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The Bio-Based Economy: Dynamics Governing Transition Pathways in the Swedish Forestry Sector

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Abstract: A transition to a bio-based economy would entail change in coupled social–ecological systems. These systems are characterised by complexity, giving rise to potential unintended consequences and trade-offs caused by actions aiming to facilitate a transition process. Yet, many of the analyses to date have been focusing on single and predominantly technological aspects of the bio-based economy. The main contribution of our work is to the development of an integrated understanding of potential future transition pathways, with the present paper focusing specifically on terrestrial biological resources derived from the forestry sector in Sweden. Desired change processes identified include a transition to diversified forest management, a structural change in the forestry industry to enable high-value added production, and increased political support for the bio-based economy concept. Hindrances identified include the ability to demonstrate added values for end consumers of novel biomass applications, and uncertainty linked to a perceived high level of polarisation in the forestry debate. The results outline how these different processes are interrelated, allowing for the identification of high order leverage points and interventions to facilitate a transition to a bio-based economy.

Keywords: bio-based economy; bio-economy; systems analysis; causal loop diagrams; forestry

1. Introduction

The development of a bio-based economy may be understood as a transition from a society mainly dependent on fossil-based resources, to an economy built on the use of bio-based resources [1]. The growing interest in the bio-based economy, also referred to as the knowledge-based bio-economy or the bio-economy, can be explained by factors such as its proposed ability to contribute to a resource efficient, competitive, and low-carbon economy, as well as to economic activity and new employment opportunities in rural areas. The bio-based economy has also been conceptualized, similarly to other emerging concepts such as the circular economy or sharing economy, as contributing to the development of a green economy [2].

The premises of a bio-based economy lie partly in its cross-sectoral reach, and a transition would involve multiple actors and interactions across scales and societal domains. The transition process might entail changes in the way bio-based resources are managed and utilized to provide goods and services, enabled by factors such as emerging technologies, new institutions, and shifts in attitudes and values. One way to approach the concept is to employ a coupled social–ecological systems frame [3]. The social in this context refers to all human dimensions relevant to the bio-based economy, including

politics, culture, and cooperation. The ecological refers to the biosphere in which all human activity is embedded, and in the case of the bio-based economy more specifically to the dynamics governing the growth and regeneration of bio-based natural resources. Change in social–ecological systems involves complex, simultaneous processes, characterized by multiple and interacting feedbacks, non-linear dynamics, and cause and effect relationships distant in time and space [4]. This complexity gives rise to elements of uncertainty, but also to potential trade-offs and unintended consequences following interventions to facilitate change. In order to fathom the possibility of success of a transition to a bio-based economy, it is crucial to develop an integrated understanding of the seemingly independent processes governing the necessary change in its different components. However, up until now, many of the analyses have been addressing aspects of a transition process in isolation. Moreover, the debate and visions of a bio-based economy have to a large extent been informed by an engineering and technological perspective, potentially overlooking broader ecological, economic, and societal implications [5–8]. This paper seeks to contribute to the development of an integrated structural understanding of the social and ecological processes governing a transition to a bio-based economy. The following guiding research questions served as a starting point for the study:

- What are the social–ecological dynamics currently enabling or hindering a transition to a bio-based economy?
- What actions are proposed to facilitate a transition to a bio-based economy, and what pathways do they form?

In order to answer these overarching research questions, we combine systems analysis and expert interviews in the development of conceptual system maps. We depart from the proposition that such structural analysis can provide a space for learning, a basis for discussion, and a qualitative understanding of the interconnectedness of pathways towards a bio-based economy, allowing for the identification of high order leverage points for intervention. There are several tools that may help visualise how components of systems are interrelated, such as high-level system frameworks, maps of actor networks, subsystem diagrams, stock and flow maps, and policy structure diagrams [9,10]. In this study, the specific diagramming tool of Causal Loop Diagrams (CLDs) is used, with the empirical basis in the expert interviews. CLDs are made up by variables connected by arrows, representing hypotheses about causal relationships. In respect to the purpose of this study, the strength of CLDs lies partly in their ability to close sequences of causes and hypothesized effects, thereby moving from linear to feedback thinking. Aside from identifying higher order leverage points, such analysis may support the identification of unintended consequences and sources of policy resistance, the latter referring to the tendency of interventions to fail due to the response of the system triggered by the intervention itself [10,11].

The study focuses on the case of terrestrial biological resources derived from the forestry and agricultural sectors in Sweden, a country that is promoting a transition on a national scale, and where both biophysical and socio-economic preconditions are perceived as favourable [1,12]. The present paper outlines transition pathways in the forestry sector, highlighting how dynamics directly related to primary production and processing are coupled with a political dimension of the bio-based economy concept. For reasons of space, the results related to dynamics in the agricultural sector are not covered in this paper, but presented in Bennich et al., (in review). The remaining part of the paper is structured as follows: First, the research design and methodological framework are outlined. Thereafter the results in the form of CLDs are presented. These are subsequently used to explore potential transition pathways for the future. The paper ends with a concluding discussion and areas for future research.

2. Research Design and Methodological Framework

2.1. Tools for Systems Analysis: System Dynamics Modelling

The research design is based on the system dynamics modelling process [10]. System dynamics is a method that addresses the structural and endogenous cause of time-dependent system behaviour [13].

Through qualitative causal maps and formal simulation models, dynamic hypotheses about the functioning of complex systems are developed and tested. These models may then be used for policy design and testing, to support management of the systems under study. System dynamics deals explicitly with characteristics of complex systems, such as non-linear behaviour, delays, and feedback processes. The system dynamics modelling process typically consist of the following steps [10]:

- (1) Problem identification: What is the aim of the modelling process? What is the behaviour of interest? What are the key variables and concepts giving rise to the behaviour of interest?
- (2) Formulation of dynamic hypothesis: What are current theories about the behaviour of interest? What are endogenous consequences of the feedback structures in the system?
- (3) Formulation of simulation model to test the hypothesis (e.g., specification of model parameters and initial conditions).
- (4) Model testing: Does the model replicate reference data? Is the behavioural output robust? What are the results of the sensitivity analysis?
- (5) Policy design and testing: How can proposed policy options be represented in the model and what are their potential impacts? How do different policy options interact?

