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Understanding the Transition to a Bio-Based Economy: Exploring Dynamics Linked to the Agricultural Sector in Sweden

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Abstract: There is a growing interest in the bio-based economy, evident in the policy domain as well as in the academic literature. Its proponents consider it an opportunity to address multiple societal challenges, and the concept has broad reach across different sectors of society. However, a potential transition process is also linked to areas of risk and uncertainty, and the need for interdisciplinary research and for the identification of potential trade-offs and synergies between parallel visions of the bio-based economy have been emphasized. The aim of this paper is to contribute to addressing this gap by using an approach combining tools for systems analysis with expert interviews. Focusing specifically on dynamics in the agricultural sector in Sweden, an integrated understanding of the social and ecological processes contributing to or hindering a transition in this area is developed, high order leverage points are identified, and potential impacts of proposed interventions explored. The paper also considers cross-sectoral linkages between the forestry and agricultural sectors.

Keywords: sustainability transitions; systems analysis; causal loop diagrams; bio-based economy; bio-economy; agriculture

1. Introduction

Efforts aimed at understanding and supporting the transition to a bio-based economy have been increasing over the past two decades, to a large extent linked to developments in the policy sphere. Strategies on regional, national, and local levels have been brought forward, and now at least 45 countries have developed their own bio-based economy agendas [1]. Partly as a consequence of the broad reach of the concept, these strategies adopt different visions and definitions of the bio-based economy, often reflecting the context and preconditions of a specific nation or actor [2–4]. For example, the bio-based economy is variously seen as an opportunity to achieve climate change mitigation, competitive advantage linked to knowledge generation and novel biomass applications, improved global governance of biological resources, decentralized modes of production, rural development, and a lower dependency on finite, fossil-based resources [5–8]. One example of how a transition to a bio-based economy is defined is as a shift away from an economy dependent on fossil-based resources, to an economy utilizing renewable, biological resources to provide the products and services demanded in society [9,10]. A parallel understanding does instead stress the role of biotechnology, perceiving it as central to the bio-based economy, and aiming for its use and share of economic output to increase [7,11].

In Sweden, factors such as biomass availability, a long history of traditional industries, a skilled labor force, and high access to infrastructure and markets have been identified as beneficial in the context of facilitating a transition process [12–14]. Specific initiatives addressing developments toward a bio-based economy include a research and innovation strategy, commissioned by the Swedish Government and published in 2012. It outlined overarching aims of the Swedish bio-based economy, such as replacing fossil-based resources with bio-based resources, developing smarter products, increasing resource use efficiency, and to change consumption patterns and behaviors. The strategy further stressed the need for collaboration, knowledge generation, and formation of new partnerships in order to enable a transition [9]. Moreover, the bio-based economy could directly, or indirectly, affect the attainment of several of the Swedish Environmental Quality Objectives [15], in addition to climate-related targets such as achieving zero net emissions of greenhouse gases by 2045 and a fossil-free transport fleet [16–18]. Furthermore, the bio-based economy is an integral part of the current Innovation Partnership Program initiated by the Swedish Government to address critical societal challenges [19]. Thus, also in Sweden the bio-based economy is considered a mean to achieve multiple objectives, and its premises to a large extent seen as based on the broad and cross-sectoral reach of the concept.

Nevertheless, a large number of the road maps and initiatives promoting the Swedish bio-based economy have been centered around single sectors and technological pathways. The forest sector plays a dominant role, reflected in many of the ongoing efforts to facilitate a transition process [20–22]. Additionally, in the broader debate surrounding the concept, aside from the opportunities being highlighted, uncertainty and potential risk factors have also been brought forward. Questions about the viability and sustainability of the emerging bio-based economy have been raised, stressing potential conflicts and adverse environmental and social impacts arising from the multitude of competing and growing claims on biological resources [23–25], a lack of focus on multi-functionality, public goods, local knowledge and social innovation in the bio-based economy [26], and that ecological sustainability is often overlooked in official strategies and the broader bio-based economy discourse [23,27,28]. The discourse surrounding the concept has further been criticized for being promissory [29], and a lack of clear meaning, indicators for sustainability, or measures of success have been underlined [2,30,31]. Additionally, the need for interdisciplinary approaches, the identification of synergies and trade-offs between parallel visions of the bio-based economy, and insight into the larger societal impacts of a transition process have been highlighted [4,9,32–34].

The aim of our work is to contribute to an integrated understanding of the multiple processes and proposals suggested to underpin and facilitate a transition to a bio-based economy in Sweden. The focus of the study is on terrestrial sources of biomass from forestry and agriculture. For the sake of space, the present paper outlines the results focused on the agricultural sector. Results linked to dynamics in the forestry sector, also emphasizing a political dimension of a transition process, are presented in Bennich et al. (2018) [35]. This paper is organized as follows: The first section outlines the methodological framework. Thereafter, the results are presented, divided into the change processes identified as key by the actors participating in the study, followed by an exploration of interconnectedness, the impact of proposed interventions, and of the potential future transition pathways to which they might contribute. Our conclusions are drawn in the final section, together with suggestions for future work.

2. Methodological Framework and Research Process

The study was structured around the following guiding research questions: 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? The research design was based on the use of qualitative tools for systems analysis, specifically Causal Loop Diagrams (CLDs). The empirical basis for the CLDs was expert interviews. This section gives an overview of the methodological framework and research process, while a more in-depth presentation can be found in Bennich et al. (2018) [35].

CLDs are diagramming tools, originating from the fields of system dynamics and cybernetics [36]. They consist of variables connected by arrows, where the links between the variables represent hypotheses about causal relationships. CLDs are commonly used to conceptualize and communicate system structure, for clarification of assumptions, and for creating new knowledge and learning in situations where problems are perceived as complex or unstructured [37,38]. Lane (2008) provides an overview of the emergence of the use of CLDs, as well as a critical reflection on their strengths and weaknesses [39]. In relation to the aims of this study, the strength of CLDs lies in their ability to simultaneously map social and ecological systems, as well as different actor perspectives, in an integrated way. CLDs are in addition meant to document both chains of cause and proposed effects, but also any possible system feedbacks, thereby moving from linear to non-linear conceptualization. The limitations of CLDs include potential trade-offs between precision and simplification. The specific focus on depicting and communicating key elements and feedbacks of the system under study might make the underlying rationale of the causal relationships less evident. Moreover, while CLDs can provide structural insight, they do not allow for rigorous inference about the dynamic behavior arising from the system structure [39]. For more information on the process of developing CLDs, as well as on their use in this research, see Bennich et al. (2018) [35]. Expert interviews are often referred to as efficient means to gain exploratory insight about a specific topic and as an entry points to fields where it might otherwise be difficult to gain access [40]. In the context of this study, expert interviews were used to identify key drivers, hindrances, and interventions linked to the transition to a bio-based economy in Sweden, as perceived by different actor groups. The interview data were then used as a basis for elicitation of the causal relationships included in the CLDs.

Thus, our starting proposition is that systems analysis and the use of CLDs as an analytical tool can contribute to developing and documenting a qualitative understanding of the structural components governing a transition to a bio-based economy, by mapping expert knowledge in integrated conceptual maps. Based on this understanding, effective interventions may be identified, in contrast to technical, end-of-pipe solutions, and the ability to avoid policy resistance can be strengthened. Policy resistance refers to the failure of interventions to generate anticipated results, caused by unexpected internal responses in the system, and partly attributed to linear cause and effect thinking [39,41].

To support reasoning about potential leverage points and to qualitatively assess the potential impact of suggested proposals to facilitate change, we build on the Leverage Points Framework [42]. Leverage points can be understood as places in a system where a small disturbance or initial change may ultimately lead to large-scale system change, i.e., places where well-directed interventions may lead to substantial and lasting improvements [43]. The framework may serve as a basis for analyzing the effectiveness of interventions, starting from leverage points at the lower end of efficiency (e.g., changing the value of parameters, constants, the physical structure of a system, or the relative length of delays), to higher impact leverage points (changing the relative strength of balancing and reinforcing feedback loops, adding information feedbacks, or changing the rules guiding the behavior of the system) [42].

