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Land-use change in a Nordic future towards bioeconomy: A methodological framework to compare and merge stakeholder and expert opinions on qualitative scenarios

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ABSTRACT

Future development of bioeconomy is expected to change land use in the Nordic countries in agriculture and forestry. The changes are likely to affect water quality due to changes in nutrient run-off. To explore possible future land-use changes and their environmental impact, stakeholders and experts from four Nordic countries (Denmark, Finland, Norway and Sweden) were consulted. The methodological framework for the consultation was to identify a set of relevant land-use attributes for agriculture and forestry, e.g. tillage conservation effort, fertiliser use, animal husbandry, biogas production from manure, forestry management options, and implementation of mitigation measures, including protection of sensitive areas. The stakeholders and experts provided their opinions on how these attributes might change in terms of their environmental impacts on water quality given five Nordic bioeconomic scenarios (sustainability, business as usual, self-sufficiency, cities first and maximizing economic growth). A compilation methodology was developed to allow comparing and merging the stakeholder and expert opinions for each attribute and scenario. The compiled opinions for agriculture and forestry suggest that the business-as-usual scenario may slightly decrease the current environmental impact for most attributes due to new technologies, but that the sustainability scenario would be the only option to achieve a clear environmental improvement. In contrast, for the self-sufficiency scenario, as well as the maximum growth scenario, a deterioration of the environment and water quality was expected for most of the attributes. The results from the stakeholder consultations are used as inputs to models for estimating the impact of the land-use attributes and scenarios on nutrient run-off from catchments in the Nordic countries (as reported in other papers in this special issue). Furthermore, these results will facilitate policy level discussions concerning how to facilitate the shift to bioeconomy with increasing biomass exploitation without deteriorating water quality and ecological status in Nordic rivers and lakes.

1. Introduction

A developing bioeconomy is considered as an opportunity for the Nordic countries with their vast land areas, warming climate and potentially improved conditions for biomass production (Gíslason & Bragadóttir, 2017). To meet the expectations of more efficient food production, demand for bioenergy and need for biobased raw materials for novel products, practices in agriculture and forestry will change. The changes depend also on consumer demand, climate actions and various geopolitical changes and are partly controlled by policies and strategies set at EU (EC, 2018), regional (Nordic Council of Ministers, 2018) and national levels (Regjeringen 2016; Finnish Government 2022).

The shift to bioeconomy is likely to have undesirable effects on water quality, the ecological status and biodiversity of rivers and lakes and the ecosystem services they provide (EEA 2018, 2020, 2021; Marttila et al. 2020; Skarbøvik et al. 2020). These effects, which are most probably

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exacerbated by climate change (e.g. Sorteberg et al. 2018), are in conflict with the implementation of the EU Water Framework Directive (WFD) (EC 2000), as well as with the Zero Pollution Action Plan and the EU Biodiversity 2030 Strategy (Biodiversity strategy for 2030 (europa.eu); Dashboard | Knowledge for policy (europa.eu)). These changes may also have severe impacts on recreation and human well-being (Juutinen et al. 2022, Immerzeel et al., 2022). To evaluate potential future effects of a developing bioeconomy on water systems, there is a need to integrate current understanding of the factors that govern land use change with knowledge of relationships between land-use drivers, pressures, state and impact on water and societal responses to reduce those impacts (Smeets and Weterings, 1999).

The BIOWATER Nordic Centre of Excellence (BIOWATER - Integrating land and water management for a sustainable Nordic bioeconomy - Nibio) has focused on the possible effects on water of a shift towards a greater role for bioeconomy production in the four Nordic countries; Denmark, Finland, Norway and Sweden in the future (with a time horizon of 2050). A set of five narratives, Shared Socio-economic Pathways (SSPs), describing possible future scenarios for socio-economic development and their implications for climate and land use change at the global scale have been developed within the climate change research community (O'Neill, 2017, Riahi et al. 2017; Mitter et al. 2020). These SSPs have been extended and adapted to Nordic conditions with a focus on potential bioeconomic development (Rakovic et al. 2020). The resultant five narratives, identified as Nordic Bioeconomy Pathways (NBPs), combined global trends with national trends within the four Nordic countries (Rakovic et al. 2020). All these scenarios have been included to address alternative futures because a bioeconomy cannot be considered as self-evidently sustainable (Pfau et al. 2014), although it is meant to substitute fossil carbon sources.

Land use changes occur due to large scale regional drivers (e.g. demand for food, fodder, fibre and biofuels) and regional factors that can constrain or promote the conversion of land (van Asselen and Verburg 2013). Brown et al. (2021) shows by comparing different land use change models that "top-down" approaches produce results that agree with economic theories, whereas "bottom-up" approaches provide more heterogenous and multifunctional land systems. Also, locally important adaptive capacity and measures are rarely included in land use models, which could be important in impact modelling (Acosta et al. 2013). Compared to land use change assessment, changes in water resources are often assessed at the regional or local catchment scale (Skarbøvik et al. 2014). At this scale, there are two main approaches for developing future water quality scenarios for land use activities such as agriculture and forestry (Pulido-Velazquez et al. 2022). One option is based on data driven modeling of land-use change (LUC) using past historical observations (e.g. Pulido-Velazquez et al. 2015). Another option is the use of participatory approaches, involving relevant actors in scenario-building workshops to develop plausible alternative futures (e.g., Rinaudo et al. 2013; Faysse et al. 2014; Pulido-Velazquez et al. 2022).

Qualitative participatory scenario analysis in environmental research contexts (Kok et al. 2007, Oteros-Rozas et al. 2015, Martin-Ortega et al. 2022) articulates alternative descriptions of the future. It facilitates stakeholders' engagement in a collaborative process to investigate alternative scenarios (Waylen et al., 2015; Mitter et al. 2020). Stakeholder participation in scenario analysis can serve to empower them, to stimulate innovation, to mitigate conflicts and encourage social learning, and to integrate different types of knowledge (e.g. scientific, local), perceptions, expectations, and aspirations usually in a solutions-oriented way (Oteros-Rozas et al. 2015). Involving diverse stakeholders in the social-ecological system can also create action to achieve desired goals (Martin-Ortega et al. 2022). Future analyses of bioeconomy effects on land-use and possible impacts on water resources, require that the catchment models used at this scale must be fed with reliable land use change data at the corresponding local and catchment scale.

These two methods (modelling and participatory approaches) can be classified as top-down and bottom-up approaches, relying on modelling experts and local or national stakeholders (e.g. Wilby and Dessai 2010; Ekström et al. 2013). Similar approaches have been used for land use change assessment (van Asselen and Verburg 2013) (Pulido-Velazquez et al. 2022) but there are no such studies focusing specifically on the Nordic countries.

The objectives of this paper are 1) to document our combined top-down and bottom-up approach to analyze possible land-use changes under future scenarios and their potential impacts on water quality in the Nordic countries and 2) to explore and compare patterns in views among experts about the consequences of a developing bio-economy for their sector (agriculture or forestry). The paper begins with a description of the land-use and land management attributes, the national stakeholder consultations and the method for their quantification. We present the results from these consultations and assess the similarities and differences of opinions across the countries. The results are then discussed in the light of different possible interpretations of the scenarios and attributes and the methodology used in the study. The results have been used as inputs to catchment scale modeling (see Trolle et al. 2019, other papers in this special issue).

2. Materials and methods

2.1. Main approach

The method and application of this top-down and bottom-up approach consisted of three steps (Fig. 1). We first identified a series of land-use attributes for agricultural and forestry practices (top-down) based on the NBPs (Rakovic et al., 2020). Secondly, the attributes were presented to and evaluated by stakeholders in focus groups and structured interviews to provide estimates of land-use changes in each of the Nordic countries (bottom-up). The results from the consultations with stakeholders were then quantified (ranked) to be used for modelling the impact on water at a catchment level and in this study for cross-country comparison.

2.2. Scenarios

In this paper, we have used labels and short titles for the different Nordic Bioeconomic Pathways (NBPs), which are helpful to reduce the wordiness and ease the reading:

- NBP 1: Sustainability first
- NBP 2: Business as usual
- NBP 3: Self-sufficiency
- NBP 4: Cities first
- NBP 5: Maximum growth

These scenarios are further described in Rakovic et al. (2020) and in the Supplementary Material (section 2b). The current land use was also included as a baseline to help the stakeholders consider each of the scenarios. For simplicity, this baseline is given the label NBP 0.