For the aim of this study, system dynamics was used as a stepwise method for the description of the system and for performing qualitative analysis of proposed interventions and pathways for a successful social–ecological transition to a bio-based economy. In this respect, the study did not extend to a numerical assessment of potential transition pathways, thereby excluding steps three and four and instead focusing on steps one, two, and five of the standard modelling process. The dynamic hypothesis was formulated in the form of conceptual maps, using the tool of CLDs (for further introduction to connotation and use, see Appendix A). CLDs represent causal hypotheses of system structure, and were initially used to communicate formal simulation models, or as an intermediary step between system conceptualisation and the development of a quantitative simulation model [14]. CLDs may however also be used as an analytical tool by their own means. Aside from making hypothesised system structures explicit, potential uses include structuring of problem spaces, identification of research questions, identification of areas of risk and uncertainty, and the development of shared learning and collaboration [15]. Applications of qualitative system dynamics and CLDs are found in a diverse number of areas, where examples specifically related to the sustainability field include ecological economics [16,17], environmental management and governance [18,19], community development [20], and stakeholder participation in environmental decision making [21].

2.2. Expert Interviews

Expert interviews served as the empirical basis for the CLDs. Expert interviews have long been used in research, considered an efficient way of gathering data in an exploratory phase of a research project, a means to obtain knowledge in situations where it might otherwise be difficult to gain access (e.g., where subjects are considered sensitive or taboo), or as a way to identify and reach out to a larger circle of interviewees in a specific context [22,23]. However, the purpose, form, and method for data analysis related to using expert interviews vary. Additionally, multiple perspectives on critical issues such as what constitutes an expert, how expert knowledge is distinguished from other types of knowledge, and on the different types of expert knowledge that exist, are still present in the methodological debate [24].

The main purpose of using expert interviews in this research was to gain exploratory insight into the drivers and hindrances of a transition to a bio-based economy, broadening the debate around potential development pathways for the future. Fourteen experts were selected for participation in the study (for further information about the sample, see Appendix B). The selection was based on an initial literature review and snowball sampling, informed by the approach for actor identification outlined by Lelea et al., (2014) [25]. The interviewees were chosen based on their expertise in terms of experience and knowledge from the forestry and agricultural sectors in Sweden, as well as on their ability to

represent larger actor groups of relevance to the bio-based economy. To elicit multiple perspectives on the subject, interviewees were also chosen based on their ability to represent diverse standpoints. In the snowball sample, specific questions were directed towards identifying actors and perspectives that may previously have been overlooked in the broader debate.

Semi-structured interviews were selected as means for data collection, as they are well suited to explore perceptions and views on complex issues, in a sample group with varied professional, educational, and personal backgrounds [26]. The interviews were based on a number of open-ended questions (Appendix C), aiming to elicit central variables, causal relationships, and feedback processes that the interviewees perceived as key to the bio-based economy. The questions were also aiming to support reasoning about desired as well as unintended changes following proposed interventions to facilitate a transition. The interviews were carried out in 2017 and early 2018, and took place either in Stockholm or via Skype. Each interview lasted between 60 and 120 min, and was digitally recorded and transcribed. Issues of validity and reliability in the data collection phase were addressed drawing on the process outlined by Barriball and While (1994) [26]. Specific measures undertaken include the formulation and internal testing of an interview schedule before the actual interviews took place, interviewer training, and continuous and reflexive analysis to identify and avoid any potential ambiguities, leading questions, or inappropriate use of probes throughout the interview process.

2.3. Data Analysis and Development of Dynamic Hypotheses

The process of data analysis and development of the CLDs was based on the method presented by Kim and Andersen (2012) [27]. First, for each interview transcript open coding was used to identify key variables and proposed interventions to facilitate a transition to a bio-based economy. Second, the variables were analysed for thematic content, to define relevant system boundaries. In the next step, the interview transcripts were revisited with the aim of identifying causal links between variables, expressed as causal arguments by the interviewees. Moreover, desired or unintended consequences of proposed interventions were identified, exploring their proposed impacts. The data segments were subsequently translated into CLDs, one for each interviewee.

Next, the CLDs were integrated by maintaining differences while aggregating similarities, in a process utilising elements of axial coding. In this step, as emphasised by Kim and Andersen (2012), there is a leap in conceptualisation [27]. The integrated CLDs combine structures collected from multiple interviews, and specific variable names are replaced with more generalizable terms, in order to compare and combine the diagrams. As an additional step, to ensure that the CLDs were able to represent the mental models of the interviewees, a workbook was sent out to the initial interview sample for confirmation. It contained the integrated CLDs, written descriptions, and a set of questions. The questions were probing additional feedback thinking, clarification, and missing or redundant system structure. After receiving and analysing the response to the workbook, the CLDs were revised accordingly. The final step of model development consisted of simplifying the CLDs, to increase clarity and coherence. The process was documented to allow for traceability between the data segments and model structure. Two system analysts worked in parallel on the development of the CLDs, and the results were compared and discussed to reduce researcher biases.

2.4. The Leverage Points Framework

In order to understand the potential impact of the suggested policies and proposals to facilitate a transition to a bio-based economy, we built on the leverage points framework initially developed by Meadows in 1997 [28]. Leverage points are places in a system where a small initial shift may create large-scale change, and the framework provides a basis for analysing the nature and effectiveness of interventions. Interventions targeting physical parts of a system fall at the lower end of efficiency. Such interventions may entail changing parameter values (e.g., tax rates, minimum wages, and fractions of land set aside for conservation), the size of buffers in the system as compared to the rate at which these buffers change (such as lowering or increasing an inventory), the physical arrangement of the system

(e.g., construction of infrastructure), or the length of delays in the feedback processes in the system as compared to the rate of change in the state of the system. Interventions falling at the higher end of efficiency include efforts to change the relative strength of balancing or reinforcing feedbacks (where balancing feedbacks work as control mechanisms in the system and reinforcing feedbacks amplifies system change), and the creation of new information feedbacks (as a lack of information is suggested to be a root cause of systems malfunctioning). Even higher on the scale of effectiveness are actions to change the ability to self-organise, and the overarching rules and goals of the system (acknowledging the role of power, i.e., where the ability to create and change the rules of a system resides). Lastly, the leverage points framework emphasises the role of paradigms as sources of systems, and that the ability to critically reflect on paradigms may prove one of the highest leverage points for system change [28].

3. Results

While parallel visions and understandings of the bio-based economy exist, the results provide an integrated understanding of the change processes perceived as key by the interviewed experts. The results, in the form of CLDs, are presented under the following themes: (1) The dynamics directly linked to primary production and processing in the forestry sector, and (2) The political dimension of the bio-based economy concept. The thematic separation is made for reasons of clarity, but interlinkages are indicated and further elaborated in Section 3.4. Variable names are designated by quotation marks in the text.