As also outlined in Bennich et al. (2018) [35], the first step of the research process consisted of actor analysis and outreach. The process was informed by an initial literature review, and was structured by the guidelines for actor analysis as presented by Lelea, et al. (2014) [44]. Fourteen experts were selected for semi-structured interviews. The experts were selected based on (1) their knowledge and experience of sectors relevant to the Swedish bio-based economy; (2) their ability to represent larger actor groups in these sectors; and (3) their ability to provide diverse standpoints. The process made use of snowball sampling, specifically aiming to identify actor perspectives that might currently be overlooked in the bio-based economy debate. Semi-structured interviews were selected for data collection, as they allow for an in-depth exploration of perceptions and views in situations where issues are complex, information seemingly conflicting, and where there is diversity in the personal history, profession, and educational background of the study group [45,46]. In the second step, the interviews were carried out, either physically in Stockholm or via Skype. The interviews, lasting from 60 to 120 min, were based on a number of open ended questions, formulated to enable the identification of key variables, causal relationships, and reinforcing or balancing feedbacks. Measures to ensure validity and reliability in the data collection phase included the development and testing of an interview guide in preparation for the interviews, as well as digitally recording and transcribing the interviews. In the third step, the data was analyzed and used as a basis for the development of the CLDs, following the method presented by Kim and Andersen (2012) [47]. For each interview an initial CLD was developed. These were subsequently integrated by aggregating similarities while maintaining differences, thereby ensuring that the multiple perspectives of the interviewees remained visible. The process was documented, to create visible connections between the data segments and the integrated CLDs. The CLDs were then sent to the interviewed experts for confirmation, along with an explanatory text and a set of complementary questions. The questions were aimed at generating additional insight, clarification, and completeness of coverage in terms of proposed system structure. The CLDs were subsequently revised based on the feedback from the participants, and then used as a basis to perform a qualitative exploration of the impact of proposed interventions and the transition pathways they formed. Two researchers were engaged in the process of developing and analyzing the CLDs, and the resulting output was compared and discussed in an iterative process, aiming to reduce researcher biases. For an interviewee overview and interview guide, see Bennich et al. (2018) [35].

3. Results

The results, in the form of CLDs, are presented under different sub-headings. Firstly, the four dynamic change processes in the agricultural sector identified as important in the context of the broader transition to a bio-based economy are outlined. More specifically, the first section presents dynamics governing the overarching objective of expanding and maintaining farming activities in Sweden. This is followed by three more disaggregated CLDs focusing on the desired objectives of employing more environmentally friendly practices in conventional agriculture, of securing biomass supply for both food and non-food purposes, and of facilitating a shift to regenerative production, respectively. The next section presents an integrated CLD, highlighting cross-scale interactions. This section also introduces the leverage points and interventions that were identified during the interviews. The final section elaborates on interconnectedness between the agricultural and forestry sectors. Variable names are indicated by quotation marks.

3.1. Identification of Dynamics Governing the Expansion and Maintenance of Farming Activities

The first change process identified as important during the interviews relates to the underlying ability to expand and maintain activities within the agricultural sector, perceived as a pre-condition to achieve other objectives of the bio-based economy. It was emphasized that change in the agricultural sector is path dependent, and that it takes time and effort to reverse a potential decline in the size of the sector. The variable "Farming activities" (capitalized, Figure 1) represents the combinations of activities directly enabling primary production in the agricultural sector (e.g., tilling, planting, fertilizing, irrigation, pathogen mitigation and harvesting), thus referring to farming in a general sense. During the interviews, several reinforcing feedbacks either supporting an expansion or triggering a loss of "Farming activities" were identified. The more "Farming activities" carried out, the higher the "Learning-by-doing" among the practitioners, making the "Agricultural capacity" expand. The expansion of "Agricultural capacity" drives the "Conversion of fallow land to actively cultivated land", enabling further "Farming activities" (reinforcing feedback, R1, Figure 1). Additionally, more "Farming activities" make the "Available support functions for farmers" increase, including advisory services and research centers. Having such support functions in place contributes to the buildup of "Agricultural capacity", a higher "Conversion of fallow land to actively cultivated land", and ultimately to more "Farming activities" (reinforcing feedback, R2, Figure 1). An expansion of "Farming activities" could also contribute to a higher "Attractiveness of profession", through increasing visibility and awareness in society, in turns supporting the "Education of new farmers" (reinforcing feedback, R3, Figure 1).

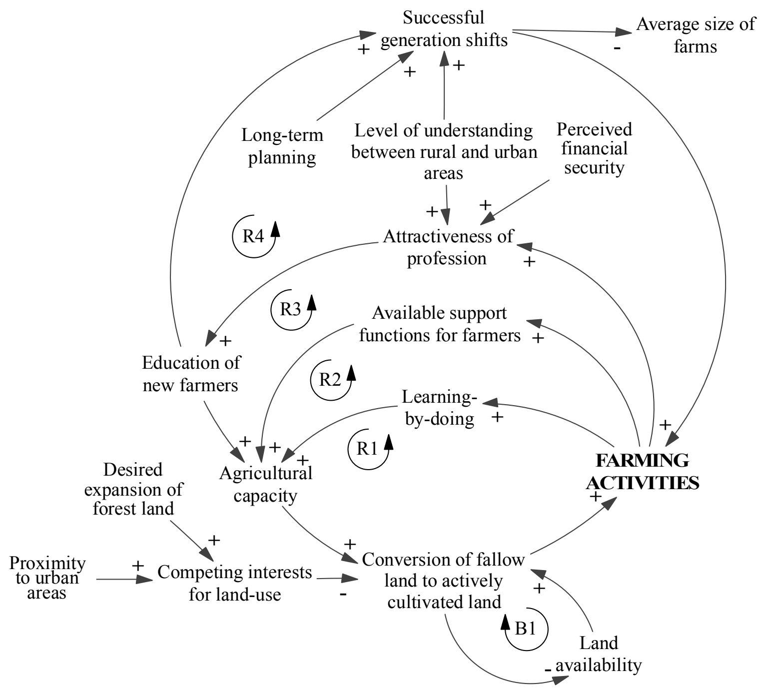

Figure 1. Causal Loop Diagram (CLD) displaying the dynamics suggested to govern the expansion and maintenance of "Farming activities". CLDs consist of variables connected by arrows, representing hypotheses about causal relationships among the variables. Each link is assigned a polarity, either positive (+) or negative (−). A positive link indicates that the dependent and independent variable move in the same direction (if the independent variable increases, so does the dependent variable, and if the independent variable decreases, so does the dependent variable). A negative link indicates that the variables move in opposite directions (if the independent variable increases, the dependent variable decreases, and if the independent variable decreases, the dependent variable increases). Important feedbacks are highlighted in the diagram. These could be either reinforcing (denoted by a R) or balancing (indicated by a B). For a further introduction to the use of CLDs in this research, see Bennich et al. (2018) [35].

The difficulty of generation shifts was identified as a key issue to overcome in the agricultural sector. The larger the number of people educated to become farmers, the higher the number of "Successful generation shifts", resulting in more "Farming activities" than what would otherwise have been (reinforcing feedback, R4, Figure 1).

Some variables affect, but are not part of, the reinforcing feedbacks R1–4 (Figure 1). A lack of "Long-term planning" was identified as a factor hindering the process of handing over farms from one generation to the next. The higher the degree of "Long-term planning", the more "Successful generation shifts". Another variable potentially having an impact on the amount of "Successful generation shifts" is the "Level of understanding between rural and urban areas". A higher "Level of understanding between rural and urban areas" could make the pool of potential new farmers grow, the level of trust between the current and potential future generation of farmers increase, and additionally ensure that the needs of the part of the population living in rural areas are recognized to a larger extent. In terms of the latter, it was suggested that the social welfare system is poorly adapted to the living conditions and work situation of farmers, where potential improvements include better pensions and financial support in the case of sickness. Aside from access to social welfare, enabled by a high "Level of understanding between rural and urban areas", also the "Perceived financial security" in the agricultural sector was identified as having an impact on the "Attractiveness of profession". The variable "Perceived financial security” refers specifically to the views and understandings of the financial situation of farmers among those not themselves active in the profession.

As emphasized by the balancing feedback B1 (Figure 1), land is a limited resource. The more land that is converted to cultivated land, the lower the potential to further expand cultivation. In addition, the “Conversion of fallow land to actively cultivated land” is affected by “Competing interest for land-use”. Factors such as “Proximity to urban areas” and a “Desired expansion of forest land” could increase competition and pressure on the land, drive prices up, and thereby make it more difficult to allocate land to farming activities. Another proposed relationship with respect to land is that between “Successful generation shifts” and the “Average size of farms”. If the farm is not handed over from one generation to the next, it is likely that the land will be transferred to the neighboring farm, thereby making the average farm size increase.

