative case studies, on the other hand, may miss broader trends and features of a bioeconomy transition.

The need to capture innovation from a different angle than patents becomes even more urgent when taking the third vision for a bioeconomy into account. Ecological economists refer to it as bioeconomics (Allain et al., 2022), while Bugge et al. (2016) list it as the bio-ecology vision. In contrast to the two visions already discussed, this vision prioritizes ecological sustainability over economic interests. The aim is an economy which is compatible with the biosphere (Vivien et al., 2019) and conserves ecosystems (Bugge et al., 2016). Vivien et al. (2019) argue that it is therefore incompatible with the other two bioeconomy visions. Central to this stance is the pessimism that the currently dominating bioeconomy visions are continuations of an extractive industrial regime based on false believes regarding the feasibility of substitution and decoupling (Allain et al., 2022). After reviewing the dominant bioeconomy visions and their criticisms, Allain et al. (2022) argue that the debate should take a constructive turn by considering emerging research opportunities.

Theoretical Frameworks

Studying innovations to understand the bioeconomy transition is useful for at least two reasons. First, the prominent role innovation explicitly plays in all visions of a bioeconomy. From the science grounded bio-technology to the bio-ecology vision with its social orientation, innovation is needed, in different forms and from different actors, to transform the current economic system. Second, innovation has a long tradition of being viewed as embodied ideas, making it possible to study the directionality of societal change (Dosi, 1982).

Many approaches to studying innovation exist, but for the purpose of understanding change in the forest based bioeconomy taking a systemic view of innovation helps to understand the dynamic interplay between innovation output, actors and context.

Innovation Systems

The innovation systems literature recognizes innovation as a process involving different interacting actors and institutions From there, the innovation system approach was adapted to different analytic levels. Most prominently to cover regional, technological and sectoral innovation systems (Souzanchi Kashani & Roshani, 2019). Innovation systems have been widely applied to study a range of technological transitions.

Although technological innovation systems (TIS) have been criticized as potentially ill-suited for sustainability transitions (Altenburg & Pegels, 2012), methodological advances have contributed to their sustained popularity (Markard et al., 2015). A major reason for this popularity is that they do not aim to provide a definitive theoretical framework, but rather serve as a middle range framework, which can be combined with other insights to analyze innovation systems (Köhler et al., 2019). In recent works, TIS serves more as a general background, with focus now shifting to understanding the drivers, dynamics and implications of sustainability transitions (Truffer et al., 2022).

Technological innovation systems were proposed by Carlsson & Stankiewicz (1991) with strong ties to evolutionary economics and the concept of development blocks (Dahmén, 1989). At their introduction they were defined as

> [...] a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilization of technology,

and in terms of

> knowledge/competence flows rather than flows of ordinary goods and services. They consist of dynamic knowledge and competence networks. In the presence of an entrepreneur and sufficient critical mass, such networks can be transformed into development blocks, i.e. synergistic clusters of firms and technologies within an industry or a group of industries. (Carlsson & Stankiewicz, 1991, p. 111).

Transitions Literature

Innovation systems are one of the core concepts in transition literature (Bergek, 2019). As previously stated, in the current literature, innovation systems provide a conceptual background against which questions of drivers, mechanism and direction are posed (Truffer et al., 2022).

Directionality of Transitions

Question of direction have become central in the current innovation policy frame (Schot & Steinmueller, 2018). Innovation policy 3.0 as it is sometimes referred to shifts the attention to using innovation to solve social challenges and achieve socially desirable outcomes. As such, it adds on to previous aims and theories about innovation as drivers of general growth through competition hindered by market failures (1.0), or systemic failures (2.0) (Schot & Steinmueller, 2018).

Influencing the direction of transformation change by promotion of certain innovation, is referred to as directionality (Parks, 2022). Responsibility for directionality is often located with institutions, or more specifically with institutional entrepreneurs who act as reflective change agents and create divergence from existing institutions (Grillitsch et al., 2019). But these actors are engaged and connected with local and global networks, hence directionality depends on the interaction within these networks (Grillitsch et al., 2019). To promote a direction for social change, shared visions are frequently cited as a core mechanism (Grillitsch et al., 2019), yet the wicked problem nature of social challenges makes finding the "right" solutions contested between stakeholders (Parks, 2022; Wanzenböck et al., 2020). Central questions therefore are whose, or which social interest get promoted on the ground of which expectations (Hodson & Marvin, 2010).