3.1. Dynamics Governing a Transition in Primary Production and Processing

During the interviews, key desired change processes identified were a “Shift to diversified forestry” in primary production, and a “Shift to high value-added production” in processing (variables in capital letters, Figure 1). The two processes are described in the following subsections.

3.1.1. Drivers of a Transition in Primary Production

A “Shift to diversified forestry” was identified as essential to a transition to a bio-based economy. It may be understood as a shift away from the currently dominant industrial forestry management model based on mono-cultures, volume maximization, and clear-cuts. This shift would imply change in multiple areas, such as management practices, the number of productive species, and the characteristics of the forest biomass. The larger the “Shift to diversified forestry”, the higher the “Nature values”, encompassing productive, ecological, recreational, and cultural forest values. Four reinforcing feedbacks govern the potential “Shift to diversified forestry”. The higher the “Nature values”, the more “Public engagement”, which in turn gives rise to higher “Demand for non-market values”, reflecting the use value of the forest. Different underlying factors explain this proposed relationship, such as proximity to urban areas (demand increases when proximity increases), and accessibility (demand increases with accessibility). As the “Demand for non-market values” increases, so does the “Forest owner self-confidence and motivation” to take on an active management role. The impact of changes in demand for non-market values on the forest owner’s self-confidence and motivation depends on factors such as the sense of community in the region (the higher the sense of community, the larger the considerations of public interests in forest management). With active forest management, the overall diversity of management practices increases, thereby supporting the “Shift to diversified forestry” (reinforcing feedback, R1, Figure 1).

The larger the “Shift to diversified forestry” and the higher the “Nature values”, the higher the forest owners’ “Perceived ability to provide non-market values”. Similarly, with more diversified forestry, the “Ability to meet demand for high quality biomass” increases. Successfully providing these diverse services has an important positive impact on the self-motivation and confidence of the forest owner. The higher the fulfillment of management goals, the higher the self-motivation and confidence, leading to a larger “Shift to diversified forestry” (reinforcing feedbacks, R2-3, Figure 1). This effect is further enhanced by diversified forestry contributing to higher “Soil quality”, which in the long-term supports the attainment of productivity related management goals (reinforcing feedback, R4, Figure 1).

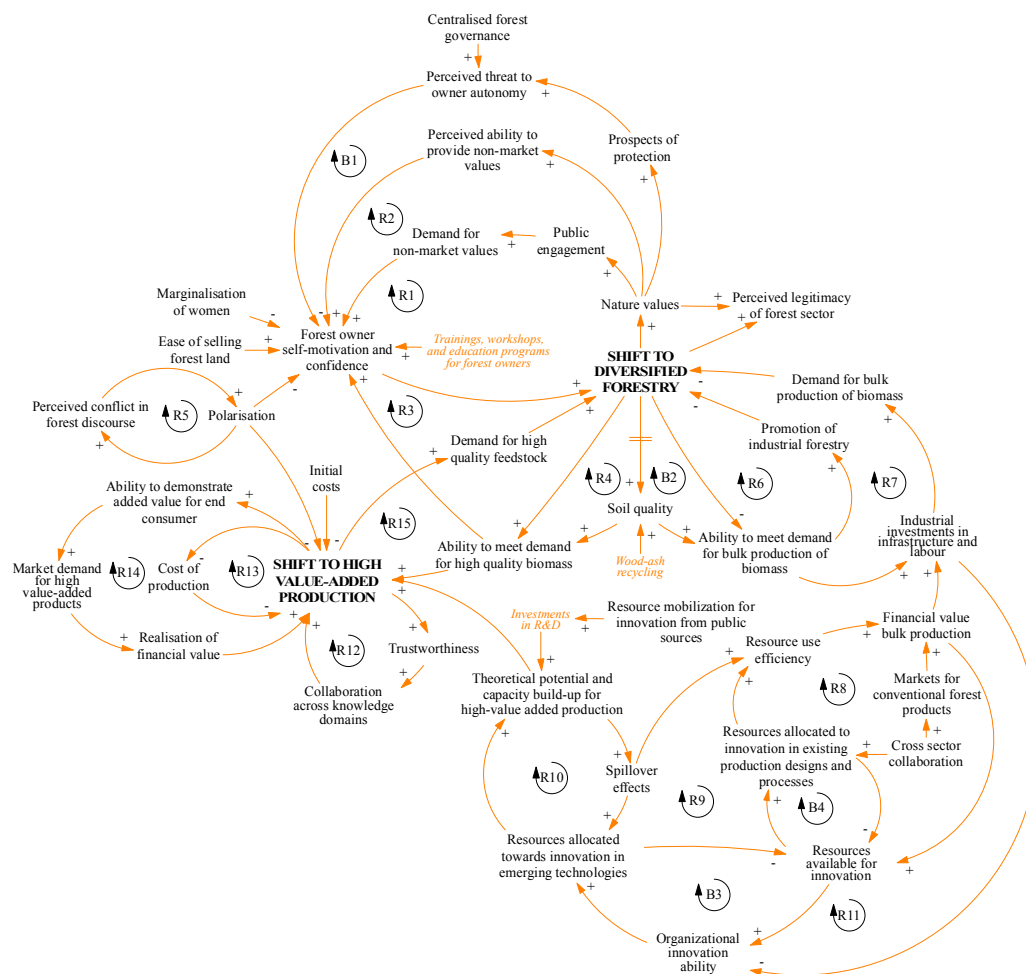


Figure 1. Feedback processes governing key elements of a transition process in the forestry sector. Capitalized variables represent desired change processes, and variables in italic denote proposed interventions. Causal Loop Diagrams (CLDs) make use of arrows to indicate causal relationships between system variables. These relationships can be either positive (represented by a plus sign) or negative (represented by a negative sign). A positive relationship implies that, if variable X is connected to variable Y, they move in the same direction (an increase in X will lead to an increase in Y, and a decrease in X will lead to a decrease in Y). A negative relationship suggests that the variables move in opposite directions (an increase in X will lead to a decrease in Y, and a decrease in X will lead to an increase in Y). Feedbacks may be either reinforcing or balancing (denoted by a R and B, respectively). For a further introduction to CLDs, see Appendix A.

3.1.2. Hindrances of a Transition in Primary Production

One balancing and one reinforcing feedback counteract the shift to diversified forestry. First, when “Nature values” increase, so do the “Prospects of protection”, that is, the prospects of conservation of land areas with high nature values. These prospects increase the “Perceived threats to owner autonomy”, causing the “Forest owner self-motivation and confidence” to decrease, thereby hampering the shift to more diversified forestry management models (balancing feedback, B1, Figure 1). Second, the discourse in the forestry sector is described as polarized. The higher the “Perceived polarization in forest discourse”, the higher the “Polarization”, and vice versa (reinforcing feedback, R5, Figure 1). Polarization erodes “Forest owner self-motivation and confidence”, through creating uncertainty regarding the relative sustainability and financial viability of different management options.