3.2. Employment of More Environmentally Friendly Practices in Conventional Agriculture

A second change process identified as important in the context of the transition to a bio-based economy is the “Employment of more environmentally friendly practices” in conventional agriculture (capitalized, Figure 2). The need to adopt more environmentally friendly practices relates to a number of overarching challenges in the agricultural sector, where examples highlighted during the interviews include a need to reduce greenhouse gas emissions from primary production and processing, to lower the use of mineral fertilizers and pesticides, and to overcome the dependency on fossil-based sources of energy. Three drivers explaining the employment of more environmentally friendly practices were suggested: A financial logic (it makes sense from a cost saving perspective), an emotional rationale (arising from factors such as personal experience of the negative impacts of intensive use of production inputs), and the availability of options (i.e., the farmer would employ more environmentally friendly practices if the option to do so was available).

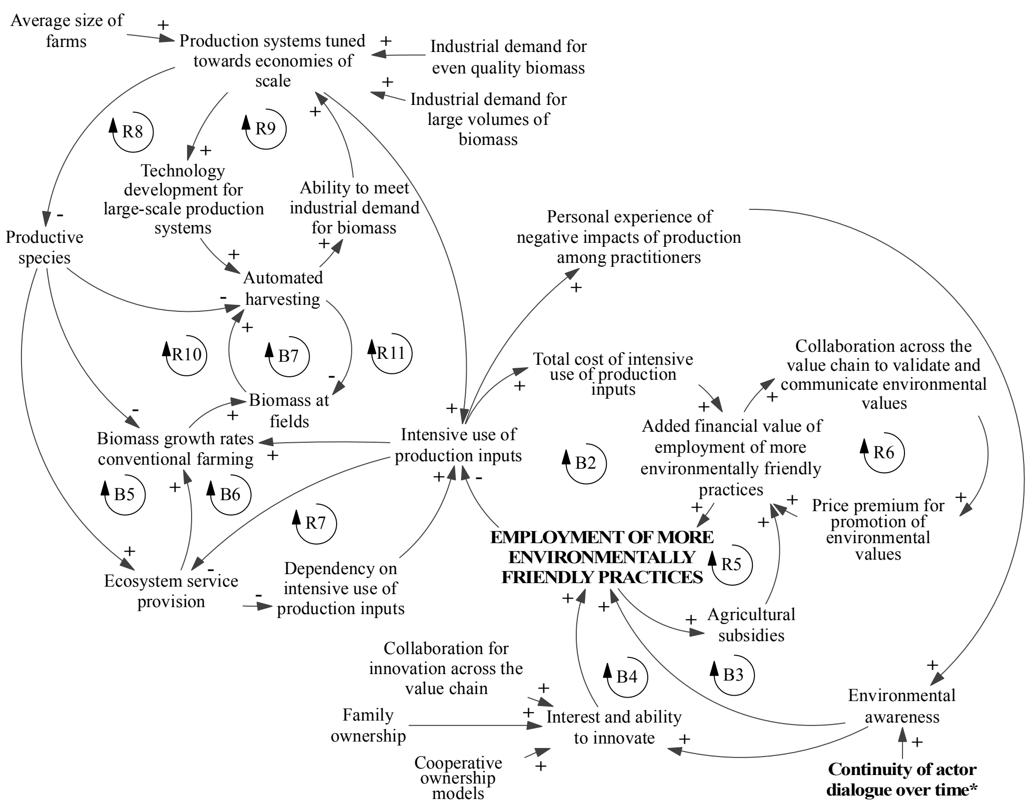

Figure 2. Dynamics hypothesized to govern the employment of more environmentally friendly practices in conventional agriculture. * Underlying dynamics of variable related to the political dimension of the bio-based economy concept, explained in further detail in Section 3.6.

The higher the "Intensive use of production inputs", the larger the "Total cost of intensive use of production inputs". Consequently, the "Added financial value of employment of more environmentally friendly practices" increases, supporting the "Employment of more environmentally friendly practices", thereby reducing the "Intensive use of production inputs" (balancing feedback, B2, Figure 2). Adhering to sustainability criteria opens up the possibility of receiving "Agricultural subsidies" for environmentally sound practices, adding to the financial incentives for promoting environmental values (reinforcing feedback, R5, Figure 2). The financial viability of environmentally friendly practices is, aside from being affected by potential cost reductions or subsidies, to a certain extent dependent on the ability of the farmer to receive a price premium. With "Collaboration across the value chain to validate and communicate environmental values", the willingness of the end consumer to pay a price premium is expected to increase. The price premium, in turns, contributes to the added financial value of employing environmentally friendly practices, consequently also increasing the ability to engage more actors in the work to promote environmental values (reinforcing feedback, R6, Figure 2).

The emotional rationale for employing more environmentally friendly practices is partly explained by the "Personal experience of negative impacts of production among practitioners", creating a stronger "Environmental awareness", in turns reducing the "Intensive use of production inputs" (balancing feedback, B3, Figure 2). Additionally, with higher "Environmental awareness", a greater "Interest and ability to innovate" for sustainability may be created. Innovation is suggested to be important as it can allow for the development of less harmful production inputs and more resource efficient methods, thereby further contributing to the "Employment of more environmentally friendly practices" (balancing feedback, B4, Figure 2).

While a high environmental awareness could support innovation for sustainability, a number of additional variables explaining relative innovation capabilities for sustainability in the bio-based economy were identified during the interviews. One factor to consider is the role of ownership, where it was suggested that cooperatives and family owned businesses might be better able to support innovation for sustainability. This may partly be explained by these structures allowing for longer planning horizons, and in terms of cooperatives, the possibility to spread risk among the owners. An additional factor thought of as supporting innovation is "Collaboration for innovation across the value chain", the underlying assumption being that novel ideas and solutions are created when actors with different perspectives meet and work together. Examples of areas of innovation brought up during the interviews include digitalization, precision agriculture, and new means of collecting and analyzing data to inform decision making (e.g., the internet of things).

Another factor suggested to affect the ability to employ more environmentally friendly practices is the structure of the agricultural system. In the current industrial system, a strive to maximize "Biomass growth rates in conventional farming" requires a low number of "Productive species" and an "Intensive use of production inputs" such as mineral fertilizer and pesticides. Intensive use of production inputs harms the "Ecosystem service provision", thereby creating a self-reinforcing dependency on these same inputs (reinforcing feedback, R7, Figure 2). This reinforcing feedback may create a lock-in effect, where it becomes increasingly difficult shift to more environmentally friendly modes of production.

An additional number of reinforcing feedbacks linked to industrial agricultural production that may create lock-in effects, and that have an impact on the ability to employ more environmentally friendly practices, were identified during the interviews. "Industrial demand for large volumes of biomass", "Industrial demand for even quality biomass", and an increasing "Average size of farms", drive the expansion of "Production systems tuned towards economies of scale". In these systems, the fewer the "Productive species" and the more extensive the use of "Automated harvesting", the larger the "Ability to meet industrial demand for biomass", further generating "Production systems tuned towards scale" (reinforcing feedback, R8, Figure 2). Additionally, "Production systems tuned towards economies of scale" require "Technology development for large-scale production systems". This technology further supports "Automated harvesting", and therefore leads to a larger "Ability to meet industrial demand for biomass", again reinforcing the development of production systems based on economies of scale (reinforcing feedback, R9, Figure 2). Aside from technology, the selection of specialized species and the intensive use of production inputs in these systems boost biomass growth rates, thereby also supporting the "Ability to meet industrial demand for biomass" (reinforcing feedbacks, R10–11, Figure 2). In the long run, however, two balancing feedbacks counteract this development. Few productive species and the intensive use of production inputs negatively affect the provision of ecosystem services (such as natural pest control), thereby having an adverse impact on biomass growth rates and consequently also on the ability to meet industrial demand for biomass (balancing feedbacks, B5 and B6, Figure 2).

3.3. Identification of Dynamics Governing Biomass Availability

The sources and quantities of biomass available in a transition process were brought forward as central during the interviews. These sources include the biomass derived from "Domestic food production" as well as the production contributing to the "Total biomass supply for non-food applications". Examples of non-food applications are biomass being converted into bioenergy, chemicals, industrial products, or manufactured goods. During the interviews, it was stressed that national food self-sufficiency and domestic production capacity are increasingly perceived as key issues for the future. In addition, the biomass demand for non-food applications is expected to grow, for instance with an emerging "Interest and ability to innovate". With innovation, novel biomass applications are developed and demonstrated, and at the point when maturation is reached and markets materialize the "Non-food biomass applications" in the agricultural sector would start to increase, as long as the "Total biomass supply for non-food applications" is able to support this development.