Negotiating these questions by opening up the innovation process to diverse stakeholders creates challenges for finding direction through consensus. This problem is pronounced in societies where consensu building provides a corner stone of the legitimization process, such as in the Swedish forestry sectory (Holmgren et al., 2022). In additon, social networks are unpredictable in their repsonse to exogenous shocks (Vespignani, 2009).

Analyzing the output of the innovation system, can give a fuller picture of direction in social transitions than looking at inputs alone.

Data

This PhD project will use data from various sources. The backbone of empirical material stems from the SWINNO database, located here at the department. Additional material will be gathered to supplement, complete and verify the database. This data will be both quantitative and qualitative sourced from interviews or field observations.

SWINNO

The central concern is of course how to measure innovation. While there is too little space to discuss different approaches, the two data gathering methods included in SWINNO need to be highlighted.

Patent data is frequently used to measure innovation. However, it is flawed in at least two regards. First, not every innovation is patented. Second, even if every innovation were patented, not all patents would be innovations. As patents are given for inventions, many might never be commercialized. In fact, companies might patent purely for strategic reasons. Nevertheless, patent data does allow to draw interesting conclusions and remains a widespread and well-established tool to measure innovation.

The core of SWINNO is formed by innovation data gathered from trade journals (Sjöö et al., 2014). Using a literature based innovation output (LBIO) method has established itself as a viable option to capture innovation. The method's key feature is that the innovation are pre-selected by journalists and journal editors and hence do not misrepresent smaller product reconfiguration as an innovation (van der Panne, 2007). 4774 innovations between 1970 and

2019 have been collected for SWINNO by reading the most relevant trade journals in Sweden, and work is constantly ongoing to expand the time period and journals covered.

In the publicly available data set, 3544 companies are reported to have produced 4774 innovations between 1970 and 2019. The average firm produced 1.35 innovations. 86.88% of firms (3079 / 3544) have only one innovation associated with them. As is to be expected with LBIO methods (van der Panne, 2007), the amount of internal process innovation is much lower than the number of process or product innovation brought to market (4595 (96.25%) to 179).

While this is a truly unique data set, allowing to measure actual innovation output, it does come with limitations. Some should be of concern for the research aim. The manner by which SWINNO is constructed, makes it biased towards *commercialized* innovation. New processes which are used internally might be crucially important for the transition to a bioeconomy (however, as soon as an internal process is commercialized, it is captured). Likewise, social innovation which changes the behavior of forest bioeconomy actors will not be recorded. Related, innovation which is system wide, as argued for under the bioecology vision are potentially not included.

To give an impression of the SWINNO database Table 1 shows an example of selected variables for four randomly chosen entries.

Table 1: SWINNO Example

SINNO ID	**Innovation Name**	**Description in Swedish**	**Year**	**Innovating Firm**
7607001		Metod för skogsrensning som eliminerar riskerna med rotvältor och träd som fastnat i spänt läge. Metoden innebär att rotstocken kapas med hjälp av en lämpligt placerad sprängladdning.	1970	Nitro Nobel AB
7609001		Tyst högtrycksdiffusor för ventilationssystem.	1970	Industrifilter AB
7610001	GL 110	Högtalare avsedd för användning i klassrum med dålig akustik.	1970	AB Philips

SINNO ID	Innovation Name	Description in Swedish	Year	Innovating Firm
7611001		Pneumatisk oljebarriär för att hindra olja från att sprida sig på vattnet. Vid katastroftillfällen kopplas ett tryckluftsaggregat till slangarna och oljebarriären sätts i funktionen.	1970	Atlas Copco AB

Although information on innovation in SWINNO is rich in detail and scope, it is not necessarily uniform as Table 1 shows. In addition to the recorded data, all underlying journal articles are linked which provides an option to gain a deeper understanding of each innovation. Additionally, SWINNO innovation have been linked to patents, allowing for complementary analysis grounded on actual innovation (Johansson et al., 2022).

Additional Data

Still, it is unlikely that SWINNO will be able to answer all questions likely to arise over the project. In those cases it will be necessary to use qualitative methods to gain a deeper understanding of sustainable innovation. For the time being the most likely qualitative methods to be applied are interviews with relevant stakeholders (e.g., research managers at firms or other organizations) and participant observation (e.g., during public-private collaboration workshops).

Additionally, while SWINNO can shed light on innovation output, it needs to be combined with additional sources to measure innovation outcomes. Informed by previous research and the planetary boundaries, the most relevant outcome variables are emissions and biodiversity harms. Potential data sources for these papers are discussed in the relevant sections.

