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The Global Forest Trade Model

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GFTM

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Abstract
A meaningful assessment of policy options within the forest-based bioeconomy presupposes the capability to model market implications. To this end, an economic forest-based sector model, the Global Forest Trade Model (GFTM), is being developed at the Forest Resources and Climate unit of the Institute for Environment and Sustainability (IES). The GFTM is an equilibrium trade-based model for the forest sector with the aim of providing projections of production and trade of wood-based products and pellets for 48 countries/sub-regions of the world, with a focus on EU. This technical report describes the set-up of the model.The study outlines the theoretical framework, the programming of the model in MatLab, data collection, parameters used, and the calibration of the model. Presented test runs with GFTM indicates that the model behaves in a logically consistent way, all in all well in line what can be expected from economic theory. The next steps in the development process entail trying out linkages with a forest resource model and a dedicated energy model.

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Introduction

In accordance with the implementation of the European Union (EU) Forest strategy (European Commission 2013), a Forest Information System for Europe (FISE) is currently being set up at the European Commission Joint Research Centre (JRC). FISE consists of four inter-related modules, focusing on:

a) ecosystem services,

b) climate change,

c) forest disturbances, and

d) bioeconomy.

The Bioeconomy module of FISE comprises the sub-modules (i) Forest Resources Availability, (ii) Forest Resources Management. (iii) Forest Resources Uses, and (iv) Policy Assessment.

The forest-based sector plays an important role within the European Union (EU) in terms of value-added, trade balance, and job creation. In addition, the forest-based sector contributes in a decisive way to climate change mitigation, sequestering carbon and substituting for fossil-fuel based materials and energy. As an example, woody biomass accounts for 50 percent of renewable energy within the EU.

There are several EU policy initiatives affecting the forest-based sector. The Climate and Energy Framework, Natura 2000, and the Water Framework Directive are among the most important. Modelling the impact of EU policies affecting the forest-based sector is thus necessary to ensure coherence among the different objectives set by those policies. Consequently, policy assessment is being addressed through a modelling framework for the forest-based sector at the Forest Resources and Climate unit of the Institute for Environment and Sustainability (IES) at the Joint Research Centre (JRC). This modelling approach comprises a modular system of four inter-related components: the Wood Resource Balance (WRB), the European Forestry Dynamics Model (EFDM), the forest owner decision model Expected Value Asymmetries (EVA), and finally the Global Forest Trade Model (GFTM), an economic model of the global forest-based sector.

GFTM is developed to model market implications of policy options within the forest-based bioeconomy. GFTM is an equilibrium trade-based model for the forest sector with the aim of providing projections of production, trade and hence consumption of solid wood products, pulp & paper, and wood pellets for 48 countries/sub-regions of the world, with a focus on EU. GFTM is a stand-alone model, but it is designed to be integrated with the WRB (Mantau et al. 2010), EVA (Rinaldi et al. 2015), and EFDM (Packalen et al. 2014).

This technical report describes the set-up of the GFTM. The study presents the theoretical framework, the data collection, the parameters used, the calibration of the model, and some results from test runs of the model. The report concludes with an outline of the next steps in the model development. The programming of the model in MatLab is presented in an appendix (Appendix O).

Theoretical Framework

GFTM is an equilibrium trade-based model for the forest sector, with the objective of providing projections relative to: ten final products (sawnwood coniferous and non-coniferous, plywood, particle board, fibreboard, wood pellets, household & sanitary paper, printing & writing paper, newsprint, packaging paper), four intermediate products (chemical pulp, recovered paper, coniferous and non-coniferous sawdust) and four primary products (coniferous and non-coniferous sawlogs and pulpwood) for 48 countries/regions of the world, with particular focus on EU. As such, the model is also suitable for investigating how the above mentioned variables are affected by possible ecological and other exogenous factors.

The structure of the model is fairly simple; in particular, it shares with other similar models — notably the Global Forest Products Model, henceforth GFPM (see http://labs.russell.wisc.edu/buongiorno/welcome/gfpm/), and the European Forest Institute Global Trade Model, henceforth EFI-GTM (see http://www.efi.int/files/attachments/publications/ir_15.pdf) — the theoretical formulation based on spatial equilibrium theory in competitive markets for several commodities, first solved by Samuelson (1952). The model is based on the maximization of the whole forest sector welfare (consumer, primary products/industrial products producers and traders) subject to feasibility, resources, productivity and equilibrium constraints.