Three ways of meeting future biomass demand were identified during the interviews, all with different implications. First, harvest residues and waste products from the food industry could be utilized to a further extent. The larger the "Domestic food production", the more "Litter" and "Food waste" generated and potentially available to the bio-based economy, contributing to the "Total biomass supply for non-food applications". The "Outtake of harvest residues" is hindered by a lack of "Perceived market potential for residues", described as a match-making problem where farmers are not connected with potential industrial customers. Nevertheless, when the "Ability and interest to innovate" increase, solutions such as more data driven and automated means of connecting actors across the value chain are expected to be developed and employed, thereby increasing the "Perceived market potential for residues".

A second way to increase biomass supply in the bio-based economy is to increase the "Conversion of fallow land to actively cultivated land", thereby giving rise to more "Land available for expanding food or non-food crop production". The choice between producing food and non-food crops is represented by the balancing feedbacks B8 and B9 (Figure 3). The more land allocated to the production of food crops, the less land is available for the production of non-food crops, and vice versa. Third, biomass supply for the bio-based economy can increase by utilizing "Novel crop rotation schemes", alternating between the production of crops for food consumption and crops for other purposes. The balancing feedbacks B10–B13 (Figure 3) stress the limits to biomass supply, in the sense that any allocation of biomass or area of use is restricted by the biomass availability. The reinforcing feedbacks R12 and R13 (Figure 3) highlight that the "Biomass growth rate" is affected by the soil quality, which is enhanced by the amount of "Litter" returned to the soil. The effect of increasing agricultural production may thereby be reinforced by an improvement in soil quality caused by more litter and harvest residues on the farm land and hampered by a larger "Outtake of harvest residues". Crop rotation schemes hold the potential to improve "Biomass growth rates" through an improvement in soil quality, thereby creating synergies between productivity related objectives and novel uses of biomass in the bio-based economy.

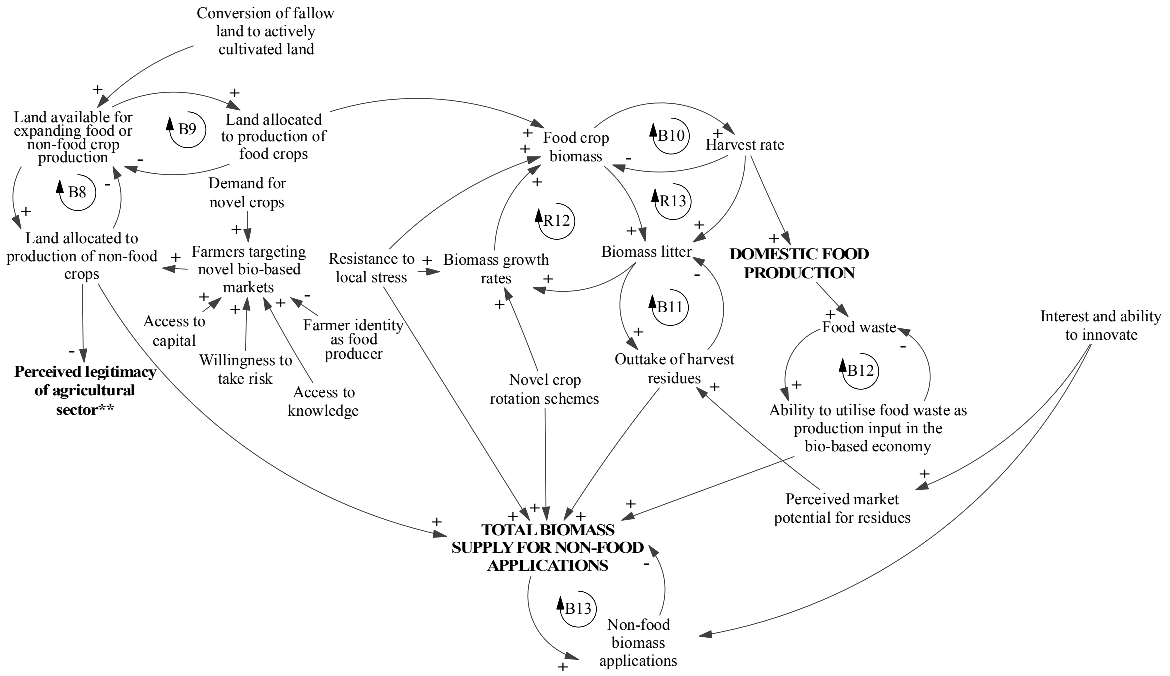

Figure 3. Sources of biomass in the bio-based economy. ** Variable influencing the political dimension of the bio-based economy, for further explanation see Section 3.6.

3.4. Introduction to Diversified Farming and Regenerative Production

An additional perspective brought forward during the interviews stresses the need for a shift towards diversified farming and regenerative production. While the variable "Employment of more environmentally friendly practices" (Figure 2) represents a shift in conventional farming toward more sustainable modes of production (e.g., toward practices enabling a higher resource use efficiency), the variable "Regenerative production" (capitalized, Figure 4) refers to a more fundamental shift in the way agricultural production is carried out. The creation of value in regenerative production is based on ecological improvement, thereby placing ecosystem functioning at the core of the agricultural practice. Diversity is a fundamental characteristic of regenerative production, as it is assumed to increase both resilience and productivity. Thus, the term diversified farming is in this context used to refer to the practices allowing for the production to be regenerative. Diversified farming is based on a number of design principles, striving to maximize the ability of plants to photosynthesize, to optimize the use of surface areas, and to utilize the qualitative components of biomass, as well as the synergetic relationships between species. Energy use should be optimized in every step of the process, aiming to realize the potential of agricultural production to have a positive energy balance. Another aspect highlighted as important during the interviews is the need to achieve self-sufficiency within each farm or cluster of farms, through utilizing combinations of animal husbandry, fodder production, and food crop production.

3.4.1. The Transition to Diversified Farming and Regenerative Production

The practices enabling regenerative production were identified as knowledge intensive, requiring both specific practical knowledge and commitment. When "Regenerative production" is carried out, practical knowledge is generated through learning-by-doing, and feelings of confidence and will-power among the practitioners grow. As a result, the overall "Ability to carry out diversified farming" increases, which in turns facilitates more "Regenerative production" (reinforcing feedback R14, Figure 4). Additionally, diversified farming requires a shift in mind-set among farmers. "Successful generation shifts" (see Figure 1) are perceived as an opportunity in this regard, as they may create an "Openness to new ideas", allowing for changes in the way agricultural production is carried out.

