EFORWOOD
Tools for Sustainability Impact Assessment

Documentation of the Forest Sector Model

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Preface

This report is a deliverable from the EU FP6 Integrated Project EFORWOOD – Tools for Sustainability Impact Assessment of the Forestry-Wood Chain. The main objective of EFORWOOD was to develop a tool for Sustainability Impact Assessment (SIA) of Forestry-Wood Chains (FWC) at various scales of geographic area and time perspective. A FWC is determined by economic, ecological, technical, political and social factors, and consists of a number of interconnected processes, from forest regeneration to the end-of-life scenarios of wood-based products. EFORWOOD produced, as an output, a tool, which allows for analysis of sustainability impacts of existing and future FWCs.

The European Forest Institute (EFI) kindly offered the EFORWOOD project consortium to publish relevant deliverables from the project in EFI Technical Reports. The reports published here are project deliverables/results produced over time during the fifty-two months (2005–2010) project period. The reports have not always been subject to a thorough review process and many of them are in the process of, or will be reworked into journal articles, etc. for publication elsewhere. Some of them are just published as a “front-page”, the reason being that they might contain restricted information. In case you are interested in one of these reports you may contact the corresponding organisation highlighted on the cover page.

Uppsala in November 2010

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EFORWOOD

Sustainability Impact Assessment
of the Forestry - Wood Chain

Project no. 518128

EFORWOOD

Tools for Sustainability Impact Assessment

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Documentation of the Forest Sector Model

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PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

1. Introduction

The purpose of this report is to document the choice of model structure and development of the forest sector model to be applied in EFORWOOD, specified in EFORWOOD's WP 1.3. as deliverable D1.3.1.

The report is divided in 3 main parts. First, a brief historical overview of forest sector models is presented. Then the model structure of EFI-GTM is described. Finally, in Section 4, a brief account of the planned development of EFI-GTM in EFORWOOD is given. In addition, in Appendix 1, the spatial dimension (specification of regions) and data input requirements for the model are described.

2. Historical overview – forest sector models

The use of forest sector models that integrate dynamics of forest resources, timber supply, forest industry, and forest product market demand has a long tradition. Among the most well known of such models are the SOS model developed in Scandinavia (Randers 1977), the Timber Assessment Market Model/TAMM developed in USA (Adams and Haynes 1980), the PELPS model developed at the University of Wisconsin (Buongiorno and Gilles 1984, Zhang et al. 1993) and further used in the Global Forest Product Model (GFPM) (Zhu et al. 1998, Buongiorno et al. 2003), and the Global Trade Model (GTM) developed at the International Institute for Applied Systems Analysis (IIASA) in the late 1980s (Kallio et al. 1987). The work of Gilles and Boungiorno has been further developed by Zhang et al. (1993) and applied in e.g. FAO (1997) and Trømborg et al. (2001). The model of Kallio et al. (1987) has been developed as documented in Kallio et al. (2004) and applied in Moiseyev and Solberg (2001), Solberg et al. (2003) and Kallio et al. (2006).

Besides EFI-GTM, global applications of the GTM include the CGTM-model applied at the University of Washington (e.g., Cardellichio et al. 1989, Perez-Garcia 1993). In addition, there are or have been several regional applications of the GTM, e.g., ATM for Austria (Kornai and Schwarzbauer 1987), SF-GTM for Finland and Western Europe (Ronnila 1995), and NTM for Norway (Trømborg and Solberg 1995, Bolkesjø and Solberg 2003).

The multiregional partial equilibrium model GTM has been tailored by various research institutes to best suit their research orientation. The EFI-GTM model is largely based on the same structure as the original GTM described in Kallio et al. (1987). However, the model is more disaggregated regarding regions, products and technologies.

The two main forest sector model types (GTM and PELPS) are rather similar in structure, but compared to PELPS III, the EFI-GTM is a more detailed model with respect to regions and production technologies, has elastic timber supplies coupled with a forest growth model for each region, and incorporates trade endogenously for all products. In addition, it is programmed in GAMS, which makes model changes easy, while PELPS is programmed in Borland turbo-pascal and contains about 10 000 lines of code, which is very large and difficult to maintain or modify. All these factors were decisive when the EFI-GTM model was chosen as the forest sector model to be applied in EFORWOOD.

3. Model structure

3.1. Overview

Somewhat simplified one may say that the main function of the EFI-GTM is to make possible consistent analysis of how and by how much production, consumption, imports, exports, and prices of roundwood and forest industry products may change over time as a consequence of changes in external factors like economic growth, forest biodiversity protection, energy prices, trade regulations, transport costs, exchange rates, forest growth, forest management, and consumer preferences. This type of information is expected to be of considerable interest for improved policy making and investment decisions, both in the relevant public and private sectors.