2.3. Land-use attributes

The initial drafting of the attributes was performed using expert judgement by the same scientists working with parallel development of the NBPs. The initial motivation for developing system attributes was to be able to move from generalized descriptions of the five NBP scenario outcomes to a set of indicators which could be used to describe how land use might change under each of the NBP narratives. In the initial draft in Spring 2018, a set of land use attribute (system indicators) was defined for two different land use sectors: agriculture and forestry. Each individual attribute was described for three situations moving from less intensive land use practices to more intensive practices, as well as a situation in the middle (medium intensity). The three situations for each

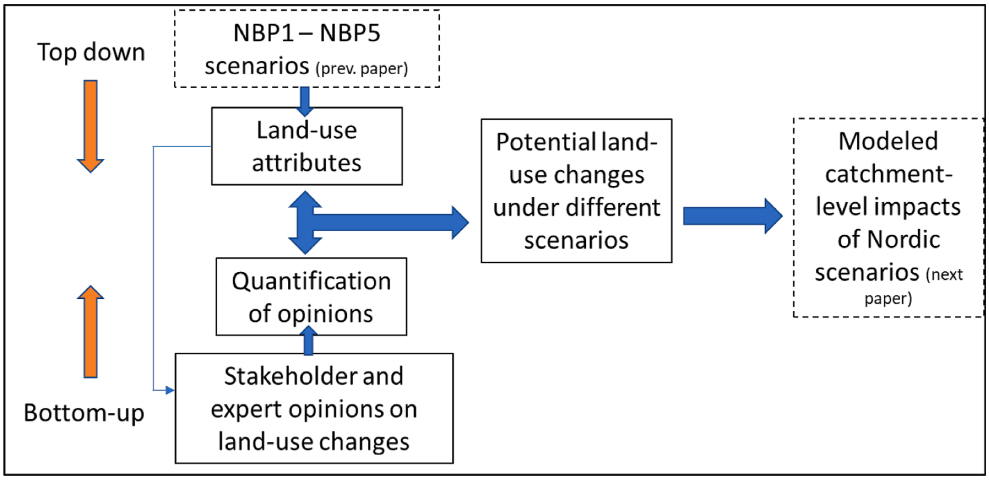

Fig. 1. Flowchart illustrating the main process used to identify potential land-use changes under different scenarios and the integration of stakeholder opinions. Further details are explained in the following sections.

of the attributes are described in Table 1 (Explanations column).

In June 2018 the draft set of attributes was presented and discussed at a two-day workshop by 30 Nordic researchers drawn primarily from the BIOWATER consortium. The researchers represented a wide cross section of disciplines related to agriculture, forestry and the bio-economy, as well as catchment sciences, including hydrological/biogeochemistry modelling and freshwater ecological impacts of land-use pressures causing eutrophication of rivers and lakes. Participants in this workshop were divided into focus groups, each led by a member of the BIOWATER core group, where the attributes were evaluated individually, and the results discussed collectively. The results of these discussions led to revision of both the attributes and the descriptions of intensity associated with these. The revised draft of attributes was then circulated among BIOWATER researchers and colleagues at their respective institutions for comments. In December 2018 the attributes and their descriptions were finalized and released for use in the national stakeholder workshops and interviews.

2.4. Stakeholder consultation

The approach used here was not meant to provide saturated results for all stakeholders (as in large-scale surveys), but rather to ask the opinions of selected knowledgeable representatives from different sectors. They all have specific experience with current land-use and their impacts on water in the case study catchments, which have been used for modeling of land-use and nutrient loads (Vermaat et al. and other papers in this issue). The individual stakeholders comprise representatives from sectoral organizations in agriculture, forestry, industry (biorefinery), NGOs and public authorities at various administrative levels. Some experts from research organizations were also consulted. The idea was to get reality-oriented inputs for further modeling. So, we opted for high quality of stakeholders and not high quantity. The invited stakeholders and research experts were put together in focus groups across sectors within each country (e.g. agriculture or forestry, biorefinery industry and water management), discussing the most likely land-use changes for the different scenarios. In addition to the groups, single additional stakeholders with the same level of knowledge and experience (who could not attend the workshops) were invited to provide their replies using the same approach as that used in the group sessions. The time frame of the workshops and additional individual consultations was from late 2018 to early 2020.

In Finland and Norway, a large variety of different stakeholder organizations were consulted, ranging from local, regional and national managers and NGOs representing agriculture, forestry, energy, industry (biorefinery) and water management in addition to high-level experts from research organizations. In Finland and Norway, 14 and 16 stakeholders, respectively, were attending a national workshop where they were divided into small groups with 3–5 people, four groups for agriculture and two for forestry. In Norway, the stakeholders considered both agriculture and forestry, focusing on the conditions in South-Eastern Norway when replying. This is the region where both agriculture and forestry are most important. Both sectors were also considered in Finland, focusing on the Simojoki catchment in the Lapland region. In Denmark and Sweden, 5 and 7 stakeholders, respectively, were invited to give their opinions on agricultural land-use. In Denmark, only agricultural land-use was considered, as this is the dominant bioeconomic sector, while there is very little forestry (Suppl. Mat. Table 1). As Danish conditions are relatively similar throughout the country, no regional or catchment focus was considered necessary. In Sweden, the stakeholders considered agricultural land-use, primarily focusing on small lowland catchments. Swedish stakeholders for forestry were also consulted in a separate process but were not able to provide replies due to difficulties with interpreting several of the attributes. Therefore, there are no results from Sweden on the forestry attributes.

The stakeholder and expert consultations performed in each country are further described in the supplementary material (Suppl. Mat. Section 3 and Table S2).

Stakeholders were first presented with descriptions of the NBPs and the characteristics which defined these, and then with the list of land-use attributes. The most and least intensive practices for each attribute were shown as start and end-points on a horizontal line (or axis) (see Suppl. Mat. section 2c. Land management systems attributes). For each attribute the stakeholders were asked to first consider the current land-use and indicate the position of this by putting a zero at the axis somewhere between the left and right end of each attribute axis (Fig. 2a). This was used as a baseline (NBP 0) for considering the positions which might be expected given the characteristics of the scenarios (NBPs 1–5). For each scenario and each attribute, the stakeholders were asked to consider the direction of a possible change from the baseline (less intensive, more intensive or no change) and the possible magnitude of the change by indicating the distance along the axis from the baseline position. These distances were indicated by putting the number of each NBP (1 – 5) on the appropriate position along the axis. Each of the attributes was designed so that the left endpoint indicated a high level of intensity, i.e. was regarded to be less environmentally friendly, while the right endpoint was the opposite (a low level of intensity and thus more environmentally friendly).

Sometimes, opinions among group members differed due to contrasting interpretations of a scenario. For example, in NBP 4 (cities first), one view was that large landowners may aggregate many current farms

Table 1
List of land-use attributes with explanations.

Agricultural attributes		
No.	**Agricultural attributes**	**Explanation**
1	Diversity of cropping systems: from simple & intense to diversified & novel	**Simple, intense:** low diversity of crops used such as alternating spring and winter cereals **Middle:** some diversity of crops used such as implementing crop rotation including ley grass **Diversified, novel:** high diversity of crops used, a complete shift from monocultures to polycultures with multiple crops planted together in novel cropping systems such as agroforestry
2	Conservation effort in tillage system: from conventional till to conservation till	**Conventional till:** no environmental considerations **Middle:** intermediate environmental consideration such as spring tillage **Conservation till:** maximum environmental consideration, such as no till, direct sowing
3	Fertiliser use: from intense, conventional to circular biological	**Intense:** mineral fertilisers, no consideration of circulation of soil nutrients **Middle:** use of manure to establish some nutrient cycling by partly replacing mineral fertilisers **Circular biological:** nitrogen fixing legumes, manure and other regional biological by-products including household waste to establish soil nutrient cycling
4	Animal husbandry: from large-scale, concentrated to small-scale, free range	**Large scale, concentrated:** large number of animals per hectare and per farm, high regional concentration of farms **Middle:** intermediate number of animals per hectare and per farm, some regional diversity **Small scale, free range:** low number of animals per hectare and per farm, high regional diversity, free range farms close to arable lands
5	Biogas production from manure: from none to complete	**None:** no biogas production from manure **Middle:** some small-scale biogas production for on farm use, some use of N and P in residues for fertiliser **Complete:** all manure is used for bioenergy generation, all possible residual N and P is used as fertiliser
6	Implementation of mitigation measures where land is taken out of production to reduce nutrient losses (e.g. buffer zones, constructed wetlands, sedimentation ponds): from none to best available	**None:** no effort, cultivation also on field edges **Middle:** uniform measures, low information costs, e.g. grass buffer strip along main surface ditch **Best available:** high effort, locally specific, high information costs, considering hydrological flow path, e.g. constructed wetland, integrated/intelligent buffer zone
7	Implementation of in-field mitigation measures which reduce nutrient losses while maintaining crop production (e.g. cover crops, soil testing, structural liming, nutrient management): from none to best available	**None:** no effort **Middle:** intermediate effort, using some general advice for nutrient management e.g. some of cover crops, soil testing, structural liming etc. **Best available:** high effort, using multiple locally specific and optimal measures for improving long term soil nutrient cycling/nutrient management
8	Catchment management strategy: from farm where possible to protect all sensitive areas.	**Farm where possible:** if the land can be farmed, it is; no consideration of sensitive areas/soils, water bodies, biodiversity, etc. **Middle:** there is production on some sensitive areas but also an interest in protecting the most vulnerable sites **Protect all sensitive areas:** no production on any sensitive area, protection of water bodies and sensitive soils, consideration of biodiversity
9	River channel management: from channeling, culverts to unbounded (free-flowing)	**Channelling, culverts:** the channel of the river has been straightened or has been hidden through the use of culverts or pipelines **Middle:** there are some active river restoration measures taken **Unbounded:** the river channel is allowed to meander freely driven by natural conditions
Forestry attributes		
No.	**Forestry attributes**	**Explanation**
1	Dominant tree species: from novel monoculture to mixed natural	**Novel monoculture:** single species stands of non-native exotic conifers (e.g. Sitka spruce, Contorta pine) or deciduous (e.g. poplar clones) **Middle:** conventional mix, Norway spruce, Scots pine and birch spp. in single or mixed species stands **Mixed natural:** local broadleaves (e.g. oak, beech, lime) and/or local coniferous trees in mixed species stands
2	Stand management: from intensified biomass to nature based	**Intensified biomass:** higher planting density (e.g. of spruce in conifer stands) and reduced thinning focussed on maximising biomass volume **Middle:** even aged stand with multiple thinnings followed by clearfelling; managed primarily for timber value **Nature based:** uneven aged stands, continuous cover forestry and a focus on non-timber or non-biomass values such as biodiversity and other ecosystem services
3	Biomass removal at harvest: from intensified to reduced	**Intensified:** greater removal of needles, branches and stumps primarily for energy production, harvesting of riparian and other currently protected areas **Middle:** stem only harvesting with forest residues (needles, leaves and branches) left on site, current protection of riparian and other sensitive areas **Reduced:** selective harvesting and a focus on non-timber or non-biomass values such as biodiversity and other ecosystem services
4	Catchment management strategy: from production forests where possible to protection of sensitive areas	**Production forests where possible:** if the land can be used for forest production, it is; there is no consideration of sensitive areas/soils, water bodies, biodiversity, etc. **Middle:** there is production on some sensitive areas but also an interest in protecting the most vulnerable sites **Protection of sensitive areas:** no production on any sensitive area, protection of water bodies and sensitive soils, consideration of biodiversity
5	Fertilizer use: from intensified to none	**Intensified:** greater rates of nutrient input, either as mineral nitrogen fertiliser or as organic residues, more frequent fertiliser applications **Middle:** single nitrogen fertiliser application late in the rotation to maximise harvestable timber value, current ash return practices **None:** no inputs of nutrients, base cations (i.e. ash return) or other elements
6	Land cover: from increased agricultural land to increased forest land	**Increased agricultural land:** more land converted to agricultural production **Middle:** current land cover proportions **Increased forest land:** more land converted to forest production