In addition, there are lock-in effects created by feedbacks linked to the current structure of the forestry industry, which have an impact on the likelihood of a shift to diversified forestry. Currently,

the “Ability to meet demand for bulk production of biomass” is high, promoting the industrial use of forests, and decreasing the “Shift to diversified forestry”. The promotion of industrial forestry can be explained by factors such as high confidence in the current model as long as it remains profitable, and actor mobilization creating a larger ability to protect industrial interests. The less forest land allocated to diversified modes of production, the larger the ability to meet demand for bulk production of biomass (reinforcing feedback, R6, Figure 1). Second, as the “Ability to meet demand for bulk production of biomass” increases, so does “Industrial investments in infrastructure and labor”. The larger these investments are, that is, the higher the production capacity of the forestry industry, the higher the demand for “Bulk production of biomass”, and the lower the “Shift to diversified forestry” (reinforcing feedback, R7, Figure 1). However, taking into account a longer time horizon, low diversity in the forestry industry can lower the “Soil quality”. This can be explained partly by the industrialized mode of production having negative environmental impacts, but also by an increasing demand for biomass leading to pressure to utilize harvest residues to a larger extent. Lower soil quality, in turns, erodes the “Ability to meet demand for bulk production of biomass”, thus weakening the ability to maintain a highly industrialized mode of forest management over time (balancing feedback, B2, Figure 1).

3.1.3. Drivers of a Transition Linked to Innovation in the Processing Stage

Two change processes have been identified as important with regards to the innovation potential of the forestry sector. First, the process of the conventional industrial production becoming more advanced and resource efficient, and second the potential shift towards high value-added production built on economies of scope rather than economies of scale.

The process of making the current industrial structure more advanced depends on the “Resources allocated to innovation in existing production designs and processes”. The more resources allocated towards these ends, the larger the “Resource use efficiency”, in turns leading to higher “Financial value of bulk production”. The “Financial value of bulk production”, that is, the profit streams from conventional production, determines the “Resources available for innovation”, further enabling resource allocation towards innovation in existing product designs and processes (reinforcing feedback, R8, Figure 1). An additional factor identified as important in this respect is the “Cross sector collaboration”. The more collaboration across sectors, the higher the innovation potential in conventional forestry production, and the larger the “Markets for conventional forest products”, thereby contributing to both the “Resources allocated to innovation in existing production designs and processes” and the “Financial value of bulk production”.

There is a choice between allocating resources towards existing production processes, or towards completely novel modes of production. The latter may be described as a new form of forestry, where biomass is utilized based on qualitative characteristics, rather than on bulk. More “Resources allocated towards innovation in emerging technologies” makes the “Theoretical potential and capacity build-up for high value-added production” increase. As long as this entails “Spillover effects”, increasing “Resource use efficiency” in conventional production processes (i.e., contributing to and being compatible with the existing industrial structure), the “Resources allocated towards innovation in emerging technologies” will increase (reinforcing feedbacks, R9-10, Figure 1). The choice of allocating resources towards emerging technologies depends on the “Organizational innovation ability”, referring to the ability of an organization to innovate when phasing pressures. The higher the “Organizational innovation ability”, the larger the tendency to allocate resources towards innovation in new areas. Counteracting such developments is a reinforcing feedback working through the “Financial value of bulk production” and “Industrial investments in infrastructure and labor”. The larger the industrial investments in existing production processes, the larger the lock-in effect, and the lower the “Organizational innovation ability” (reinforcing feedback, R11, Figure 1). The balancing feedbacks B3 and B4 (Figure 1) represent the fact that resources are limited, and that the more that is allocated either to innovation in emerging technologies or to strengthening current production processes, the less remains to spend elsewhere.

The “Shift to high value-added production” depends on the “Theoretical potential and capacity build-up for high value-added production”, as well as the “Ability to meet demand for high quality biomass” in primary production. Four feedbacks reinforce a potential transition process. As the “Shift to high value-added production” starts to unfold, the “Trustworthiness” of the actor increases, facilitating new forms of collaboration across the value chain and related knowledge domains. Collaboration strengthens innovation capabilities, and creates knowledge about new markets. It also allows for learning effects through interaction, and for validation of production processes. Thus, the “Collaboration across knowledge domains” supports the shift to high value-added production (reinforcing feedback, R12, Figure 1). Another reinforcing feedback is the cost reduction loop. As the “Shift to high value-added production” occurs, the cost of production decreases, for example through learning effects. With a lower “Cost of production”, a “Shift to high value-added production” is further supported (reinforcing feedback, R13, Figure 1). Market development has been identified as a main hindrance in the transition process towards high value-added production in the Swedish forestry sector. However, it has also been noted that it is the “Shift to high value-added production” itself that holds the potential to create new markets for these products. This development hinges on the “Ability to demonstrate added value for end consumer”. Unless these new applications of biomass are able to showcase better performance quality wise, markets are not likely to materialize. If the “Market demand for high value-added products” increases, so will the “Realization of financial value”, further supporting a “Shift towards high value-added production” (reinforcing feedback, R14, Figure 1). High initial costs, as well as “Polarization” in the forestry debate, are hindering factors in a transition process. Lastly, the larger the “Shift to high-value added production”, the greater the “Demand for high quality feedstock”, driving the “Shift to diversified forestry”. The larger the shift to diversified forestry, the higher the “Ability to meet demand for high quality biomass”, further enabling the “Shift to high value-added production” (reinforcing feedback, R15, Figure 1).

3.2. The Political Dimension of the Bio-Based Economy Concept

In addition to the dynamics linked directly to primary production and processing, a political dimension to the transition to a bio-based economy was highlighted during the interviews.