The EFI-GTM can be classified as a multi-periodic, spatial, partial equilibrium model. It is a partial equilibrium model because (i) it includes only forestry and the forest industry as endogenous sectors and (ii) the existence of the other sectors in the economy are only accounted for indirectly, via exogenous specification of demand functions, production input prices on labour, energy and capital, and via predictions of technological change and economic growth. The model is spatial because it gives, for each period and forest product, equilibrium solutions which assume trade between all regions in the model.

The theoretical basis for the model is that of spatial equilibrium in competitive markets as first solved by Samuelson (1952) for several commodities. The model thus simulates the behavior of profit maximizing producers and utility maximizing consumers in the forest products markets. The competitive market equilibrium is found by maximizing the sum of producer and consumer surpluses net of transportation costs subject to material balance, trade, and capacity constraints.

The model is multi-periodic, but the model optimization is static as it gives an equilibrium solution for each future period modeled. The model solution of a particular period is used to update the model input for the subsequent period for the data on market demand, timber supply, prices and changes in production costs and available technologies. Thereafter, a new equilibrium is computed subject to the new demand and supply conditions, new technologies, and new capacities. As such, the dynamic changes from year to year are modeled using a forward recursive programming approach, meaning that the long run spatial market equilibrium problem is broken up into a sequence of short run problems, one for each year. Hence, the modeling is based on the assumption that the decision makers in the economy have imperfect foresight.

The model consists of a group of competing economies that are willing to trade forest sector commodities whenever the trade increases economic welfare in the regions. In each economy, consumers are assumed to maximize their utility and producers are assumed to maximize their profits. For each region we define demand functions for the final products (mechanical forest industry products, paper and paperboard), supply functions for waste paper and timber, as well as a set of technologies for producing intermediate (pulp, chips) and final products.

Following Samuelson (1952), this multi-regional multi-agent forest sector model is cast into a single mathematical programming problem with a clear economic interpretation. Each region maximizes its social welfare function, which is the sum of consumer and producer surpluses less the transportation costs resulting from trade with the other regions. The outcome of this maximization is restricted by resources, capacity and budget constraints, as well as by possible barriers of trade.

Before going to the particular details of the EFI-GTM in Section 3.3, we describe the structure of a general partial equilibrium model in the next section. The presentation is to a large extent adopted from Chapters 19–25 of Kallio et al. (1987) - in particular the framework by Salo and Kallio (1987) - and Kallio et al. (2004). The specification of regions and data input requirement are presented in Appendix 1.

3.2. General Structure of a Partial Equilibrium Model

We shall start by clarifying a general structure of any partial equilibrium model by considering several levels of hierarchy. At the lowest level, the sectors' agents - producers, consumers, and trade agents - maximize their welfare given specific constraints. Together they form a regional economy, where the objectives and the constraints of the individual agents are aggregated and a further constraint is added for each product in each region: the sum of consumption in the region and exports from the region to other regions must equal the sum of production in the region and imports to the region from the other regions. The global model links the regional modules together through inter-regional trade.

Let us now briefly look into problems at each level and how they are aggregated into a single mathematical programming model, which is used to solve for competitive equilibria in all the markets simultaneously.