to fewer and larger farms (shown as “4 land”), while another view could be that the urban elites would prefer smaller farms with more diverse cropping systems (shown as “4 city”) (Fig. 2a). During the workshops, the facilitators and group leaders noted down key views and information from the discussions. These notes have been important when interpreting the results and are a vital background for the discussion.

2.5. Compilation of stakeholder replies

During the workshops, there were no numerical values on the axis for each attribute. A transformation from the qualitative responses into rank-scale values was performed after the workshops to allow a comparative analysis. This transformation also guided the setting of numeric input variables in catchment models for the BIOWATER case study catchments (Carstensen et al., Farkas et al., Immerzeel et al., and Rankinen et al, all this issue). The rationale for only adding ranks on the attribute axis after the workshops was twofold: (a) we wanted to avoid confusion beyond the complexity of five scenarios and to stimulate a free discussion rather than lock-ins on precise positions; (b) overall, we think it would overstretch the expertise of our participants to project future developments more precisely than ‘a bit more or less’ or ‘a lot more or less’ than the current land use.

The transformation from qualitative to ranked values was done by dividing the axis for each attribute into 11 segments going from −5 to + 5 (zero included, Fig. 2b). This segmentation transformed the responses into ranked values (integers) for the baseline (NBP 0) and the five NBP scenarios (NBPs 1–5) for each attribute. In some cases, the stakeholder replies happened to be just at the border between two rank values (Fig. 2b). In those cases, the decision of the rank value was done by one of the authors, to ensure consistency, but group leaders and their notes were consulted whenever the stakeholders’ replies were exactly at the vertical lines. For scores being very close to such borders, the knowledge rule applied was to round the value down or up depending on the position of the score, e.g. if a score was close to the left side of the border between two rank values, e.g. −4 and −3, the score was set to −4, if a score was close to the right side of the border, the score was set to −3. The rank value indicated relative distance between each of the responses. For each attribute response, the distance from the baseline (the expected change given the particular NBP characteristic) represents a change in land use intensity; i.e. a degree of environmental improvement (a move towards the right along the axis) or degradation (a move towards the left along the axis) with respect to the baseline (NBP 0).

For comparative analysis the ranked responses from the stakeholder groups in the four countries were first aggregated into median values per country to express the central tendency across the groups. This was done for each of the six scenarios (including baseline) and for each of the attributes.

The median values were then assessed in three ways, two were country specific and one was cross-country for the Nordic region. Firstly, the baseline values were calculated by country for each land-use attribute to identify the country with the highest (environmentally best) rank values and the country with the lowest (environmentally worst) rank values. In addition, the number of highest and lowest baseline rank values across the attributes for each country was calculated to assess stakeholder opinions of the current land-use concerning its environmental impacts. Secondly, the difference between the country-specific baseline score and the median score for each of the other scenarios (NBPs 1, 2, 3, 4, 5) was calculated to identify the country with the highest and lowest deviation from baseline for each attribute and for each scenario across attributes. The country with the highest positive difference for most of the attributes represents the country where the stakeholders expect the largest environmental improvement, while the country with the highest negative difference represents the country where the stakeholders expect the largest environmental deterioration.

Thirdly, the median value and the quartiles (25th and 75th percentiles) of the rank values were calculated across all groups in all four countries for each attribute and each scenario (including the baseline) to allow evaluation at the regional (Nordic) level. Quartiles were selected to show the divergence of opinions across groups instead of ranges, which are more prone to outliers. To compare the overall divergence of opinions between the scenarios, we calculated the sum of quartiles across all the agricultural attributes. For forestry, there were only 4 groups, which would not allow the calculation of quartiles. Instead we calculated ranges of opinions for each attribute and the sum of the ranges across all the forestry attributes. The cross-country comparison would mainly be representative for small-medium sized lowland agricultural catchments and for medium-large spruce-dominated forested catchments, which also reflects the types of case study catchments used for modeling, (Carstensen et al., 2023; Farkas et al., 2023).

3. Results

3.1. Examples of primary results for single land-use attributes

The primary compilation of replies from the stakeholders and experts in the different Nordic countries for each attribute was used as a basis for further comparison of similarities and differences in stakeholder replies between the countries. Such primary results are illustrated below for one agricultural attribute and one forestry attribute. For the other attributes listed in table 1, the primary results are given in the Supplementary Material (Sections 4 & 5). Notes made during the workshops and interviews have been used to tentatively explain the variations in answers between countries.

3.1.1. Attribute Agri #6. Taking land out of production (to replace with buffer zones, wetlands, sedimentation ponds): From none to best available.

Taking land out of food production and replacing it with permanently vegetated land or wetlands/ponds are costly measures for the farmers and/or for the society (Jacobsen and Hansen, 2016). For the current situation (NBP 0), the replies indicated that such measures are used to a very little extent in Sweden, scoring −4 on the axis in Fig. 3. In the other Nordic countries, the extent of such measures was estimated to be larger than in Sweden, with Finland having a slightly higher extent (score close to zero) than Norway and Denmark (scores close to −1).

For the sustainability first scenario (NBP 1), the replies were quite consistent across all countries that such measures (buffer zones, wetlands, sedimentation ponds) would be used to a much larger extent than today. In the business-as-usual scenario (NBP 2), as well as the cities first scenario (NBP 4), the countries in general scored around ‘zero’, which reflected a 50–50 distribution between developing vegetation/wetlands or cultivating the land. All the countries believed that this measure would increase in NBP 2 and NBP 4 as compared to the current situation (NBP 0). In the self-sufficiency scenario (NBP 3), the stakeholders and experts in all countries except Denmark believed that most land would be used for food production, and little land would be ‘saved’ for more permanently vegetated land or wetlands. The Danish stakeholders assumed that the extent of such measures would not be much different from the current situation (NBP 0). This deviating result for Denmark can be explained by the current land-use in Denmark, where 55% of the total area is used for intensive agriculture, in contrast to 3–6% in the other Nordic countries (Supplementary Material and Table S1). Interestingly, in the maximum growth scenario (NBP 5), Finland and Denmark are assumed to use almost all the suitable land for agricultural production, whereas Norway and Sweden assumed that less land would be needed. For Norway’s part, the assumption was that in the NBP 5, the world would still depend on oil and gas, thus no more land than today would be needed for agricultural production, as food and fodder could be imported, and the mitigation measures could be implemented to safeguard natural lands and water resources. For Sweden, the rationale was that with maximum economic growth, the costs for such measures could be more easily covered by society than today.

