BETA
Bureau
d'économie
théorique
et appliquée

Documents de travail

« Integrating non-timber objectives into bio-economic models of the forest sector: a review of recent innovations and current shortcomings »

Auteurs

Miguel Rivière, Sylvain Caurla

Document de Travail n° 2018 – 26

Juin 2018

Bureau d'Économie Théorique et Appliquée

BETA Université de Strasbourg
Faculté des sciences économiques et de gestion
61 avenue de la Forêt Noire
67085 Strasbourg Cedex
Tél. : +33 (0)3 68 85 20 69
Fax : +33 (0)3 68 85 20 70
Secrétariat : Géraldine Del Fabbro
g.delfabbro@unistra.fr

http://www.beta-umr7522.fr

Integrating non-timber objectives into bio-economic models of the forest sector: a review of recent innovations and current shortcomings

Miguel RIVIERE[a,*] , Sylvain CAURLA[a]

[a] : *BETA, Université Lorraine, INRA, AgroParisTech, 54000, Nancy, France*
[*] : Corresponding author: miguel.riviere@agroparistech.fr. BETA, Campus AgroParisTech, 14 rue Girardet, 54042 Nancy cedex, France. +33 3 83 39 68 58

Abstract

This paper gives an overview of non-timber objective modelling in forest sector models (FSM) research through a systematic literature review followed by an in-depth narrative review. Originally conceived to perform projections of timber supply and wood products markets, FSM have been growingly used for forest and climate policy analysis. For this purpose, they have gradually integrated objectives other than timber production, such as habitat conservation, carbon sequestration and bioenergy production. We identify these non-timber objectives and elicit technical innovations that have enabled their integration into FSM. We also discuss their current limits and the new perspectives they bring for a better economic-environmental assessment of forest policies. Results show that the study of non-timber objectives is a growing topic in FSM research, with bioenergy production and climate change mitigation as the most commonly studied. However, there are discrepancies regarding the respective contributions of different families of models, and not all non-timber objectives have been integrated to the same degree. On the one hand, bioenergy production has been thoroughly integrated through marginal modifications of the market component of models. On the other hand, the modelling of carbon sequestration and habitat protection entails deeper changes, such as the addition of new resources to the models, an increase in the complexity of the objective function and associated constraints, or the use of tools and models outside the FSM.

Keywords: forest sector model, forest, forestry, ecosystem services, non-timber, economic model.

JEL codes: C61, L7, Q21, Q23, Q57

Acknowledgements

This work was supported by the French Ministère de l'Agriculture et de l'Alimentation. The BETA contributes to the LabEX ARBRE ANR-11-LABX-0002-01. The authors want to thank Dr. Philippe Delacote and Pr. Harold Levrel for their attentive help.

1. Introduction

Forests are multifunctional ecosystems that provide a wide array of market and non-market ecosystem services, linked by complex antagonistic or synergistic relationships at different spatial and temporal scales [1]. Hence, while forest management often pursues timber production as its main objective, it also affects the provision of other ecosystem services [2]. Since the 1990s, a growing set of policies involving the forest and land-use sectors have been designed to address a wide range of socio-environmental issues. The most emblematic ones encompass the mitigation of climate change and the conservation of biodiversity and habitats. Carbon sequestration from forests is recognised to various extents in policy frameworks such as the Paris Agreement[1] [3], the EU climate and energy framework[2], or the REDD+ approach, where conservation and enhancement of forest carbon stocks are key objectives [4]. Meanwhile, carbon substitution mechanisms are considered through the promotion of energy production from forest biomass in renewable energy programmes such as the European Union (EU) renewable energy directive [5,6]. Regarding conservation, protected areas have been promoted as a way to ensure biodiversity protection and the sustainable provision of forest ecosystem services [7]. This is well illustrated in the emblematic Natura 2000 network of protected areas throughout Europe, half of which consists of forests [8]. Besides, the importance of conservation has also been stated in the EU Forest Strategy [9], where the joint production of wood products and other ecosystem services as well as conservation efforts are both key priorities. Even though many policy instruments have been primarily dedicated to one issue, climate mitigation policies such as REDD+ are likely to yield biodiversity co-benefits [10–12], highlighting the need for forests and the forest sector to be managed in an integrated manner.

These several issues are growingly explored using integrative modelling frameworks, which makes it possible to analyse their mutual complementarities or trade-offs and their interactions with the production of timber. Within these modelling frameworks, forest sector models (FSM) encompass a set of simulation tools commonly used for policy analysis in the field of forest economics. Originally designed to carry out projections of timber supply, forest inventories and wood products trade and consumption, FSM have also been used to answer questions related to the conservation of forest resources, renewable energy and climate change [13]. Hence, while timber production and market dynamics have stayed a core focus, FSM have also been used to investigate issues related to forest objectives other than timber production, thus providing policy-decision makers valuable insights in order to design and implement environmental policies.

Previous contributions have documented the history, evolution and theoretical foundations of FSM [13–15], while also discussing the applications of such models from a broad perspective [13,16]. However, to date, no analysis has focused specifically on the integration of non-timber objectives into FSM. The objective of this paper is to fill this gap by investigating how and to what extent forest objectives other than timber production have been integrated into FSM. First, we want to identify which non-timber objectives have been studied in FSM research, give an overview of research questions and quantify the extent to which non-timber objectives have been studied over time. Second, we aim at eliciting modelling innovations that have allowed for the integration of non-timber objectives into FSM. Third, we look to highlight the respective contribution of different models and families of models to the study of non-timber objectives. Finally, we will discuss new possibilities brought by the integration of non-timber objectives, as well as its current limits. While other types of FSM exist, we focus on partial equilibrium models, widely used in research in the last 40 years [13]. Our approach relies on the combination of two complimentary methods: a systematic literature review and an in-depth narrative review.

[1] Article 5, paragraph 1 states that "Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases (…), including forests".

[2] The European Council adopted on 14/5/2018 a regulation on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, following a proposal from the European Commission in 2016 [129]. The final document was not yet published in the Official Journal at the time this article was written.

This allows us to provide a quantitative overview of the field as well as to focus on specific aspects through selected examples.

The paper is structured as follows: in the materials and methods section, we introduce the reader to FSM, which is necessary to understand the remainder of the article, and we present the methodology. Results are organised in two steps. In a first step, we present findings from a general bibliometric analysis to provide an overview of the field. In a second step, we present in-depth results from the review thematically, focusing on non-timber objectives one at a time. The main achievements in modelling non-timber objectives, as well as current limits, are discussed in the last section, where proposals for future research are made.

2. Materials and methods

2.1. Forest Sector Models

We define FSM as bio-economic, partial equilibrium models of the forest sector where both biological resources and the economic system are represented, and where the influence of other economic sectors is introduced through exogenous variables. FSM are projection models, used to assess the impacts of a user-defined modification[3] brought to the forest sector as well as to investigate the underlying market mechanics behind the observed changes. This is usually done by comparing a Business-As-Usual scenario to another scenario where the modification is introduced. As a consequence, FSM are particularly well-suited to perform forest and climate policy analyses [13,17].

FSM are usually separated into two categories based on their handling of temporal issues [18]. On the one hand, static-recursive models solve market equilibria one at a time, and are made dynamic by recursively updating the model's parameters. On the other hand, intertemporal models solve all equilibria at the same time. Static-recursive models have myopic agents or agents with adaptive anticipations [19], and are better suited for shorter-term positive analysis (one-two decades). Intertemporal models assume agents with perfect foresight, which behave optimally and in a dynamically consistent way. Such models are better suited for longer-term analyses [13]. In addition, FSM can be regional [20], national [21] or global [22] in scope.

FSM can be thought of as being made of several components or modules [23]: (1) a timber supply component where forest resources are represented and from which timber supply originates, (2) an industrial production component where primary products are converted into secondary and/or end-products, (3) a demand component where demand functions for end-products are specified, and (4) a trade component where various spatial formats can be employed, ranging from a one-region format to a multiple demand and supply regions format [14].

FSM differ a lot regarding the representation of forest resources. Some models only represent overall forest inventories aggregated at the regional level, while the most detailed models describe forests spatially, at the strata and stand or inventory unit levels. In most static-recursive models, forest management and investment decisions are exogenous, and timber supply is derived from price-elastic and inventory driven supply curves. On the contrary, most intertemporal FSM contain a forest investment module where management decisions are endogenously determined. The French Forest Sector Model (FFSM) [24] is a case of spatially explicit recursive model with endogenous investment. In addition, some models such as the Forest and Agricultural Sector Model (FASOM) [25] include the agricultural sector and land-use changes.

From a technical point of view, FSM are solved by optimising an objective function under a set of constraints usually forming a non-linear programming problem. Equilibrium is commonly found by maximising total economic surplus for the whole sector based on Samuelson's [26] spatial price equilibrium framework, allowing for an endogenous determination of quantities and prices. More details on FSM can be found in Solberg [17] and Buongiorno [27] regarding early models and their uses, and Adams and Haynes [14] and Latta, Sjolie and Solberg [13] regarding the general evolution of modelling techniques.

[3] Modifications can be the introduction of biotic (e.g. increased tree mortality) or abiotic (e.g. decreased demand for a given product) shocks, the introduction of a policy (e.g. a new tax or subsidy) or changes in some of the model's parameters (e.g. different values for elasticities in demand and supply functions), etc.

2.2. Review methodology

Our review follows a two-step process. In a first step, we conduct a systematic literature review of studies using a FSM. Publications to be analysed are gathered using Scopus database. A first search query aims at retrieving publications based on historically significant FSM, using the models' names and abbreviations for them (e.g. "French Forest Sector Model", "FFSM"). The list of FSM included in the query is based on literature reviews on the development and history of FSM [13,14]. A second search query uses keywords related to (1) common denominations used to describe FSM (e.g. "partial equilibrium model", "timber supply model", "spatial equilibrium model"), alongside (2) keywords related to the forest sector (e.g. "timber", "wood products", "forest sector") and economics (e.g. "market", "trade", "supply"). This allows us to retrieve publications where other FSM are used.

We use a set of criteria to define publications where a FSM is actually used. We consider a FSM to be a model (1) rooted in economic theory, (2) representing the forest sector, which we define as forestry plus forest industries, (3) at the sector scale, and (4) at a temporal scale relevant to forest-related questions (for dynamic models). In addition, publications where a multi-sector model is used are only considered when the forest sector is the main focus of the paper. These criteria lead us to dismiss some models, such as forest growth and optimal forest management models (where the forest industry is not represented), models of the energy sector where non-energy uses of wood are not modelled, models at the individual owner/company scale, most biomass supply models (which usually operate at the yearly scale), and studies using multi-sector models not focusing on the forest sector.

This systematic search procedure yields a set of publications. To give an overview of the field and map it, we carry out a bibliometric network analysis based on keyword co-occurrence using VOSviewer software [28,29] on data exported from Scopus[4]. Subsequently, based on titles, abstracts and keywords (and, when necessary, full-texts), we systematically identify (1) the research question, (2) the model used in the paper, and (3) if the focus of the paper is on a non-timber objective. This allows us to analyse the evolution of FSM studies' foci on various non-timber objectives, to quantify the extent to which each model/type of model has contributed to the study of each non-timber objective, and to discuss which aspects of non-timber objectives are being investigated in terms of research question.