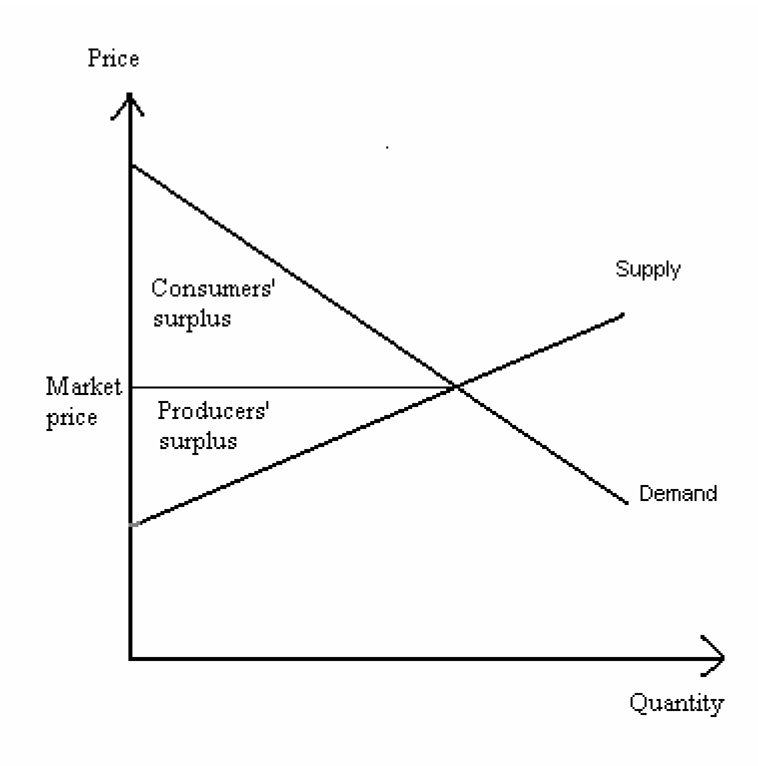

Figure 1 Consumers' and producers' surplus in market equilibrium

Consumers

Assume that consumers attempt to maximize their welfare, which depends on the consumption of the final products. With the separable demand functions, this welfare is greatest when consumers' surplus, defined as the area below the demand curve and above the equilibrium price, as illustrated in Figure 1, is maximized for each product.

The consuming sector is assumed to consist of numerous agents that take prices as given. In a given region *i*, let $q^i = (q_k^i)$ be a vector of the consumed quantities, and $P_k^i(q_k)$ be the inverse demand function for product *k*. Assume that $P_k^i(q_k)$ is differentiable and non-increasing. Let $\pi^i = (\pi_k^i)$ be a vector of product prices, and let Q^i denote the consumption possibility set, which is assumed to be closed, convex, and non-empty. Then the consuming sector's problem is

(1) $$Max_{q^i} \quad \sum_k \int_0^{q_k^i} P_k^i(q_k)\,\mathrm{d}q_k - \pi^i q^i$$

s.t.

(2) $$q^i \in Q^i.$$

Producers

Assume that producers (e.g., timber growers and forest industry firms) of a given region *i* maximize their profits, defined as producer's surplus. Let $z^i = (z_k^i)$ be a vector of net output volumes for products *k* in region *i*, let $C_k^i(z_k)$ be the marginal cost function for product *k*, and let V^i be a closed, convex, and non-empty production possibility set. Under competitive markets, the producers take product prices π_k^i as given. Then the producers' problem is the following:

(3) $$Max_{z^i} \quad \pi^i z^i - \sum_k \int_0^{z_k^i} C_k^i(z_k)\,\mathrm{d}z_k$$

s.t.

(4) $$z^i \in V^i.$$

Trade agents

Trade can be considered as a separable activity carried out by trade agents. These agents can, of course, be the initial producers. To maximize the profit from trade, exporters buy goods at the domestic price, pay for the transportation, and sell at the price of the importing region. Similarly, importers buy at import prices and aim to make profits by selling at the domestic prices. The problem faced by a trade agent operating in region *i* is the following:

(5) $$Max_{e_k^{ij}, e_k^{ji}} \quad \sum_{jk} \left[\left(\pi_k^j - \pi_k^i - D_k^{ij} \right) e_k^{ij} + \left(\pi_k^i - \pi_k^j - D_k^{ji} \right) e_k^{ji} \right]$$

where π_k^i is the price for product *k* in region *i*; π_k^j is the price for product *k* in region *j*; e_k^{ij} are exports for product *k* from region *i* to *j*; e_k^{ji} are imports from region *j* to *i*; and D_k^{ij} is the transportation cost for a unit of product *k* from region *i* to *j*.

Regional models

The objective function for region *i* is specified by adding up the agents' objectives (1), (3), and (5), while the feasible set for the regional problem consists of the constraints (2) and (4) of the agents and the material balance equations

(6) $$q_k^i + \sum_j e_k^{ij} = z_k^i + \sum_j e_k^{ji}, \qquad \forall k.$$

As equations (6) hold in equilibrium, the regional objective function can be reduced to a form where the vector π^i of domestic prices vanishes. The problem related to economy *i* will then be

(7) $$Max \quad \sum_k \int_0^{q_k^i} P_k^i(q_k)\mathrm{d}q_k - \int_o^{z_k^i} C_k^i(z_k)\mathrm{d}z_k + \sum_{jk} \left[\left(\pi_k^j - D_k^{ij} \right) e_k^{ij} - \left(\pi_k^j + D_k^{ji} \right) e_k^{ji} \right]$$

subject to constraints (2), (4) and (6).