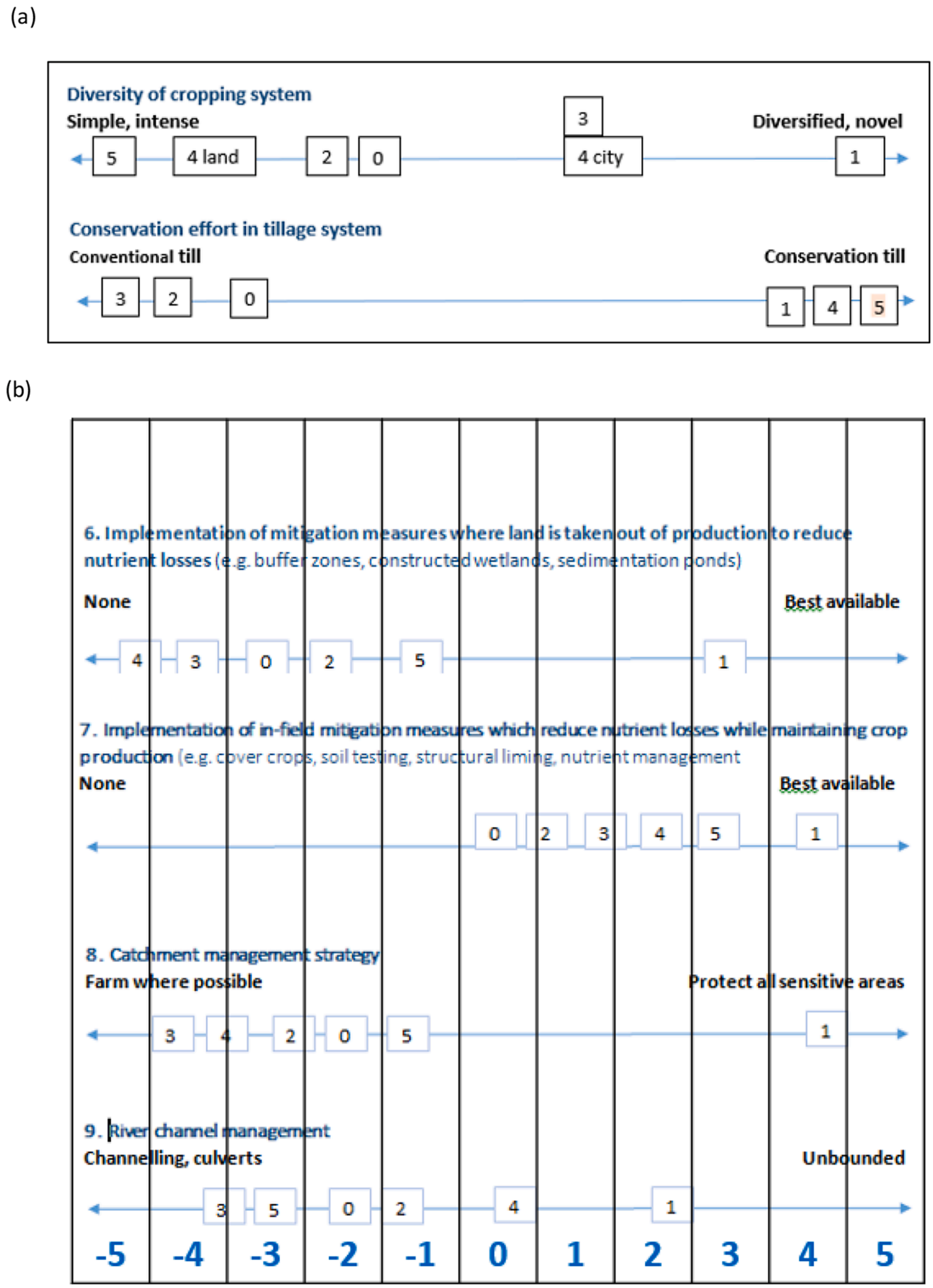

Fig. 2. An example of the templates used to collect stakeholder opinions for various land-use attributes (see Suppl. Mat. section 2 for further details). a) sheet with scenario numbers for the different Nordic Bioeconomic pathways (NBPs 0, 1, 2, 3, 4, 5) along the axis from left to right for each attribute; the location of the different scenarios along the axis reflects the opinion of one stakeholder or a group of stakeholders; example shows two attributes from the Norwegian workshop; NBP 4 was sometimes put in two different positions along the axis due to diverging interpretations among the stakeholders. This is seen as “4 land” and “4 city” b) Examples of results from the Finnish workshop showing the stakeholder opinions for a set of attributes and vertical lines dividing the axes into ten segments numbered from – 5 to + 5 (blue numbers at the bottom of the sheet) to allow ranking of the stakeholder opinions.

3.1.2. Attribute Forestry #4: Catchment management strategy: From production forests where possible to protection of sensitive areas

The trend in catchment management has been towards methods that have reduced environmental footprint or given some protection of the natural environment to preserve biodiversity and other values. In Finland, the current situation (NBP 0) is therefore quite balanced between the conventional forestry production and the environmental protection needs, giving a score of zero in Fig. 4. In Norway, less forest is protected and there is considerable resistance amongst forest owners against more protection. Therefore, the stakeholders put more weight to conventional forestry production versus nature protection, thus giving a score of −1 for NBP 0 in Fig. 4. For NBP 2, business as usual, the trend towards more environmental protection (green values) is expected to increase slightly in both countries compared to the current situation (NPB 0). For NBP 1, sustainability first, the protection of sensitive areas is expected to increase considerably in both countries, as society accepts protection. For NBP 3, self-sufficiency, the stakeholders in both countries expect forestry production to be prioritized even in many sensitive areas, especially in Norway. In cities first (NBP 4), city people are expected to want nature protection close to the cities but willing to prioritize forestry production elsewhere in order to substitute fossil fuel energy and other products. In NBP 5, maximum growth, more forestry production is expected in both countries, but more in Finland than in Norway where fossil fuels will still be the dominant source of energy and economic growth, the timber price is high and thus export is more difficult.

3.2. Opinions on agricultural land use

3.2.1. Agriculture baseline (NBP 0)

The overall scores for NBP 0, which represents the current situation in the different countries, are on the average less than zero in all the four Nordic countries (Table 2). The stakeholders in Sweden and Norway consider the present state of agricultural practices to be negative for the environment. In Denmark, which has a much larger agricultural sector than the other countries, the stakeholders also consider the present practices to be negative for the environment. The Finnish stakeholders consider the current agricultural practices to be more environment-friendly than the stakeholders in the other countries but still on the negative side for five of the nine attributes.

Biogas production from manure got low scores in the current situation, as such production is relatively small in all the four countries at present, although such production has increased substantially during the later years (Weltec Biopower commissions liquid manure biogas plant in Finland | Bioenergy International, Ahlberg-Eliasson et al., 2021, Biogas in Denmark | Energistyrelsen (ens.dk), Esteves et al. 2019, Lyng et al. 2015). In contrast, in-field mitigation measures, including cover crops and soil testing, got higher scores, indicating that such measures are applied to a moderate extent in most of the countries, while in Norway, the stakeholders indicate only limited use (score −3).

3.2.2. Deviation from baseline for the different scenarios

Country-specific deviations from the baseline for each scenario (NBPs 1, 2, 3, 4, 5) and each attribute are given in the Suppl. Mat., section 5. A positive deviation from the baseline means that environmental improvement is expected by the stakeholders, while a negative deviation means that environmental deterioration is expected. To analyze potential differences between these expectations in the different countries, we have counted the number of attributes with the most positive deviation from the baseline and the most negative deviation from the baseline. This analysis reveals some large differences between the countries (Table 3).

For the NBP 1 scenario, sustainability first, Norway is expected to have the largest improvement for 8 of the 9 agricultural attributes, while Sweden is expected to have the least improvement for 8 of the 9 attributes. This striking result could be caused by a main focus on the sustainability related to water resources by the Norwegian stakeholders, while the Swedish stakeholders have included also wider aspects of sustainability related to climate change mitigation, such as eating less meat, which would mean converting grasslands that are currently used to produce fodder for animals to cereals or legumes, which would need more fertilization and more tillage. In Norway, the potential for such a conversion is more limited than in Sweden due to many current grasslands not being suitable for cereals or legumes due to harsher natural conditions, especially in Western and Northern Norway.

For the NBP 2 scenario, business-as-usual, the most striking difference was found between Finland and Denmark, where Finland is expected to have the largest improvement for 7 of the 9 agricultural attributes, while Denmark is expected to have the smallest improvement for 6 of the 9 attributes. This difference may be due to the difference in the current situation (Table 2) and the trends that the stakeholders have observed.

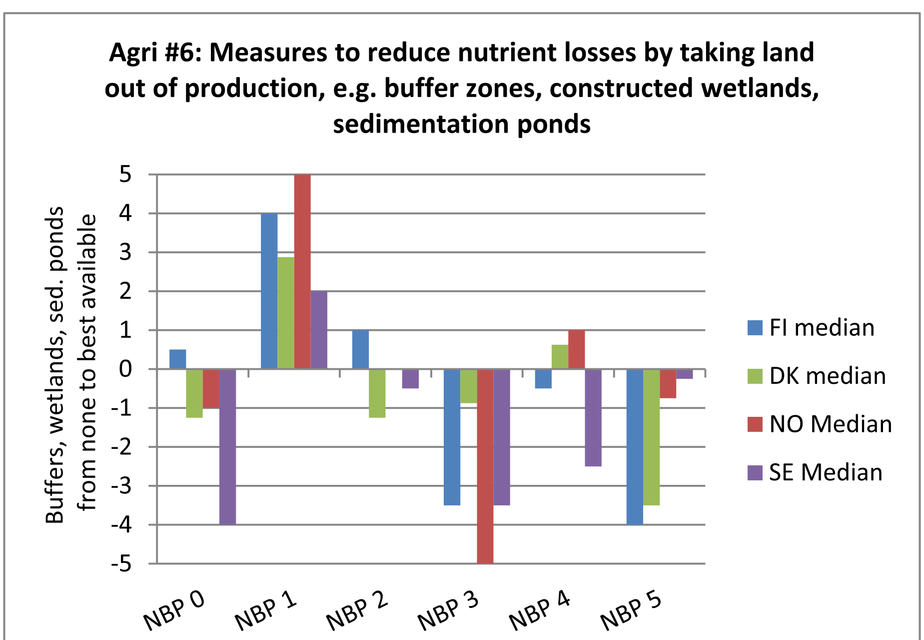

Fig. 3. Agricultural attribute no. 6: Implementation of mitigation measures where land is taken out of production to reduce nutrient losses (e.g. buffer zones, constructed wetlands, sedimentation ponds): from none to best available. The bars show the median scores of all stakeholder groups in each country for each of the scenarios: Nordic bioeconomic pathways 0: current situation, 1: sustainability first, 2: Business as usual, 3: Self-sufficiency, 4: Cities first, 5: Maximum growth.