3.2.1. Key Feedbacks Governing Political Support for the Bio-Based Economy

In order for a transition process to be facilitated, “Political support for the bio-based economy” is central. Eight reinforcing feedbacks have been identified as important in this regard. The higher the political support for the bio-based economy, the higher the “Resource mobilization for innovation”. Both directly, in terms of allocation of public funding to, for instance, research programs, and indirectly by the means of reducing political uncertainty (currently perceived as high), thereby attracting resources from private funding sources. Resource mobilization for innovation enables the “Development of flagship products with high symbolic value”, which in turns increases the “Awareness among decision makers”, creating more political support for the bio-based economy (reinforcing feedback, R1, Figure 2). Flagship products with high symbolic value could also create “Public support”, ultimately increasing legitimacy and political support (reinforcing feedback, R2, Figure 2). Political support may also facilitate initiatives of other kinds, such as collaborative programs and platforms for dialogue, engaging actors from different sectors of the bio-based economy. Such programs would ensure a “Continuity of actor dialogue over time”, enabling the development of a “Shared definition and understanding of the bio-based economy”. With a shared understanding and consensus on the bio-based economy concept and its objectives, even stronger political support can be facilitated (reinforcing feedback, R3, Figure 2). Similarly, clarity on the meaning of the bio-based economy would increase “Public support”, thereby reinforcing the legitimacy of the bio-based economy and thus further make the political support increase (reinforcing feedback, R4, Figure 2). Additionally, political support could enable “Investments in green jobs and traineeship programs”, suggested as a means to create “Public support”. The underlying idea is to highlight the ability of the bio-based economy

to contribute to addressing societal challenges such as unemployment, integration, and inequality. Yet again, when “Public support” increases, so does the political support (reinforcing feedback, R5, Figure 2). Moreover, political support enables “Investments in measurement and follow-up” of developments towards a bio-based economy, increasing the “Perceived contribution of the bio-based economy to the total economy”. As the perceived importance grows, so does the political support (reinforcing feedback, R6, Figure 2). With investments in the measurement and follow-up, the ability to develop “Indicators for communication purposes” also increases, contributing to a transition process through strengthening public support for the bio-based economy (reinforcing feedback, R7, Figure 2). These indicators would for instance be designed to broaden the public understanding of the bio-based economy, so that the concept is perceived to encompass more than bio-energy, and to communicate specific environmental gains (e.g., reductions in greenhouse gas emissions following a transition). This development is further strengthened by “Investments in measurements and follow-up” from actors other than the government, enabled by the “Shared definition and understanding of a bio-based economy” (reinforcing feedback, R8, Figure 2). The relative strength of the feedbacks in Figure 2 are potentially affected by factors not part of the feedbacks themselves. One such driver is the “Novelty of bio-based economy concept”, creating a political window of opportunity which increases the “Political support for the bio-based economy”. Another example is the variable “Service-based share of the bio-based economy”, encompassing activities related to health, recreation, and tourism, having a positive impact on the “Perceived contribution of bio-based economy to total economy”. It was suggested that the potential to further develop the service-based share of the bio-based economy is relatively high, but currently overlooked in the debate.

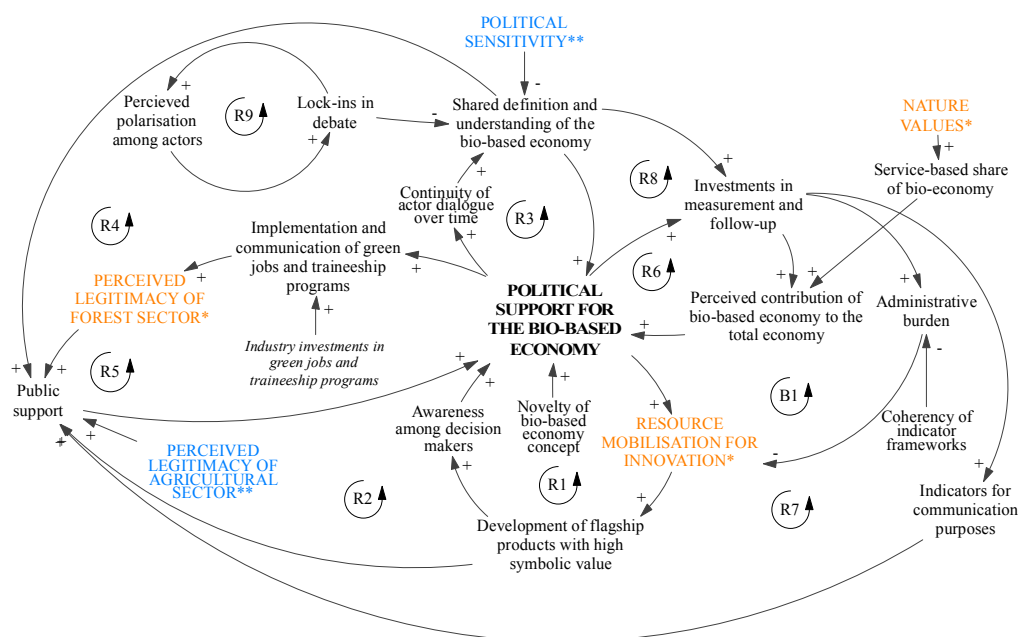


Figure 2. The political dimension of the bio-based economy concept, coupled with developments in primary production and processing. Desired change includes an increase in the political support for the bio-based economy. Variables in *italics* represent proposed interventions, and capitalized variables in orange/blue the connections between sectors. * Developments linked to forestry sector (see Figure 1). ** Developments linked to dynamics in the agricultural sector, see Bennich et al., (in review).

3.2.2. Dynamics Eroding Political Support for the Bio-Based Economy

Two feedbacks counteract the build-up of political support for the bio-based economy. The attainment of a shared understanding of the bio-based economy is hindered by a “Perceived polarization among actors”, creating “Lock-ins in the debate”. The more lock-ins, the

higher the perceived polarization (reinforcing feedback, R9, Figure 2). It was emphasized that these lock-ins make the debate evolve around details rather than the greater picture or systemic vision of the bio-based economy, that it makes it difficult find common ground to continue the dialogue, and that polarization currently constitutes a significant hindrance for the overall transition process. Another potential hindrance that may become increasingly pressing is linked to administration. Measurements and follow-up are considered important, but do also increase the “Administrative burden” on actors of the bio-based economy, thereby reducing “Resource mobilization for innovation” (balancing feedback, B1, Figure 2). The underlying assumption is that the greater the administrative burden, the more resources need to be allocated towards meeting reporting requirements, thereby reducing the willingness and ability to innovate. The higher the “Coherency of indicator frameworks” for the bio-based economy, the lower the “Administrative burden”.