Methods

The project is envisioned to use a diverse mix of qualitative and quantitative methods. Since it makes more sense to discuss methods attached to each individual paper in the relevant section later, the problem of how to operationalize environmental innovation and especially their reach shall be developed here. The following taxonomy of green innovation is based on a review of the relevant literature.

Eco-innovations Taxonomy

A first challenge is delineating what should be studied. Various concepts of innovation directed towards sustainability exist and have been used largely interchangeably in this text. Eco-innovation, environmental innovation, green innovation, while these all differ slightly in scope and come from different academic communities, Chaminade (2018) argue that they form an umbrella concept of sustainable innovation. She defines these innovations as

> Technological, social and institutional innovations that maintain or increase global development within the safe operating space defined by the planetary boundaries. (p. 97).

Screening for keywords related to this umbrella term, García-Granero et al. (2018) review the literature on sustainable innovation and develop a list of key performance indicators (KPI) to measure them (Table 2). These provide a good departure point to enrich SWINNO with more information than relevant innovation origins (see also Figure 2 in the Appendix), use- or source-sectors. They are, however, only a first step to identify shades of green. A mapping algorithm needs to be developed to identify which innovation type corresponds with which bioeconomy vision. Where possible the description and additional information on innovation origins will be used for classification. Should there be doubt cases, the underlying journal or linked patent might provide additional insights. Otherwise, the procedure for including innovation under uncertainty in SWINNO should serve as an inspiration: mark it as a doubt case. The validity of this will be crucial, therefore expert interviews might be a feasible option to verify a first classification this fall.

A second issue related to transition relevant innovation lies in the fact that not all such innovation will be attributable to an eco-innovation KPI. The method to clean forest floors from tree stumps in Table 1 illustrates this problem. Such an innovation clearly matters for the vision of a bioeconomy, however, it would be difficult to motivate a KPI as fitting. Therefore, it is necessary to include a broader set of innovation than those directly aimed at realizing one of the three bioeconomy visions.

Additionally, it might be useful to add categories for clear non-environmental innovation. For example, if an innovation explicitly states that an aspect of the forest ecosystem will be destroyed, it might be sensible to label it as likely harmful. An example of such an innovation is the nameless Nitrogen Nobel AB innovation in Table 1. It is clearly forestry related and needs to be considered in the project. However, it is at least questionable whether it should be called a sustainable innovation.

Two Topics, Four Papers

The project is designed as a cumulative thesis consisting of two topics with two papers each. The order of the papers or topics does not correspond to a writing timeline, but rather serve to capture two central aspects of the forest based bioeconomy system: its behavior in terms of technical and ecological outcomes, and the factors determining its behavior; the system structure and dynamics. As a PhD project is also an education, I included a box of desired learning outcomes for each paper.

Topic One: Shades of Green Innovation in the Bioeconomy Transition

The first topic concerns the outcomes of the Swedish forest bioeconomy system. The two outcomes of interest are technical (i.e., the innovations produced) and ecological (i.e., the ecological impact of its innovation).

Paper One: Shades of Green Innovation

A first step in the next weeks is to enrich SWINNO with classification of innovation into intended functions of eco-innovation (García-Granero et al., 2018) and bioeconomy visions (Allain et al., 2022). From previous research we know that the forest sector underwent significant pollution reduction over the second half of the twentieth century (Karlsson, 2012). And while innovation played a central role in this process (Bergquist & Söderholm, 2011), little is known about what “shades of green” (Kleinschmit et al., 2014) the involved innovations were. Hence the research questions for this paper: What shade of green were the innovation developed by the forest bioeconomy TIS between 1970 and 2020? Which dominate? And have there been clear trends over time, as, for example, the dominance of the bio-technology vision at the end of the 21st century would suggest?

The central data source for this paper is SWINNO with its rich information on innovation output. Qualitative data will very likely also be needed. One, to evaluate and improve the classification into shades of green. Two, to identify process, social or non-commercialized innovation deemed important by stakeholders. To identify the stakeholders and contact them, the network of this project's funding agency – VINNOVA – will be a good starting point. Additionally, expert scholars in the forest research community will be identified and contacted.

This paper might also be a valuable opportunity to establish the extent to which a bioeconomy transition has progressed in Sweden. Ronzon et al. (2022) use input-output and shift share analysis to argue that Europe has begun a transition, although at vastly different stages. Their results indicate that Sweden's bioeconomy is only in its early stages. From an innovation perspective, at least in parts, important formative work towards a bioeconomy (especially of bio-resource vision) have occurred for different aspects of the system, e.g., for biomass energy substitution in the 1980s and 1990s (Jacobsson, 2004).