In a second step, we analyse in details how non-timber objectives are modelled in FSM studies. Since the literature is very abundant, we choose to conduct a narrative literature review where we focus on meaningful examples we believe are able to give valuable insights on the modelling of non-timber objectives. The choice of examples is based both on their policy relevance and on results from the quantitative review. We identify and discuss technical innovations that have enabled the integration of non-timber objectives into models, the limits of this integration, and compare innovations developed for different types of models. In order to document the evolution of modelling techniques over time, examples are mostly taken from FSM where sets of studies published several years apart are available. Examples from other models are presented when an approach we believe to be especially innovative is employed. The majority of examples are taken from papers retrieved in the systematic search and a few come from other publications.

3. Systematic review analysis

3.1. Non-timber objectives in FSM studies: topics and temporal trends

The systematic review step yields a total of 217 publications falling within the previously defined scope (see fig.1). 110 studies do not investigate issues related to non-timber objectives. 44 of these are review, theory or

---

[4] A co-occurrence link is formed between two keywords when they appear in the same publication. The more often keywords appear together, the stronger the link. Keywords and links are then represented on a network where distances between items indicate their level of relatedness, and items are further separated into clusters. Keywords whose spelling varies across publications are merged using a thesaurus.

model presentation papers, while another 66 are analyses focused on timber production and wood products markets. In the keywords network analysis (Figure 2a), timber production and wood products markets are topics that can be found in two clusters: cluster D contains keywords related to forestry and the upstream segment of the forest sector, while cluster A contains keywords related to markets, trade and the downstream segment of the forest sector.

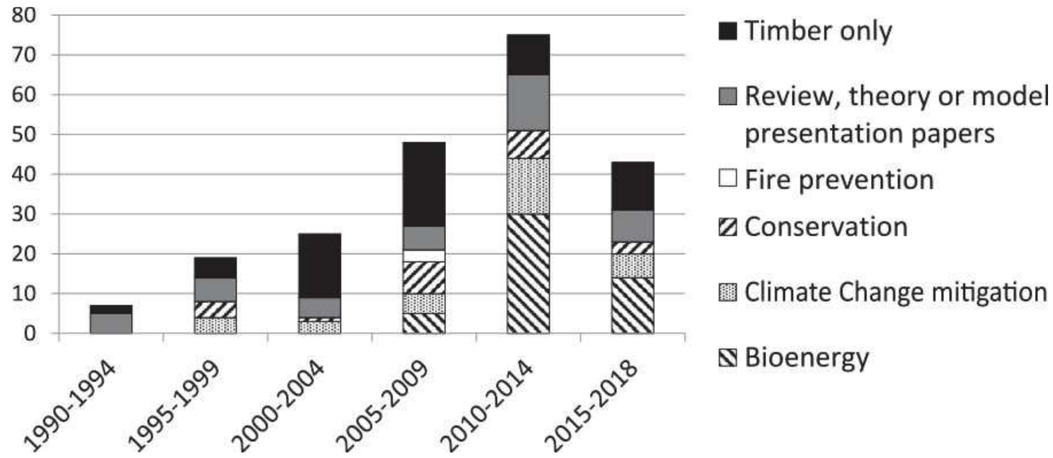
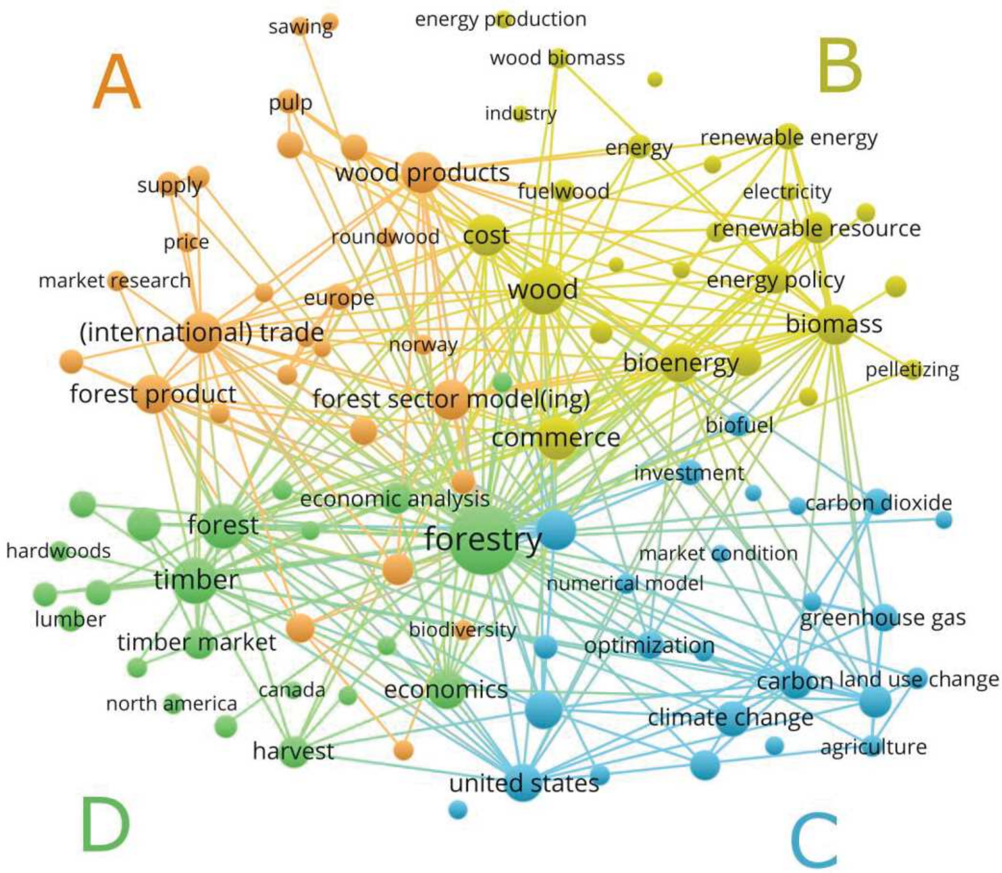


Fig.1 Distribution of reviewed papers per date of publication and thematic focus

The remaining 107 papers are analyses that do focus on a non-timber objective. More precisely, we identify 4 non-timber objectives as being the core focus of at least one study. First, the production of wood-based bioenergy (49 papers), which appears as a major focus, and keywords related to bioenergy products, forest biomass and energy markets can be found in cluster B. Second, climate change mitigation through carbon sequestration and/or substitution (32 papers). This topic corresponds mostly to cluster C, which contains keywords related to climate, carbon sequestration and land use, but also to some extent to cluster B. Third, the conservation of forest resources and habitats (23 papers). Despite a relatively important number of publications, this topic remains relatively unseen in the network analysis. The keywords “conservation”, “ecology” and “biodiversity” do appear, but they occur rarely, are distributed among 3 clusters and have few links to other keywords. The topic thus seems less common and more isolated. Finally, fire prevention (3 papers) is a minor focus and does not appear in the keywords network.

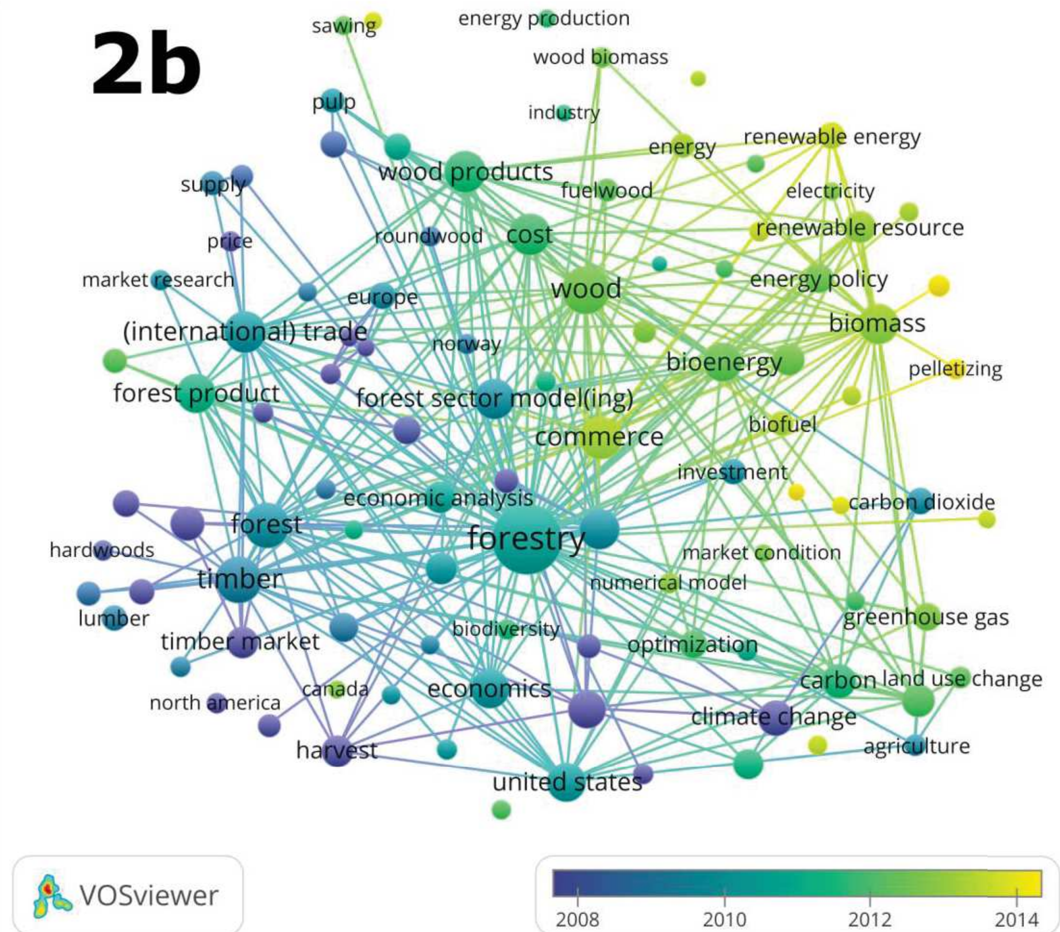
Fig.2 Bibliometric network analysis based on keyword co-occurrence (a) clustering based on keyword relatedness, (b) temporal trends in keyword use. The size of items is proportional to their number of occurrences, and distances between items indicate their level of relatedness. For visibility purposes, only the 100 keywords with the greatest total link strengths and the 300 strongest links are displayed. In figure (a), keywords clusters are represented in different colours, while figure (b) displays the average year keywords were used in.

2a



A
B
C
D
sawing
energy production
wood biomass
pulp
industry
energy
renewable energy
supply
wood products
fuelwood
electricity
price
roundwood
cost
renewable resource
market research
europe
wood
energy policy
(international) trade
norway
biomass
bioenergy
pelletizing
forest product
forest sector model(ing)
commerce
biofuel
investment
economic analysis
carbon dioxide
forest
forestry
hardwoods
market condition
timber
numerical model
lumber
greenhouse gas
timber market
biodiversity
optimization
carbon
land use change
canada
economics
north america
climate change
harvest
agriculture
united states

2b



sawing
energy production
wood biomass
pulp
industry
energy
renewable energy
wood products
supply
fuelwood
electricity
price
roundwood
cost
renewable resource
market research
energy policy
europe
wood
(international) trade
biomass
norway
bioenergy
pelletizing
forest product
forest sector model(ing)
commerce
biofuel
investment
economic analysis
carbon dioxide
forest
forestry
hardwoods
market condition
timber
numerical model
lumber
greenhouse gas
timber market
biodiversity
optimization
carbon
land use change
canada
economics
north america
climate change
harvest
agriculture
united states
VOSviewer
2008
2010
2012
2014

Some clear temporal trends can be identified regarding the investigation of non-timber objectives. Among analysis papers (i.e., excluding review, theory and model presentation papers), 20% and 50% focus on a non-timber objective in the periods 2000-2004 and 2005-2009 respectively. This percentage increases to 84% and 66% for the periods 2010-2014 and 2015-2018 respectively. The study of non-timber objectives is thus recent and, over time, the proportion of FSM studies focused only on timber production has decreased.

