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Analysis

Centre for studies and strategic foresight

N° 204 - July 2024

Foresight modeling and public policy in the forest sector

At the heart of economic, industrial and environmental issues, the forest sector plays a decisive role in addressing climate change. In this context, foresight modeling is an indispensable tool for informing public policy. This approach, which explores probable futures through numerical simulations, offers a valuable framework for anticipating developments in the sector and making informed decisions. This note shows how simulation models can contribute to shaping public policy in the forest sector. It also indicates their optimal conditions of use, their main advantages and limitations, as well as research trends in this field.

The forest sector (FS) encompasses interconnected activities, from upstream forestry to downstream industries, and forests constitute a multifunctional space at the origin of multiple economic productions and ecosystem services. This complex system is at the core of intertwined issues (economic, industrial, environmental, cultural, etc.) and related policies.

Recently, the FS has become very prominent, in particular because of its climate mitigation potential and due to the strong impacts climate change is expected to have in this sector (e.g. fires). Climate policies are a long-term process, and the FS is characterized by a strong inertia, in terms of both resources and industry. The need for anticipation is therefore high, and public authorities need to be able to plan ahead on the basis of robust data. In this context, simulation models are increasingly used to explore the future. This note describes this phenomenon and sheds light on it from several angles.

The first part looks at the notions of "model", "simulation" and "scenario", and the types of models that can be mobilized to support public policy. This is followed by a comparison of contrasting international foresight modeling exercises in the FS. The final section looks at the limits and advantages of modeling, as well as some recent trends.

1 - Exploring the future through digital simulation

Models, simulations and scenarios

A model is a representation, often simplified, of a "target" (e.g. object, system) in the real world. It can be of various kinds : physical for a scale model, mathematical for a system of equations, etc. The user then interacts experimentally with the model, which substitutes itself for reality. Studying the model's "behavior", rather than that of the real target, then enables the user to obtain information about the target through "subrogative" reasoning.

Forestry models used to support public policy are mainly "computational". They are systems of mathematical equations solved numerically on a computer, giving quantified results *via* simulation. Projecting into the future requires "dynamic" models, i.e. models where time is a variable. Time horizons considered are often very long : 10 to 20 years for wood market issues, up to the end of the century for climate issues. Simulation focuses on "scenarios", i.e. possible and plausible trajectories involving a coherent set of key variables that can be described in narrative form.

The FS contains objects of various natures: biological (trees, etc.), economic and behavioral (trade, etc.), technological (industries, etc.). It is therefore often necessary to use several models. These models, developed by research institutes and think tanks (e.g. INRAE, Resources for the future), are based on theories from several disciplines and calibrated on the basis of observed data or expert opinion.

Models based on several disciplines

The natural sciences provide ideal tools for studying the upstream FS. Growth models (tree, stand scales) can simulate productivity and compare several silvicultural itineraries ; landscape models are ideal for studying groups of forest units spatially and the impact of disturbances ; inventory models project the evolution of forest resources on a large scale ; and vegetation models replace the evolution of ecosystems at the heart of biogeochemical cycles (Figure 1).

Economics sheds light on the downstream side of the FS. "Optimal rotation" models have been used since the 19th century to assess the economic profitability of forest management, sometimes taking into account environmental benefits (e.g. carbon storage)[1]. Econometric models can be used to establish and project statistical relationships between variables (e.g. wood supply and price, input availability), while equilibrium models represent supply, demand and price formation jointly. Trade models, such as gravity models inspired by physics, focus on the spatial representation of goods flows.

"Forest sector models" combine representations of the resource, management, industry and markets. They enable integrated analysis and identification of the impacts of intervention along value chains. Conversely, the analysis of specific phenomena requires the use of specialized models (e.g. fire, carbon).

1. Peyron J.-L., Maheut J., 1999, « Les Fondements de l'économie forestière moderne : le rôle capital de Faustmann, il y a 150 ans, et celui de quelques-uns de ses précurseurs et successeurs », *Revue forestière française*, 51 (6), pp. 679-698.