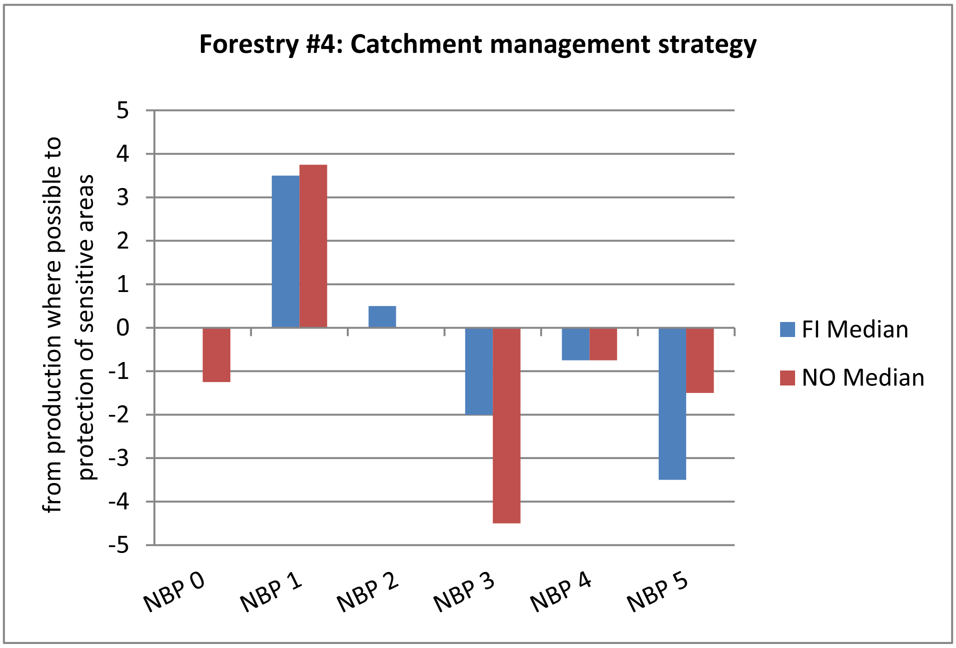

Fig. 4. Forestry #4: Catchment management strategy: from production forests where possible to protection of sensitive areas. The bars show the median scores of all stakeholder groups in each country for each of the scenarios: Nordic bioeconomic pathways 0: current situation, 1: sustainability first, 2: Business as usual, 3: Self-sufficiency, 4: Cities first, 5: Maximum growth.

For the NBP 3 scenario, self-sufficiency first, the results here are also very different in Denmark versus Finland and Norway, where Denmark is expected to have the largest improvements for 5 of the 9 attributes, while Finland and Norway are expected to have the smallest improvement for 6 and 5 attributes, respectively. Again, the large difference could be due to a difference in the baselines of Denmark versus Finland and Norway, where Denmark is seen as having a far less environmentally friendly current agriculture than Finland. Denmark can achieve more self-sufficiency simply by using more of their currently high agricultural production rather than exporting a lot to other countries. Therefore, the stakeholders could assume that Denmark is more likely to improve their current agricultural policy to become more environmental-friendly. In contrast, Finland and Norway have a small agricultural production and would need to increase that to become less dependent on imported food. Thereby, many of the agricultural attributes could be expected to change to a less environmental-friendly practice.

The NBP 4, cities first, did not show major differences between the countries. This pattern could be due to multiple interpretations concerning the agricultural impact on the environment in that scenario, as the urban elites might dictate the protection of environment close to cities, as well as close to leisure houses in the countryside, but simultaneously demand more local food production in most of the countryside. The only exception from this pattern is found for Sweden, where only one of the attributes were expected to have large improvements, while 5 of the attributes were expected to have negative impacts on the environment.

For the last scenario, NBP 5, maximum economic growth, the major difference between the countries is found for Finland and Sweden, where Finland is expected to have the largest deterioration for 8 attributes, while Sweden has the largest improvement for 7 attributes. This could be due to baseline differences, as Finland is perceived by the stakeholders to have quite environmental-friendly agriculture, while the opposite is expected for Sweden (Table 2). Therefore, the stakeholders expect less room for further improvement in Finland than in Sweden.

Table 2
Baseline scores (NBP 0) for AGRICULTURAL attributes in the four Nordic countries.

Agricultural attributes		DK	FI	NO	SE
Agri #1	Diversity of cropping systems	−2	−1	−2	−2
Agri #2	Conservation effort in tillage system	−2	1	−2	−2
Agri #3	Fertiliser use	−1	0	−3	0
Agri #4	Animal husbandry	−3	−2	1	−1
Agri #5	Biogas production from manure	−2	−3	−4	−4
Agri #6	Mitigation measures where land is taken out of production	−1	0	−1	−4
Agri #7	In-field mitigation measures cover crops, soil testing	1	2	−3	1
Agri #8	Catchment management strategy	−2	−2	−1	−4
Agri #9	River channel management	−3	−1	−2	−2

3.3. Opinions on forestry land-use

3.3.1. Forestry baseline (NBP 0)

The overall scores for NBP 0, which represents the current situation in the countries, are zero or close to zero (+1 or −1) in both Finland and Norway and the differences are small between the countries for most of the attributes (Table 4). This means that the stakeholders in both countries agree that current forestry has moderate environmental impacts.

For attribute #1, the forestry in Finland is seen as much closer to mixed natural (score 3) than the Norwegian one (score 0). This difference can be due to the quite dense spruce dominated forests seen in many parts of Norway today, including the alien sitka spruce forests in Western Norway. The other attribute with quite big difference between the two countries is #5 Fertilizer use, where the Norwegian score (3) is much better than the Finnish score (0). This is probably due to very little fertilization of forests in Norway today, which is only tested in small areas (Kaste et al. 2021). The Finnish forestry is perceived to use fertilization to a larger degree, although the score of 0 indicate that this done only to a quite small extent.

The forestry attribute with the most negative baseline score is #2 Stand management ranging from intensified biomass to nature-based management. The median scores in the two countries are slightly

Table 3
Count of AGRICULTURAL attributes with the largest improvement (# best) and the smallest improvement or largest deterioration (# worst). Countries with a count of 5 or more are given in bold font. Details for each attribute are given in the Suppl. Mat. Table S3a.

Country	Deviations from baseline	NBP 1 Sustainability first	NBP 2 Business-as-usual	NBP 3 Self-sufficiency first	NBP 4 Cities first	NBP 5 Max economic growth
DK	# best	1	0	**5**	3	0
	# worst	2	**6**	0	2	3
FI	# best	1	**7**	2	4	1
	# worst	1	0	**6**	3	**8**
NO	# best	**8**	4	1	**5**	**5**
	# worst	0	4	**5**	3	0
SE	# best	1	4	4	1	**7**
	# worst	**8**	3	0	**5**	0

negative (-1 or −2). The Norwegian stakeholders had quite a disagreement on this attribute, however, ranging from the extreme negative end of the scale (-5) to the middle (0).

3.3.2. Deviation from baseline for the different scenarios

As for agriculture above, we have counted the number of attributes with the most positive deviation from the baseline and the most negative deviation from the baseline (Table 5). This analysis is based on the detailed results given in the Suppl. Mat., section 5. The differences between Finland and Norway are quite small for NBP 4, where the countries have the same number of most positive and most negative deviations from the baseline. There are however quite large differences in the deviations for several attributes in these scenarios, which are briefly discussed below. For NBP3 and NBP5, the differences are larger with Finland being expected to have more negative deviations than Norway for most of the attributes (Table 5).

For the NBP 1, Finland is expected to be slightly better than Norway for the forestry attribute #1, dominant tree species moving towards more mixed natural forests. The baseline for this attribute is quite different between the two countries, with higher scores given by the Finnish stakeholders (3) than by the Norwegian stakeholders (0) (Table 4). This expectation therefore indicates a more ambitious expectation of further change towards more mixed natural forests among the Finnish stakeholders than among the Norwegian stakeholders. Attributes #2, Stand management, and #4 Catchment management are expected to move strongly towards the best environmental forestry going from rather intensified biomass to more nature-based stand management and towards more protection of sensitive areas, which is quite logical under this scenario. For attribute #3, Biomass removal at harvest, and attribute # 5, Fertilizer use, the deviation is much more positive for Finland than for Norway, indicating that the Norwegian stakeholders see a larger need for wood fiber for substituting fossil fuel products, while the Finnish stakeholders put more emphasis to biodiversity and other ecosystem services. The last attribute #6, Land cover change, show a slight change in opposite directions in the two countries with Finland moving towards more agricultural land and Norway towards more forested areas. These responses could be due to Finnish stakeholders emphasizing the need for more local food production, while the Norwegian ones emphasize the need to reduce the impact of agriculture on water quality, as well as to get more wood fiber to substitute fossil fuel products.

Table 4
Baseline scores (NBP 0) for FORESTRY attributes in Finland (FI) and Norway (NO) (no data from Denmark and Sweden, see Materials and methods).

Forestry attributes		**FI**	**NO**
Forestry #1	Dominant tree species	3	0
Forestry #2	Stand management from intense to nature-based	−1	−2
Forestry #3	Biomass removal at harvest	−1	0
Forestry #4	Catchment management strategy	0	−1
Forestry #5	Fertilizer use	0	3
Forestry #6	Land cover: from agriculture to forest	0	−1

For NBP 2, business-as-usual, the deviations from the baseline are quite similar for the two countries for attributes #2, 3, 4 and 6, mostly indicating a small to moderate change towards more environmental-friendly forestry in both countries. For attribute #1, dominant tree species, the expectation for Finland is a move towards more mixed natural forests in the future when the current policies are continued. In Norway, however, the continuation of current policies is expected to cause a slight change towards more monocultures. For the attribute #5 on fertilizer use, the deviations show that the stakeholders in Finland expect a small change towards less fertilization, while in Norway the opinions are that fertilization is likely to increase with the continuation of the current policies.