The model itself is static since, given a certain number of iterations (that is, the number of periods that one wants to project), at each iteration the optimal welfare is computed, with imperfect foresight. Once a solution is reached, the parameters of the model are updated based on endogenous (e.g., harvest levels) and exogenous (e.g., GDP growth, changes in productivity, etc.) drivers, and a new iteration begins. As mentioned above, GFTM is populated by three groups of agents: consumers, producers, and traders. In the following we will present each of them separately.

Consumers

Consumers' welfare is derived by the consumption of final products *FP* (sawnwood coniferous and non-coniferous, plywood, particle board, fibreboard, wood pellets, household & sanitary paper, printing & writing paper, newsprint, packaging paper). Thus, the welfare of the whole (world) consumption sector is measured by:

$$\sum_i \sum_{FP} \int_0^{q^i_{FP}} D^{-1}\left(q^i_{FP}\right) dq^i_{FP} - p^i_{FP} q^i_{FP} \qquad q^i_{FP} \geq 0, \forall i, FP \qquad (1)$$

where *i* is a country-index (in our case, since there are 48 countries, *i* ranges from 1 to 48), *FP* is the index used for characterizing final products, q^i_{FP} is the quantity of final product *FP* consumed in country region *i*, $D^{-1}(q^i_{FP})$ is the inverse demand function for product *FP* in region *i*, and p^i_{FP} is the price at which product *FP* is sold in region *i*.

More specifically, we assume that the demand function has the following functional form:

$$D(p^i_{FP}): \; q^i_{FP} = (1-\theta^i_{FP}) q^{0i}_{FP} + (\theta^i_{FP} q^{0i}_{FP}) \times (p^i_{FP} / p^{0i}_{FP})$$

where θ^i_{FP} denotes the demand elasticity to price for final product *FP* in region *i*, and q^{0i}_{FP} and p^{0i}_{FP} denote respectively reference (for a particular year set as reference) quantity and price for final product *FP* in region *i*.

From one period t to the following $t+1$, the GDP growth rate for region i, GDP_i, is the only variable which is assumed to affects the demand function for that region by means of the reference quantity q^{0i}_{FP}. More specifically:

$q^{0i}_{FP,\,t+1}=(1+\theta^{i}_{FP,GDP}\,GDP_i)\;q^{0i}_{FP,\,t}$

where $\theta^{i}_{FP,GDP}$ is the elasticity with respect to GDP for product FP in region i.

Producers

Primary products PP (coniferous and non-coniferous sawlogs and pulpwood) are harvested and then transformed into intermediate products (chemical pulp, coniferous and non-coniferous sawdust), or directly into final products. Intermediate products also contribute to final products' production.

Denoting by y^{i}_{IP} the quantity of produced product IP (final or intermediate product) in region i, we assume that the costs of production are linear, that is, $y^{i}_{IP}\,c^{i}_{IP}$, where c^{i}_{IP} is the unitary cost for producing one unit of product IP in region i. Next, we denote by p^{i}_{IP} the unitary price for the product IP produced in region i, so that total revenues for the production of the quantity y^{i}_{IP} are $p^{i}_{IP}y^{i}_{IP}$. Finally, we assume that the supply function for primary products PP is given by

$$p^{i}_{PP} = a^{i}_{PP}{q^{i}_{PP}}^{\theta^{i}_{PP}}$$

where p^{i}_{PP} is the timber price for cubic meter of primary product PP in region i. q^{i}_{PP} is the harvested quantity of primary product PP in region i, a^{i}_{PP} is a shift parameter and θ^{i}_{PP} is the inverse of the supply elasticity. From one period t to the following $t+1$, such supply function changes depending on the new attainable maximum harvestable level, specifically:

$$a^{i}_{PP,t+1} = \frac{a^{i}_{PP,t}}{\left(H^{i}_{PP,t+1}/H^{i}_{PP,t}\right)^{\theta^{i}_{PP}}}$$

where H^{i}_{PP} is the maximum harvestable level of primary product PP in region i.