The global model

The eventual global model consists of the constraints (2), (4) and (6) for all regions *i* and the sum of objective functions (7) of all the regions. As the imports of product *k* to region *i* from region *j* equal the respective exports from *j* to *i*, the import variables e_k^{ji} match the export variables e_k^{ij}. Thereby, the global problem is to find q^i, z^i, and e_k^{ij} to maximize

(8) $$\sum_{ik}\left[\int_o^{q_k^i} P_k^i(q_k^i)\mathrm{d}q_k^i - \int_o^{zi_k} C_k^i(z_k^i)dz_k^i\right] - \sum_{ijk} D_k^{ij} e_k^{ij}$$

subject to constraints (2), (4) and (6) for all i .

The optimality conditions for the problem above equal the equilibrium conditions for regional competitive markets – as proved first by Samuelson (1952).

3.3 Detailed structure of EFI-GTM

Let us now discuss the more detailed specification of the EFI-GTM. We shall start with the different sectors in the model: consumers, forestry and the forest industry. Thereafter we present the eventual NLP (nonlinear programming) program for the multi-regional model. Because the model is solved by calculating the results for each period separately, the subscript *t* referring to a time period has been left out, whenever it has not been considered necessary for understanding the presentation.

Consumer Sector

Consumers of the final products *f* are represented via demand functions, which are specified for each product and each region *i* employing the data on the reference (observed) demand, $\breve{q}_f^i$, reference price, $\breve{\pi}_f^i$, and the econometrically estimated price elasticity of the demand, γ_f^i, in a region. For solving the model, we use a linearization of a (constant elasticity) demand function.

We assume that the observed reference values of price and quantity are taken from the demand function. The parameters of the demand function are specified so that at the reference point, the demand elasticity equals γ^i_f. Consequently, the following linear demand function arises:

$$(9) \qquad q^i_f = (1-\gamma^i_f)\hat{q}^i_f + \left(\frac{\gamma^i_f \hat{q}^i_f}{\hat{\pi}^i_f}\right)\pi^i_f \quad .$$

where q^i_f is a quantity of product *f* demanded at price π^i_f in region *i*. In solving the model, the inverse $P^i_f(q_f)$ of Eq. (9) is used.

The reference demand $\hat{q}^i_f$ is updated in each period after the base year to account for the exogenously given forecasts of the GDP growth, b^i_t, in period *t*, and the econometrically estimated elasticities of the demand of product *f* with respect to the GDP, ε^i_f, in region *i*. The updated reference demand $\hat{q}^i_f$ in period *t* is

$$(10) \qquad \hat{q}^i_{f,t} = (1 + b^i_t \varepsilon^i_f)\hat{q}^i_{f,t-1}.$$

Respectively, Eq. (9) is redefined based on (10).

<u>Roundwood supply and forestry</u>

Throughout the project report, we assume that timber markets are perfectly competitive and that timber growers maximize their income for each period separately. Marginal costs are assumed to be an increasing function of the harvested volume.

When defining the regional timber supply functions for regions *i*, the starting point was the observed harvesting quantities, $\hat{h}^i_w$, for different timber categories *w*, observed timber prices, $\hat{\pi}^i_w$, respectively, and econometric estimates for the inverse supply elasticities of timber, β^i_w. The inverse supply function for timber category *w* in region *i* is specified as:

$$(11) \qquad \pi^i_w = \alpha^i_w {h^i_w}^{\beta^i_w},$$

where π_w^i is a timber price per cubic meter, h_w^i is a harvest level and α_w^i is a shift parameter, which accounts for the other factors affecting timber supply than timber price. The value of α_w^i is calculated for the first period by substituting $\hat{h}_w^i$, $\hat{\pi}_w^i$, and β_w^i in equation (11).

The level of the total growing stock volume of timber, G_t^i, in period *t* affects the wood supply tightness in the region via the shift parameter α_w^i. The growing stock levels in the base year are given as data. Thereafter, the regional growing stock volumes are updated in each period *t* employing the specification

(12) $$G_t^i = (1 + g^i)G_{t-1}^i - H_{t-1}^i$$

where g^i is a growth rate of the growing stock given as data and H_{t-1}^i is the aggregated harvest of roundwood ($\sum_w h_w^i$) in region *i* in period *t-1* obtained from the model solution. Assuming unitary inventory elasticity for timber supply, the supply shifter α_w^i is updated in each period *t* setting

(13) $$\alpha_{w,t}^i = \frac{\alpha_{w,t-1}^i}{(G_t^i / G_{t-1}^i)^{\beta_w^i}} \quad .$$

Forest Industry

To each region, a set of alternative production technologies *l* for forest industry production are defined. For each technology, input-output coefficients are given that determine the amounts of the inputs used and outputs obtained when one unit of the main product *m* of the technology is produced. Besides endogenous sector commodities *k* (roundwood, pulp, waste paper, chips, and final products) with input-output coefficients a_{kl}, there are inputs *n* coming from the exogenous sectors, for which the input-output coefficients are denoted by a_{nl}. These variable inputs *n* include net electricity (kWh/unit of main output), process heat (GJ/unit), labor (h/unit), and the aggregate of other exogenous sector inputs, e.g., chemicals and other materials (USD/unit). In addition, maintenance costs for old capacity (USD/unit) and investment costs for new capacity (USD/unit) are accounted for in the production costs.