3.3. Proposed Leverage Points and Interventions

Proposed interventions (variables in italic, Figures 1 and 2) target four different leverage points: The “Forest owner self-motivation and confidence”, the “Theoretical potential and capacity build-up for high value-added production”, the “Soil quality”, and the “Implementation and communication of green jobs and traineeship programs”. The specific intervention proposed to increase forest owner self-motivation and confidence is to implement “Trainings, workshops, and education programs for forest owners”, reversing a perceived decline in such activities. This would increase the ability to shift to diversified forestry, directly strengthening the reinforcing feedbacks R1, R2, R3, and R4 (Figure 1). With independent decision making, the overall ability to cope with the uncertainty created by the polarized debate is also expected to increase, weakening the effect of the reinforcing feedback R5 (Figure 1). Taken together, these developments could support the “Shift to diversified forestry”. The intervention suggested to increase the “Theoretical potential and capacity build-up for high value-added production” is to ensure “Investments in R&D”, thereby creating greater “Resource efficiency” in the current industrial structure, as well as higher potential for a “Shift to high-added value production”. The proposal to increase levels of “Wood-ash recycling” is emphasizing the need to increase nutrient circularity, in order to improve “Soil quality”.

The proposal to facilitate “Industry investments in green jobs and traineeship programs” is targeting the fourth leverage point, “Implementation and communication of green jobs and traineeship programs”. By this means, developments within the forestry sector could serve as a way to address societal challenges such as inequality, unemployment, and segregation. This would strengthen the perceived legitimacy of the forestry sector, and so contribute to the build-up of both “Public support” and “Political support for the bio-based economy” (Figure 2).

3.4. Interconnectedness

During the interviews, it was highlighted that developments in primary production are tightly coupled with a political dimension of the bio-based economy concept. For example, political developments have an impact on the access to financial capital, as the “Political support for the bio-based economy” enables “Resource mobilization for innovation”, thereby supporting “Investments in R&D” in the forestry sector. Political support, in turns, is partly dependent on perceptions among the public. The “Perceived legitimacy of the forest sector” makes the “Public support” for the bio-based economy increase. The perceived legitimacy of the forestry sector is built on the ability of the forestry sector to provide nature values (including production as well as use-values of the forest), and additionally on the level of alignment between societal values opposing industrial use of the forest and actual forest management practices. Moreover, “Nature values” constitute the basis for the “Service-based share of the bio-based economy”. The more “Nature values”, the higher the ability of the “Service-based share of the bio-based economy” to expand. The larger the “Service-based share of the bio-based economy”, the higher the “Perceived importance of bio-based share of all economy”, ultimately having a positive impact on the “Political support for the bio-based economy”.

In addition to the interconnectedness between developments in the forestry sector and the political dimension of the bio-based economy, linkages between the forestry and agricultural sector were identified. A specific example is the proposal to introduce environmental taxes as a means to support the adoption of more environmentally friendly practices in the agricultural sector (Bennich, et al., in review). While this proposal provides an opportunity to support the attainment of the objectives of a bio-based economy in the agricultural sector, it is suggested to simultaneously increase the “Prospects of loss of jobs in fossil-based sectors”, making the “Political sensitivity” of the bio-based economy concept grow, thereby reducing the ability to create a “Shared understanding and definition of the bio-based economy”, and so lowering the “Political support for the bio-based economy”. Another factor highlighted during the interviews is that the perceived legitimacy of the agricultural sector, just as the “Perceived legitimacy of the forestry sector”, has an impact on “Public support”. While the legitimacy in the forestry sector to a large extent is determined by the ability to provide nature values, the legitimacy in the agricultural sector is suggested to be based on the provision of food for human consumption (Bennich, et al., in review). The lower the adherence to the food first principle, the lower the perceived legitimacy of the agricultural sector, and the less the “Public support” for the bio-based economy. Hence, the interconnectedness of different dimensions of the bio-based economy could be seen as an opportunity, where developments within a single sector can support the broader transition process. It may however also become a hindrance, as developments perceived as undesirable in one sector might have negative spillover effects in another, thereby impeding the transition.

4. Transition Pathways towards a Bio-Based Economy

4.1. Summary of Proposed Interventions

Transition pathways towards a bio-based economy can be explored by asking “what-if” questions, departing from the CLDs and interventions proposed during the interviews. In the forestry sector, proposed interventions rank relatively high on the scale of effectiveness in accordance with the leverage points framework, as they directly target the relative strength of balancing and reinforcing feedbacks, and the goals of the system. Worth noting is that the feedbacks identified as drivers of a transition may also work in the opposite direction, moving the system away from the desired state or outcome, and that many of the proposed interventions are aiming to ensure shifts in loop dominance to avoid this. Table 1. provides a summary of suggested interventions and their desired impact, as well as examples of controversies, uncertainties and questions remaining to be explored. The summary is limited to suggestions and factors specifically brought up during the interviews.

Additional leverage points identified during the interviews include the variable “Centralisation of forest governance” (where actions to decentralise forest governance is expected to lower the perceived threat to owner autonomy, and thereby increase self-motivation among forest owners), the “Ease of selling forest land” (where efforts to keep the markets well-functioning are assumed to lead to a larger proportion of engaged forest owners), and the “Marginalisation of women” (where actions to ensure the inclusion of women would have a positive impact on overall levels of active decision making in the forestry sector). One of the proposed interventions identified and currently carried out is the “Investments in R&D”. However, it was emphasised that efforts should be redirected, from interventions targeting the theoretical potential and capacity build-up through research investments, to interventions targeting the commercialisation of novel biomass applications. No specific proposals were identified, but such a shift could supposedly entail addressing any of the variables surrounding the “Shift to high value-added production”, such as the “Market demand for high value-added production”, the “Ability to demonstrate added value for end consumer”, or the “Initial costs” (Figure 1). Another proposed leverage point, linked to the political dimension of the transition to a bio-based economy, is the “Shared definition and understanding of the bio-based economy concept” (Figure 2).

Table 1. Summary of proposed interventions in the forestry sector.