Hence, the net welfare of the whole (world) primary/industrial products producers sector is measured by:

$$\sum_i \left(\sum_{IP} \left(p^{i}_{IP} y^{i}_{IP} - c^{i}_{IP} y^{i}_{IP} \right) - \sum_{PP} \int_0^{q^{i}_{PP}} a^{i}_{PP} {q^{i}_{PP}}^{\theta^{i}_{PP}} dq^{i}_{PP} \right) \qquad q^{i}_{PP}, y^{i}_{IP} \geq 0, \forall i, IP, PP$$

However, notice that the regional availability of primary products is limited by resources constraints, hence $q^{i}_{PP} \leq H^{i}_{PP}$.

Similarly, production activity is limited by capacity constraints and also by the technology used for production. Denoting by K^{i}_{IP} the maximum quantity of product IP that can be produced in region i, one has $y^{i}_{IP} \leq K^{i}_{IP}$. Unfortunately, for most countries these capacity data are not available, or, in any case, not really reliable. Hence, for the moment, it is assumed that capacity is exploited up to 82.5% in each country/region. Ideally, if data were available, we would model investment in new capacity, following the approach proposed in GFPM. In particular, assuming that the annual change in year t, ΔK_{IPt}, in world' capacity of production activity IP is governed by:

$\Delta K_{IPt}=b_1 \Delta Y_{IPt-1}+ b_2 \Delta Y_{IPt-2}+b_3 \Delta Y_{IPt-3}$

where ΔY_{IPt-i} denotes the annual change in year t-i of the world production level of product IP. The previous equation is thus coherent with the accelerator theory

according to which output is the primary driver for investments in new capacity. Once ΔK_{IPt} is computed, capacity changes are endogenously allocated according to:

$$\Delta K_{IP}^{i} = \frac{y_{IP}^{i}\pi_{IP}^{i}}{\sum y_{IP}^{i}\pi_{IP}^{i}}\Delta K_{IP}$$

where π^{i}_{IP} is the shadow price of capacity for production of product *IP* in region *i* and henceforth it measures the marginal value of capacity itself.

Technology is described as usual in the literature by means of industry matrices. Specifically, for each region *i*, we construct a matrix M^i, where the number of columns equalizes the number of produced products (intermediate and final) and the number of rows is the total number of products (in our case 18). Next, for each region i, we construct the vector y^i whose components are simply the produced products y^i_{IP}s in region *i*. Similarly, we construct a vector x^i whose components are all products (final, intermediate and primary) of region *i.* Finally, we set each coefficient of M^i, m^i_{rc}, to be equal to (minus) the number of units of product $x_r{}^i$ obtained (used) in the production of one unit of product y^i_c, if product $x_r{}^i$ is an output (input) of the production process. Hence, for each product $x_r{}^i$ the total number of units obtained (or used) at the end of the overall production is $x_r{}^i=\sum_c m^i{}_{rc} \times y^i{}_c$.

Even if the use of matrices for describing production processes is well established in the economic literature, it still has quite relevant drawbacks since it might induce undesired relations among different inputs co-participating into the production process of a specific product. In particular, here, linearity would force increases in the production of coniferous sawnwood to be equal to increases in the production of non-coniferous sawnwood and also to increases in the production of pellets. This, of course would be highly unrealistic; we have thus replaced the two equilibrium constraints for coniferous and non-coniferous sawdust with two feasibility constraints requiring that the amount of produced (coniferous and non-coniferous) sawdust is enough for producing the requested amount of pellets. In particular, this would imply $\sum_z m_z^i y_z^i \geq 0$, where *z* denotes coniferous and non-coniferous sawdust, respectively.

For what concerns recovered paper, we assume that consumed quantities of printing & writing paper, newsprint, packaging paper can be collected in region *i* in proportion φ^i_{WP}, φ^i_{NP} and φ^i_{OP}, respectively, at the costs g^i_{WP}, g^i_{NP} and g^i_{OP}. Taking this into account, the net welfare of the whole (world) primary/industrial products producers sector becomes:

$$\sum_i \Big(\sum_{IP} \big(p_{IP}^i y_{IP}^i - c_{IP}^i y_{IP}^i \big) - \sum_{PP} \int_0^{q_{PP}^i} a_{PP}^i q_{PP}^{i\,\theta_{PP}^i} dq_{PP}^i \quad + \\ + \sum_{j=WP,NP,OP} g_j^i \varphi_j^i \, q_j^i \Big) \qquad q_{PP}^i, y_{IP}^i \geq 0, \forall i, IP, PP \tag{2}$$