Figure 1 - **Examples of forest models**

Disciplines	Models	Description
Natural sciences	CAPSIS	Growth model platform developed by INRAE and other research organizations
	LANDIS	Landscape model developed and used for 20 years by USDA researchers
	MARGOT	Inventory model by diameter class developed from French national forest inventory data
	European Forest Information Scenario Model (EFISCEN)	European Forest Institute inventory model, by age class and including ecosystem service indicators
	ORCHIDEE	Global vegetation model developed by IPSL
	JRC Forest Carbon Model (EU-CBM-HAT)	Carbon budget model for the European forest sector developed by the European commission's Joint research centre
	Firelihood	Fire occurrence and propagation model developed by INRAE
Economics	Lungarska et Chakir (2018)	Econometric model of land use applied to the French case
	Global Forest Model (G4M)	Land use model with biological resource representation, developed by IIASA
	Faustmann (1849), Reed (1984), Van Kooten (1995)	Optimal rotation model with extensions to natural disturbances and carbon amenities
	FOR-DICE	Integrated energy-climate model including the forest-wood sector
Integrated models	French forest sector model (FFSM)	Model of the French forest sector
	Global forest products model (GFPM)	Global forest sector model
	Global biosphere management model (GLOBIOM)	Global model for the agricultural, forestry and bioenergy sectors
	FOrest Resource Outlook Model (FOROM)	Model used for the latest RPA reports in the United states

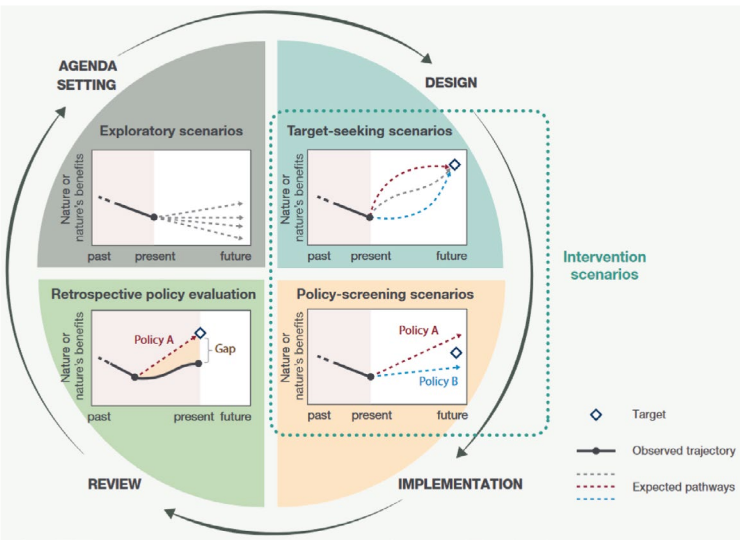
Source : author

Different types of scenarios depending on policy needs and objectives

Modeling can be used to conduct several types of analysis, depending on the objectives of decision makers. The life cycle of a public policy can be broken down into phases, with distinct knowledge requirements (Figure 2). Foresight aims to inform decision-making in a "pre-active" logic, and is involved in the first three of these phases. When setting the political agenda, models simulate contrasting exploratory scenarios, involving a large number of variables. This allows intervention needs to emerge and be prioritized. Once the objective has been set, normative scenarios help to identify different trajectories capable of achieving it, using optimization models in particular. At the end of this phase, different intervention instruments can be outlined. Comparing the impacts of each intervention, of different intervention intensities (e.g. tax rates), and measuring deviations from the target facilitates the decision-maker's final choice.

The European commission, for example, carries out impact studies prior to drafting legislation. The GLOBIOM and G4M models are listed by the institution as contributors to the exploration and development phases of public policy. In particular, they have been used to quantify the European Union's (EU) climate objectives for 2030 and 2040[2]. In France, the Quinet[3] commission, aiming for carbon neutrality in 2050, estimated the trajectory of evolution of the "value of climate action" using optimization models. At the local scale, the French National forestry office (ONF) uses growth models to build silvicultural guides used by forest managers[4].