In addition, there has been a shift with regards to which non-timber objectives are being investigated. When looking at the average years in which keywords are used (Figure 2b), there is a clear shift from cluster A and B towards clusters C and especially cluster B. This trend is confirmed when analysing dates of publications more closely. 90% of studies on bioenergy have been published after 2010, and 63% for climate change. Conservation is an older focus, with only 43 % of studies published after 2010. In addition to being a recent topic, bioenergy production is also the most important non-timber focus in FSM research today, accounting for 49% and 40% of analysis papers in the periods 2010-2014 and 2015-2018 respectively.

3.2. Which model for which topic?

Among analysis papers, the most widely used models are the Global Forest Products Model (GFPM, 32 papers) [22], the FASOM (16 papers) [30], the Sub-Regional Timber Supply Model (SRTS, 13 papers) [31], and the European Forest Institute Global Trade Model (EFI-GTM) [32] alongside its national-level derivatives SF-GTM in Finland [33] and the Norwegian Trade Model (NTM) [34] for Norway, which together represent 20 papers. In addition, despite not always explicitly naming the models in use, 11 papers use modelling frameworks similar to Sedjo and Lyon's [35] Timber Supply Model (TSM), and another 11 papers use a framework similar to Stennes and Wilson's [36] Spatial Price Equilibrium (SPE) model and Johnston and Van Kooten's [37] REPA-FTM model. Together, these models account for 103 (60%) of our results. 30 studies (18%) use a FSM occurring only once.

All models have not been used for the same purpose. On the one hand, studies using static-recursive models at the global and international scales primarily concern timber production and trade in wood-based products. Examples include the GFPM (24 out of 32), SPE (8 out of 11) and the Cintrafor Global Trade Model (4/6). On the other hand, studies where a static-recursive model with a local/regional focus is used tend to lean towards the study of bioenergy production. Such examples include EFI-GTM (global with a European focus), SF-GTM and NTM, with 10/20 studies focused on bioenergy, the Fibre Allocation Models of the Canadian Provinces (3/3) [38–40] and the SRTS (South-Eastern US, 7/13). Among the 4 studies using the Austrian FOHOW model, 2 studies focus on bioenergy, while the 2 others use bioenergy policy as a strong assumption in scenario building. Similarly, among the 6 studies using the FFSM, 1 has bioenergy production as its main focus, while 2 others, despite focusing on climate change mitigation, include bioenergy policies in several scenarios. Intertemporal optimisation models are mostly used to investigate climate change mitigation: omitting models occurring only once, 21 (55%) studies have climate change as their main focus, against 10 for bioenergy and 7 for conservation. This rises to 11/16 (69%) for FASOM, the most represented intertemporal model.

3.3. Investigating non-timber objectives: a typology of research questions

Two different categories of research questions arise from our analysis: "*market projections*" and "*policy analyses*" (see Fig. 3). On the one hand, *market projections* simulate an exogenous shock on the forest sector - usually a policy or a change of assumptions regarding the sector's behaviour – and assess its impacts on timber supply, forest inventories and industrial production over time: the focus is on the sector impacts of the studied shock/policy. On the other hand, *policy analyses* go further: while sector impacts of the simulated policy are still assessed, the focus is on discussing policy instruments themselves. As such, *policy analyses* usually simulate either several policy instruments (different approaches to the same issue) or several levels of the same policy (for quantitative instruments such as taxes) and discuss the features of each alternative: the focus is therefore on policy design.

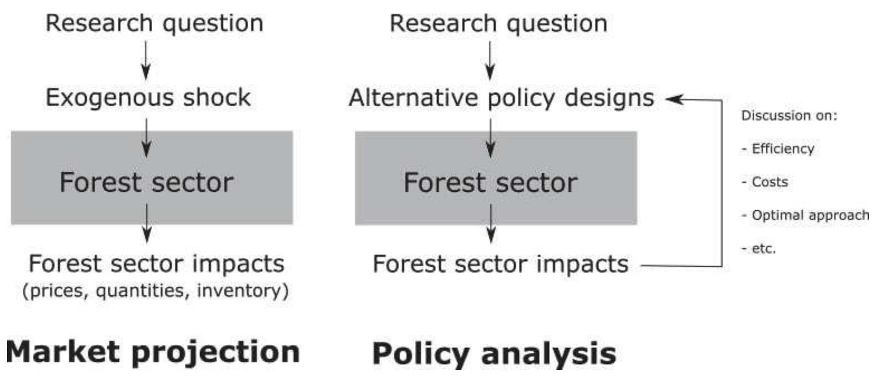


Fig.3 Concepts of market projection and policy analysis in FSM research

The following sections each concern one of the non-timber objectives identified. In each section, we first give an overview of research questions investigated based on our corpus of retrieved publications. Then, we focus on the modelling of non-timber objectives from a more technical point of view. No examples are given on fire prevention, for which too few papers are available.

4. Bioenergy production

4.1. Research questions

The main research question regarding bioenergy is to assess the consequences for the forest sector of an increased demand for (or use of) wood for energy production. However, not all studies assess the same impacts. First, 30 studies focus on economic impacts on the forest sector. Among them 23 are *market projections*, most of which investigate the general use of woody biomass for energy [41] while others have a more specific focus such as heat and/or power generation [42] or second-generation biofuels [43]. Another 7 studies perform *policy analyses* and are concerned with the competitiveness of wood-based bioenergy under varying levels of subsidies and taxation [44,45]. Second, 10 additional studies assess impacts in terms of climate change mitigation and carbon balance, focusing either on sequestration in-situ [46], or on emission reductions [47,48]. Only one of these is a *policy analysis,* where a carbon tax policy and a bioenergy subsidy are compared [49]. Third, the ecological impacts of bioenergy are addressed by 5 studies. Two of them are *market projections* focusing on land-use and land-use change [50,51], while another addresses the impacts of stump removal on biodiversity [52]. The two remaining studies are *policy analyses* comparing sustainability guidelines for biomass supply, with criteria on land-use and greenhouse gases (GHG) emissions [53,54]. Fourth, another important research question many studies were dealing with is the potential for various feedstocks to provide biomass. While most studies do address feedstocks, 10 of the papers reviewed put a particularly strong emphasis on assessing supply potential and costs for various feedstocks [55–57].

4.2. Modelling bioenergy markets in forest sector models: a focus on the value chain and competition with fossil energies

Forest biomass feedstocks show a significant potential for the production of various bioenergy commodities, promoted for their potential to decrease GHG emissions by substituting for fossil fuels [58,59]. As seen previously, a significant part of current FSM research focuses on assessing the potential and impacts of wood-based bioenergy. As a consequence, our narrative focus will be on how FSM have been modified to include both (1) bioenergy commodities and related biomass feedstocks and (2) competition and substitution with fossil energies.

4.2.1. Disaggregation of the value chain: biomass feedstocks and supply

On the supply side, the disaggregation of products is seen in the many feedstocks represented, which are common to many FSM (fig 4).

(1) The roundwood feedstock is derived directly from timber supply, which is either represented as a price-elastic supply function, or is an implicit result of endogenous management decisions. Some models have a dedicated roundwood fuelwood category [60–62], and many frameworks allow pulpwood and/or sawlogs to be diverted to energy uses when it becomes economically viable to do so. Examples include the "*cascading substitution"* used in later versions of the USFPM/GFPM, where all higher-value fibre can be used for energy [63]. In the SRTS, a very different solution is found: bioenergy demand must first be met by harvest residues: the unmet demand is then used to shift pulpwood demand, which can then be diverted to energy uses [64].

(2) The harvest residue feedstock is also commonly found, and comprises lower-value remnants such as tree tops and branches. Potential supply is usually represented as a share of harvest volumes, and a marginal cost (supply) function is defined to represent the extra costs when retrieving residues. Most models determine supply of harvest residues during the model run where a shock is introduced, while in the SRTS, it is estimated *ex-ante,* in the base model run [64]. A notable exception to including harvest residues is the REPA-FTM, where they are omitted because of their low economic viability [62].

(3) The industrial residues feedstock is present in all models where processing activities (such as plywood or sawnwood production) are modelled, and encompass sawmill chips, dust and bark. Industrial residues are represented as a by-product of input-output processes. In addition to constituting bioenergy feedstocks, industrial residues can also be used as an input for manufacturing activities using lower-grades materials, such as the production of pulp, paper or particleboard. Hence, in most models, the bioenergy sector competes with other segments of the forest sector for this feedstock.

(4) Finally, some models diversify feedstocks even more. This includes agricultural residues in FASOM [47], short-rotation coppices in GFPM [63] or recycled wood in EU-FASOM [61]

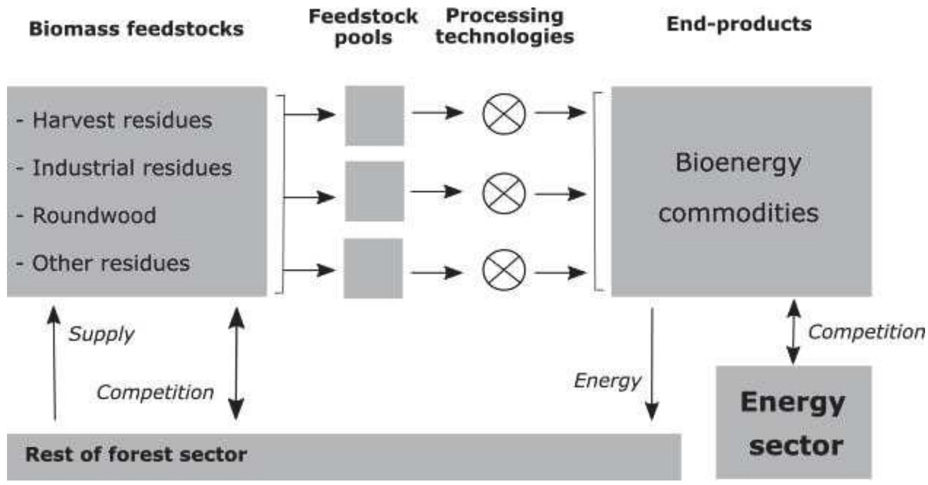


Fig.4 The bioenergy value chain in Forest Sector Models

4.2.2. Disaggregation of the value chain: bioenergy commodities and demand

On the demand side, the disaggregation of products goes through a multiplication of the bioenergy commodities represented. In early model versions, fuelwood was modelled as a broad category of end-product, and not converted into energy. Models were later refined with the addition of bioenergy commodities, sometimes disaggregated into several end-products. Later versions of the EFI-GTM [65] include both heat and electricity as energy commodities, while the GFPM [63] also models bioethanol markets. For other models, the choice was made to focus on one particular bioenergy commodity, and to model it with more details. Examples include the bioheat market in NTM [66], and biofuels in the Nordic Forest Sector Model (NFSM) [67]. These innovations go hand in hand with the development of ways to represent the conversion of biomass into bioenergy commodities. All models reviewed use input-output processes to represent the conversion of biomass into bioenergy commodities, with coefficients indicating the quantity of inputs necessary to produce one unit of energy/biofuel.