For NBP 3, self-sufficiency, the differences between Finland and Norway are larger than for NBP 2 for most of the attributes: For Finland, the deviations from the baseline indicate a moderate change towards more intensive forestry. For Norway, the deviations from the baseline vary between the attributes from expecting quite massive change towards more fertilization (attribute #5) and less protection of sensitive areas in catchment management (attribute #4) to minor deviations from the baseline for the other attributes. The reason for those minor deviations may be related to the huge hydropower sector in Norway, which means less need for biomass for energy production.

For NBP 4, cities first, the differences between the two countries for deviations from the baseline were moderate to large with largest differences for the attributes #1, 5 and 6. For Norway, the deviation is expected to change towards more fertilization, but also more agricultural land, while in Finland, the deviations are opposite for the same attributes, showing a slight change towards less fertilization and more forest areas. For attribute #1, dominant tree species, the differences are opposite from those seen for the attributes #5 and 6. Here, Finland is expected to move towards more monocultures, while in Norway the expectation is a move towards more mixed natural forests. The Norwegian opinions may be related to the need for urban populations to find more natural forests for recreation. The Finnish expectation towards more monocultures was related to the push from urban elites to use more renewable forest biomass for heating houses/apartments in cities instead of using fossil fuels (e.g. gas) or electricity generated by nuclear power.

For NBP 5, maximum economic growth, the differences between the countries are larger than for any of the other scenarios. Finland expects a larger change towards more intensive forestry than Norway for most of the attributes, except for fertilizer use, where Norway is expected to have a larger change than Finland towards more fertilization. The landcover (attribute #6) is expected to change towards more forests and less agricultural areas in both countries, but a smaller change is expected in Finland than in Norway. The latter can be due to the higher importance of forestry for generating income from export in Finland than in Norway, where fossil fuels are expected to remain the major income source under this scenario.

Table 5
Count of FORESTRY attributes with the largest improvement (#best) and the smallest improvement or largest deterioration (# worst). Countries with a count of 4 or more are given in bold font. Details for each attribute are given in the Suppl. Mat. Table S3b.

Country	Deviations from baseline	NBP 1 sustainability	NBP 2 business-as-usual	NBP 3 self-sufficiency	NBP 4 cities first	NBP 5 max economic growth
FI	# best	4	5	2	3	1
	# worst	2	1	4	3	5
NO	# best	3	3	4	3	5
	# worst	3	3	2	3	1

3.4. Synthesis of replies for the Nordic region for the different scenarios and attributes

The compilation of all the replies given across the Nordic countries reveals some striking patterns among the scenarios for agriculture (Table 6) and forestry (Table 7). The patterns are presented and discussed below, including insight gained during the stakeholder interactions, to highlight consistencies and divergence in opinions about potential future land-use for lowland, small-medium agricultural catchments in the Nordic region as a whole. For forestry, the results are only representative for medium-large forested catchments dominated by spruce in Finland and Norway.

3.4.1. Agriculture

The current situation (NBP 0) was the situation the stakeholders already were familiar with and was seen to have negative impacts on the environment for most of the attributes (Table 6). The most negative impact was seen for attribute #4 Biogas production from manure, as this is quite negligible so far in Norway, Finland and Sweden, although a more comprehensive in Denmark. Also attribute #8 related to protection of sensitive areas got a clearly negative median value (-3). Only NBP 3 (self-sufficiency) and NBP 5 (maximum growth) had agricultural practices more damaging to the environment than the current situation (many red-coloured cells in Table 6).

Interestingly, NBP 2 (business as usual) depicts a tendency towards more environmentally friendly practices in agriculture compared to the current situation (NBP 2 show many green cells in Table 6). Hence, the stakeholders of Nordic countries see a general trend towards improved protection of water resources for most of the attributes related to agriculture. Such improvements could be related to technological progress providing possibilities for precision farming concerning more targeted fertilization, tillage, irrigation and biogas production from manure. However, for diversity of cropping systems and animal husbandry, no improvements were expected. The quartiles are however overlapping between the baseline and NBP 2, so the seemingly small improvements indicated by the median values may not be real changes compared to the baseline.

Not surprisingly, in NBP 1 (sustainability first) the four countries chose the most environmentally friendly agricultural practices for all nine attributes. Whether this will ensure food security is not part of the assessment, as this scenario is mainly focusing on environmental issues related to water quality. Thus, NBP 3, with a focus on self-sufficiency, is interesting in this regard: Here, the changes from the current situation are especially noted in the intensification of animal production towards large scale and concentrated (Agri #4); and that all available land areas will be used for food production (Agri#6). The only move towards more environmentally friendly practices in this scenario are more diversified cropping systems (Agri#1) (probably due to the need to produce a variety of crops for food consumption) and increased biogas production (Agri#5).

NBP 4 is the 'cities first'-scenario, which is described by Rakovic et al. 2020 as a situation with "unequal investments in human development and rising differences in economic opportunity and political power, a gap widens across and within countries between a small affluent elite and underprivileged lower-income groups". This was the scenario with quite large divergence of opinions between the stakeholders within each country. An example from the Norwegian stakeholder workshop is the following confusion: Should we assume that this scenario entails a group of 'land owners', living in the cities and exploiting the land, although feeling the need to appear environmental and therefore maintaining a sustainable profile on, at least, the lands closest to the cities; or should we assume that the country-side is mainly forgotten, and we import the food we need in addition to whatever we can gain from the country's own agriculture? Typically, this scenario would often have two diverging answers on the extreme right and left would get a median around zero on the scale shown in Fig. 2b. Hence, the results of is difficult to interpret.

The NBP 5-scenario with maximum growth as the main goal was seen as the scenario that likely will have the most negative impact on environment and water quality (mostly red colours in Table 6). This scenario also got the highest divergence in opinions (=highest sum of quartiles across all the agricultural attributes in Table 6). This scenario represents a future where we still rely on fossil fuels, and therefore a bioeconomy with a high dependence on local food production and biomass extraction was thought to be less developed. In Norway, where fossil fuels are exploited, this scenario could mean business as usual, importing the food needed from income gained from oil and gas exports, whereas in an agricultural country like Denmark, this scenario could mean intensified agriculture. In Sweden and Finland, intensification of both agriculture and forestry might be foreseen. However, if fossil fuels are to be exploited also in the future, the stakeholders anticipate the same situation as the baseline for two attributes: increased production of biogas from manure (Agri#5), and protection of sensitive areas from farming (Agri#8) (both indicated with no colour in Table 6).

3.4.2. Forestry

The results for Finland and Norway are shown in Table 7. There are no results from Denmark and Sweden, as explained in the Methods.

The current situation (NBP 0) was the situation the stakeholders already were familiar with. It was considered very close to the middle of the scale (median score from -1 to $+1$) for most of the attributes. Fertilizing of forests (attribute #5) is not much used today, so got the most positive median value (+2). Only NBP3 (self-sufficiency) and NBP5 (maximum growth) are envisaged to result in environmentally adverse forestry practices with median scores -2 and -3 respectively across all the attributes (Table 7).

Interestingly, NBP 2 (business as usual) depicts a slight tendency towards more environmentally friendly forestry practices compared to the current situation for some attributes (NBP 2 median score $+ 1$). Hence, the stakeholders in Finland and Norway see a slight general trend towards improved protection of water resources for three of the six forestry attributes, no change for the dominant tree species and for biomass removal at harvest, while fertilizer use is expected to have slightly worse impact than the baseline. The attributes expected to improve in NBP 2 may be related to increased political focus on the green shift, as well as taking technological innovations into account (e.g. traceless forestry, Øvergård 2018).

Not surprisingly, in NBP 1 (sustainability first) the two countries chose the most environmentally friendly forestry practices concerning biodiversity and water quality for five of the six attributes, showing

Table 6
Agricultural land-use attributes and scenarios: median values of scores along an axis from −5 to + 5 and divergence of opinions given as quartiles across the group replies (25th and 75th percentiles) in stakeholder opinions across Nordic countries. Colour coding of median values: current = no colour (baseline); green = more environment-friendly than baseline; light green = slightly more environment-friendly than baseline; purple = less environment-friendly than baseline; light purple = slightly less environment-friendly than baseline.