Because the construction and validation of innovation classes will take some time, work on this aspect will commence this fall. By winter a first round of verification interviews should occur. Because this paper will be narrative and provide more of an overview, it is likely to benefit from insights generated in other projects. Hence, it appears logical to continue work on this paper for the duration of the PhD project.

Paper Two: Green Innovations, Green Effects?

A central concern is the actual outcome of innovation. To which extent have innovation contributed to the forestry sector reducing its environmental impact? Before the bioeconomy transition unfolds, the potential impacts of different visions can at best be estimated or simulated. However, the Swedish forestry sector has undergone substantial greening in the past decades. Especially the pulp and paper sector has become more environmentally friendly, at times reducing its emissions by up to 90% according to Bergquist & Söderholm (2015, p. 65). A core driver of reducing harmful pollution in the industry was technological change. Internal process changes, such as the use of non-chlorine chemicals for bleaching paper, drastically reduced the pollution emitted into atmosphere and water (Bergquist & Söderholm, 2018). Changes in demand, energy supply and policy regulation all contributed to a profound change in the industry (Karlsson, 2012) accompanied by public-private cooperation to innovate (Bergquist & Söderholm, 2011). The effects were not only present in the pulp and paper sector, but extended to other forest based sectors. Heating, for example, increasingly sought to find fuel from non-fossil sources due to the oil crisis and found it in biomass from small wood branches. Previously considered waste, branches and other small tree mass had now become economically feasible to transport from forests to district heating plants, which were being developed at the same time (Jacobsson, 2004).

While this paper is the currently least developed, a number of interesting research questions emerge: Which innovations were involved in greening the pulp and paper industry? Did the opening of windows of opportunity spur continued environmental innovations that eventually even spilled over to other industries? Did sets of innovation or development blocks (Dahmén, 1989) emerge which could be (re) used for the larger bioeconomy transition? Or were these innovations, as successful as they were, limited in scope and duration? Comparing the Swedish innovation output with data in the Finnish LBIO data base (SFINNO) would allow an additional, comparative perspective on these questions.

An alternative set of questions could examine tools to monitor bioeconomy transitions using innovation data from this period and sector. Jander & Grundmann (2019) develop a framework for monitoring the transition. An indicator of the share of fossil resources substituted by bio-based production ins proposed as a measure of transition. Jander et al. (2020) add patents as innovation indicators to the substitution share. However, as discussed in the data section, patent data comes with significant drawbacks when measuring innovation output. Interesting questions in this line could be: To what extent did the innovation recorded in SWINNO contribute to substituting fossil fuels already? What additional potential does already developed innovation hold for fossil input savings in the near future? Could a similar indicator be devised for other sustainability aspects such as biodiversity? This last question could depart from reducing water pollution in the pulp and paper industry.

Topic Two: System Properties

Understanding the transformation of a system would miss important aspects if it only considered observable effects. From a systems perspective, it is more important to understand the mechanisms by which the system operates (Meadows, 2009). Depending on the ultimate goal of an analysis different aspects can be conceptualized as constituting the system. For this PhD project, I propose two aspects relevant to understanding the transformation. First, the interactions of actors, expressed as networks, second the dynamics which arise from these interactions.

Paper Three: Network Analysis of Bioeconomy Transition Actors

Networks matter for innovation. Collaboration forms an important mechanism to transport and develop both explicit and tacit knowledge (Jacobsson, 2004). Because these types of knowledge have high impacts on the direction in which search for new innovation happens, they play an important role in the directionality of the innovation system (Bergek, 2019).

Previous research on SWINNO data has made use of networks and found that they tend to form in highly persistent, hierarchical structures, where main supply industries act as central hubs (Taalbi, 2020). Moreover, previous innovation ties predict future ties, making even disruptive, system driving innovation predictable (Taalbi, 2017).