Some models use one conversion process per commodity [63] while others enable the production of commodities from several competing technologies [61,66,68].

While models do not differ much in the way they model energy products themselves, choices regarding the modelling of demand for bioenergy commodities vary more strongly. These choices condition the research questions that can be investigated using the models, and three main approaches can be identified. (1) Some models use price elastic demand functions, similar to those commonly used for material wood products [62,63,69]. In this case, both produced quantities and prices are defined endogenously. (2) Others use horizontal demand curves, based on the assumption that bioenergy commodities will replace fossil fuels until marginal costs equal the exogenously fixed price [66]. In this case, prices are exogenous but quantities endogenous. (3) Finally, some studies elected to have an exogenously fixed level of demand constraining energy production [61,65,70]. In this case, the model is limited to endogenously determining the allocation of production among different regions/technologies.

4.2.3. Modelling the climate impacts of bioenergy: fossil fuels and avoided emissions

Several different approaches to including competition between bioenergy and fossil energy have been developed. On the one hand, some models include competition between bioenergy and fossil fuels indirectly, at the demand level. When using horizontal demand curves, changes in the exogenously fixed energy price can emulate price-based competition between bioenergy and fossil energy. When using price-elastic demand curves, cross-price elasticities for fossil fuels can be introduced. One the other hand, other models opt for modelling a direct competition between bioenergy and fossil fuels by introducing fossil fuels as inputs for fossil-fuelled and co-fired technologies alongside biomass-fired technologies in the input-output production processes. Combined with fixed levels of production, this approach enables to study the allocation of the energy mix between alternative energy sources [45,61].

In addition, methods to calculate the substitution effect taking place when bioenergy is used rather than fossil fuels (i.e., to calculate avoided GHG emissions) have been developed. A common methodology is to introduce emission factors for each conversion technologies, where emissions both at combustion and over the production process are taken into account. When fossil-based technologies are represented, a direct comparison of emissions can be made [49]. When only biomass-fired technologies are modelled, an additional assumption must be made regarding the fossil fuels which is substituted and the substitution coefficients used [45,65]. The calculation of avoided emissions allow models to be driven by carbon prices, which consequently enables a better investigation of the mitigation potential of bioenergy as well as of the interlinkages between climate and bioenergy policies. In cases where a forest carbon accounting module is also present, it enables investigating the climate impacts of bioenergy and the potential conflicts between sequestration and substitution policies.

5. Climate change mitigation

5.1. Research questions

Climate change mitigation as a non-timber objective has been investigated in two different ways. On the one hand, 26 out of 32 reviewed studies assess the potential of different mitigation strategies and mostly perform *policy analyses*. The main focus is on market instruments, especially the creation of carbon markets where a payment/tax for carbon sequestration/emissions is put into place. While most studies assess the general implications of such carbon policies [71,72], some others deal with specific features such as the incorporation of albedo [73], dual discounting [74] or the comparison of mandatory versus voluntary schemes [75]. Two studies focus on comparing a substitution policy to a sequestration policy [69,76]. In addition to market instruments, 7 papers focus on mitigation strategies based on land use policy and/or direct changes in forest management [77,78], 2 papers combine land use/management tools and market instruments [79,80] and 3 papers investigate the mitigation potential of structural changes in specific segments of the forest sector: construction [81,82] and transport [83]. On the other hand, 6 studies in our review perform *market projections* to assess the impacts of climate change on the forest sector.

5.2. Modelling climate change mitigation in forest sector models: carbon accounting and mitigation policy instruments

The development of policy instruments addressing climate change has sparked much debate on methods for carbon accounting [84–86], and current mitigation efforts in the forest sector rely on two potentially antagonistic solutions: *in-situ* sequestration and emission reduction through substitution [87,88]. Hence, our modelling focus concerns the way carbon accounting modules have been developed for FSM, and how this has allowed for substitution and sequestration strategies to be introduced in the models.

5.2.1. Carbon accounting in forest sector models

The ability of FSM to investigate climate mitigation strategies relies on the development of carbon accounting modules. We discuss their development focusing on forest carbon accounting (i.e., carbon in forest pools and associated fluxes) and sector carbon accounting (i.e. carbon in forest products pools, associated fluxes and net gains from substitution effects), as seen on figure 5.

The main pools included in forest carbon accounting modules are live and dead tree biomass, sometimes disaggregated into more compartments, understory biomass, carbon in residues and on the forest floor and, sometimes, forest soils. Forest carbon accounting has mostly been developed in intertemporal models such as FASOM [89], NorFor [90] and TSM [91], but some static-models such as FFSM [92] and SRTS [64] also contain a carbon accounting module. Forest carbon accounting relies on the presence of a sufficient level of detail in forest resources description. The static-recursive FFSM is a very good illustration of this phenomenon: the early FFSM 1.0 version only had regionally aggregated data on resources, and a very rough form of carbon accounting [76], while the more spatially disaggregated FFSM++ version has spatially explicit, strata-level data on resources and a detailed carbon accounting module [92]. Similarly, the regional SRTS and most intertemporal models include strata/plot level data on forest resources. Other static-recursive models either do not perform forest carbon accounting, or rely on linkages to other models [93].

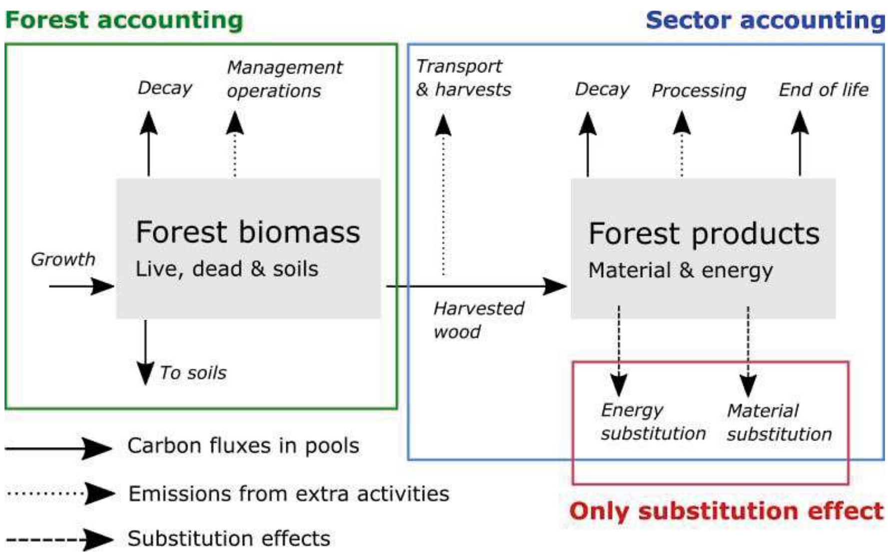


Fig.5 Main pools and fluxes in FSM carbon accounting modules

The development of sector accounting modules relies on the existence of forest carbon accounting, from which fluxes to forest products pools are originating. Fluxes from harvests, transport and processing are included, and end-of-life destinations for wood products are modelled. Solutions commonly found are decay over time, indefinite sequestration in products and/or landfills, recycling and combustion. Net gains from energy or material substitution are modelled using substitution coefficients and assumptions on substituted materials/fuels. Most studies consider bioenergy to be carbon neutral at combustion, meaning that CO_2 emitted when fuels are consumed is re-sequestered by growing forests. Emissions of other GHG gases at combustion, and carbon emissions during fuel production are usually included. Only a few papers [69,94,95] discuss the assumption that forest biomass is carbon neutral, even though such an assumption is controversial since neutrality depends on the sequestration efficiency of the forest and its future evolution [96].

While not having developed accounting modules *per se*, many models are able to estimate net gains from substitution without needing to estimate pools in forests or wood products, as shown in section 4.2.3. regarding energy substitution. Material substitution has been a minor focus of FSM research, and mostly performed by linking several models together [81,82].

5.2.2. Modelling of mitigation policy instruments

The development of carbon accounting allows models to be driven by climate policy. Two different types of analysis have been conducted. First, target-oriented climate policies have been modelled. They integrate carbon to the optimisation problem as a constraint on the objective function. For instance Im, Adams and Latta [78] impose minimum forest carbon flux targets. Under this approach, climate mitigation enters the model as a secondary objective, behind the maximisation of economic surplus. This is similar to methods employed to study optimal reserve allocation [97,98] as we will see in section 6.

Methods based on market-based instruments and carbon pricing are more common. Two different kinds of market-based mitigation instruments have been modelled: taxes on GHG emissions and carbon offset payments. Taxes on emissions aim for reduced net emissions of GHG and pertain to the substitution strategy. They are usually modelled as an exogenous increase in price/costs for fossil fuels, which impacts agents' behaviours and, consequently, the models' solution. When fossil-based energies are modelled explicitly, the tax increases costs for fossil inputs, making biomass-based solutions more price-competitive as a result [65]. In models where only bioenergy is modelled, taxes on GHG emissions indirectly increase the demand for bioenergy through cross-price elasticities [69] or upwards shifts of demand curves [49].

Offset payments belong to the sequestration strategy and aim at increasing the amount of carbon stored in forest biomass and soils. Sequestered carbon becomes an additional product for which forest owners are remunerated at an exogenously defined price. Payments are usually symmetrical, meaning that negative payments take place when pools decrease. Annual rental prices for sequestered carbon are also used in the literature [76,99,100]. From a technical point of view, the difference between the carbon pool and a reference level multiplied by the carbon price (or rental price) is added as an extra term to the model's objective function or to the timber supply function, which changes the model's solution. Details are given in Im, Adams and Latta [101] and Sjolie, Latta and Solberg [102] in the case of an intertemporal model, and in Lecocq et al. [76] and Buongiorno and Zhu [71] in the static-recursive case. An important point in the modelling of offset payments is the choice of the reference level. While most studies use sequestration in the base model run (without offset scheme) as a reference, some other solutions include the use of regional averages as a lower threshold [72], or definitions based on political instruments such as the Kyoto protocol, which imposes a cap on sequestration offsets [95,103]. Some variations include the incorporation of a second discount rate specific to carbon payments [74], an additional payment linked to radiative albedo forcing converted to C02 equivalents [73], or limiting payments to forests permanently set-aside for sequestration purposes [104].

Even though most publications focus on one aspect, some assessed the two strategies (sequestration and substitution) in front of one another, for the specific cases of France [69,76] and Finland [93,95], and in theory [105].

6. Habitat and biodiversity conservation

6.1. Research questions

The most common research question regarding conservation (13 papers) is to assess the economic impacts of decreasing harvest levels to preserve forest resources. In particular, eight studies focus on the removal of forestland from production through set-asides [106] and buffer-zones around streams [107,108]. Most of these studies can be labelled as *market projections*. Two studies go further and perform *policy analyses* investigating the optimal allocation and opportunity costs of reserves [97,109] under several conservations targets/policy designs. Four of the papers we reviewed assess the sector impacts of trade measures aiming at stopping illegal logging in tropical countries [110–113]. Another four investigate conservation in the front of other land uses and land use changes: two of these focus on Europe and wetland conservation [114,115], while two others are dedicated to tropical cases [116,117]. All of these test alternative policy designs, often with several levels or targets, and can be labelled as *policy analyses*. Finally, one study focuses on the opportunity costs of a forest certification scheme [118], while the last study investigates a model's assumptions on forest owners' heterogeneity in preferences for non-timber amenities [119].