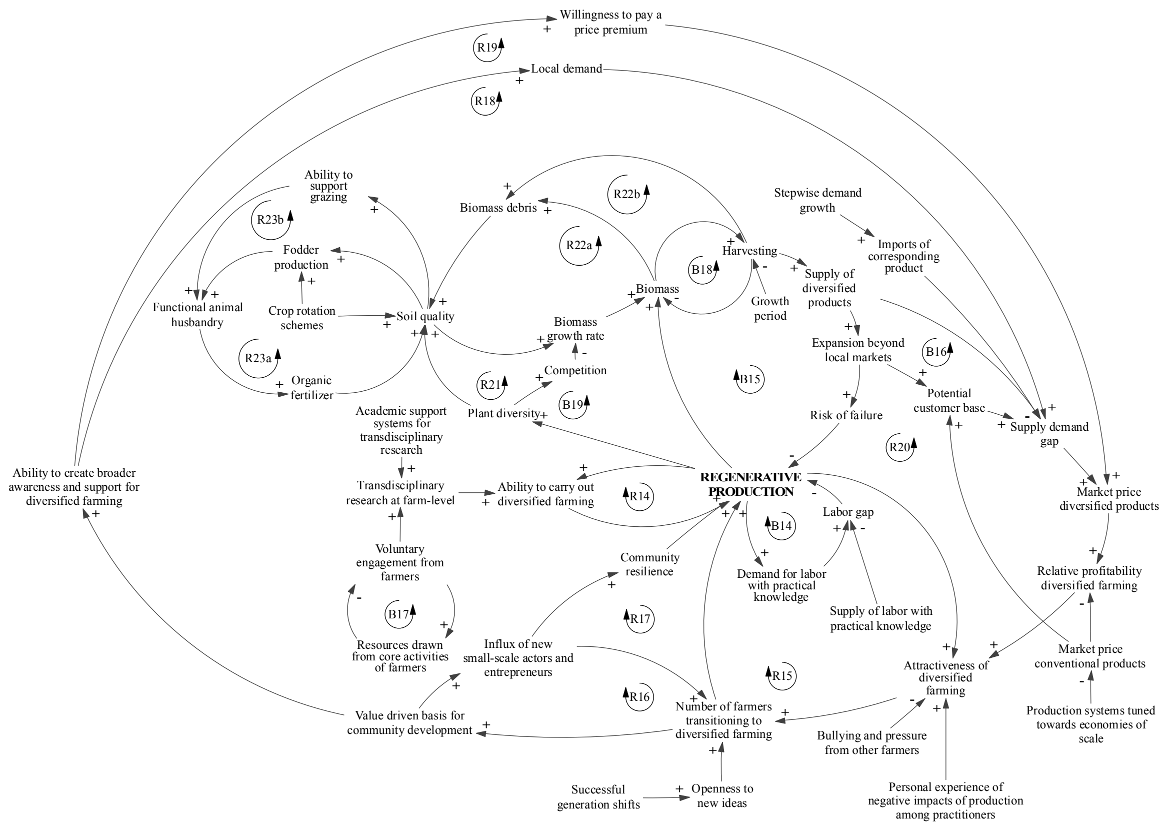

Figure 4. Dynamics suggested to govern the shift to diversified farming and regenerative production.

The variable "Attractiveness of diversified farming" was identified as crucial, as it determines the "Number of farmers transitioning to diversified farming", thereby enabling more "Regenerative production". More "Regenerative production" does, in turn, have a positive impact on the "Attractiveness of diversified farming", creating a reinforcing feedback (R15, Figure 4). Several factors were suggested to explain why an expansion of regenerative production may increase the attractiveness of diversified farming. For instance, diversified farming is expected to contribute positively to the well-being and quality of life of the practitioners. The more "Regenerative production", the larger the awareness about such benefits in the larger society, thereby making the perceived "Attractiveness of diversified farming" increase. Additionally, the more "Regenerative production", the lower the uncertainty linked to the production process, another factor contributing positively to the "Attractiveness of diversified farming".

The "Attractiveness of diversified farming" is also affected by the financial viability of this type of production, as compared to more conventional farming practices. The relative profitability is affected by the "Market price of conventional products". The higher the "Market price of conventional products", the lower the relative profitability of diversified farming, thereby having a negative impact on the attractiveness of diversified farming. A higher "Market price of conventional products" does on the other hand also give rise to a larger "Potential customer base" and demand for diversified products, in this way positively contributing to the attractiveness of diversified farming. The "Attractiveness of diversified farming" is also promoted by the "Personal experience of negative impacts of production among practitioners" (see Figure 2) in conventional farming, while being eroded by "Bullying and pressure from other farmers". "Bullying and pressure from other farmers" could arise from an underlying fear for the spread of pests or diseases among the neighboring farms, as well as from embedded cultural preferences regarding the appearance of the farm land.

Diversified farming and regenerative production are suggested to have spill-over effects not only on the quality of life of the individual farmer, but also on the surrounding community. The larger the "Number of farmers transitioning to diversified farming", the stronger the "Value driven basis for communal development". The value driven basis may refer to a common understanding and appreciation for the environmental and social benefits provided by diversified farming and regenerative production. This, in turn, may attract others with similar values, creating an "Influx of new small-scale actors and entrepreneurs". This would support the transition process, making the number of farmers shifting to diversified practices increase (reinforcing feedback R16, Figure 4) and facilitating cluster development that enhances overall "Community resilience" (reinforcing feedback R17, Figure 4). Additionally, the stronger the "Value driven basis for community development", the greater the "Ability to create broader awareness and support for diversified farming" in the larger community. This awareness is suggested to create "Local demand" as well as a "Willingness to pay a price premium" for the production output. These effects would strengthen the "Relative profitability of diversified farming", thereby further supporting the "Attractiveness of diversified farming" (reinforcing feedbacks R18–19, Figure 4). As more "Regenerative production" is carried out, the "Supply of diversified products" increases, thereby creating a potential for "Expansion beyond local markets". When entering new markets, the "Potential customer base" grows, thereby contributing to the "Relative profitability of diversified farming" through buoying the market price of diversified farming products (reinforcing feedback R20, Figure 4).

3.4.2. The Biophysical Basis for Diversified Farming and Regenerative Production

As "Regenerative production" expands, the output in terms of standing "Biomass" increases. Diversified farming supports a large "Plant diversity", and this diversity in combination with "Debris" in the form of plant litter and harvest residues enhance "Soil quality" over time. Better soil quality increases the "Biomass growth rate" and thereby also the standing volume of "Biomass" (reinforcing feedbacks R21–22b, Figure 4). A higher "Soil quality" also supports biomass production for purposes other than food crop production. Through a higher "Fodder production" and "Ability to support grazing", more "Functional animal husbandry" can be carried out. "Functional animal husbandry" refers to practices where the animals are seen as an integral part of farming, valuing their ability to optimize energy use and support production of food crops rather than holding animals primarily for meat or diary production. With a larger number of animals integrated into the farming, more "Organic fertilizer" becomes available, again enhancing the "Soil quality" (reinforcing feedbacks 23a–b, Figure 4).

Achieving an optimal animal intensity based on the capacity of the land to hold these animals is key to regenerative production. Thus, part of the ability to facilitate a transition to diversified farming and regenerative production is structural, in the sense that certain farms have better preconditions and therefore are relatively easier to convert. For example, they may already have a sufficient number of animals to provide manure for the lands, as well as enough land to grow fodder or allow for grazing, thereby ensuring self-sufficiency on the farm level.

3.4.3. Dynamics Identified as Counteracting a Transition to Diversified Farming and Regenerative Production

A number of factors could potentially counteract growth in diversified farming and regenerative production. One aspect is the ability to find labor with practical skills, considered a bottle-neck in a transition towards diversified farming as the current educational model is perceived to be built on a strong theoretical basis. As regenerative production expands, the "Demand for labor with practical knowledge" increases, thereby making the "Labor gap" grow, and if not addressed, reducing regenerative production in the long run (balancing feedback B14, Figure 4). Another aspect brought forward is the ability to expand to new markets. As the production output increases and actors move outside the local market, there is a greater deal of anonymity and competition, and therefore also a greater "Risk of failure" (balancing feedback 15, Figure 4). Anonymity in this case refers to a shift from selling on a local market where demand is built on reputation and personal contacts, to a market where the producer has no means to directly communicate with the end consumer (but rather is dependent on the communication and marketing carried out by the distributor). Also, the nature of demand growth matters. If the demand growth is step-wise rather than smooth, an immediate shortage of supply might follow. In response, demand might be met with imports rather than by the domestic production capacity adjusting to the higher level of demand, thereby halting the transition to regenerative production on a national scale. Additionally, as the supply of the product increases, the price would normally fall, negatively affecting the "Relative profitability of diversified farming" (balancing feedback B16, Figure 4).

The "Ability to carry out diversified farming" is dependent on the problem-solving ability of the farmer, which is assumed to increase with "Transdisciplinary research at farm-level". "Voluntary engagement" from farmers enables this type of research, but the larger the voluntary engagement the more "Resources drawn from core activities of farmers", ultimately reducing the "Voluntary engagement" (balancing feedback B17, Figure 4). Additionally, to be able to carry out "Transdisciplinary research at farm-level", not only the "Voluntary engagement" from farmers needs to be in place, but also the necessary "Academic support systems for transdisciplinary research".

There are also biophysical limits to "Regenerative production". For example, the more biomass that is harvested and sent to the market, the less standing biomass (balancing feedback B18, Figure 4), the longer the "Growth period" of a specific specie the lower the "Harvesting", and the larger the plant diversity the higher the "Competition" for resources, also limiting "Biomass growth rates" (balancing feedback B19, Figure 4).

3.5. Proposed Leverage Points and Interventions

Aside from the dynamics governing the change processes suggested to underpin a transition to a bio-based economy, a number of leverage points (i.e., places to intervene in the agricultural system to support the transition), as well as specific proposals targeting these leverage points, were suggested during the interviews. Additionally, while the individual CLDs in Figures 1–4 depict dynamics on different scales, also cross-scale interlinkages were identified in the interview process. Figure 5 displays an integrated CLD, highlighting suggested interventions (in italics), as well as the proposed cross-scale interlinkages.