Traders

All products (with the exception of coniferous and non-coniferous sawdust) are tradable, in particular product $e_r{}^{ij}$ is purchased in region *i* at price $p^i{}_r$ and exported to region *j*, where it is sold at price $p^j{}_r$ .The trade from region *i* to region *j* of product $e_r{}^{ij}$ generates a cost $T_r{}^{ij}$. Thus, the welfare of the whole (world) trade sector is:

$$\sum_i \sum_r \big(p_r^j - p_r^i - T_r^{ij} \big) e_r^{ij} + \big(p_r^i - p_r^j - T_r^{ji} \big) e_r^{ji} \qquad e_r^{ij} \geq 0, \forall i, r \tag{3}$$

World equilibrium model

The world equilibrium is obtained by maximizing the total welfare (obtained by aggregating (1), (2) and (3)) subject to feasibility, resource, capacity and equilibrium constraints. Equilibrium constraints act at regional and also global level. Specifically, at regional level production minus consumption levels must equal net trade, for each region and each product, while at global level net trade has to be zero for each product. Since GFTM considers net trade only, the following variable is introduced for each country $E_x^i = \sum_j (e_x^{ij} - e_x^{ji}), \forall x = FP, u, PP, RP$ where E_x^i denotes net trade for product *x*. Finally, we also introduce the net country-specific trade cost T_x^i.

Thus optimal equilibrium quantities can be found by solving:

$$MAX_{q_{FP}^i, y_{IP}^i, q_{PP}^i, e_r^{ij}} \sum_i \sum_{FP} \int_0^{q_{FP}^i} D^{-1}(q_{FP}^i) dq_{FP}^i - \sum_i \sum_{IP} c_{IP}^i y_{IP}^i -$$

$$\sum_i \sum_{PP} \int_0^{q_{PP}^i} a_{PP}^i q_{PP}^{i\,\theta_{PP}^i} dq_{PP}^i - \sum_i \sum_{j=WP,NP,OP} g_j^i \varphi_j^i q_j^i - \sum_i \sum_x T_x^i E_x^i \quad (4)$$

Subject to:

$q_{FP}^i, q_{PP}^i, y_{IP}^i \geq 0, \forall i, q_{FP}^i, q_{PP}^i, y_{IP}^i$ *(feasibility constraints)* (4a)

$q^i{}_{PP} \leq H^i{}_{PP} \forall i, q_{PP}^i$ *(resources constraints)* (4b)

$y^i{}_{IP} \leq K^i{}_{IP} \forall i, y_{IP}^i$ *(capacity constraints)* (4c)

$q_{FP}^i - \sum_{IP} m_{FP,IP}^i y_{IP}^i + E_{FP}^i = 0, \forall i, FP$ *(equilibrium final products)* (4d)

$-\sum_{IP} m_{,IP}^i y_{IP}^i + E_z^i = 0, \forall i$ [1] *(equilibrium for chemical pulp)* (4e)

$-q_{PP}^i - \sum_{IP} m_{PP,IP}^i y_{IP}^i + E_{PP}^i = 0, \forall i, PP$ *(equilibrium primary products)* (4f)

$\sum_{j=WP,NP,OP} \varphi_j^i q_j^i - \sum_{IP} m_{RP,IP}^i y_{IP}^i + E_{RP}^i = 0, \forall i$ [2] *(equilibrium recycled paper)* (4g)

$\sum_z m_z^i y_z^i \geq 0 \ \forall i$ [3] *(feasibility constraints for pellets production)* (4h)

$\sum_i E_x^i = 0, \forall x = FP, u, PP, RP$ *(equilibrium for global trade)* (4i)

Additional bounds can be set to establish trends, inertia constraints etc. for all/some variables.

[1] *z* denotes chemical pulp.
[2] *RP* denotes recycled paper.
[3] z denotes coniferous and nonconiferous sawdust, respectively.

Input data

Input data here refers to the scope in geographical and product terms as well as the choice of sources for input data (starting and reference values) and numerical assignment to model parameters. Hence, the report delineates the countries and products dealt with in the modelling, the choice of the base year and data sources, the collection, the re-analysis and, possibly, re-elaboration of the data for the base year, as well as the choice and collection of external drivers.