Figure 2 - **Scenarios and the public action cycle**



Source : IPBES, 2016, *The methodological assessment report on scenarios and models of biodiversity and ecosystem services*

2 - Supporting public policy by modeling the forest sector

There are several categories of foresight modeling. This section compares two of them : recurrent, generalist foresight ; and specific, targeted foresight (e.g. carbon sinks and the EU's climate objectives).

Recurring exploratory forecasts in the USA and Europe

In the USA, the Forest and rangeland renewable resources planning act (RPA) of 1974 requires the department of agriculture (USDA) to report every ten years on the status and evolution of forest resources, recognizing the importance of long-term planning. In Europe, the European forest sector outlook studies (EFSOS) have been a regular feature of the work program of the Committee on forests and the forest industry and the European forestry commission, two United Nations bodies, since 1953. They are carried out by experts from research institutes, universities and government agencies. EFSOS relies mainly on external agents via a one-off mandate : continuity from one study to the next is limited. Conversely, the visibility provided by the RPA's legislative mandate has enabled the USDA to set up a long-term program relying largely on its own staff.

The first RPA exercises focused on timber markets, using econometric models to project supply and demand separately. From 1980 to 2000, analyses were extended to non-wood resources (water, recreational use, etc.). The RPA 2000 report was the first to include sustainable management indicators, and more recent studies, such as RPA 2020, focus on climate (mitigation, impacts, adaptation)[5], the identification of drivers of change and interactions with other sectors.

This systemic approach is reflected in the choice of models : model couplings and sectoral models are increasingly used. The latter tool is explicitly mentioned in the EFSOS 2021

2. These models are developed by the International Institute for Applied Systems Analysis (IIASA) and inventoried in the Modelling Inventory and Knowledge Management System of the European commission.
3. Quinet A. *et al.*, 2019, *La valeur de l'action pour le climat*, France Stratégie.
4. Fournier S. *et al.*, 2022, "Dendrometric data from the silvicultural scenarios developed by Office National des Forêts (ONF) in France: a tool for applied research and carbon storage estimates", *Annals of Forest Science*, 79 (1), p. 48.
5. An amendment to the RPA Act enacted in 1990 requires the inclusion of these elements.

framework mandate, and all simulations employ the GFPM for its ability to model the majority of the scenarios selected. The RPA 2020 report uses the FOROM sector model, as well as land use, hydrological and climate models. This diversity should be seen in the context of the USDA's larger resources.

Early studies involved a limited number of scenarios and variables (e.g. demographics, GDP). The terms "projection", "forecast" and "business as usual" were commonly used. In contrast, EFSOS 2021 began by organizing workshops to identify the issues to be addressed, select variables, formulate hypotheses and so on. The scenarios used in recent studies involve large sets of variables, internal or external to the FS (Figure 3), referred to as "megatrends" in EFSOS 2021.

The RPA report is the first step in the USDA's forestry planning process. It serves as the basis for the 5-year review of its strategy (including objectives and indicators) and for budget requests approved by Congress. An annual progress report provides an opportunity to reassess objectives and budgets.

Ownership of EFSOS is more diffuse. The mandate governing the exercise stipulates that the team of experts will disseminate the results to stakeholders (policy briefs, conferences) and support member states in carrying out national exercises (e.g. the Swedish foresight exercise in 2011[6]).

Setting EU forest climate targets : one-off, targeted exercises

Climate policies are based on quantified targets : emission reductions, carbon budgets, etc. By testing several hypotheses, modeling enables to estimate the capacity of the FS to sequester carbon in forests and wood products, and to avoid emissions through substitution effects.