6.2. Modelling forest reserves and set-asides in forest sector models

Protected areas have been promoted as a way to ensure biodiversity protection and the sustainable provision of ecosystem services [7,120]. This echoes the fact that, despite being quite heterogeneous, FSM research on conservation primarily focuses on tradeoffs between timber production and forest reserves. Our narrative focus will thus be on the way forest reserves and set-asides have been modelled in FSM.

The modelling of reserves and set-asides in FSM entails the *ex-ante* identification of areas to conserve. Two cases should be distinguished: either the study focuses on investigating already-existing reserves, or on the impacts of establishing new reserves. While the former relies on extant data to identify conserved areas, the latter requires a way to assess the suitability of forests for conservation. In early studies, newly established set-asides are not targeted and concern a fixed quantity/proportion of all forests in a specific region [121,122]: areas suitable for conservation are not identified, and, among these, there is no choice regarding where conservation will actually be applied. This shortcoming was addressed by two waves of innovation.

A first innovation is to allow models to identify areas relevant for conservation using one or several sets of criteria. In a group of studies using static-recursive models focused on Europe, reserves target mature forests only, which are identified using a structural criterion: forest density [106,123], while in two studies using intertemporal models of the US Pacific North-West region, reserves are buffer-zones of varying width around streams, which are thus defined using a geographical criterion [107,108]. Using ecological data, Kallio et al. [97] go further and build habitat quality indices from which the amount of forest land suitable for conservation in each region of Finland is identified and used as input in the FSM.

A second innovation is to make the choice of areas to be preserved endogenous. This new paradigm is easily observable when comparing Hänninen and Kallio [123] and Kallio et al. [97] . In the former, a fixed percentage of all forests deemed suitable is removed from production. In the latter, a new agent is introduced, whose aim is to distribute a conservation target among all forests identified as having a high habitat quality. This translates as an additional constraint on the optimisation problem: conservation becomes a decision variable. The use of such constraints can also be seen in Hauer et al. [109], Montgomery, Latta and Adams [98] and Schleupner and Schneider [114,115].

Both in the case of already-existing and newly established reserves, another innovation has greatly benefited to FSM research on conservation: the increasing use of spatially explicit tools. All FSM are to some extent spatialised, and in the most basic case, regions with separate inventories and forest industries are represented. In the SF-GTM for instance [123], these correspond to the Finnish Forestry Centres, and in the EUFASOM [114], to European countries. However, many studies present a finer level of spatial detail, and usually rely on one of two solutions: the use of an FSM built with more spatial details than in the basic case described above, or a linkage between an FSM with basic spatial features and a more spatially detailed tool, usually GIS based. In both cases, it entails the use of spatially explicit data. When studying newly established reserves, the use of spatial tools has enabled the investigation of optimal reserve allocation, which was not possible without those tools, while in the case of already existing reserves, spatial tools were a requirement. Examples of papers using spatially explicit tools are given in Table 1.

Table 1 Examples of FSM studies using a spatial tool. Lines indicate why the spatial tool is used, while columns separate studies using an already spatialised FSM versus those using a spatial tool outside the FSM.

	Supplementary spatialised tool	Spatialised FSM
Optimal allocation of newly established reserves	Kallio et al. [97] Schleupner and Schneider [115]	Montgomery, Latta and Adams [98] Hauer et al. [109]
Location of already existing reserves	Schleupner and Schneider [114,115] Galik and Abt [53]	Adams and Latta [107,108] Merry et al. [117] Mosnier et al. [124]

While these tools and approaches have mostly been developed to study fixed reserves where a permanent area is removed from production [117,123], some studies propose a dynamic approach to conservation, where the location of preserved areas can vary over time: conserved areas are not chosen but emerge from the management decisions taken by the model's agents [98,109]. We consider this alternative approach to the design of reserves to be an innovation *per se*. Its significance is highlighted by Adams and Latta [107,108], where this new approach is compared to a scenario with the more common fixed reserves.

Regarding the implications of conservation, a majority of FSM studies only assess economic consequences on the forest sector, that is to say, impacts on products prices and quantities produced and traded. Impacts on habitat quality, biodiversity and non-timber amenities are often cited as benefits that conservation policies can help secure, but they are rarely assessed. Kallio et al. [97] for instance suggests that if benefits derived from forest conservation were actually evaluated, they could alleviate the estimated welfare losses. Some attempts have been made at assessing the ecological impacts of reserves, performing *ex-post* analyses on habitat suitability for local species and bird abundance, supplementing FSM with ecological models [109,119]. The impacts of reserves in terms of land use changes have also been assessed, focusing on tradeoffs between forestry, agriculture and wetland conservation [114,115] and deforestation in the Congo Basin in the wake of REDD+ programmes [124]. In both cases, the study of land use changes is made possible by the use of multi-sector models: EU-FASOM (forest and agriculture) for the former, GLOBIOM (forest, agriculture and energy) for the latter.

7. Discussion and future prospects

7.1. Different categories of modelling innovations

Several waves of innovations have allowed for the modelling of non-timber objectives. These vary regarding the extent to which they modify models and the components of the model they concern, as shown on figure 6 on which we can distinguish four groups of innovations.

First, most innovations target market components. These primarily consist of increases in complexity of the value chain with additions of products, technology inputs and transformation processes (4a, 4b, 5, 7a). Such technical innovations are marginal since they modify neither the model's structure nor the way it is solved.

Second, other innovations bring a deeper change and modify agents' behaviours, the model's solution, and enable the user to perform new types of analyses: they are more advanced and can be labelled as methodological innovations. In this vein, 6 and 7b introduce new specifications for demand equations and, similarly, market instruments related to carbon management (9a and 9b) add new terms to the objective function and allow energy or climate policies to be used as model drivers. Such innovations are enabled by structural and supporting innovations, which add new products and functionalities to the model. For instance, innovations 8, 10a and 10b add carbon as a non-wood product, carbon accounting as a new functionality, and they enable the development of carbon-based instruments (9a and 9b).

Third, only three innovations occur at the level of the forest resources component, and all increase the complexity in resource description (1, 2a and 2b). Developing a spatial format for forest inventory can be done both inside the model (2a), which is a structural change, while 2b requires the use of extra-model tools. On the other hand, improving the location of areas for conservation does not change the way resources are represented, but is a methodological innovation where new constraints are imposed on the optimisation problem.

Fourth, the assessment of ecological consequences (3) almost represents a change of paradigm in the way FSM are used, since it adds a new dimension to the analysis besides the economic analysis usually allowed. However, it often relies on the use of extra-model tools using the FSM's outputs as inputs.

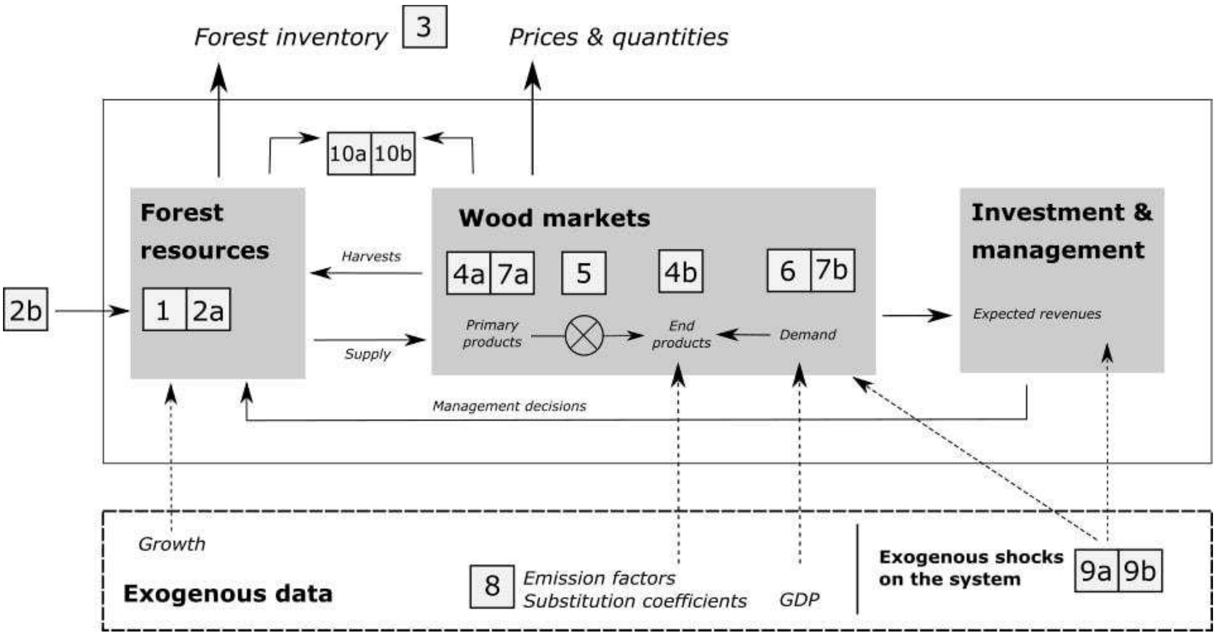


Fig.6 Innovations in modelling non-timber objectives in FSM. Grey boxes represent the different components of FSM, while arrows represent information flows within the model. Innovations are represented by numbered boxes located in the model component where they intervene. Innovations considered are: (1) Targeted set-asides for conservation, (2) The use of spatially explicit tools (a) inside or (b) outside the model, (3) Assessment of ecological impacts, (4) Disaggregation of products, (5) Disaggregation of processing technologies, (6) New specifications for demand functions, (7) The inclusion of fossil fuels (a) as technology inputs or (b) in demand functions, (8) The assessment of avoided emissions, (9) Market-based instruments for carbon management as (a) taxes on emissions or (b) sequestration payments, (10) Carbon accounting in (a) forests and (b) wood products.

7.2. Current limits and future prospects

The innovations discussed all along this review have allowed for new ways to use FSM and are the main reason why the investigation of non-timber objectives has gradually become a central topic with a high amount of publications, despite a significant number of papers still solely considering timber production. Even though the time seems ripe for the study of non-timber objectives, our results reveal that only four non-timber objectives have been addressed: conservation, climate change mitigation, bioenergy production and fire prevention. Many ecosystem services provided by forests such as recreation and erosion control have not been addressed within FSM literature. In addition, studies are unevenly distributed among the non-timber objectives identified, and there exist discrepancies regarding the respective contributions of various families of FSM to the field.

As pointed out on several occasions, this is usually related to the technical limitations and underlying assumptions behind each model, which in turn influences the research questions investigated. The integration of bioenergy production only requires the addition of new market segments, which does not require fundamental changes in the models' structure. The modelling of carbon sequestration requires more complex changes, but relies primarily on forest inventory data which is already present in most FSM. Contrary to carbon sequestration, which can potentially occur on any forest land and be remunerated regardless of location, the spatial component of most other ecosystem services is stronger and entails the use of a level of spatial detail most FSM have not yet achieved. Such a limit is observable in conservation studies, where exogenous data and extra-model tools regularly need to be employed.

Finally, our results clearly show that not all non-timber objectives benefit from the same level of integration. Timber and bioenergy production, for instance, are integrated into FSM as a perfect loop (figure 7): agents' behaviours determine the output (production), which in turn influences agents' behaviours through the objective function where economic returns from wood products are maximised. In addition, constraints on production can be added to the optimisation problem. On the other hand, many studies on forest reserves model conservation through exogenous constraints imposed on the model, which do not enter the objective function *per se* [106,123]. The effectiveness of conservation is not assessed, and there is no feedback.