GFTM currently covers 48 countries/sub-regions of the world, with particular focus on the EU. Countries modelled individually comprise Austria, Belarus, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Russian Federation, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, UK, Ukraine, Canada, USA, Brazil, Chile, China, India, Japan, and Turkey. Aggregated regions are South East Asia, North Africa, South Africa, Rest of Latin America, Oceania, and Rest of the World.

Since GFTM is a trade model, only products traded internationally on a significant level are considered: ten final products (sawnwood coniferous and non-coniferous, plywood, particle board, fibreboard, wood pellets, household & sanitary paper, printing & writing paper, newsprint, packaging paper & paperboard), four intermediate products (chemical pulp, recovered paper, coniferous and non-coniferous sawdust), and four primary products (coniferous and non-coniferous sawlogs and pulpwood). Firewood is not included as it is not traded internationally.

Reference Data

Data regarding production and trade for sixteen wood-based products for the years 2010 and 2011 were sourced from FAOSTAT and EUROSTAT databases for the purpose of providing starting and reference values for production and trade quantities, and to derive prices and exogenous production costs for products used in GFTM (Table 1).

Production and trade quantities

Table 1 Data sources and procedures

Data	Sources and procedure
Sawlogs, coniferous	FAOSTAT production values, corresponding to removals. The customs classification systems do not allow the division of industrial roundwood trade statistics into sawlogs and pulpwood. An expert assessment of the share of sawlogs and veneer logs in industrial roundwood trade, was conducted to split the category industrial roundwood into saw/veneer logs and pulpwood. In the assessment, input/output coefficients used in the industrial processing was taken into account
Sawlogs, non-coniferous	FAOSTAT. See comment for sawlogs coniferous
Pulpwood, coniferous (incl. wood chips)	FAOSTAT. See comment for sawlogs coniferous
Pulpwood, non-coniferous (incl. wood chips)	FAOSTAT. See comment for sawlogs coniferous
Sawnwood, coniferous	FAOSTAT
Sawnwood, non-coniferous	FAOSTAT
Plywood	FAOSTAT
Particle board	FAOSTAT

Fibreboard	FAOSTAT
Chemical Pulp	FAOSTAT. Includes chemical and semi-chemical pulp
Newsprint	FAOSTAT
Printing & Writing	FAOSTAT
Household & Sanitary	FAOSTAT
Packaging paper	FAOSTAT. Proxy calculated as other paper & paperboard minus household & sanitary paper
Wood Pellets	FAOSTAT
Recycled Paper	FAOSTAT

Prices

Prices for all commodities are derived from trade unit values (value in US$ divided by quantity exported or imported). Following the same approach as for the time series cross sectional approach in Jonsson (2012), the largest trade stream (in quantity terms) is used to derive the price (e.g. for the Swedish coniferous sawnwood, the export trade unit value is used as the price for sawnwood). For sawlogs and pulpwood, where trade unit values cannot be derived, it is assumed that two thirds of the export unit value for industrial roundwood was accounted for by sawlogs.

Production costs

Production costs for wood-based products are derived from FAOSTAT as the price (trade unit values) for the product minus the price of the input(s) weighted by input coefficients (Appendix M).

Transportation costs

Unit transportation costs in GFTM are the same as the ones of the GFPM, with the exception for wood pellets, which are based on Sikkema et al. (2011) and the modelers' judgment (Appendix N).

External Drivers

The only external driver considered at this stage of the model development is the GDP growth rate. The choice of the source for GDP projections is important in light of possible future data harmonization with other JRC models. Indeed, an integrated framework including different models necessarily requires its components to use economic data coming from a unique source. Other integrated frameworks, such as the ones applied in EUwood (Mantau et al. 2010) and EFSOS II (UN 2011), have used the projections included in the IPCC scenarios as economic drivers. However, such projections are now quite dated and, most importantly, they do not take into account the latest economic crisis. Two main possibilities have been considered as sources of GDP data: (i) the Macro-econometrics of the Global Economy model (MAGE) developed by CEPII, and (ii) the Shared Socioeconomic Pathways (SSPs) provided by the joint work of IIASA and OECD.