The prices, π_k^i, for the endogenous sector inputs and outputs are determined by the model, while the prices, π_n^i, for exogenous, non-forest sector outputs *n* are given as data.

Regarding input-output coefficients, we follow the sign convention that $a_{kl} \leq 0$ for inputs, $a_{kl} \geq 0$ for byproducts and $a_{ml} = 1$ for the main output. The same applies to coefficients a_{nl}.

Each activity *l* in a region *i* has a linear production cost function

$$\text{(14)} \qquad \Gamma_l^i(y_l) = \left(c_l^i - \sum_{k \neq m} \pi_k^i a_{kl} \right) y_l^i$$

where y_l^i is the output of main product *m* ot the technology and c_l^i is the unit cost resulting from the exogenous sector inputs $\sum_n \pi_n^i a_{nl}$ and capital cost as discussed below.

A unit investment costs for production capacity of technology *l* in region *i*, S_l^i, is given as data. The capital cost incurring from a unit investment on new production capacity for technology *l* in region *i* is defined as a certain exogenously specified percentage, σ_l^i, of the unit investment cost S_l^i as $\sigma_l^i S_l^i$. This parameter reflects the required return on capital and it may vary across regions due to differences in regional investment risk. For production capacity that has already been taken to use, capital costs have become sunk ($\sigma_l^i = 0$), but the use of such capacity is subject to maintenance cost that also is assumed to be a certain fraction, μ_l^i, of the unit investment costs, i.e., $\mu_l^i S_l^i$. Hence, for existing capacity, $c_l^i = \mu_l^i S_l^i - \sum_n \pi_n^i a_{nl}^i$, while for a new capacity that is only available through investments, $c_l^i = \sigma_l^i S_l^i - \sum_n \pi_n^i a_{nl}^i$. In the next paragraph we discuss capacity dynamics more closely.

<u>Capacity dynamics in the forest industry</u>

In addition to the existing production activities with a certain region-specific periodical capacity K_l^i in the model, we define a set of possible new activities for each product and region, which may be identical to or different from the existing ones in their input use. Also for these new production activities *l* that are only available through investment, maximum periodic-production capacities K_l^i are defined. Alternatively, the maximum production level with the new activities can be defined to be shared by several regions. Note that K_l^i for the new activities can be set to be arbitrarily high to avoid constraining investments. (Choices for the capacity limits are discussed with the data in Moiseyev et al. 2004).

New production units using any of the new technologies can be taken to use in a region, given that such an investment is considered profitable. Thus, it is required that the market price of the products produced by employing the new technology must cover the per unit variable production costs and the capital costs, i.e., $\sum_k a_{kl}\pi_k^i + \sum_n a_{nl}\pi_n^i - \sigma_l^i S_l^i \geq 0$ in the market equilibrium. As discussed above, the capital costs resulting from an investment in the new capacity are accounted for only in the period when the installation takes place; thereafter they become sunk costs.

If technology *l* is not (or is not likely to be) available in region *i*, we set $K_{lt}^i = 0$. If the technology related to the new capacity investments is identical to technology already in use in the region, the amount of capacity installed (interpreted as an amount produced with a new technology in the previous period) are added to the existing capacity with the same input structure in the period after investment. Else, a separate production activity with that technology and capacity with sunk investment costs is defined to it in the period after investment.

In order to simulate realistically investments inertia in the real world, one can in the model limit the capacity expansion so that the production capacities do not expand unrealistically much in one period even though the investment would be profitable. This is done so that for each product, one can constrain the sum of the total new capacity investments in certain larger region groups (North America, EU, USSR, Latin America etc.) to remain below a certain prespecified fraction of the total existing capacity in that larger region. The choices of maximum constraints here are based on historical data, and are discussed with the other exogenous data input to be specified.

In the real world, not all capacity increases that are taken place, derive from investments in new production capacity. The forest industry production capacity increases also due to learning or minor regular improvements of the existing capacity. This kind of increase is accounted for in the model by letting the capacity of the low cost technologies to increase by an exogenously determined % annually.