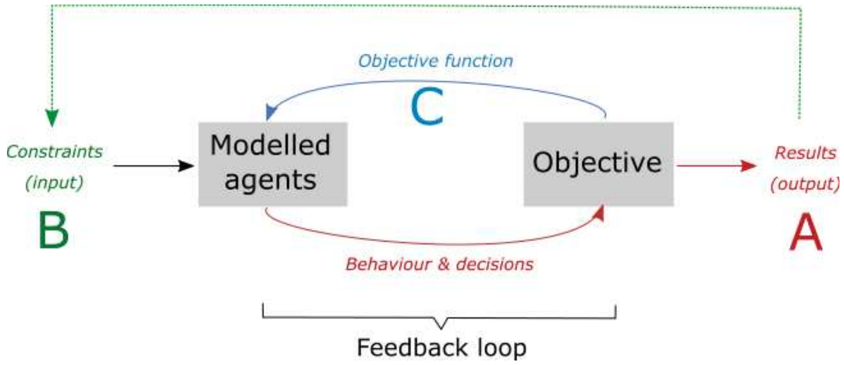


Fig.7 Integrating objectives into FSM: a feedback loop

This leads us to consider three approaches to integrating forest objectives into FSM. Under approach A, the objective is studied as an output, i.e., impacts of a scenario on said objective are assessed. Under approach B, targets for the objective are integrated as constraints on the objective function: the objective is secondary to surplus maximisation, but influences it. Under approach C, the objective is integrated into the objective function *per se*, which requires it to be monetised. Under both approaches B and C, the objective is more deeply integrated and enters the optimisation problem. While approach B requires targets to be introduced exogenously, approach C enables an endogenous determination of the optimal level. Table 2 gives examples for habitat conservation and carbon sequestration. We can notice that we did not identify any example of integrating habitat conservation through approach C in our review.

Table 2 Examples of FSM studies using the identified approaches to integrating habitat conservation and carbon sequestration into FSM.

	Approach A	Approach B	Approach C
Habitat conservation	- Pattanayak et al. [119] uses habitat suitability models for an ex-post analysis. - Hauer et al. [109] uses bird abundance models for an ex-post analysis.	- Kallio et al. [97] impose constraints on the amount of forest reserves to allocate. - Hauer et al. [109] imposes constraints on the minimum amount of old mesic forests to exist at a given time. - Montgomery, Latta and Adams [98] impose constraints on the minimum amount of structurally old-growth forests to exist at a given time	
Carbon sequestration	- Lobianco et al. [92] explains the	- Im, Adams and Latta [78] impose targets	- Sjølie, Latta and Solberg [103]

	development of a carbon accounting module. - Galik et al. [48] follow carbon stocks in the South-Eastern US under different bioenergy policy scenarios.	on carbon fluxes to be attained under several harvest scenarios. - Tavoni, Sohngen and Bosetti [125] set a target for c02 concentration in the atmosphere.	introduce a Kyoto-based carbon offset programme. - Lauri et al. [61] introduce taxes on carbon emissions. - Caurla et al.[69] study interactions between taxes on emissions and carbon offset payments.

Our analysis relied on two different but complementary methods: a systematic review followed by a narrative review. This framework allowed us to give a comprehensive, quantitative and reproducible overview on the field while also enabling a more detailed analysis on several key points. However, our approach may suffer from some shortcomings. First, the definition and subsequent implementation of criteria to identify relevant papers in the systematic review entail some level of subjectivity. This may have led us to dismiss (or include) a small amount of papers not clearly falling in (or out) of the scope of this study. However, this kind of bias is hardly avoidable. Regarding the narrative review step, we focused on key points through a selection of examples, which entails a stronger bias. To mitigate this, we based our choices not only on our experience in the field of forest sector modelling, but also on current political issues and results from the quantitative analysis. Even though some level of subjectivity persists, we believe such a choice was necessary in order to provide a more in-depth analysis of our topic.

Because FSM rely on the maximisation of economic surplus, currently, the deepest integration of non-timber objectives requires them to be monetised. The next logical step would be the development of an approach where non-timber objectives enter the objective function without being monetised. Such an evolution would require a change in optimisation techniques, since several variables of different nature would be optimised simultaneously.

Such an approach would fall within the scope of multi-criteria decision analysis (MCDA), which encompasses a set of methods, including numerical optimisation methods, used to compare alternatives across several dimensions using weights, distances or classification of outcomes to define trade-offs [126,127]. MCDA has been increasingly used in environmental sciences [126] and forest and natural resources management [128], even though it has not entered FSM research yet. Indeed, while MCDA explicitly considers multiple objectives, optimisation techniques used in FSM are more akin to multi-objective planning methods using single-objective optimisation and constraints on secondary objectives as defined in Mendoza and Martins [128]. Adapting MCDA methods to FSM could prove useful to the study of synergies and tradeoffs between multiple forest objectives within a framework able to account for market dynamics.

References

[1] Garcia, S., Abildtrup, J., & Stenger, A. (2018). How does economic research contribute to the management of forest ecosystem services? *Annals of Forest Science*, 75 (2), 53.

[2] Duncker, P.S., Raulund-Rasmussen, K., Gundersen, P., Katzensteiner, K., De Jong, J., Ravn, H.P., et al. (2012). How Forest Management affects Ecosystem Services, including Timber Production and Economic Return: Synergies and Trade-Offs. *Ecology and Society*, 17 (4), art50.

[3] UNFCCC (2015). Paris Agreement.Resource Document. UNFCCC. http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf. Accessed 7 June 2018.

[4] UN-REDD (2015). Fact Sheet: About REDD+. Resource document. FAO UNDP UNEP. http://www.un-redd.org/AboutREDD/tabid/102614/Default.aspx. Accessed 7 June 2018.

[5] European Parliament (2009). Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009. *Official Journal of the European Union*, 140 (16), 16–62.

[6] European Commission (2017). Proposal for a directive of the European Parliament and of the council on the promotion of the use of energy from renewable sources (recast). *Official Journal of the European Union*, 0382 (2016),.

[7] Maes, J., Paracchini, M.L., Zulian, G., Dunbar, M.B., & Alkemade, R. (2012). Synergies and trade-offs between ecosystem service supply, biodiversity, and habitat conservation status in Europe. *Biological Conservation*, 155 1–12.

[8] European Commission (2015). Natura 2000 and Forests. Part I - II. Brussels. Resource document. European Commission. http://ec.europa.eu/environment/nature/natura2000/management/docs/Final Guide N2000 Forests Part I-II-Annexes.pdf. Accessed 7 June 2018.

[9] European Commission (2013). A new EU Forest Strategy: for forests and the forest-based sector. Brussels. Resource document. European Commission. https://scholar.google.com/scholar?q=Communication+from+the+Commission+to+the+Council+and+the+European+Parliament&btnG=&hl=en&as_sdt=0%2C5#8. Accessed 7 June 2018.

[10] Busch, J., Godoy, F., Turner, W.R., & Harvey, C.A. (2011). Biodiversity co-benefits of reducing emissions from deforestation under alternative reference levels and levels of finance. *Conservation Letters*, 4 (2), 101–115.

[11] Bryan, B.A., Runting, R.K., Capon, T., Perring, M.P., Cunningham, S.C., Kragt, M.E., et al. (2016). Designer policy for carbon and biodiversity co-benefits under global change. *Nature Climate Change*, 6 (3), 301–305.

[12] Magnago, L.F.S., Magrach, A., Laurance, W.F., Martins, S. V., Meira-Neto, J.A.A., Simonelli, M., et al. (2015). Would protecting tropical forest fragments provide carbon and biodiversity cobenefits under REDD+? *Global Change Biology*, 21 (9), 3455–3468.

[13] Latta, G.S., Sjolie, H.K., & Solberg, B. (2013). A review of recent developments and applications of partial equilibrium models of the forest sector. *Journal of Forest Economics*, 19 (4), 350–360.

[14] Adams, D.M. & Haynes, R.W. (2007). Resource and market projections for forest policy development : twenty-five years of experience with the U.S. RPA timber assessment. Springer, .

[15] Caurla, S. (2013). Une typologie et une histoire des modèles économiques de secteur forestier. *Revue Forestière Française*, (2), 163–181.

[16] Toppinen, A. & Kuuluvainen, J. (2010). Forest sector modelling in Europe-the state of the art and future research directions. *Forest Policy and Economics*, 12 (1), 2–8.

[17] Solberg, B. (1986). Forest sector simulation models as methodological tools in forest policy analysis (Norway). *Silva Fennica*, 20 (4), 419–427.

[18] Sjølie, H.K., Latta, G.S., Trømborg, E., Bolkesjø, T.F., & Solberg, B. (2015). An assessment of forest

sector modeling approaches: conceptual differences and quantitative comparison. *Scandinavian Journal of Forest Research*, 30 (1), 60–72.

[19] Muth, J.F. (1961). Rational Expectations and the Theory of Price Movements. *Econometrica*, 29 (3), 315.

[20] Mustapha, W. (2016). The Nordic Forest Sector Model (NFSM): Data and Model Structure. Resource document. Norwegian University of Life Sciences. http://www.umb.no/statisk/ina/publikasjoner/fagrapport/if38.pdf. Accessed 3 October 2017.

[21] Caurla, S., Lecocq, F., Delacote, P., & Barkaoui, A. (2010). The French Forest Sector Model: version 1.0. Resource document. INRA. http://agris.fao.org/agris-search/search.do?recordID=LV2016027831. Accessed 7 June 2018.

[22] Buongiorno, J. (2014). Global modelling to predict timber production and prices: The GFPM approach. *Forestry*, 88 (3), 291–303.

[23] Northway, S., Bull, G.Q., & Nelson, J.D. (2013). Forest sector partial equilibrium models: Processing components. *Forest Science*, 59 (2), 151–156.

[24] Lobianco, A., Delacote, P., Caurla, S., & Barkaoui, A. (2014). Introducing forest management in forest sector models: impact of active management and risk attitude on forest resources in the long term. resource document. INRA. https://lobianco.org/antonello/_media/academic:pubs:cahier_lef_2014-05.pdf. Accessed 22 November 2017.

[25] Adams, D.M., Alig, R.J., Callaway, J.M., McCarl, B. a, & Winnett, S.M. (1996). The Forest and Agricultural Sector Optimization Model (FASOM): Model Structure and Policy Applications. *Evaluation*, No. PNW-RP (September), 1-.

[26] Samuelson, P.A. (1952). Spatial price equilibrium and linear programming. *American Economic Review*, 42 (3), 283–303.

[27] Buongiorno, J. (1996). Forest sector modeling: A synthesis of econometrics, mathematical programming, and system dynamics methods. *International Journal of Forecasting*, 12 (3), 329–343.

[28] van Eck, N.J. & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, 84 (2), 523–538.

[29] van Eck, N.J. & Waltman, L. (2014). Visualizing Bibliometric Networks. Springer, .

[30] Adams, D., Mccarl, B.A., & Murray, B.C. (2005). FASOMGHG Conceptual Structure, and Specification: Documentation. Resource document. http://agecon2.tamu.edu/people/faculty/mccarl-bruce/papers/1212FASOMGHG_doc.pdf. Accessed 7 June 2018.