At EU level, all large-scale initiatives are accompanied by impact studies analyzing the appropriateness of the intervention and its consequences. To achieve carbon neutrality by 2050, the EU recently set itself a target of reducing emissions by 90 % by 2040 compared with 1990[7]. The impact study mobilizes GLOBIOM, for the land-use sector, to explore 4 scenarios based on different levels of emission reductions, and on assumptions of greater sustainability of the economy : waste management, reorientation of eating habits, etc. Among other things, the simulation shows that implementing the latter increases the contribution of the land-use sector by 13 % (45 $MtCO_2eq$), notably through afforestation, for the same level of emission reduction.

The FS's contribution to climate efforts is framed by Regulation (EU) 2018/841. For managed forests, emissions are calculated compared to a reference based on a "continuation of sustainable forest management practices", as observed from 2000 to 2009. This projection, which runs until 2030, is known as the "Forest reference level" (FRL) and must be calculated by member states in a "National forestry accounting plan", which explains the approach adopted and the data used. These were submitted to the European commission and evaluated starting in summer 2018. The final versions were approved by a delegated act in October 2020.

Modeling was used extensively[8]. On the one hand, it enabled the calculation of FRL, with the European commission's Joint research center recommending the use of inventory and carbon budget models. On the other hand, the exercise highlighted a) the conceptual difficulty of a projected reference based on a hypothetical case, b) the heterogeneous modeling capabilities of national teams, and c) the strong dependence of projected FRL on assumptions, for example on the distribution of tree age classes.

These debates, together with the observation of a recent decline in forest carbon sinks, have contributed to the revision of the regulation in 2023, as well as to the increased competence of modeling teams in EU member states.

3 - Limits, benefits and trends in forest sector modelling

Validation and dealing with uncertainty

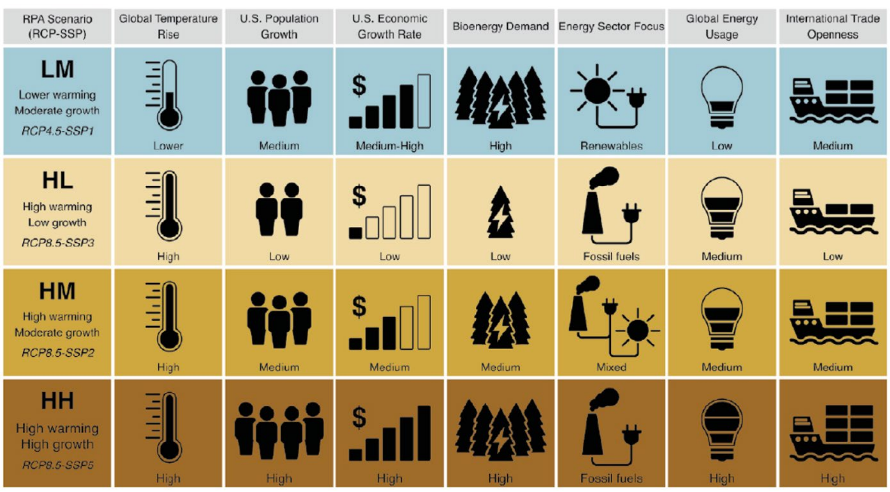
Relying on modeling means ensuring its quality. "Validating" means checking that the results are sufficiently accurate for their intended use[9]. For example, to evaluate *ex ante* a public policy instrument with potentially far-reaching consequences, validation needs to be thorough : it requires the use of objective methods (e.g. sensitivity analysis) and comparison with real data. Conversely, it can be more limited for an exploratory exercise, and use subjective methods (e.g. discussion with experts). Nevertheless, in all cases, results, even once validated, remain dependent on the initial hypotheses.

Some dynamics are uncertain due to their complexity (climate change) or difficulty of measurement (carbon emission factors). Policies that set targets are bets on the future, and decision-makers need to be able to gauge the level of risk involved. There are several ways of incorporating uncertainty into these exercises.