While existing capacity may be left idle or divested whenever production with it is unprofitable, a certain fraction of the old capacity can also be specified to be divested exogenously in each period.

Finally, in order to allow alternative input-mixes, different production technologies may be defined to have shared production capacities. A natural example is a sawmill that could produce both hardwood and softwood sawnwood.

Recycled Paper Supply

For each paper grade *k* and region *i*, we assume that there is a certain maximum percentage (collection rate), ϕ_f^i, of the consumption q_f^i of paper product f that can be collected. Paper collection is subject to a grade specific unit collection cost, c_f^i, defined as data. These costs set the minimum prices for waste paper grades that are eventually endogenously determined in the model.

Furthermore, for each f, we define a set Θ_f that determines, to which recycled paper categories *r* (old newspapers and magazines, mixed grade, high grade etc.) collected paper of grade f is suitable. The availability of domestic recycled paper of category *r* is limited by the paper consumption through these collection rates. In addition, collected paper can be imported and exported. The model decides endogenously the amount of paper collected, R_f^i, in a region *i* as well as its allocation, x_{fr}^i, to different waste paper categories *r*. The costs of processing the waste paper to pulp are accounted for in the cost components of technologies *l* using waste paper *r* as an input.

Interregional Trade

For each endogenous sector product *k,* a variable cost of transporting one unit of *k* per one distance unit has been defined. Then the interregional distance matrix is used to compute the unit variable transportation costs, D_k^{ij}, as a product of distances and unit variable costs. Alternatively, D_k^{ij}, can be specified directly.

It is common in trade models to constrain the inter-temporal changes in inter-regional trade. The fact that the trade patterns in real world do not seem to change dramatically from one period to another can be caused by various reasons not captured in the models, e.g., heterogeneity of the products or long-term contracts between the trade partners. Such trade inertia can be accounted for in the model by setting lower, L_k^{ij}, or upper U_l^{ij}, boundaries for trade flow, e_k^{ij}, of product *k* from region *i* to *j*.

The EFI-GTM model specification

Let us now look at how the global problem in Section 3.2 is modified to include the necessary details. We refer to the forest sector products by index *k*, of which final products are denoted by *f*, pulp grades are denoted by *u*, the wood categories are denoted by *w*, and the recycled paper categories are denoted by *r*. For rest of the notations, the reader is referred to the descriptions above. The problem below is solved for one period *t* at a time. Thereafter the parameters (e.g., parameters in timber supply function, production cost function and demand function) are updated, based on the model solution or external data on the future parameter values.

$$(15)\ Max_{q^i, h_w^i, y_l^i, e_k^{ij}, R_f^i, x_{fr}^i} \left[\sum_{if} \int_o^{q_f^i} P_f^i(q_f)\mathrm{d}q_f - \sum_{iw} \int_o^{h_w^i} \alpha_w^i {h_w^i}^{\beta_w^i} dh_w^i - \sum_{il} c_l^i y_l^i - \sum_{if} c_f^i R_f^i - \sum_{ijk} D_k^{ij} e_k^{ij} \right]$$

s.t.

$$(16)\qquad q_f^i - \sum_l a_{fl} y_l^i + \sum_j (e_f^{ij} - e_f^{ji}) = 0 \qquad \forall f, i$$

$$(17)\qquad -\sum_l a_{ul} y_l^i + \sum_j (e_u^{ij} - e_u^{ji}) = 0 \qquad \forall u, i$$

$$(18)\qquad -\sum_l a_{wl} y_l^i - h_w^i + \sum_j (e_w^{ij} - e_w^{ji}) = 0 \qquad \forall w, i$$

$$(19)\qquad -\sum_{f(r \subset \Theta_f)} x_{fr}^i - \sum_l a_{rl} y_l^i + \sum_j (e_r^{ij} - e_r^{ji}) = 0 \qquad \forall\, r, i$$

(20) $$y_l^i \leq K_l^i \qquad \forall l, i$$

(21) $$R_f^i \leq \phi_f^i q_f^i \qquad \forall f, i$$

(22) $$\sum_{r \in \Theta_f} x_{fr}^i - R_f^i \quad = 0 \qquad \forall f, i$$

(23) $$L_k^{ij} \leq e_k^{ij} \leq U_k^{ij} \qquad \forall i, j, k.$$

(24) $$e_k^{ij}, q_f^i, y_l^i, h_w^i, x_{fr}^i, R_f^i \geq 0 \qquad \forall i, j, k$$

The equations (15) – (24) define a convex optimization problem. Therefore, any solution satisfying the Karush-Kuhn-Tucker conditions of the problem is optimal.