[31] ABT, R.C., CUBBAGE, F.W., & PACHECO, G. (2000). SOUTHERN FOREST RESOURCE ASSESSMENT USING THE SUBREGIONAL TIMBER SUPPLY (SRTS) MODEL. *Forest Products Journal*, 50 (4), 25–25.

[32] Kallio Moiseyev, A., Solberg, B., a M.I. (2004). The global forest sector model EFI-GTM. The model structure. Resource document. EFI. http://www.efi.int/files/attachments/publications/ir_15.pdf. Accessed 19 January 2017.

[33] Ronnila, M. (1995). Medium-Term Scenarios for the Finnish Pulp and Paper Industry. Laxemburg. Working paper. IIASA. http://pure.iiasa.ac.at/4554/1/WP-95-038.pdf. Accessed 20 October 2017.

[34] Trømborg, E. & Sjølie, H.K. (2011). Data applied in the forest sector models NorFor and NTMIII. *INA Fagrapport. Department of Ecology and Natural Resource Management Norwegian University of Life Sciences*, 17.

[35] Sedjo, R.A. & Lyon, K.S. (1996). Timber Supply Model 96 : A Global Timber Supply Model with a Pulpwood Component. Washington DC.

[36] Stennes, B. & Wilson, B. (2005). An analysis of lumber trade restrictions in North America: Application

of a spatial equilibrium model. *Forest Policy and Economics*, 7 (3), 297–308.

[37] Johnston, C.M.T. & Van Kooten, G.C. (2014). Economic consequences of increased bioenergy demand. *Forestry Chronicle*, 90 (5), 636–642.

[38] Peter, B. & Niquidet, K. (2016). Estimates of residual fibre supply and the impacts of new bioenergy capacity from a forest sector transportation model of the Canadian Prairie Provinces. *Forest Policy and Economics*, 69 62–72.

[39] Niquidet, K. & Friesen, D. (2014). Bioenergy potential from wood residuals in Alberta: a positive mathematical programming approach. *CANADIAN JOURNAL OF FOREST RESEARCH*, 44 (12), 1586–1594.

[40] Stennes, B.K., Niquidet, K., & Cornelis van Kooten, G. (2010). Implications of expanding bioenergy production from wood in British Columbia: An application of a regional wood fiber allocation model. *Forest Science*, 56 (4), 366–378.

[41] Buongiorno, J., Raunikar, R., & Zhu, S. (2011). Consequences of increasing bioenergy demand on wood and forests: An application of the Global Forest Products Model. *Journal of Forest Economics*, 17 (2), 214–229.

[42] Trømborg, E. & Solberg, B. (2010). Forest sector impacts of the increased use of wood in energy production in Norway. *Forest Policy and Economics*, 12 (1), 39–47.

[43] Trømborg, E., F. Bolkesjø, T., & Solberg, B. (2013). Second-generation biofuels: impacts on bioheat production and forest products markets. *International Journal of Energy Sector Management*, 7 (3), 383–402.

[44] Trømborg, E., Bolkesjø, T.F., & Solberg, B. (2007). Impacts of policy means for increased use of forest-based bioenergy in Norway-A spatial partial equilibrium analysis. *Energy Policy*, 35 (12), 5980–5990.

[45] Moiseyev, A., Solberg, B., & Kallio, A.M.I. (2014). The impact of subsidies and carbon pricing on the wood biomass use for energy in the EU. *Energy*, 76 161–167.

[46] Sedjo, R. & Tian, X. (2012). Does Wood Bioenergy Increase Carbon Stocks in Forests? *Journal of Forestry*, 110 (6), 304–311.

[47] Latta, G.S., Baker, J.S., Beach, R.H., Rose, S.K., & McCarl, B.A. (2013). A multi-sector intertemporal optimization approach to assess the GHG implications of U.S. forest and agricultural biomass electricity expansion. *Journal of Forest Economics*, 19 (4), 361–383.

[48] Galik, C.S., Abt, R.C., Latta, G., & Vegh, T. (2015). The environmental and economic effects of regional bioenergy policy in the southeastern U.S. *Energy Policy*, 85 335–346.

[49] Sjølie, H.K., Trømborg, E., Solberg, B., & Bolkesjø, T.F. (2010). Effects and costs of policies to increase bioenergy use and reduce GHG emissions from heating in Norway. *Forest Policy and Economics*, 12 (1), 57–66.

[50] Costanza, J.K., Abt, R.C., McKerrow, A.J., & Collazo, J.A. (2017). Bioenergy production and forest landscape change in the southeastern United States. *GCB Bioenergy*, 9 (5), 924–939.

[51] Duden, A.S., Verweij, P.A., Junginger, H.M., Abt, R.C., Henderson, J.D., Dale, V.H., et al. (2017). Modeling the impacts of wood pellet demand on forest dynamics in southeastern United States. *Biofuels, Bioproducts and Biorefining*, 11 (6), 1007–1029.

[52] Geijer, E., Andersson, J., Bostedt, G., Brännlund, R., & Hjältén, J. (2014). Safeguarding species richness vs. increasing the use of renewable energy—The effect of stump harvesting on two environmental goals. *Journal of Forest Economics*, 20 111–125.

[53] Galik, C.S. & Abt, R.C. (2016). Sustainability guidelines and forest market response: an assessment of European Union pellet demand in the southeastern United States. *GCB Bioenergy*, 8 (3), 658–669.

[54] Böttcher, H., Frank, S., Havlík, P., & Elbersen, B. (2013). Future GHG emissions more efficiently

controlled by land-use policies than by bioenergy sustainability criteria. *Biofuels, Bioproducts and Biorefining*, 7 (2), 115–125.

[55] Moiseyev, A., Solberg, B., Kallio, A.M.I., & Lindner, M. (2011). An economic analysis of the potential contribution of forest biomass to the EU RES target and its implications for the EU forest industries. *Journal of Forest Economics*, 17 (2), 197–213.

[56] Niquidet, K., Stennes, B., & van Kooten, G.C. (2012). Bioenergy from Mountain Pine Beetle Timber and Forest Residuals: A Cost Analysis. *Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie*, 60 (2), 195–210.

[57] Martinkus, N., Latta, G., Morgan, T., & Wolcott, M. (2017). A comparison of methodologies for estimating delivered forest residue volume and cost to a wood-based biorefinery. *Biomass and Bioenergy*, 106 83–94.

[58] Lauri, P., Havlík, P., Kindermann, G., Forsell, N., Böttcher, H., & Obersteiner, M. (2014). Woody biomass energy potential in 2050. *Energy Policy*, 66 19–31.

[59] Demirbas, M.F., Balat, M., & Balat, H. (2009). Potential contribution of biomass to the sustainable energy development. *Energy Conversion and Management*, 50 (7), 1746–1760.

[60] Raunikar, R., Buongiorno, J., Turner, J.A., & Zhu, S. (2010). Global outlook for wood and forests with the bioenergy demand implied by scenarios of the Intergovernmental Panel on Climate Change. *Forest Policy and Economics*, 12 (1), 48–56.

[61] Lauri, P., Kallio, A.M.I., & Schneider, U.A. (2012). Price of CO 2 emissions and use of wood in Europe. *Forest Policy and Economics*, 15 123–131.

[62] Johnston, C.M.T. & van Kooten, G.C. (2016). Global trade impacts of increasing Europe's bioenergy demand. *Journal of Forest Economics*, 23 27–44.

[63] Zhang, S., Gilless, J.K., & Stewart, W. (2014). Modeling price-driven interactions between wood bioenergy and global wood product markets. *Biomass and Bioenergy*, 60 68–78.

[64] Abt, K.L., Abt, R.C., & Galik, C. (2012). Effect of bioenergy demands and supply response on markets, carbon, and land use. *Forest Science*, 58 (5), 523–539.

[65] Moiseyev, A., Solberg, B., & Kallio, A.M.I. (2013). Wood biomass use for energy in Europe under different assumptions of coal, gas and CO2 emission prices and market conditions. *Journal of Forest Economics*, 19 (4), 432–449.

[66] Bolkesjø, T., Trømborg, E., & Solberg, B. (2006). Bioenergy from the forest sector: Economic potential and interactions with timber and forest products markets in Norway. *Scandinavian Journal of Forest Research*, 21 (2), 175–185.

[67] Mustapha, W.F., Trømborg, E., & Bolkesjø, T.F. (2017). Forest-based biofuel production in the Nordic countries: Modelling of optimal allocation. *Forest Policy and Economics*, (September 2016), 1–10.

[68] Kallio, A.M.I., Chudy, R., & Solberg, B. (2018). Prospects for producing liquid wood-based biofuels and impacts in the wood using sectors in Europe. *Biomass and Bioenergy*, 108 415–425.

[69] Caurla, S., Delacote, P., Lecocq, F., Barthès, J., & Barkaoui, A. (2013). Combining an inter-sectoral carbon tax with sectoral mitigation policies: Impacts on the French forest sector. *Journal of Forest Economics*, 19 (4), 450–461.

[70] Mustapha, W.F., Bolkesjø, T.F., Martinsen, T., & Trømborg, E. (2017). Techno-economic comparison of promising biofuel conversion pathways in a Nordic context – Effects of feedstock costs and technology learning. *Energy Conversion and Management*, 149 368–380.

[71] Buongiorno, J. & Zhu, S. (2013). Consequences of carbon offset payments for the global forest sector. *Journal of Forest Economics*, 19 (4), 384–401.

[72] Latta, G.S., Adams, D.M., Bell, K.P., & Kline, J.D. (2016). Evaluating land-use and private forest

management responses to a potential forest carbon offset sales program in western Oregon (USA). *Forest Policy and Economics*, 65 1–8.

[73] Sjølie, H.K., Latta, G.S., & Solberg, B. (2013). Potential impact of albedo incorporation in boreal forest sector climate change policy effectiveness. *Climate Policy*, 13 (6), 665–679.

[74] Sjølie, H.K., Latta, G.S., & Solberg, B. (2013). Dual discounting in climate change mitigation in the forest sector. *Journal of Forest Economics*, 19 (4), 416–431.

[75] Latta, G., Adams, D.M., Alig, R.J., & White, E. (2011). Simulated effects of mandatory versus voluntary participation in private forest carbon offset markets in the United States. *Journal of Forest Economics*, 17 (2), 127–141.

[76] Lecocq, F., Caurla, S., Delacote, P., Barkaoui, A., & Sauquet, A. (2011). Paying for forest carbon or stimulating fuelwood demand? Insights from the French Forest Sector Model. *Journal of Forest Economics*, 17 (2), 157–168.

[77] Alig, R.J. & Bair, L.S. (2006). Forest environmental investments and implications for climate change mitigation. *Journal of Environmental Quality*, 35 (4), 1389–1395.

[78] Im, E.H., Adams, D.M., & Latta, G.S. (2010). The impacts of changes in federal timber harvest on forest carbon sequestration in western Oregon. *CANADIAN JOURNAL OF FOREST RESEARCH-REVUE CANADIENNE DE RECHERCHE FORESTIERE*, 40 (9), 1710–1723.

[79] Sathaye, J., Makundi, W., Dale, L., Chan, P., & Andrasko, K. (2005). GHG Mitigation Potential, Costs and Benefits in Global Forests:A Dynamic Partial Equilibrium Approach. Resource document. Laurence Berkeley National Laboratory. http://www.scopus.com/inward/record.url?eid=2-s2.0-47249111482&partnerID=40&md5=c536d0d2474f25d472a11933b24bb851. Accessed 22 December 2017.