Proposed Intervention	Desired Change	Potential Unintended Consequences	Additional Leverage Points	Uncertainties and Examples of Related Questions
“What if training programs, workshops, and courses for forest owners are implemented?”	Through increasing forest owner self-motivation and confidence, the shift to diversified forestry would be supported.	As long as the linkage between nature values, prospects of protection, and the perceived threat to the autonomy of forest owners remain, the resulting balancing feedback might hinder the continued shift to diversified farming.	“Centralization of forest governance” (where decentralization is assumed to support a shift to diversified forestry) “Ease of selling forest land” (where better functioning markets are hypothesized to increase the fraction of active forest owners) “Marginalization of women” (where efforts to ensure the inclusion of women in the forest sector would make the fraction of active forest owners increase)	How to overcome the policy resistance created by the perceived conflict between centralized and decentralized forms of forest governance?
“What if industrial investments in green jobs traineeship programs were enabled?”	Investing in and communicating these activities would make the perceived legitimacy of the forestry sector increase, ultimately supporting a broader shift to a bio-based economy through a build-up of public and political support.		The “Shared definition and understanding of the bio-based economy concept” (the more developed the shared definition and understanding, the higher the public and political support for the bio-based economy)	What other measures can be taken to recognize societal values and ensure that forest management practices are aligned with these? Are negative attitudes towards mono-cultures predominant also for species other than spruce and pine (e.g., willow)?
“What if higher levels of wood-ash recycling were achieved?”	Nutrient circularity would be enhanced, preserving soil quality and thereby supporting production values in both diversified and industrial forestry.	Potential negative environmental impacts, such as an increasing presence of pollutants in the forest environment.		What factors govern the decision to increase wood-ash recycling? How to avoid potential negative environmental impacts?
“What if investments in R&D are supported?”	Theoretical potential and capacity of the forest industry are built up, in order to facilitate a shift to high-value added production.	A lock-in effect might be created and reinforced, through innovation strengthening the current industrial structure, thereby lowering the ability for structural change.	“Ability to demonstrate added value for end consumer” (the greater the ability to demonstrate added values, the higher the shift to high-value added production) “Market demand for high value-added products” (the larger the market demand, the higher the shift to high-value added production) Cost of production (the higher the cost of production, the lower the shift to high-value added production) Initial costs (the higher the upfront cost, the lower the ability to facilitate a shift to high-value added production)	How to leverage the theoretical potential of the bio-based economy through bringing novel applications to the market? What should forest biomass ideally be used for?

4.2. Synergies and Trade-Offs

As suggested by these results, there are many leverage points and resulting ways in which the forestry sector can contribute to a transition to a bio-based economy, and large potential for developing efficient and coherent bundles of proposals to facilitate change. Yet, the multiple change processes identified as desirable during the interviews result in different priorities in terms of action. Are these change processes compatible, in the sense that achieving one of the objectives of the bio-based economy supports, or at least does not hinder, the attainment of other goals? In the forestry sector, there seems to be a trade-off between diversified and industrial modes of production. Diversified forestry promotes both productive and use-values of the forest in the long-term, while industrial use promotes productive values in the short-term. However, diversified forestry hinges on the emergence of markets valuing qualitative aspects of the biomass, enabled by a shift to high value-added production in the processing stage. This shift is partly dependent on the current industrial structure, as it generates and directs capital to the build-up of theoretical potential and capacity for high-value added production. Thus, the currently dominant industrial use of forests both hinders and enables the shift to diversified forestry and high value-added production. A shift in loop dominance may facilitate an overall change in the system, but such developments might be dependent on either timing or, as suggested during the interviews, actors other than the forestry industry taking the lead in the process.

5. Conclusions and Future Research

The transition to a bio-based economy has been described as a solution to multiple societal challenges, be they social, economic, or environmental. However, change in coupled social–ecological systems entails great complexity and uncertainty, and multiple and sometimes contradictory views on the objectives and priorities of a transition still exist. Yet, until now many of the analyses have mainly been focused on isolated and, to a large extent, technological transition pathways. This paper attempts to contribute to a more systemic and integrated understanding of transition pathways for a bio-based economy, with a specific focus on the forestry sector in Sweden. Our approach combines qualitative system dynamics and expert interviews in the development of conceptual system maps, depicting the interplay of key change processes suggested to underpin a transition to a bio-based economy.

The findings make explicit the prevailing diversity in aims and priorities of the bio-based economy held by different actors in Sweden. Objectives, as expressed by the interviewees, include a shift to diversified forest management, a structural change in the forestry industry to focus on high-value added production, and the creation of stronger political support for the bio-based economy. While recognizing that objectives and priorities differ, the contribution of our study is an integrated causal theory of change towards meeting these aims. Enabling dynamics identified during the interviews include the build-up of forest owners' self-motivation and confidence to take on an active management role, and the emergence of markets for high-quality feedstock. Hindrances include a perceived uncertainty about the relative sustainability of forest management practices, and a low ability to demonstrate added values of novel biomass applications.

The results also highlight a number of leverage points and proposed interventions. Some of these interventions may have synergetic effects, as in the example of efforts directed towards achieving forest owners' active participation in management processes, which are expected to contribute to both production and environmental management goals. There are also processes that create change that could potentially inhibit the attainment of other objectives. One example might be investments in R&D, leading to a larger potential for high-value added production but also making the current structure of the forestry industry more advanced, thereby creating lock-in effects. The identification of potential lock-ins supports the possibility to redirect efforts to other points of intervention. Additionally, the results point to interventions that could result in unintended consequences and policy resistance, such as centralized decisions to promote conservational efforts without simultaneously intervening to ensure self-motivation and active decision making among forest owners. Finally, and perhaps unexpectedly, many of the proposed leverage points and interventions are addressing values, beliefs,

and attitudes, for instance related to perceptions about risk, uncertainty, and conflict, as well as to expectations about future market developments, awareness about characteristics of novel biomass applications among consumers, and the build-up of trust between actors in the bio-based economy.

The examination of transition pathways serving as a basis for this study is exploratory, and there is room to further test and discuss the propositions made. Avenues for future research may include re-examining the causalities identified, to deepen the understanding of the conditions under which they hold. The proposed system structure is also limited to the accounts made by the selected experts, and further research could entail identifying additional system structures within the boundaries of this study that for different reasons may not have been identified during the interviews. For example, it was recognised that developments in the agricultural and forestry sectors are interrelated through the political dimension of the bio-based economy concept. One way to further explore transition pathways could include identifying additional interlinkages, in primary production as well as other sectors, and how these relationships are perceived among different actors.

In terms of proposals suggested to facilitate change, next steps could entail an analysis of the feasibility of options, identifying where power and responsibilities lie, as well as the causal structure linked to the implementation phase. Moreover, the CLDs presented in this paper may be used as a basis to discuss additional proposals and their potential impacts. One example of an area that might currently be overlooked is the perceived conflict in the forest discourse and the resulting high level of polarisation. Constituting a barrier to both the shift to diversified forestry and to structural change enabling high-value added production, interventions lowering the perceived level of conflict may be crucial to facilitate a transition process. A second example might be the political dimension of the bio-based economy, where there is large potential to explore additional interventions.

Another possibility for future research lies in further capturing interactions across scales. Each variable and feedback structure presented in this paper may be disaggregated and analyzed in sub-systems, adjusted to the level of detail relevant to specific decision-making contexts of actors in the bio-based economy. An additional aspect to consider is how the dynamics identified at the regional and national scale relate to broader geographical dynamics, linking to fundamental questions of distribution of resources, fairness, market powers, and overall levels of consumption. By accounting for interactions not only between domains but also across scales, different pathways and their potential implications may be discussed in an explicit way.