MAGE is a growth model with three factors (labor, capital and energy), for 147 countries, with time horizon 2050 under 6 possible scenarios. The SSPs scenarios instead derive from the IPCC request for an update of the currently used scenarios. Based on an OECD model, 5 storylines have been quantified for 175 countries, with time horizon 2100. The available database already includes projections for population and economic development. The projections from MAGE and SSPs are broadly in line, but

with some differences. In particular, MAGE's projections are more optimistic for China, Russia and, in general, for surplus countries, while they are more pessimistic for deficit ones.

The possible use of MAGE presented mainly two difficulties: the SSPs are likely to become a standard in future forest, and in general environmental studies and the quantification of them in MAGE has only been discussed by CEPII, but not yet implemented. Further, the integration with other JRC models that receive inputs from macro-economic models might be quite problematic. In addition, "the SSPs are part of a new framework that the climate change research community has adopted to facilitate the integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation" (IIASA website https: //secure.iiasa.ac.at /web-apps/ene/SspDb/dsd?Action=htmlpage&page=about).

Hence, as an example, the SSPs are used in the Integrated Modelling Platform for Agro-economic Commodity and Policy Analysis (IMAP), see M'barek et al. (2015). Due to these considerations, the SSPs scenarios seem to be the most suitable default source for the economic exogenous inputs (see Appendix A). However, depending on scenario assumptions, any source of GDP projections can be used.

Parameters Estimates

Demand elasticities

The price and income (GDP) elasticities used in the GFTM, as regards Europe, derive from the ones used in EFSOS II (UN 2011), see Jonsson (2012), while for non-European countries and sub-regions the elasticities of Jonsson and Whiteman (2008) are used (see Appendices C-K) . For two product groupings, Newsprint and Printing & writing paper, a specific evaluation of elasticities was carried out in order to update the GDP elasticities used in the GFTM.

As for wood pellets, econometric analysis (time-series cross-sectional analysis) was performed on data for household use in Austria (sources: *Propellets Austria*), Germany (sources: *Deutsche Energieholz und PelletVerband, Deutsche Pelletinstitut*, and *Centrales Agrar-Rohstoff Marketing- und Energie-Netzwerk e.V*), Italy (sources: *Associazione Italiana Energie Agroforestali*), and Sweden (sources: *Svebio, PelletsFörbundet*, and *Energimyndigheten*) to derive price and GDP elasticities (Appendix B). These elasticities are used for countries where the use of wood pellets are deemed to be dominated by household use, while for countries where wood pellets are used both by households and for larger scale use for heating and/or power, weighted elasticities are estimated, based on expert assessment of the respective quantity share of respective user category (Appendix L).

Timber supply parameters

For the first (starting) period, using the equation $p^i_{PP} = a^i_{PP} q^i_{PP}{}^{\theta^i_{PP}}$, the shift parameter, $a^i{}_{PP}$, is derived from actual data for sawlogs and pulpwood removals (production), corresponding to $q^i{}_{PP}$ in the equation above, and prices of sawlogs and pulpwood, corresponding to $p^i{}_{PP}$ in the above equation. Doing so, the value for θ^i_{PP}, i.e., the inverse of the supply price elasticity, is set to 3 for all countries and sub-regions. Hence, timber supply is assumed to be rather inelastic. A shortcoming in this context is the absence of (recent) empirically based timber supply price elasticities.

Industry Module Calibration

The industry module of the GFTM simulates the production in each country of final or intermediate products starting from wood or recycled paper. The transformation of products implicit in the production process is described in GFTM by means of industry matrices M_i, as detailed above. For most countries these data are not available, further production data are often unreliable.

The calibration process consists of establishing the input-output coefficients of the matrix that require least adjustment of starting data (production, consumption, and trade), while remaining coherent with established knowledge as to techniques of production, also satisfying the equilibrium conditions stated above. The input/output coefficients used build on Fonseca (2010). For countries and sub-regions not covered in said study, input/output coefficients were extrapolated, using expert assessment.

The transformation process simulated in GFTM by means of the industry module is outlined in Figure 1 below. Please note that although EFDM will provide the timber supply split in sawlogs and pulpwood, the real proportion is derived depending on the demand for final products.