Attribute no.	Attribute description	Scenarios	NBP 0 Current situation	NBP 1 Sustainability first	NBP 2 Business as usual	NBP 3 Self-sufficiency	NBP 4 Cities first	NBP 5 Maximum growth	N (# groups)
Agri #1	Diversity of cropping system: from simple intense to diversified novel	Median	-2	3	-2	-1	-2	-4	13
		25th %ile	-2,0	2,5	-3,0	-2,0	-4,0	-4,5	
		75th %ile	-1,5	5,0	-1,5	1,0	-1,0	-2,0	
Agri #2	Conservation efforts in tillage system: from conventional to conservation effort	Median	-2	3	-1	-2	1	-1	12
		25th %ile	-2,0	2,5	-1,6	-3,1	-0,4	-2,6	
		75th %ile	0,0	4,3	0,3	-1,0	2,0	-0,4	
Agri #3	Fertilizer use: From intense conventional to circular biological	Median	0	4	-1	0	0	-1	12
		25th %ile	-2,0	2,8	-1,3	-1,8	-2,3	-4,0	
		75th %ile	0,0	5,0	0,3	1,0	1,3	-0,6	
Agri #4	Animal husbandry: From large scale concentrated to small scale free range	Median	-1	1	-1	-3	-1	-4	12
		25th %ile	-2,0	0,0	-2,3	-3,0	-3,1	-5,0	
		75th %ile	-0,8	2,3	-0,8	-1,8	-0,8	-1,4	
Agri #5	Biogas from manure. From none to complete	Median	-4	3	-2	-1	-1	-4	13
		25th %ile	-4,0	0,0	-3,0	-1,0	-3,0	-4,0	
		75th %ile	-2,5	4,0	0,0	1,0	0,0	-2,5	
Agri #6	Measures to reduce nutrient losses by taking land out of production (to replace with buffer zones, wetlands, sedimentation ponds): From none to best available	Median	-1	4	0	-4	-1	-3	13
		25th %ile	-4,0	2,0	-1,0	-4,5	-2,0	-4,0	
		75th %ile	0,0	4,0	0,0	-3,0	1,0	-0,5	
Agri #7	In-field measures (other than till and fertilization); such as cover crops, soil testing: From none to best available	Median	1	4	1	2	0	-2	13
		25th %ile	-1,0	3,5	0,3	-3,0	-1,0	-3,0	
		75th %ile	1,0	5,0	2,0	2,0	1,5	2,0	
Agri #8	Catchment management strategy: From farm wherever possible, to protect sensitive areas	Median	-3	4	-1	-4	0	-3	13
		25th %ile	-4,0	2,0	-3,0	-5,0	-3,0	-4,0	
		75th %ile	-1,0	4,0	0,5	-2,0	2,0	-0,3	
Agri #9	River channel management. From a high degree of channelling with culverts, to restoration and unbounded, meandering channels	Median	-2	3	0	-3	0	-4	13
		25th %ile	-2,0	0,8	-2,0	-3,5	-1,5	-4,0	
		75th %ile	-2,0	4,0	1,0	-1,5	1,0	-2,1	
Agri all	Median values per scenario across all attributes	Median	-2	3	-1	-2	0	-3	
	Divergence of opinions across all attribute expressed as absolute sum of quartiles	Sum of quartiles	16	22	19	23	27	27	

Table 7
Forestry land-use attributes and scenarios: median values of scores along an axis from −5 to + 5 and divergence of opinions given as quartiles across the group replies (25th and 75th percentiles) across Nordic countries. Colour coding of median values: current = no colour (baseline); green = more environment-friendly than baseline; light green = slightly more environment-friendly than baseline; purple = less environment-friendly than baseline; light purple = slightly less environment-friendly than baseline.

Attribute no.	Attribute description	Scenarios metrics	NBP 0 Current situation	NBP 1 Sustainability first	NBP 2 Business as usual	NBP 3 Self-sufficiency	NBP 4 Cities first	NBP 5 Maximum growth	N (# groups)
Forestry #1	Dominant tree species: from non-native monoculture to mixed natural	Median	1	3	1	1	2	-2	4
		Minimum	0,0	0,5	-1,0	0,0	-2,0	-5,0	
		Maximum	4,0	5,0	4,0	2,0	4,0	2,0	
Forestry #2	Stand management from intensified biomass volume to nature-based biodiversity	Median	-1	4	1	-3	-1	-4	4
		Minimum	-3,0	2,5	-1,0	-4,0	-3,0	-5,0	
		Maximum	0,0	4,0	1,0	1,0	2,5	0,0	
Forestry #3	Biomass removal at harvest: from intensified to reduced	Median	0	3	0	-2	1	-1	4
		Minimum	-2,0	-0,8	-3,0	-5,0	0,0	-5,0	
		Maximum	0,0	4,0	2,0	4,5	2,0	0,0	
Forestry #4	Catchment management: from production where possible to protection of sensitive areas	Median	-1	4	0	-3	-1	-4	4
		Minimum	-2,0	3,0	-1,0	-5,0	-4,5	-4,0	
		Maximum	1,0	4,5	2,0	-2,0	3,0	1,0	
Forestry #5	Fertilizer use: from intensified to none	Median	2	1	1	-2	1	-4	4
		Minimum	-1,0	0,0	-1,0	-5,0	-4,0	-5,0	
		Maximum	4,5	3,5	3,0	1,0	4,0	-3,0	
Forestry #6	Major land cover types: from increased agricultural area to increased forest area	Median	0	1	1	-2	-2	3	4
		Minimum	-1,0	-4,0	-1,0	-5,0	-4,0	1,0	
		Maximum	0,0	2,0	2,0	3,0	2,5	5,0	
Forestry all	Median values per scenario across all attributes	Median	0	3	1	-2	0	-3	
	Divergence of opinions across all attribute expressed as absolute sum of ranges	Sum of ranges	19	22	22	34	36	28	

considerable improvement compared to the baseline for stand management (moving towards more nature-based biodiversity), for biomass removal at harvest (moving towards reduced removal) and for catchment management (moving towards more protection of sensitive areas). The only attribute with a change towards less environmentally beneficial forestry practices is fertilizer use (forestry #5), which is expected to be slightly intensified due to the need to intensify forestry to increase carbon sequestration to mitigate climate change. On the other hand, there is also a need to protect natural forests to enhance biodiversity and water quality, in line with the Biodiversity Strategy 2030, the upcoming Nature Restoration Law and the WFD.

Whether NBP 1 will ensure adequate provision of timber and other forest products for biofuels and fiber for bioeconomic industries is not part of the assessment, as this scenario is mainly focusing on environmental issues related to water quality and biodiversity. Thus, NBP 3, with a focus on self-sufficiency, is interesting in this regard: Here, the changes from the current situation imply an intensification of current forestry practices for five of the six attributes, especially noted in stand management (Forestry #2), catchment management (Forestry #4), fertilizer use (Forestry #5) and a change towards more agricultural areas and less forested areas (Forestry #6) (Table 7), as one might expect a demand to produce more domestic timber, biofuels, fibre, fodder and food in the Nordic countries. The NBP 3 got the second lowest median score (-2), indicating a change with negative impacts on the environment, concerning biodiversity and water quality. However, this scenario could still be beneficial for carbon sequestration, thus could be seen as a way to mitigate climate change.

The NBP 4, 'cities first', got a median value of 0, which is the same as the baseline score (Table 7). Most of the attributes show only slight deviation from the baseline. As noted under the discussion on agriculture, this scenario would often have two diverging answers, the median of which often became close to zero. The attribute on major land cover change (Forestry #6) show the largest environmental deterioration compared to the baseline (purple colour in Table 7). Thus, these results could be due to assumptions that urban populations would prefer more fertilisation of forests and at the same time decrease the proportion of forested areas, thereby keeping the production of forest products at a reasonable level, as well as providing more land for agriculture to produce local food.

The NBP 5-scenario with maximum growth as the main goal was seen as the scenario that is likely to have the most negative impact on the environment and water quality (median score −3 in Table 7). This scenario represents a future where we still rely on fossil fuels, and therefore bioeconomy with a high dependence on local food production and biomass extraction may be less developed. However, the stakeholders anticipated a substantial intensification of forestry, seen as negative scores for all the attributes, except the major land cover types (Forestry #6), where forested areas would increase, and agricultural areas decrease. The latter could be related to the increased profits based on importing food from low-cost countries rather than producing local food in the high-cost Nordic countries.

Altogether, for the forestry attributes linked to water resources issues, expert opinions suggest that the scenario NBP 1 was best suited to protect the environment, focusing on water quality and biodiversity, whereas NBP 3 and NBP 5 were the environmentally worst scenarios. For NBP 4, the median score was the same as the baseline, but the results were highly divergent, as described above.

4. Discussion

4.1. Limitations of the work

The stakeholders are not necessarily representative for all stakeholders in agriculture and forestry in the four countries but were invited to participate in the workshops due to their considerable skills and experience within agriculture and/or forestry in particular in the case study catchments selected for modeling of land-use and nutrient loads (Carstensen et al., Farkas et al., Immerzeel et al., and Rankinen et al, all this issue). The stakeholder opinions are therefore likely to be most reliable for these catchment types.

The decision to use clean attribute axes without any indicator of scale with ranked values during the workshops and rank the opinions only after the workshop was a conscious choice that may receive criticism. We explained in the methods section that we were cautious not to confuse participants with too many numbers. We were aware that opinions on a future development are inherently uncertain but envisaging a relative position for each of the NBPs would be feasible for the stakeholders. During the workshops, participants were invited to think towards the future, rather than to remain in a passive "I don't know" position. Together with evolving group discussions, this could have led to a lock-in towards extreme opinions, but the overall rank scoring does not suggest that such has happened. On the contrary, the stakeholders listened to each other and were mostly able to agree on one position for each NBP in each attribute. Therefore, we ranked the opinions, which is the most appropriate approach for aggregate comparisons (Kok et al. 2011; Sheppard et al, 2011).

An important limitation is the lack of input on forestry attributes from Sweden and the limited number of respondents overall (n = 15 participants, see Table S2, divided into 4 groups). The median values are therefore rather uncertain for each of the forestry attributes, which is also seen from the wide ranges of opinions for many of the attributes and scenarios (Table 7). However, summarising the ranges across the six forestry attributes for each scenario (Table 7) still provides an indication of which scenario had the least and most divergence of opinions.