Networks have also been applied to study the bioeconomy transition of the Swedish forestry sector. Holmgren et al. (2022) apply network analysis to the discourse surrounding the transition and find that few, central actors dominate the public debate. These are RISE Processum AB, The Swedish Forest Industries Federation (SFIF), RISE, The Federation of Swedish Farmers (LRF), Department of Forest Owners (LRF Skogsägarna) and BioFuel Region. RISE, RISE Processum and BioFuel Region are all organizations with public involvement. From past environmental innovation in the Swedish forestry sector, such private-public collaboration organizations are known to have contributed heavily to eco-innovation and reduction of harmful emission in the pulp and paper industry (Bergquist & Söderholm, 2011). Hence, there is nothing inherently speaking against influential cooperation organizations providing an arena for public-private exchange. However, Holmgren et al. (2022) also argue that such a hierarchy can lead heterodox opinions to be further marginalized; especially in a cultural setting in which consensus building is a central legitimization tool.

Sustainability transitions are wicked problems, without easy solutions. Potential solutions can hardly be tested and the question of what characterizes a good solution may be subject to normative rather than empirical criteria (Laatsit, 2022). Consequently, the intensity with which discourse around different visions of a bioeconomy is carried may be positive rather than negative, despite the high urgency of the issue. However, in a field where actors causing problems may also be the ones solving them (Laatsit, 2022), questions of lock-ins into a particular vision can be challenging to asses.

Using collaboration networks and innovation data from SWINNO may be a unique chance to measure (future) lock-ins of the innovation system and the directionality of the bioeconomy transition. First, a network of innovating firms will show if the same actors which stress the importance of innovation walk their talk. Second, the network topology will yield the hierarchy structure. The first central research question is if few, well connected firms dominate the forest based bioeconomy innovation system. Second, using previous innovation from SWINNO and patent data, the likelihood of future innovation can be predicted. Considering that Arranz et al. (2021) support the notion that past eco-innovations predict future eco-innovation, the following hypotheses can be tested: Does the linkage of firm A to firm B result in more eco-innovation for firm A, if firm B has previous experience with eco-innovation? And two, does this extent to the three visions for a bioeconomy? In other words, if company B has experience in innovating for the bio-resource vision, will this create a spillover effect to company A? Lastly, if the innovation system is dominated by few, well-connected hubs, in which direction does their past innovation point? If these central nodes have strong previous ties to one of the three visions, is this vision “locked-in” to the innovation system?

Paper Four: Different Structure, Different Transitions? Comparison of Sweden and Finland

Previous work has begun to investigate structural differences between the Swedish and Finnish forest related innovation systems. Preliminary results suggest that the Finnish innovation system is characterized by more collaboration between actors. But not only is the network more connected, there also seems to be a difference in innovation outcomes between the two systems.

Differences in system behaviors, such as innovation output are the result of the systems structure and the dynamics by which its parts interact (Meadows, 2009). System Dynamics refers to the feed-backs and delays which govern how system parts interact. In addition to being non-linear, they are often characterized by delays. System dynamics have been applied in innovation studies, for example, to model how a firm innovates, how an innovation system interacts, or the diffusion process of innovation (Uriona & Grobbelaar, 2019). While some authors attempt to model innovation systems using a systems dynamics approach (e.g., Walrave & Raven, 2016), these models can be opaque and rely on many assumptions. A recent advance in network science, however, has gained the interest of innovation scholars, as it may facilitate the identification of intervention points based on system structure alone (Holtz et al., 2015).

Bennich et al. (2018) analyse expert opinions to qualitatively identify the dynamics governing the transition to a biobased economy for the Swedish forestry system. One of the intervention points they identify is investment in R & D, although they caution that this intervention may cause undesired lock-ins. However, they also limit their study as exploratory in nature and hence call for research based on a different and larger data set then the few selected experts.

Barzel & Barabási (2013) show that the response of a network to small disturbances can be predicted from a small set of universal topology characteristics. They argue that this even holds when the dynamics of a system are unknown. The mechanism by which system structure influences system dynamics is the response of adjacent nodes (e.g., collaborating firms) to disturbances at other points in the network. This ties back to the previous research questions: if the Swedish system is centrally organized, i.e., few firms collaborate with many others, how does innovation for a bioeconomy unfold in the innovation system? In addition, previous work suggests that the Finnish forest bioeconomy innovation system is better connected than the Swedish system. Does this difference in structure explain differences in innovation outcome? Both in terms of quantity of innovation and in terms of directionality?

This paper will build both in methodology and time directly on the previous paper on the network structure in Sweden. Key data sources will be the SWINNO data base and the Finnish counter part SFINNO. Previous collaborations between the research teams exist and the results can inform policy in Finland and Sweden.

Appendix

Table 2: Eco-innovation classes (García-Granero et al., 2018, pp. 309–311).