4. Future development

The EFI-GTM model will in the EFORWOOD project be further developed. The main developments and steps, which are planned include:

- More accurate timber supply functions for Europe. Econometric studies using panel data methods (among those fixed effects and random effects statistical models) will be applied.
- More accurate description of the forest growing stock and harvest possibilities in each of the regions, in particular each of the European countries. The gain here depends on the information provided by Module 2.
- Improved data on forest industry production costs, transport costs and existing capacities. The new base year will be 2005. Data supplied from M2-M5 will be valuable for this improvement.
- Include bioenergy more explicitly in the model. This will to a large degree depend upon the data input possible to obtain from the other Modules in EFORWOOD, in particular Module 2, 3, and 4. For the moment it is rather certain that pellets will be included.
- The scenarios and/or policy changes decided upon in EFORWOOD needs to be given an interpretation, which make it technically feasible to implement them into EFI-GTM and analyze the effect.

- Procedures need to be developed for linking the EFI-GTM with TOSIA.
- Improve model solver capacity.

Literature cited

Adams, D.M. and Haynes, R.W. 1980. The 1980 softwood assessment market model. Structure, projections and policy simulations, Forest Science Monogram, 22.

Bolkesjø, T.F., and B. Solberg. 2003a. Beskrivelse av skogsektormodellen NTM II. Working Paper, Department of Forest Sciences, Agricultural University of Norway. In Norwegian.

Buongiorno, J., Zhu, S., Zhang, D.,Turner,J., and Tomberlin, D. 2003. The Global Forest Products Model. Academic Press.UK. 301p.

Buongiorno, J. and Gilles, K. 1984. A model of international trade of forest products, with applications to newsprint. J. World Forest Resource Management 1:65-80.

Cardellichio, P.A., C.Y. Youn, D.M. Adams, R.W. Joo, and J.T. Chmelik. 1989. A Preliminary Analysis of Timber and Timber Products Production, Consumption, Trade, and Prices in the Pacific Rim Until 2000. University of Washington, College of Forest Resources, Center For International Trade in Forest Products, Working Paper No. 22. 97 p.

FAO, 1997. FAO provisional outlook for global forest products consumption, production and trade to 2010. Food and Agriculture Organization of the United Nations, Rome.

Kallio, M., D.P. Dykstra, and C.S. Binkley, (editors). 1987. The Global Forest Sector: An Analytical Perspective, John Wiley & Sons, New York.

Kornai, G. and P. Schwarzbauer. 1987. The Austrian Model of Production, Consumption and Trade in Forest Products (ATM). In Cardellichio, P.A., D.M. Adams, and R.W.Haynes (eds.): Forest Sector and Trade Models: Theory and Applications. Proceedings of an international symposium. CINTRAFOR. University of Washington. Seattle. p. 71–78

Kallio, A.M.I., A. Moiseyev and B. Solberg. 2006: Economic impacts of increased forest conservation in Europe: a forest sector model analysis. Enviromental Science and policy (in print)

Kallio, A.M.I., A. Moiseyev and B. Solberg. 2004: The global forest sector model EFI-GTM- the model structure. EFI Technical Report 15. www.efi.fi/publications.

Moiseyev, A. and Solberg, B., 2001. Sensitivity of scenario analysis of the European forest sector using a partial equilibrium model. In: Solberg, B., (Ed.), Proceedings of the Biennial Meeting of Scandinavian Society of Forest Economics, Gausdal Norway, April 2000. Scandinavian Forest Economics No. 37:88-100

John Perez-Garcia .1993. Global forestry impacts of reducing softwood supplies from North America. Working Paper 43. Cintrafor, 35 p.

Randers, J., 1977. A system dynamic study of the transition from ample to scarce wood resources. Report GRS-34, Resource Policy Group, Oslo.

Ronnila, M. 1995. Medium-term scenarios for the Finnish pulp and paper industry. WP95-38. International Institute for Applied Systems Analysis. Laxenburg. Austria.104p.

Salo, S., and M. Kallio. 1987. General Approach, In: Kallio, M., Dykstra, D.P., and Binkley, C.S. (eds.), The Global Forest Sector: An Analytical Perspective, John Wiley & Sons, Inc. UK.

Samuelson, P.A., 1952, Spatial Price Equilibrium and Linear Programming, The American Economic Review 42(3):283-303.

Solberg, B., Moiseyev, A., Kallio, A.M.I. 2003. Economic impacts of accelerated forest growth in Europe. Forest Policy and Economics 3:11-19.