3.5.1. Interventions Linked to Environmentally Friendly Practices and Biomass Availability

Interventions aiming at supporting the "Employment of more environmentally friendly practices" in conventional agriculture include utilizing "Environmental taxes" or other financial instruments to a larger extent, to make the intensive use of production inputs more expensive. The "Added financial value of employment of more environmentally friendly practices" would thereby increase, ultimately lowering the "Intensive use of production inputs" (strengthening the balancing feedback, B2, Figure 5). Another proposal in this area is to facilitate a "Redirection of farming intensity from high to low quality farm land". Aside from lowering the pressure on the most productive lands, this shift would entail intensifying farming activities on lands that are on the verge of becoming overgrown. This could positively affect the "Ecosystem service provision", thereby also holding the potential to reduce the dependency on "Intensive use of production inputs" (directly affecting the reinforcing feedback R7, Figure 5).

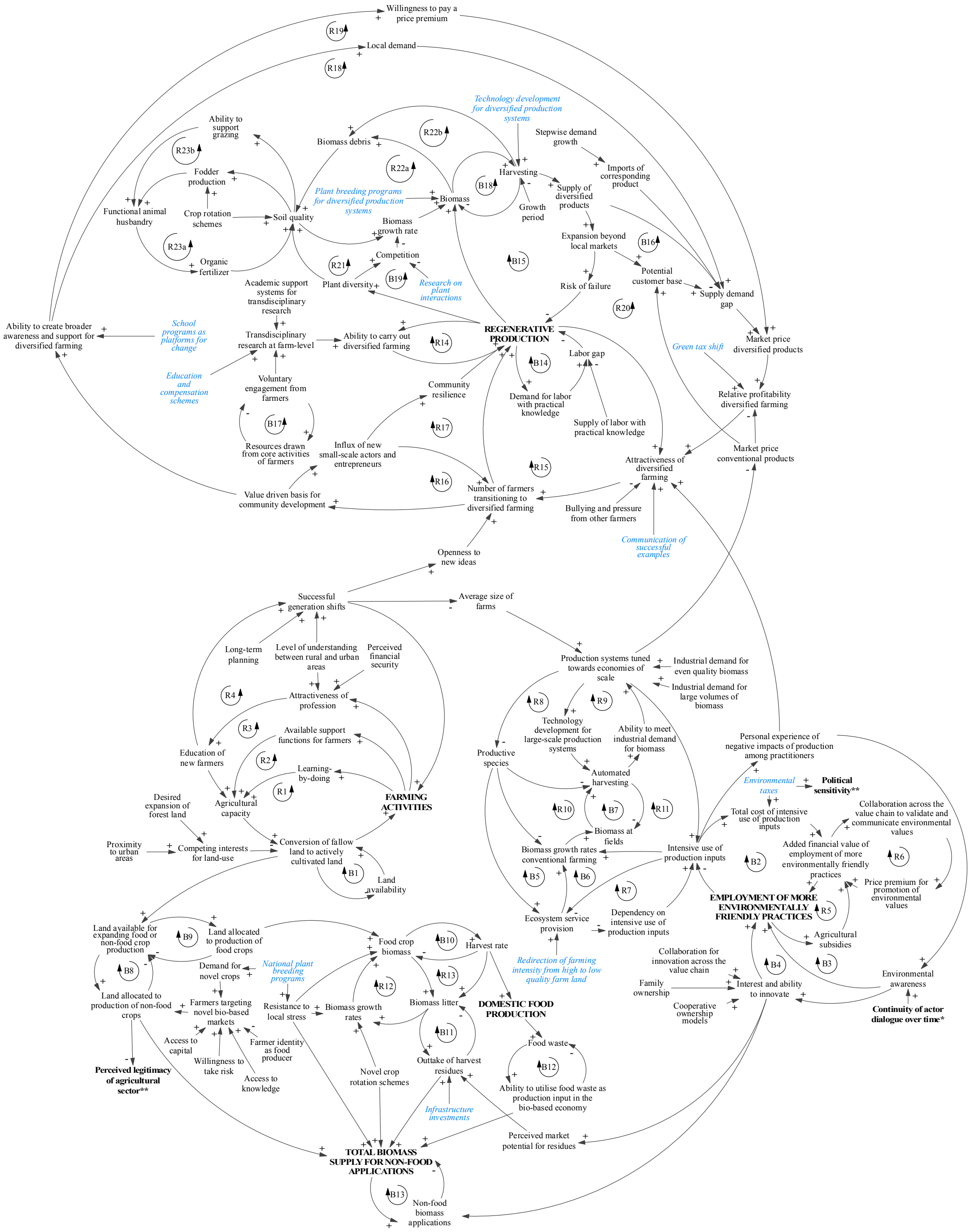

Figure 5. Proposed interventions (variables in italic) to facilitate desired change in key variables (capitalized). The CLD also highlights proposed cross-scale interlinkages, as identified during the interviews. * Impacted by the political dynamics governing a transition; ** Influencing the political dynamics governing a transition, see Section 3.6.

Specific proposals targeting biomass availability in the bio-based economy include efforts addressing a perceived lack of capacity to transport and handle harvest residues from the agricultural sector. By "Infrastructure investments" (bottom, centered, Figure 5), the "Outtake of harvest residues" would increase, contributing to the "Total biomass supply for non-food applications" and thereby enabling more "Non-food biomass applications". Infrastructure may in this context be understood in a broad sense, referring to physical but also organizational, technological, and logistical structures enabling new markets for harvest residue and production side streams to be established. Another suggestion is to develop and implement "National plant breeding programs" (bottom, left, Figure 5), aiming to generate a better fit of breeding techniques to Nordic conditions, and a larger variation in plant characteristics and chemical composition. Expected impacts of this proposal include a better plant "Resistance to local stress", generating higher "Biomass growth rates" and larger biomass supplies for both food and non-food applications. In addition, greater variation in plant characteristics would create a larger "Demand for novel crops", making the number of "Farmers targeting novel bio-based markets" increase, resulting in more "Land allocated to the production of non-food crops", thereby contributing to a higher "Total biomass supply for non-food applications".

3.5.2. Interventions Linked to Diversified Farming and Regenerative Production

Leverage points and proposed interventions affecting the feedbacks governing the transition to diversified farming and regenerative production fall within a range of categories, including knowledge production, the organization of labor and technology in diversified farming systems, and the emergence of new markets.

Developing design principles for diversified farming systems was suggested as crucial to fully utilize the potential of these systems to provide food for human consumption in a resource efficient manner. To enable this development, a need to expand the knowledge base was identified. "Plant breeding programs for diversified systems" could, if successful, increase the output from these systems in terms of edible, nutritious, and tasty yields, and make them adapted to Nordic geographical conditions (strengthening the reinforcing feedbacks R22a–b, Figure 5). Also "Research on plant interactions" could contribute to the development of smart design principles, through the identification of ways to minimize competition for resources while maximizing synergies between species (strengthening the reinforcing feedbacks R21–22b, while reducing the strength of the balancing feedback B19, Figure 5).

Another aspect of knowledge generation for diversified production systems concerns a suggested gap between scientific knowledge and the reality of the farmer. Advice is perceived as unable to account for multiple complexities and the contextual nature of challenges at the farm. Carrying out more research among practitioners was identified as a mean to address this gap, thereby enhancing the "Ability to carry out diversified farming". Transdisciplinary and farm-based research would help practitioners to formulate research questions and design suitable interventions to address them, thereby creating a better problem-solving ability at the farm level. Research processes involving practitioners would also support the development of design principles for diversified systems, integrating knowledge currently tacit among those active in the field. A proposed intervention to support this development is to implement "Education and compensation schemes" to ensure participation among farmers. By strengthening the interest and ability to participate through education and compensation, the need for voluntary commitments from the individual farmer could be reduced, thereby enabling transdisciplinary research projects without being affected by the balancing feedback B17 (Figure 5).

Moreover, a transition to more efficient, diversified farming systems would entail rethinking the organization of technology and labor. The current technology development within the agricultural sector has been described as tailored for production of scale and mono-cultures, while there is a lack of technology for diversified farming. As compared to conventional production, diversified production systems are characterized by larger complexity, holding a greater number of species within multiple habitats. In addition, these systems are smaller in scale, bound by the utilization of renewable resources and ecosystems services such as natural pest control. Acknowledging and addressing the technology development gap, through "Technology development for diversified production systems", would enable larger harvests, thereby contributing positively to the "Supply of diversified products".