Sensitivity analysis quantifies the influence of varying input parameters on model outputs. It can concern all parameters (global analysis) or just the most important ones (local analysis). For example, the INRA-IGN study of 2020[10] estimates the carbon footprint of 3 contrasting mitigation scenarios for 2050. The difference in carbon footprint between scenarios varies from 1.5 % to 12 % when the substitution coefficient for timber is modified by ± 0.6 tCO_2eq/m^3 (± 37% compared to the base value of 1.6 tCO_2eq/m^3), while the same coefficient for wood energy has less influence.

Uncertainty analysis is more ambitious, and compares the variability of model inputs and outputs. Using a probabilistic approach, it can provide confidence intervals and attribute uncertainty to several sources. For example, Fargeon *et al.* have shown that, when assessing the risk of wildfire, the uncertainty associated with the choice of a climate model

Figure 3 - **Scenarios in the RPA 2020 report**



Source : USDA, 2023, *Future of America's Forest and Rangelands: Forest Service 2020 RPA Assessment*

Note: the scenarios explored involve two different levels of warming and varying assumptions for 6 macroeconomic variables.

6. Jonsson R., Egnell G., Baudin A., 2011, "Swedish forest sector outlook study", *Geneva Timber and Forest Discussion Papers*, 58.
7. Press release of the European commission, February 6th 2024.
8. Vizzarri M. *et al.*, 2021, "Setting the forest reference levels in the European Union: overview and challenges", *Carbon Balance and Management*, 16, pp. 1-16.
9. Caurla, S., Delacote, P., Rivière, M., 2021, «La validation des modèles de simulation-prospective Panorama des méthodes et applications aux modèles de secteur forêt-bois», *INRAE Sciences Sociales, 2020* (6), pp. 1-4.
10. Roux A., Colin A., Dhôte J. F., Schmitt B., 2020, *Filière forêt-bois et atténuation du changement climatique*, Éditions Quæ.

was greater in south-western France than in the Mediterranean region[11].

Results from several models can be compared on the basis of similar simulations. In climate sciences, multi-model ensembles are commonly used[12]. In forestry, initiatives exist but are few and far between[13]. Finally, results need to be compared with knowledge from the literature, including that derived from other methods.

Why use models ?

Other approaches and methods exist for anticipating the future of the FS (natural experiments, qualitative foresight, etc.), but models have several advantages of their own.

Firstly, modeling reduces complexity. As the system represented is restricted to a limited number of variables, experimental interaction is simpler. It is also faster, thanks to digital technology. On the other hand, experimenting on the real target (e.g. a forest plot) requires monitoring over several years, and isolating the influence of variables in ecosystems is often difficult.

Models also offer good value for money. Most of the effort goes into their creation, which may require field experiments and measurements. Then, although they are perennial, the costs are limited to personnel and operating expenses, notably IT. Qualitative forecasts mobilize a working group on an *ad hoc* basis, whereas a model can be mobilized on an ongoing basis, as long as it remains under development. In this way, analyses can be regularly updated to incorporate new knowledge.

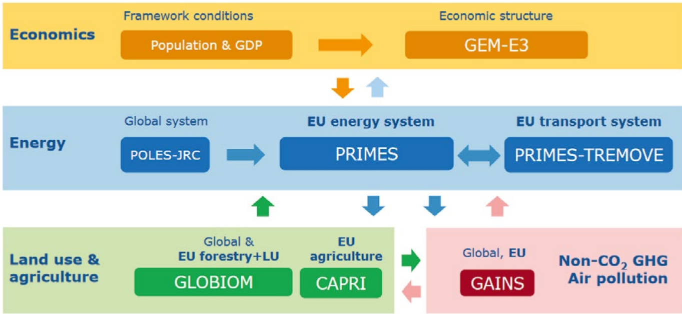
For decision-makers, modeling can be used to put a figure on an objective, or at least to provide an order of magnitude. The same models can then provide monitoring indicators to measure progress. Comparing simulations can also highlight the sensitivity of the trajectories observed in the model to different underlying factors. This identification helps prioritize the need for new knowledge and direct research efforts.

Finally, models can be used to explore hypothetical situations. Several plausible scenarios can be compared with each other or with a reference. The latter may be set in the past or be counterfactual, i.e. relate to events that did not occur but could have. This type of analysis is usually difficult to carry out without modeling.