[80] Alig, R., Latta, G., Adams, D., & McCarl, B. (2010). Mitigating greenhouse gases: The importance of land base interactions between forests, agriculture, and residential development in the face of changes in bioenergy and carbon prices. *Forest Policy and Economics*, 12 (1), 67–75.

[81] Eriksson, L.O., Gustavsson, L., Hänninen, R., Kallio, M., Lyhykäinen, H., Pingoud, K., et al. (2012). Climate change mitigation through increased wood use in the European construction sector-towards an integrated modelling framework. *European Journal of Forest Research*, 131 (1), 131–144.

[82] Nepal, P., Skog, K.E., McKeever, D.B., Bergman, R.D., Abt, K.L., & Abt, R.C. (2016). Carbon Mitigation Impacts of Increased Softwood Lumber and Structural Panel Use for Nonresidential Construction in the United States. *Forest Products Journal*, 66 (1–2), 77–87.

[83] Tromborg, E., Sjolie, H., Solberg, B., Hovi, I.B., Madslien, A., & Veisten, K. (2009). Economic and environmental impacts of transport cost changes on timber and forest product markets in Norway. *Scandinavian Journal of Forest Research*, 24 (4), 354–366.

[84] Ascui, F. & Lovell, H. (2011). As frames collide: making sense of carbon accounting. *Accounting, Auditing & Accountability Journal*, 24 (8), 978–999.

[85] Steininger, K.W., Lininger, C., Meyer, L.H., Munõz, P., & Schinko, T. (2016). Multiple carbon accounting to support just and effective climate policies. *Nature Climate Change*, 6 (1), 35–41.

[86] Kander, A., Jiborn, M., Moran, D.D., & Wiedmann, T.O. (2015). National greenhouse-gas accounting for effective climate policy on international trade. *Nature Climate Change*, 5 (5), 431–435.

[87] Vass, M.M. & Elofsson, K. (2016). Is forest carbon sequestration at the expense of bioenergy and forest products cost-efficient in EU climate policy to 2050? *Journal of Forest Economics*, 24 82–105.

[88] Mitchell, S.R., Harmon, M.E., & O'Connell, K.E.B. (2012). Carbon debt and carbon sequestration parity in forest bioenergy production. *GCB Bioenergy*, 4 (6), 818–827.

[89] Adams, D.M., Alig, R., Latta, G., & White, E.M. (2011). Regional Impacts of a Program for Private Forest Carbon Offset Sales. *Journal of Forestry*, 109 (8), 444–461.

[90] Sjølie, H.K., Latta, G.S., Gobakken, T., & Solberg, B. (2011). NorFor - a forest sector model of Norway Model overview and structure. *INA Fagrapport 18. Department of Ecology and Natural Resource Management Norwegian University of Life Sciences*,.

[91] Sohngen, B. & Sedjo, R. (2000). Potential carbon flux from timber harvest and management in the context of a global timber market. *Climatic Change*, 44 (1/2), 151–172.

[92] Lobianco, A., Caurla, S., Delacote, P., & Barkaoui, A. (2016). Carbon mitigation potential of the French forest sector under threat of combined physical and market impacts due to climate change. *Journal of Forest Economics*, 23 4–26.

[93] Kallio, A.M.I., Salminen, O., & Sievänen, R. (2013). Sequester or substitute-Consequences of increased production of wood based energy on the carbon balance in Finland. *Journal of Forest Economics*, 19 (4), 402–415.

[94] Sjølie, H.K. & Solberg, B. (2011). Greenhouse gas emission impacts of use of Norwegian wood pellets: a sensitivity analysis. *Environmental Science & Policy*, 14 (8), 1028–1040.

[95] Kallio, A., Salminen, O., & Sievänen, R. (2016). Forests in the Finnish low carbon scenarios. *Journal of Forest Economics*, 23 45–62.

[96] Valade, A., Bellassen, V., Magand, C., & Luyssaert, S. (2017). Sustaining the sequestration efficiency of the European forest sector. *Forest Ecology and Management*, 405 44–55.

[97] Kallio, A.M.I., Hänninen, R., Vainikainen, N., & Luque, S. (2008). Biodiversity value and the optimal location of forest conservation sites in Southern Finland. *Ecological Economics*, 67 (2), 232–243.

[98] Montgomery, C.A., Latta, G.S., & Adams, D.M. (2006). The Cost of Achieving Old-Growth Forest Structure. *Land Economics*, 82 (2), 240–256.

[99] Sohngren, B. & Mendelsohn, R. (2003). An Optimal Control Model of Forest Carbon Sequestration. *American Journal of Agricultural Economics*, 85 (2), 448–457.

[100] Sohngen, B., Beach, R.H., & Andrasko, K. (2008). Avoided deforestation as a greenhouse gas mitigation tool: economic issues. *Journal of Environmental Quality*, 37 1368–1375.

[101] Im, E.H., Adams, D.M., & Latta, G.S. (2007). Potential impacts of carbon taxes on carbon flux in western Oregon private forests. *Forest Policy and Economics*, 9 (8), 1006–1017.

[102] Sjolie, H.K., Latta, G.S., & Solberg, B. (2013). Potentials and costs of climate change mitigation in the Norwegian forest sector - Does choice of policy matter? *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere*, 43 (6), 589–598.

[103] Sjølie, H.K., Latta, G.S., & Solberg, B. (2014). Impacts of the Kyoto Protocol on boreal forest climate change mitigation. *Annals of Forest Science*, 71 (2), 267–277.

[104] Sun, B. & Sohngen, B. (2009). Set-asides for carbon sequestration: Implications for permanence and leakage. *Climatic Change*, 96 (3), 409–419.

[105] Hedenus, F. & Azar, C. (2009). Bioenergy plantations or long-term carbon sinks? – A model based analysis. *Biomass and Bioenergy*, 33 (12), 1693–1702.

[106] Bolkesjø, T.F., Trømborg, E., & Solberg, B. (2005). Increasing forest conservation in Norway: Consequences for timber and forest products markets. *Environmental and Resource Economics*, 31 (1), 95–115.

[107] Adams, D.M. & Latta, G.S. (2007). Future Prospects for Private Timber Harvest in Eastern Oregon. *WEST.J.APPL.FOR.*, 22 (3),.

[108] Adams, D.M. & Latta, G.S. (2007). Timber trends on private lands in western Oregon and Washington: a new look. *Western Journal of Applied Forestry*, 22 8–14.

[109] Hauer, G., Cumming, S., Schmiegelow, F., Adamowicz, W., Weber, M., & Jagodzinski, R. (2010).

Tradeoffs between forestry resource and conservation values under alternate policy regimes: A spatial analysis of the western Canadian boreal plains. *Ecological Modelling*, 221 2590–2603.

[110] Zhang, X., Xu, B., Wang, L., Yang, A., & Yang, H. (2016). Eliminating illegal timber consumption or production: Which is the more economical means to reduce illegal logging? *Forests*, 7 (9),.

[111] Moiseyev, A., Solberg, B., Michie, B., & Kallio, A.M.I. (2010). Modeling the impacts of policy measures to prevent import of illegal wood and wood products. *Forest Policy and Economics*, 12 (1), 24–30.

[112] Barbier, E.B., Bockstael, N., Burgess, J.C., & Strand, I. (1995). The Linkages between the Timber Trade and Tropical Deforestation???Indonesia. *World Economy*, 18 (3), 411–442.

[113] Sun, L. & Bogdanski, B.E.C. (2017). Trade incentives for importers to adopt policies to address illegally logged timber: The case of non-tropical hardwood plywood. *Journal of Forest Economics*, 27 18–27.

[114] Schleupner, C. & Schneider, U.A. (2010). Effects of bioenergy policies and targets on European wetland restoration options. *Environmental Science and Policy*, 13 (8), 721–732.

[115] Schleupner, C. & Schneider, U.A. (2013). Allocation of European wetland restoration options for systematic conservation planning. *Land Use Policy*, 30 (1), 604–614.

[116] Mosnier, A., Havlík, P., Obersteiner, M., Aoki, K., Schmid, E., Fritz, S., et al. (2014). Modeling Impact of Development Trajectories and a Global Agreement on Reducing Emissions from Deforestation on Congo Basin Forests by 2030. *Environmental and Resource Economics*, 57 (4), 505–525.

[117] Merry, F., Soares-Filho, B., Nepstad, D., Amacher, G., & Rodrigues, H. (2009). Balancing conservation and economic sustainability: The future of the amazon timber industry. *Environmental Management*, 44 (3), 395–407.

[118] Busby, G.M., MOntgomery, C.A., & Latta, G. (2007). The opportunity cost of forest certification on private land in western Oregon. *Western Journal of Applied Forestry*, 22 (1), 55–60.

[119] Pattanayak, S.K., Abt, R.C., Sommer, A.J., Cubbage, F., Murray, B.C., Yang, J.C., et al. (2004). Forest forecasts: Does individual heterogeneity matter for market and landscape outcomes? *Forest Policy and Economics*, 6 (3–4), 243–260.

[120] European Commission (2011). The EU biodiversity strategy to 2020. Brussels. Resource document. https://scholar.google.com/scholar?q=Communication+from+the+Commission+to+the+Council+and+the+European+Parliament&btnG=&hl=en&as_sdt=0%2C5#8. Accessed 7 June 2018.

[121] Perez-Garcia, J.M. (1993). Global forestry impacts of reducing softwood supplies from North America. *University of Washington, Center for International Trade in Forest Resources, CINTRAFOR Working Paper No. 43. 35 Pp.*,.

[122] Sohngen, B., Mendelsohn, R., & Sedjo, R. (1999). Forest Management, Conservation, and Global Timber Markets. *American Journal of Agricultural Economics*, 81 (1), 1–13.

[123] Hänninen, R. & Kallio, A.M.I. (2007). Economic impacts on the forest sector of increasing forest biodiversity conservation in Finland. *Silva Fennica*, 41 (3), 507–523.

[124] Mosnier, A., Havlík, P., Obersteiner, M., Aoki, K., Schmid, E., Fritz, · S, et al. (2014). Modeling Impact of Development Trajectories and a Global Agreement on Reducing Emissions from Deforestation on Congo Basin Forests by 2030. *Environ Resource Econ*, 57 505–525.

[125] Tavoni, M., Sohngen, B., & Bosetti, V. (2007). Forestry and the carbon market response to stabilize climate. *Energy Policy*, 35 (11), 5346–5353.

[126] Huang, I.B., Keisler, J., & Linkov, I. (2011). Multi-criteria decision analysis in environmental sciences: Ten years of applications and trends. *Science of the Total Environment*, 409 (19), 3578–3594.

[127] Kiker, G.A., Bridges, T.S., Varghese, A., Seager, T.P., & Linkov, I. (2005). Application of Multicriteria Decision Analysis in Environmental Decision Making. *Integrated Environmental Assessment and*

Management, 1 (2), 95.

[128] Mendoza, G.A. & Martins, H. (2006). Multi-criteria decision analysis in natural resource management: A critical review of methods and new modelling paradigms. *Forest Ecology and Management*, 230 (1–3), 1–22.

[129] European Commission (2016). Proposal for a Regulation of the European Parliament and of the Council for the inclusion of GHG emissions and removals from LULUCF into the 2030 climate and energy framework.... Brussels. Resource document. https://scholar.google.com/scholar?q=Communication+from+the+Commission+to+the+Council+and+the+European+Parliament&btnG=&hl=en&as_sdt=0%2C5#8. Accessed 7 June 2018.