Diversified farming is relatively labor intensive. The proposed "Green tax shift" is assumed to benefit this type of production, through reducing taxation of labor, thereby making the "Relative profitability of diversified farming" increase. In addition, it was pointed out that there is an overall need to rethink labor in the emerging bio-based economy. The agricultural sector is suggested to hold the potential to create new jobs, offering an opportunity to address societal challenges such as unemployment, inequality, and integration. To utilize this potential, diversified production systems could be based on an organizational design that combines technology for small-scale, complex systems, with a larger input of human labor. Technology development for diversified farming would then not replace, but complement, human labor, and a "Green tax shift" would be a mean to realize the potential of the agricultural sector to contribute to addressing broader societal challenges.

Uncertainty about the market potential and viability of the production process have been identified as thresholds to overcome in order to facilitate a transition to diversified farming. Market uncertainty could be reduced by targeting the leverage point "Ability to create broader awareness and support for diversified farming", in turns creating "Local demand" and a higher "Willingness to pay a price premium". By social means, a value shift could be created that aligns diets to local and seasonal supply. One proposed intervention is to design and use "Schools programs as platforms for change" (having an impact on the reinforcing feedbacks, R18–19, Figure 5). Successful examples were highlighted during the interviews, including municipalities where schools serve primarily seasonal and locally produced food. Another potential leverage point is the "Attractiveness of diversified farming", targeted by implementing proposals such as "Communication of successful examples" of diversified farming (affecting reinforcing feedbacks R15–19, Figure 5).

3.6. Interconnectedness between the Agricultural and Forestry Sectors

The study serving as a basis for the results outlined in the present paper covered bio-based resources derived both from the agricultural and forestry sector. In Bennich et al. (2018) [35], the dynamics governing transition pathways in the forestry sector are presented. During the interviews, it was highlighted that feedbacks directly related to primary production and processing in the forestry sector are also coupled with a political dimension of the bio-based economy concept. Key linkages were pointed out, such as the perceived legitimacy of the forestry sector having an impact on the political support for the bio-based economy, while political support in turns enable resource mobilization for innovation or investments in green jobs and traineeship programs [35]. Similarly, dynamics in the agricultural sector were identified as having an impact on the political support for the bio-based economy. Firstly, the "Perceived legitimacy of agricultural sector", to a certain extent determined by the adherence to the food-first principle, may influence the public support for the bio-based economy. The level of public support does ultimately either contribute to or erode political support. Secondly, the proposal to increasingly use "Environmental taxes" or other financial instruments (Figure 5) to make the use of fossil-based resources relatively more expensive is thought to create "Political uncertainty" linked to the bio-based economy concept. This sensitivity may reduce the ability to create a shared understanding and definition of the bio-based economy concept and its objectives, thereby halting a transition process, also in the forestry sector [35]. Other cross-sectoral linkages brought forward in the interviews include the connection between the ability of the bio-based economy concept to bring actors together, which is suggested to be partly governed by political factors, and the creation of environmental awareness in the agricultural sector. More specifically, the bio-based economy is perceived as a platform to discuss environmental issues in a non-threatening way. The larger the "Continuity of actor dialogue" over time, the greater the chances of creating "Environmental awareness" (Figures 2 and 5). Another factor that was emphasized is that land is a limited resource, and that developments in the forestry sector might have an impact on the ability to expand cultivated land (a potential "Desired expansion of forest land" contributing to "Competing interests for land-use", thereby lowering the "Conversion of fallow land to actively cultivated land" in the agricultural sector, Figure 1). This linkage was not recognized by interviewees in the forestry sector (i.e., acknowledging that a potential expansion of agricultural land might impede developments in the parts of the bio-based economy linked to the forestry sector). Thus, as also stressed in Bennich et al. (2018) [35], the interconnectedness of developments in the agricultural and forestry sectors, and the dynamics governing public and political support for the bio-based economy, may create synergies supporting a transition, but could also lead to negative spillover effects halting a broader transition process. Moreover, perceptions about these linkages differ among the actors in the bio-based economy.

4. Transition Pathways towards a Bio-Based Economy

4.1. Summary of Proposed Interventions

Transition pathways in the agricultural sector contributing to the emergence of a bio-based economy may be explored by asking "what-if" questions, using the CLDs and proposals identified during the interviews as a basis. Recalling the leverage points framework, not all leverage points are seen as equally efficient in terms of their ability to generate systemic change. However, with respect to the leverage points suggested during the interviews, many of them rank relatively highly in terms of efficiency, as they directly affect the relative strength of feedbacks or the overarching goals of the agricultural system. The specific proposals identified by the interviewees are summarized in Table 1, a majority of which target leverage points linked to the employment of environmentally friendly practices in conventional agriculture, biomass availability, or the shift to diversified farming and regenerative production. Leverage points related to the expansion and maintenance of farming activities were addressed to a lesser extent. The content of Table 1 is restricted to factors specifically brought up during the interviews.

In addition to the focus of the interventions summarized in Table 1, alternative leverage points were identified during the interviews. While no specific proposals to facilitate change in these variables were suggested, they may serve as a starting point for further thinking around potential interventions.

In order to support the expansion and maintenance of "Farming activities", potential leverage points identified include the "Perceived financial security" in the agricultural sector, the "Level of understanding between rural and urban areas", and the amount of "Long-term planning" carried out, all contributing to a higher number of "Successful generation shifts" or a greater "Attractiveness of profession". In terms of the "Employment of more environmentally friendly practices" in conventional agriculture, examples of additional leverage points are the "Collaboration across the value chain to validate and communicate environmental values" and the actors´ "Interest and ability to innovate".

The aim of securing biomass supplies for the emerging bio-based economy was suggested to be fulfilled for instance through the implementation of national plant breeding programs, and by expanding farming activities, thereby increasing the conversion of fallow land to actively cultivated land. Additional leverage points in regards to securing biomass supplies, particularly for non-food biomass applications, are the variables linked to the number of "Farmers targeting novel bio-based markets". A development with more "Farmers targeting novel bio-based markets" could be facilitated by a growing market demand for novel crops, but also by interventions increasing farmers "Access to capital", "Access to knowledge", and their "Willingness to take risk". The shift to "Regenerative production" is assumed to be supported by interventions targeting the relative profitability of diversified farming and the ability to create a broader awareness and support for this type of production. Other potential leverage points may be the "Supply of labor with practical knowledge" and "Community resilience". The latter was emphasized based on the observation that isolated practices are vulnerable, and therefore not likely to be sustained over time.

In summary, a broad range of proposed interventions and places to intervene have been suggested, ranging from areas such as technology development, use of financial instruments, and efforts to facilitate change in consumer habits and community values. While certain proposals and places to intervene in the system were specifically highlighted during the interviews, it should be noted that all variables in the hypothesized system structure linked to farming activities, the employment of more environmentally friendly practices, biomass availability, and the shift to regenerative production could serve as a basis for discussing additional points of intervention.

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

Targeted Objective	Proposed Intervention	Desired Change	Potential Unintended Consequences, Sources of Policy Resistance, or Systemic Risk	Uncertainty and Examples of Questions Remaining to Explore
Employment of more environmentally friendly practices in conventional agriculture	"What if the intensity of agricultural production is leveled out?" (reducing farming intensity on high quality farm land while intensifying cultivation on low quality farm land at risk of becoming overgrown)	Environmental values and long-term productivity are promoted.		How to determine and achieve optimal land-use and farming practices? What would be the net-effect on biomass availability?
	"What if financial instruments, such as environmental taxes, are used to a larger extent?"	Extracting and using fossil-based, finite resources would become relatively more expensive, promoting the employment of more environmentally friendly production practices.	The implementation, or prospect of implementing, such financial instruments could be perceived as a threat by some actors in the economy. If these interventions are linked to efforts to promote the bio-based economy, it could make the concept politically sensitive, reducing the ability to create a shared understanding of its objectives, and thereby hindering a broader transition to a bio-based economy.	How to "get the prices right" while simultaneously ensuring that the bio-based economy is perceived as an opportunity for a broad group of actors, also those currently not directly linked to bio-based sectors of the economy?
Biomass availability (total biomass supply for non-food applications, domestic food production)	"What if infrastructure is developed, allowing better transport and handling of harvest residues from the agricultural sector?"	Harvest residues would be utilized as an input to the bio-based economy to a larger extent. Resource use efficiency would increase, while pressure on other sources of biomass would be reduced.	Nutrient loss due to the removal of harvest residues and litter from agricultural land.	How can circularity be achieved, specifically in terms of nutrient recycling? How to solve the perceived match-making problem, where primary producers have biomass they cannot sell while industrial biomass demand is not fulfilled?
	"What if national plant breeding programs are further expanded?"	The resistance of plants to local stress, as well as the variability in chemical composition and plant characteristics, would increase. The demand for novel crops would grow, with a consequent increase in the number of farmers targeting new markets.	More land allocated to the production of non-food crops could make the perceived legitimacy of the agricultural sector decrease, lowering the overall ability to facilitate a transition to a bio-based economy.	What pathways make biomass demand and supply increase or decrease, and what are the consequences in terms of ability to meet biomass demand? Demand for novel crops is suggested to make the number of farmers allocating land to crop production for non-food purposes increase. What actors could take lead in this development, those currently active in the agricultural sector or completely new actors?