Trømborg, E., Buongiorno, J., Solberg, B. 2000. The global timber market: implications of changes in economic growth, timber supply, and technological trends. Forest Policy and Economics 1, 53-69.

Trømborg, E. and B. Solberg. 1995. Beskrivelse av en partiell likevektsmodell anvendt i prosjektet "Modellanalyse av norsk skogsektor". Research paper of Skogsforsk 14/95. Department of Forest Sciences, Agricultural University of Norway. Ås. 34 p. [in Norwegian]

Zhang, D., J. Buongiorno and P.J. Ince. 1993. PELPS III: A Microcomputer Price Endogenous Linear Programming System for Economic Modelling. Version 1.0. USDA Forest Products Lab Research Paper FPL-RP-526. Madison, WI: USDA Forest Service. 43p.

Zhu, S., D. Tomberlin, and J. Buongiorno. 1998. Global forest products consumption, production, trade and prices: Global forest products model projections to 2010. Global Forest Products Outlook Study Working Paper Series GFPOS/WP/01.FAO/UN. 333 pp.

APPENDIX 1: SPECIFICATION OF REGIONS, PRODUCTS AND DATA INPUT REQUIREMENTS

1. Specification of regions

The following division on regions and countries are used:

a. Europe (about 30 regions):
- Each country (except Be-Ne-Lux) is one region.

b. North America (5 regions)
- Canada (East and West)
- USA (Norh East, South East, West Coast)

c. South America (5)
- Argentina
- Brasil
- Chile
- Venezuela
- Other
  -

c. Oceania (2)
- Australia
- New Zealand

d. Asia (7)
- Siberian Russia
- China
- Indonesia
- Malaysia
- Japan
- South-Korea and Taiwan
- Other (Cambodia, North-Korea, Thailand,Vietnam, etc.)

e. Africa (3)
- South Africa (Republic of South Africa, Namibia)
- East Africa (Kenya, Tanzania, Uganda, Zambia, Zimbabwe)
- Other

2. Specification of products

The following products are included:

a. Primary products
- Sawlogs - coniferous
- Sawlogs - nonconif.
- Pulpwood- conif.
- Pulpwood - nonconif.
- Chips usable for both pulp, board and bioenergy production
- Chips usable for only board and bioenergy prod. (is thsi necessary?)

b. Sawnwood
- Sawnwood - coniferous
- Sawnwood - nonconiferous
- Other

c. Wood based panels
- Plywood and veneers
- Particle boards
- Fibreboards
- OSB
- MDF
- Others

d. Fibre furnish and bioenergy
- Mechanical pulp
- Semi-chemical pulp)
- Chemical pulp (devided in bleached/unbleached and softwood/hardwood?)
- Recycled pulp I (old newspaper)
- Recycled pulp II (mixed waste paper)
- Recycled pulp III (old corrugated)
- Recycled pulp IV (high grade deinking)
- Other pulp
- Bioenergy

d. Paper and paperboard
- Newsprint
- Magazine paper
- Office paper
- Tissues
- Wrapping and packageing paper
- Paperboard
- Other

3. Specification of data requirements - technical vintages and corresponding capacities, production coefficients and costs

For each European region and for each of the products in Section 2 , four types of technologies are used:
- Old (approx. the oldest 20 % of the existing mills by capacity. By old is meant labour intensity)
- New (approx. the newest 20 % of the existing mills by capacity)
- Medium (the remaining 60% of the capacity)
- Newest (the machinery used in new investment)

For the regions outside Europe only two vintages are used: Average and New.

For each of these vintages (and regions) the following data are needed:
(i) Nos. of mills, and capacity (and average production in base year)
(ii) Average production input coefficients:
- Labour - manhours per ton
- Energy -kwh per ton, specified on (NB- the data availability will have to decide according to the data availability in IEA statistics and other):

  - electricity from coal (and CO_2 emission per kwh electricity produced)
  - electricity from water
  - electricity from nuclear power
  - heavy oil
  - light oil
  - other
- Roundwood or fibre or pulp intermediate use (m3 per ton output)

(iii) Costs per ton (or hour) produced, specified on:

- Labour
- Energy (the above categories if possible)
- Other inputs (chemicals, consumables, machinery maintenance etc.)

(iv) Investment costs (for new investments only)

- Total investment
- Expected life-time
- Real term minimum rate of return demanded on new investment (% p.a.)
- Capacity per mill

4. Transport costs

Transport costs per ton should be estimated for the base year for all major products being traded and between all relevant regions.