What kind of modeling tomorrow ?

The growing importance of the FS in policies relating to other sectors calls for models capable of representing these interdependencies. Sectoral models, derived from economics, now routinely include spatialized inventory data[14]. Multi-sector models are becoming increasingly common, enabling to deal with trade-offs between biomass uses, and their interfacing with models from other sectors (e.g. energy, transport) enables to go even further (Figure 4). Finally, the FS can be integrated in the same way as transport or industry in more general models (e.g. integrated energy-climate models), where it is still often neglected. This development means that the mitigation potential of the FS can be explicitly taken into account, instead of using *a priori* assumptions[15]. This rise in complexity brings with it challenges in terms of methodological consistency and interpretability.

Figure 4 - Models used in impact studies related to EU climate objectives



Source : European Commission

Another trend concerns the quantification of carbon stocks and flows in forestry models. Specialized "carbon budget" models can be developed, such as the JRC Forest carbon model used by the European commission[16]. Many non-specialist models include carbon accounting, based on carbon density, emissions and substitution coefficients. This development stems from the growing importance of climate issues linked to forest carbon sinks. Thus modified, these models bring an environmental dimension to analyses, regardless of their original nature. However, uncertainties are sometimes significant for certain parameters, such as substitution factors[17]. The carbon specification of economic models is particularly delicate, as they often only represent natural dynamics in a very simplified way[18].

*

Modeling is an indispensable method for guiding public policy in the face of current and future challenges in the FS. Through simulation, decision-makers can explore multiple scenarios, estimate in advance the consequences of different interventions and anticipate future trends. This approach, based on a simplified but rigorous representation of reality, mobilizes various disciplines, from the natural sciences to economics.Recent efforts have focused on developing sophisticated models that take into account interactions with other sectors, particularly in the context of the fight against climate change. However, despite their undeniable advantages, model validation and taking account of uncertainty remain major challenges. What's more, interpretation of results and decision-making must always take account the assumptions underlying the models.

The proper use of these tools requires close collaboration between administrations, research institutes, industries, etc., which is often difficult due to distinct professional cultures. Coordination and mutual understanding can be improved by promoting exchanges of experience and joint projects, as well as staff exchanges and the building of collaborative networks.

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11. Fargeon H. et al., 2020, "Projections of fire danger under climate change over France: where do the greatest uncertainties lie ?", *Climatic Change*, 160 (3), pp. 479-493.
12. Tebaldi C., Knutti, R., 2007, "The use of the multi-model ensemble in probabilistic climate projections", *Philosophical transactions of the royal society A*, 365 (1857), pp. 2053-2075.
13. Daigneault A. J., Baker J. S., Favero A., 2020, "A forest model inter-comparison project (For-MIP) to assess the future of forests under climate, policy and technological stressors", *Agricultural & applied economics association annual meeting.*
14. The *Land Use and Resource Allocation Model* represents 130 000 forest stands; the *French Forest Sector Model* represents forest resources at the scale of 8 500 geolocalised pixel.
15. See for instance the DICE model, extended to forestry by Eriksson M., 2016, *The Role of the Forest in Climate Policy*, Umea university.
16. Blujdea, V. N. B., Rougieux, P., Sinclair, L., Morken, S., Pilli, R., Grassi, G., Mubareka, S., Kurz, A. W., *The JRC Forest Carbon Model: description of EU-CBM-HAT*, Publications Office of the European Union, Luxembourg.
17. Hurmekoski E. et al., 2021, "Substitution impacts of wood use at the market level: a systematic review", *Environmental Research Letters*, 16 (12), p. 123004.
18. Wear D. N., Coulston J. W., 2019, "Specifying forest sector models for forest carbon projections", *Journal of Forest Economics*, 34 (1-2), pp. 73-97.

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Composition : DESK (www.desk53.com.fr)
Statutory deposit: On publication © 2024