Product	
101	Use new cleaner material or new input with lower environmental impact
102	Use of recycled materials
103	Reduction / optimization of raw material use
104	Component number reduction
105	Elimination of dirty components
106	Longer life cycle products
107	Recyclability of product
Process	
201	Reduce Chemical Waste
202	Reduce Use of Water
203	Reduce Use of Energy
204	Keep waste to a minimum
205	Reuse of components
206	Recycle waste, water or materials
207	Environmental-friendly technologies
208	R&D
209	Acquisition of machinery and software
210	Acquisition of patents and licenses
Organizational	
301	Green human resources
302	Pollution prevention plans
303	Environmental objectives
304	Environmental audit
305	Environmental advisory
306	Invest in research
307	Cooperation with stakeholders

Product	
308	New markets
309	New systems (remanufacturing systems and transport systems)
Marketing	
401	Returnable/reusable packaging
402	Green design packaging
403	Quality certifications

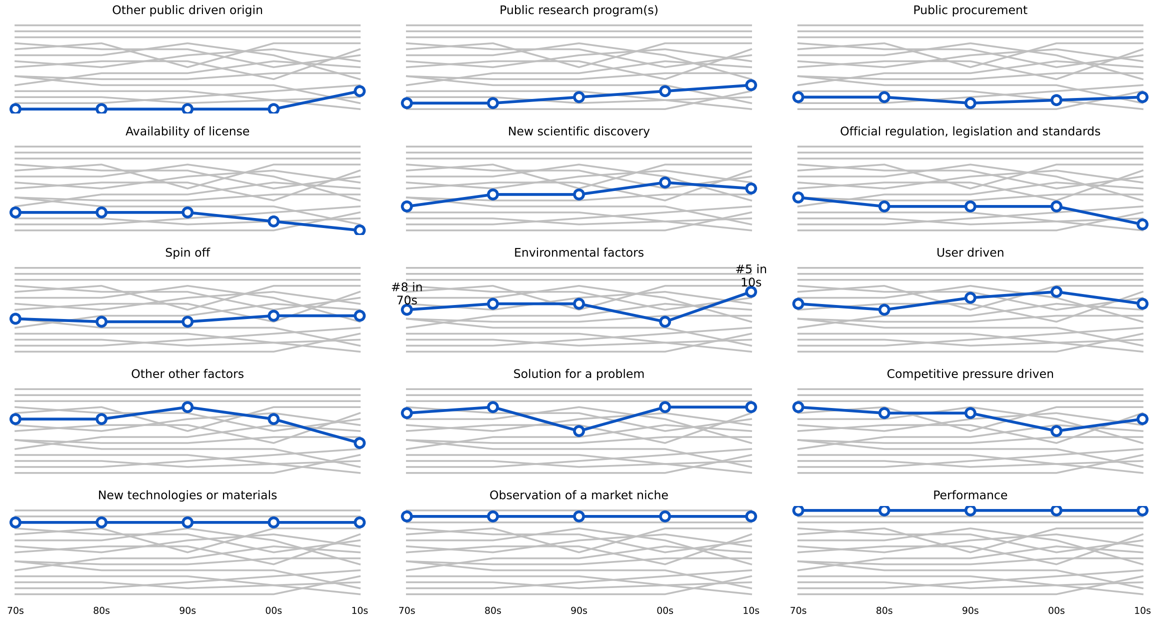


Figure 2: Reported Origins of Innovation in SWINNO by Rank

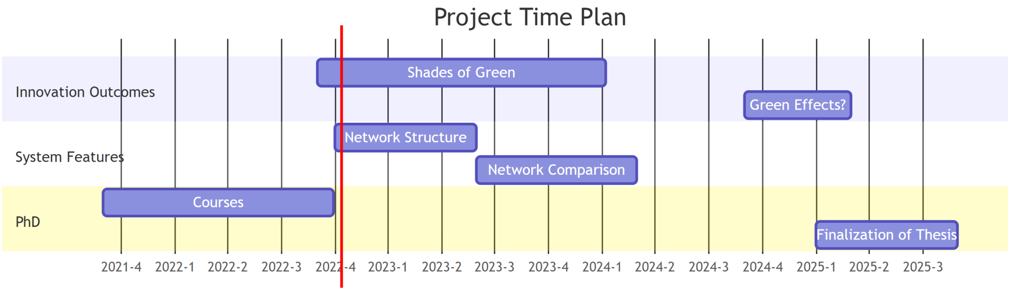


Figure 3: Indicative Time Plan for PhD Project

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