Table 1. *Cont.*

Targeted Objective	Proposed Intervention	Desired Change	Potential Unintended Consequences, Sources of Policy Resistance, or Systemic Risk	Uncertainty and Examples of Questions Remaining to Explore
Shift to regenerative production	"What if plant breeding programs for diversified production systems were implemented?"	The ability of diversified production systems to provide edible yields grows.		What are the design principles that would allow these systems to function optimally? How much food are these systems able to provide in a Nordic context? How do consumption patterns need to change to allow production to meet demand?
	"What if the knowledge base on plant interactions was expanded?"	Competition between species in diversified systems would be reduced, and productivity would thereby increase.		
	"What if education and compensation schemes to ensure that farmers can participate in transdisciplinary research programs were employed?"	The interest and ability of farmers to engage in transdisciplinary research would increase, contributing to both theoretical and practical knowledge supporting diversified farming.		How to ensure that the potential of the ideas generated in these research programs is leveraged? How to ensure that transdisciplinary research programs are supported in an academic setting?
	"What if technology for diversified production systems was developed?"	Diversified production systems would become more efficient, leveraging the potential of technology to complement manual labor, and harvests would increase.		Whom should take the lead in this development? What will be the net effect on the labor market?
	"What if taxation of labor was reduced, as part of a green tax shift?"	The relative profitability of the labor-intensive practices in diversified farming would increase, thereby strengthening the attractiveness of diversified farming.	With an increase in regenerative production, the demand for labor with practical skills would grow, increasing the labor gap. Unless measures are taken, this would limit a further expansion of regenerative production.	What are potential effects on the labor market and larger economy of reducing the tax burden on labor?
	"What if school programs were used as platforms for social change?"	Public procurement would support the expansion of diversified farming, through creating broader awareness.		What are suitable diets for a bio-based economy? What attitudinal changes are needed to support this change? How to implement these programs in a way so that they can be sustained over longer time periods?
	"What if successful examples of diversified farming practices were communicated?"	The attractiveness of diversified farming would grow, making more farmers transition and the regenerative production increase.	As regenerative production increases, also an expansion beyond local markets might take place. This could entail larger competition and risk, and unless complementary measures are taken, a larger failure rate.	

4.2. Synergies and Trade-Offs

The results outline multiple and diverse perspectives on the change needed in the agricultural sector for a transition to a bio-based economy to be facilitated. One area of controversy is the perceived need to increase adaptation of environmentally friendly practices in conventional agriculture. Views ranged from this being a necessity for the transition to a bio-based economy, to perspectives considering the Swedish agricultural sector sufficiently sustainable already. Another area where views differed, and where there are trade-offs, concerns the allocation of land. One view promotes an expansion of the cultivated land area, seeing more farm land as a requirement for meeting an anticipated increase in biomass demand in the transition to a bio-based economy. Another view suggests a shift in farming intensity rather than an expansion, with the objective of establishing agricultural practices that enhance ecosystem service provision. Different management approaches will also have different implications in terms of the combinations of labor and technology required, thus having an impact on the overall ability of the bio-based economy to contribute to new employment opportunities and rural development.

Aside from areas where priorities differ and where trade-offs exist, there are also change processes that are seemingly compatible. Interventions with synergistic effects, supporting the attainment of multiple objectives, include the implementation of new national plant breeding programs, contributing to biomass production for both food and non-food purposes. Moreover, while some of the identified objectives are seemingly separated from each other, challenges might still be shared. One example is the strive to achieve a price premium for promoting environmental values in primary production. In diversified farming, this is currently achieved predominantly through building local networks. In conventional farming, a price premium is suggested to be enabled by collaboration across the value chain to increase communication of the environmental values provided by agricultural production. Learning across domains may in this case be beneficial in order to achieve the objective of obtaining a price premium in both diversified and conventional farming. Lastly, timing and the specific order of intervention might be critical. For instance, the ability to expand and maintain farming activities might be seen as a prerequisite for a transition, as it ultimately affects the employment of more environmentally friendly practices in conventional agriculture, the utilization of new sources of biomass for the bio-based economy, as well as the shift to diversified farming and regenerative production.

5. Conclusions and Future Research

While agricultural sources of biomass have been recognized as important for the bio-based economy in Sweden, comparatively little attention has been given to the specific change processes underpinning a transition process in the agricultural sector. This paper begins to address this gap in an integrated way by using an approach combining systems analysis and expert interviews in the development of conceptual maps. These maps, representing causal hypotheses about the interplay of desired change processes and potential hindrances in the agricultural sector, were subsequently used to explore proposed interventions and the transition pathways they form. The study also considered cross-sectoral linkages between the forestry and agricultural sectors.

The results underline the diversity in objectives and views held by different actors. As identified during the interviews, desired change processes include an expansion of farming activities in Sweden, the employment of more environmentally friendly practices in conventional agriculture, securing biomass availability in the bio-based economy, and facilitating a shift to diversified farming and regenerative production. Even though no consensus on the desired change was held among the actors represented in the interviews, the process of making hypothesized system structure explicit allows for the development of a qualitative understanding of the synergies and trade-offs between different objectives. The approach and results in the form of the CLDs also highlight under which conditions certain arguments and areas of controversy apply. The polarization created by the fuel versus food debate may serve as an example. By creating a systemic analysis, the assumption that a transition process would necessarily entail an expansion of agricultural production for the purpose of growing crops for non-food biomass applications is challenged. Different pathways have different implications in terms of biomass demand, as well as supply, and depending on the objectives either one of these pathways may be supported by action for change.

The results presented in this paper are exploratory, and further research could entail re-examining each proposed causality, probing additional insight about the assumptions and conditions under which it holds. Additionally, the CLDs presented in this paper are based on the accounts of the interviewed experts. A worthwhile next step could entail comparing these results with other sources of information, to identify system structure that may have been overlooked during the interviews, as well as to support the identification of knowledge gaps in the existing literature. Another area of future research may include a further exploration of the implementation phase of the proposed interventions, identifying necessary change in causal structure for these actions to be undertaken, or alternatively to explore additional proposals and their potential impacts. Another direction for future research includes identifying actor perspectives currently being overlooked in the general debate, for example linked to the dynamics governing biomass demand. Furthermore, the aim of the study serving as the basis for the present paper was to provide an integrated understanding of change in the coupled social and ecological systems enabling or hindering a transition process in Sweden, with a specific focus on terrestrial biomass sources. Results linked to the dynamics in the forestry sector are outlined in Bennich et al. (2018) [35] and could be used to put the CLDs linked to the agricultural sector in perspective. The results also exemplify how actors perceive cross-sectoral relationships differently, and a way to further explore transition pathways could entail identifying and mapping additional ways in which the sectors in the bio-based economy are interrelated, how these linkages contribute to or hinder an overall transition process, as well as how different actors in the bio-based economy perceive these interlinkages.

Finally, CLDs do not allow for rigorous inference about the relative strength of the feedbacks identified, or about how the interplay of these feedbacks causes the variables in the system to change over time. Another avenue for further research may therefore be in the direction of simulation-based analysis, to test the hypothesized system structure and enable learning about the behavioral output of the system. The results outlined in the present paper as well as in Bennich et al. (2018) [35] provide a basis for systemic, holistic thinking around future transition pathways towards a bio-based economy. A number of feedbacks with the potential to drive or contribute to a transition were identified during the interviews. Yet, many of these might currently be working in the opposite direction, moving the system away from a desired state or outcome, thereby preventing a transition from happening. Moreover, for change to be sustained, there might be a need to pass critical thresholds. Thus, while the potential to facilitate a transition is perceived as relatively large, there is a need to acknowledge the inherent difficulties in shifting the direction and dominance of central feedbacks and to deepen the understanding of the magnitude of change actually required for a transition to happen.

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