Lastly, while the results highlight key feedbacks and stress that the order of intervention matter in a transition process, they do not allow for any inference about the relative strength of feedbacks, potential shifts in feedback dominance, or how the speed of change in different parts of the system affects goal attainment. We therefore foresee room for further work in the direction of quantification and simulation, allowing for rigorous inference and learning about system behaviour over time. Deliberate reflection on the use of combinations of qualitative and quantitative modelling in analysing the bio-based economy could also contribute to the discussion on how modelling tools may be used to better understand and manage sustainability transitions in a broader context.

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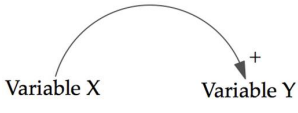
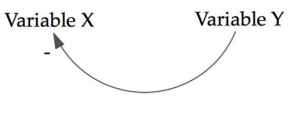
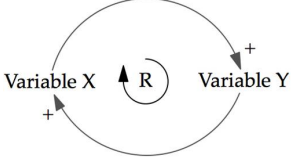
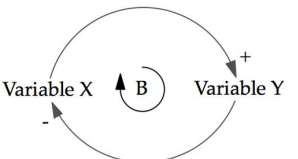
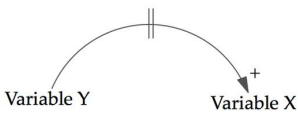
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Appendix A. An introduction to Causal Loop Diagrams (CLDs)

CLDs are graphical representations of system structure, and can be used to conceptualize a system, for communication purposes, or as an analytical tool. In the context of this research, they are used as

a medium for analyzing transition pathways to a bio-based economy in Sweden (where the present paper outlines results linked to the forestry sector, while dynamics linked to the agricultural sector are presented in Bennich, et al., in review). CLDs display key variables and their interactions through causal relationships and feedback loops. Each link included in the diagrams represent a hypothesis about the causal structure of the system under study. In our work, the CLDs are based on causal relationships elicited from expert interviews. Table A1 provides an overview of the CLD connotation.

Table A1. An introduction to the use of CLDs.

Graphical Representation:	Denotes:	Interpretation:
	The link represents a causal relationship between variable X and variable Y. The (+) suggests that the relationship is positive.	If X goes up (down), then Y will go up (down). If there is a change in X, then Y will change in the same direction. The relationship is one-directional, a change in Y has no effect on X.
	The link represents a causal relationship between variable Y and variable X. The (-) suggests that the relationship is negative.	If Y goes up (down), then X will go down (up). If there is a change in Y, then X will change in the opposite direction. The relationship is one-directional, a change in X has no effect on Y.
	The figure displays a reinforcing feedback loop.	A feedback loop is reinforcing if there are no (-) signs, or if the number of (-) signs is even. This type of feedback reinforces an initial change in the system, and is a source of growth, erosion, and collapse.
	The figure displays a balancing feedback loop.	A feedback loop is balancing if the number of (-) signs is odd. If a variable in a balancing loop changes, the feedback effect opposes and may reverse the initial change. Balancing feedback loops are self-correcting.
	The mark on the arrow indicates a delay in the system.	This mark denotes that the causal effect of a change in variable Y on variable X is significantly delayed in time. It is not the usual convention to make delays explicit in CLDs, unless they are significant in relation to other causalities in the CLD.

Appendix B. Overview of the Area Expertise, Current Position, and Educational Background of Interviewees

Interviewee No.	Specific Area of Expertise	Current Position	Educational Background
1.	Climate change, air pollution, and agriculture	Advisor at non-governmental organisation	Environmental Engineering
2.	Energy, climate change, and the bio-based economy	Expert and policy advisor, working at interest and business organisation representing the green industries in Sweden	Economics
3.	Business development, policy design, and the bio-based economy	Senior adviser at the Ministry of Enterprise and Innovation	Biology
4.	Gender equality in the forest sector, forest management models among private forest owners	Committee member, Forest owner association	Economics
5.	Sustainable food systems, policy making in the agricultural sector	Research coordinator and consultant for municipalities	Agronomy

Interviewee No.	Specific Area of Expertise	Current Position	Educational Background
6.	Business development in the green industries, sustainable agricultural production systems	Head of corporate social responsibility at agricultural cooperative	Environmental Science
7.	The bio-based economy and policy development at the EU level	International coordinator, The Swedish Forest Agency	Environmental communication
8.	Sustainable agriculture, environmental communication	Associate professor, Örebro University, Sweden	Sustainability Science
9.	The bio-based economy, innovation in the forest industry	Consultant for governments and industry in forestry related issues	Forest sector and policy analysis
10.	Sustainable forestry	Senior lecturer, Lund University, Sweden	Environmental Science
11.	Innovation policy, sustainability transitions, bio-refinery development	Associate senior lecturer, Lund University, Sweden	Economic Geography
12.	Decision making among private forest owners, policy development for the bio-based economy	Senior lecturer in environmental management, Stockholm University, Sweden	Ecology
13.	Policy development and collaboration for the bio-based economy	Coordinator for the circular and bio-based economy innovation and partnership platform at the Swedish Government	Agronomy
14.	Bio-energy, policy frameworks for the bio-based economy	Desk officer, Government Offices of Sweden	Chemistry

Appendix C. Interview Guide for Semi-Structured Interviews

a) Welcoming and gathering of participant information

1. Introduction to the AdaptEcon research project, researcher background, research process.
2. Tell me about your background and your current position?

b) Interview questions

3. Are you familiar with the bio-based economy concept from before? How would you define a bio-based economy/how do you understand the concept?
4. In what ways do you/your organisation/employer work with a bio-based economy?
5. Can you describe a desirable development that would follow from a transition to a bio-based economy? What is the desired change that a transition would bring (short term/long term)?
6. What would be desirable effects on the sectorial (agriculture/forestry) level, and on a national level?
7. What indicators could be used to trace/measure this development?
8. Can you give examples of actions or proposals to implement in order to facilitate a transition process?
9. What are the main challenges to overcome in order to facilitate a transition process?
10. Can you come to think of any unintended consequences following a transition process?
11. Can you give examples of uncertainties or areas of risk linked to a transition process?
12. What measures could reduce this uncertainty/risk?
13. What actors should take lead in the transition process?
14. Can you give examples of actors or perspectives relevant to the bio-based economy, but currently being overlooked in the general debate?

c) Closing of interview

15. Other questions/comments?
16. Thanking of participant and snowball sampling.

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