4.2. Is the framework of NBPs and the land use attributes useful for discussions with stakeholders?

Our fear was that stakeholders would find our NBP and attributes' exercise somewhat academic, difficult to grasp at a short time, and of less interest in their day-to-day work, hence be sceptic about the validity of the approach. Instead we experienced an active engagement in the discussions and or interviews. Thus, our approach appears suited for stakeholder consultations on future land use changes and their possible environmental effects. These group discussions and calibration of the views of practitioners supports directions chosen for the selected attributes across NBPs in the modelling exercises reported in Carstensen et al., Farkas et al., Immerzeel et al.

4.2.1. Agriculture

In general, the stakeholders had relatively consistent views on how the agricultural land-use attributes would develop under a sustainability scenario (NBP 1), reflecting what the stakeholders assumed would be the most environmentally friendly solutions. For the business-as-usual scenario, the countries strengthened already visible developments of the current state, but not always in the same direction. For example, in the agricultural attribute (#3) on fertilisation, more circular biological fertilisation was expected in Finland, while slightly more intense conventional fertilisation was expected in Denmark and Sweden, as compared to the current baseline.

There was also a relatively high level of agreement on how the maximum growth scenario (NBP 5) would turn out. Norway sometimes deviated from the other countries, as the scenario builds on a continued reliance of oil and gas, which means that this scenario is not that far from the current situation in a gas- and oil exporting country like Norway.

The two most difficult scenarios to transfer into land use changes were the cities' first (NBP 4) and the maximum growth (NBP 5) scenarios, as there are multiple and sometimes opposing needs for land-use change, and the weighting of those vary between the stakeholders both within and between the different countries.

4.2.2. Forestry

In general, the stakeholders in Finland and Norway had relatively consistent views on how the forestry land-use attributes would develop under a sustainability scenario, reflecting what the stakeholders assumed would be the most environment-friendly solutions. For the business-as-usual scenario, the countries strengthened already visible developments of the current state, but not always in the same direction. For example, in the attribute (# 1) on dominant tree species, more mixed natural forests were expected for Finland, while more monocultures were expected for Norway.

There was also a relatively high level of agreement on how the self-sufficiency and the maximum growth scenarios would turn out.

Also for forestry, the most difficult scenario to transfer into land use changes was the NBP 4, cities' first scenario, as the stakeholders saw multiple and sometimes opposing needs for land-use change, and the weighting of those needs varied between the stakeholders both within and between the two countries.

4.3. Summary of outputs across the two land use sectors

For NPB 1, sustainability first, was the only scenario expected to improve the environment. Sustainability is only likely if current and upcoming European and Nordic environmental policies are properly implemented and if the national and EU agricultural policies (CAP, EC 2021) are changed to become more environmentally sustainable. Green finance is needed to facilitate a change towards sustainable agricultural and forestry practices.

The NBP 3, self-sufficiency, has recently got substantially increased public and political interest due to the recent developments in Europe. The war in Ukraine prevents export of grain from Ukraine and grain and fossil fuels from Russia. Moreover, the corona pandemic and climate change have increased the political will to reduce long-range transported foods, fodder, fiber and fossil fuels. These developments are stimulating more local production to reduce the dependence on import from countries outside of Europe. Our findings for NBP 3 may therefore be particularly interesting and important, as that scenario was found to be the second worst scenario for both the agricultural and the forestry sectors causing further deterioration of water quality. Thus, increasing self-sufficiency will make it even more challenging to achieve the WFD objective of good ecological status in Nordic countries in the years to come.

The NBP 4, the cities first scenario, is becoming quite relevant in the light of the increasing economic inequality between urban and rural populations and the trend to build large numbers of leisure cottages and apartments in rural areas to satisfy the need for outdoor recreation for urban populations. The latter can cause massive land-use changes in rural areas and further pressures on water quality, quantity and biodiversity. However, this scenario was most difficult to translate into land use changes, since it can have several different outcomes. For this reason, all countries often suggested two options for this scenario, e.g., at each extreme, the result being a score near zero.

The NBP 5 – maximum growth – was not understood only as a clearly negative scenario for the environment, since the NBPs take into account the bioeconomic potential of increased biomass extraction, thus potentially substituting fossil fuels. However, if most of the economic growth is based on fossil fuels, as in Norway today, then a focus on oil and gas is likely to continue if combined with technology for carbon capture and storage (CCS). In that case, the need for biomass from the rural areas will be less needed, and this means less need for intensification of agriculture and forestry, which would be good for water quality and biodiversity.

The SSPs and NBPs and the set of land use attributes may at present be the best building blocks on which we may form a variety of articulated scenarios for future land use. Whether they are the best suited to formulate scenarios of different water management strategies is another issue, due to the different interpretations of sustainability focusing mainly on water management or also on wider aspects related to carbon sequestration. For both agricultural and forestry attributes that are clearly linked to water resources issues, we found that NBPs 1, 2 and 3 were best suited, whereas NBPs 4 and 5 had more diverging interpretations. Thus, not all the SSPs (or the NBPs based on the SSPs), may be equally useful or relevant for depicting changes in land use and their consequences for water management in a future with more focus on bioeconomy.

4.4. Use of the outputs for modelling of nutrient loads and ecosystem services

The outputs of these stakeholder consultations have been important inputs for catchment models estimating future nutrient run-off from agricultural and forestry areas to rivers and downstream lakes and coastal waters. Such catchment models cannot be expected to use all the attributes included in the stakeholder consultations but can select those that are possible to translate to quantitative variables required by the different models (e.g. Jackson-Blake et al. 2016, Couture et al. 2018). In this special issue, several papers rely exactly on these Nordic bioeconomy pathways (NBPs) and the attributes presented above (e.g. Carstensen et al., Farkas et al., Immerzeel et al., and Rankinen et al., 2023).

Likewise, the models cannot be expected to use all the scenarios but rather to focus on those that are relatively easy to interpret, can be compared to the current baseline (NBP 0) and represent clearly different trajectories for the selected attributes, e.g. the NBP 1, sustainability first (best case for environment), and the NBP 5, maximum economic growth (worst case for environment).

For ecosystem services, Immerzeel et al. (2021) found that the recreational values, including good water quality, substantially contribute to the total economic value in Nordic catchments (Immerzeel at al. 2022, Juutinen et al. 2022). A challenge is to model how the recreational benefits will change in the future due to the changes in water quality. For this purpose, the outputs of the stakeholder consultations may also be useful.

4.5. The possible importance of new technology

Both agriculture and forestry in the Nordic countries are facing major technological developments, including satellites and drones for field observations of crops; robotics and GPS-tracking allowing more precise application of fertilizer and manure application adjusted to crop needs, drip irrigation, traceless forestry practices, and the utilisation of grass for more purposes than livestock feed (Bucci et al. 2018, Ulvenblad et al. 2019, Øvergård 2018). These developments are likely to contribute to decrease current nutrient run-off to the environment in all the scenarios, including the NBP2 business as usual.

Technological development was also pinpointed by the Danish stakeholders (especially from SEGES - the Farmers advisory institute) saying that the stepwise increase in use of new technology would occur in all scenarios, including satellite images to more precise application of fertilizer - more fertilizer to lower yield areas and lower fertilizer to high yield areas within the field; GPS tracking to more precise fertilizer and manure application at the field edge and more even application; stepwise more efficient catch crops after maize or other main crops. Their point of view is that new technology will contribute to higher nutrient efficiency and therefore lower losses to the environment also in the scenario 2 business as usual.

These inputs from the Danish stakeholders are quite relevant and raise the problems of defining scenarios that both are well defined but also include possible future changes in the farm-cropping system. This task is especially difficult when including different farming potential and state of the use of new technology between the individual Nordic countries. However, the quite distinctly defined current situation, NBP 0, and the scenarios NBP 1 (sustainability), NBP 2 (business as usual), and NBP 3 (self-sufficiency), were found well suited to cover those differences across the diversity of farming, climate and natural conditions (mountains, soil types etc.).

5. Conclusions

The combined bottom-up and top-down approach presented in this paper worked well for stakeholder consultations, enabling harmonised collection of opinions across the four Nordic countries on the possible bioeconomic development for a variety of land-use attributes for agricultural land-use, as well as forestry practices and their potential impacts on water quality. The approach also allowed reality-oriented inputs to catchment modelling.

The main outputs of the stakeholder consultations of future land-use changes related to the green shift indicates which scenarios that were expected to improve or deteriorate the environment and water quality. These expectations are:

The sustainability scenario (NBP 1) would be the only option to achieve a clear environmental improvement due to more restoration of riparian areas, cover crops, protected areas, mixed natural forests, less excessive fertilisation. However, the Swedish stakeholders had a different view on this scenario, expecting more nutrient run-off due to a possible shift from grasslands to more intensive crop production reflecting less demand for meat and more demand for vegetarian food.

The business-as-usual scenario (NBP 2) was expected to slightly decrease the current environmental impact for most attributes due to new technologies (precision farming).

The self-sufficiency scenario (NBP 3) and the maximum growth scenario (NBP 5) were expected to deteriorate the environment and water quality for most of the attributes due to a focus on maximizing production.

The cities first scenario (NBP 4) was not expected to represent clear differences from the current conditions but got the highest divergence of opinions depending on the weighting of the urban elites' demand for recreational areas versus their demand for local food, fodder and fibre.

These results have been used as inputs to catchment modelling of nutrient run-off and may stimulate policy discussions on how to facilitate the green shift with increasing biomass exploitation without deteriorating water quality and ecological status of Nordic waters.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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