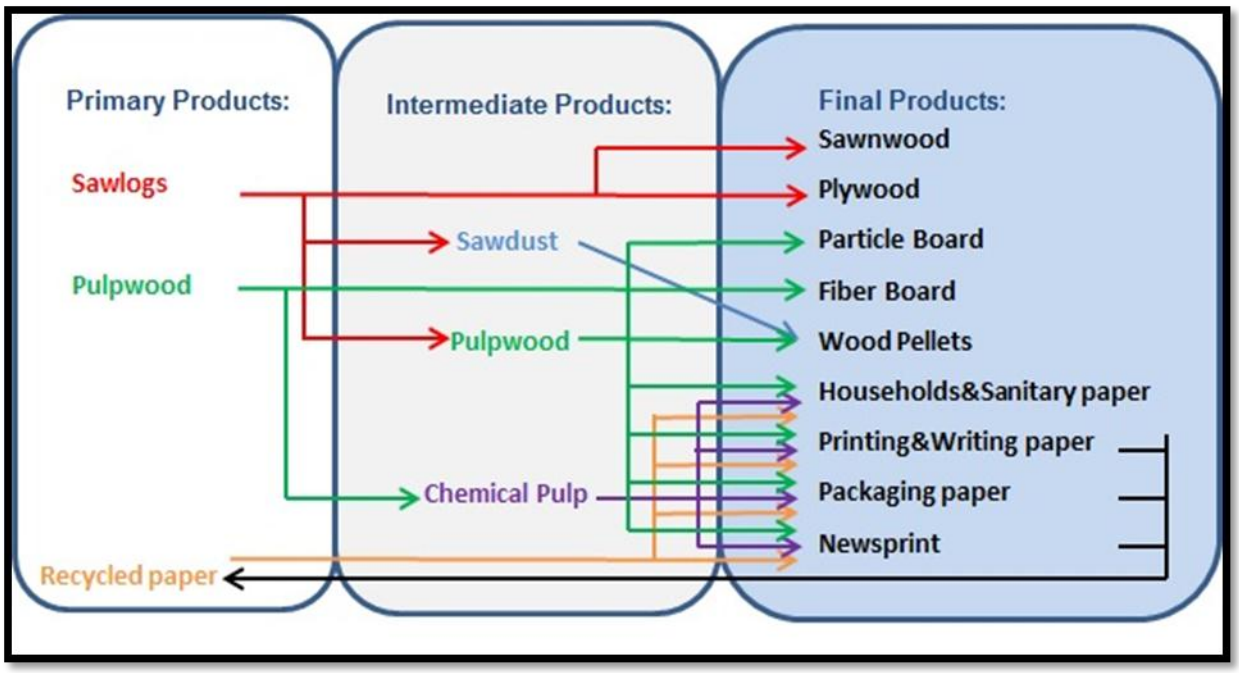

Figure 1 Industry module of the GFTM

Timber Supply

When fully operational, EFDM (Packalen et al. 2014) will provide the supply of timber (coniferous and non-coniferous sawlogs and pulpwood respectively) for the European countries to be ingested in the GFTM as an upper bound on the production of wood-based commodities. In the near term CBM, the Carbon Budget Model (Kurz et al. 2009) will be used to provide this input, in the form of stemwood (coniferous and non-coniferous). A split of stemwood on sawlogs and pulpwood will then be done based on FAOSTAT production data series.

Currently, timber supply is provided from an excel spreadsheet ("the spreadsheet forest"), where data on growing stock and increment are compiled from various sources: The Global Forest Resources Assessment

(http://www.fao.org/forestry/fra/fra2010/en/), The State of Europe's Forests (http://www.unece.org/forests/fr/outputs/soef2011.html), and EFDAC, the European Forest Data Centre (http://forest.jrc.ec.europa.eu/efdac/).

Annual potential harvest levels are set equal to annual increment (for Russia an expert assessment based on a reduction factor is applied, as the harvest potential would otherwise be nonsensical). Then this volume is converted to solid volume under bark, using the constant 0.88 (source: Fonseca 2010). Finally, as described above for CBM, this solid roundwood volume is divided into sawlogs and pulpwood respectively based on FAOSTAT production data series. Although the European part of this excel-based forest resource assessment will be substituted, first by the CBM and later by the EFDM, for non-European countries and sub-regions, "the spreadsheet forest" will still be used.

Runs of the Model

Projections

In the following, results obtained from three runs (two updates) of the GFTM (for 2010, 2015 and 2020, respectively) are presented for some selected wood-based commodities.

Consumption

The four largest consumers of coniferous sawnwood in 2010 in the EU were France, Germany, Italy, and UK. Figure 2 depicts the development projected by the GFTM. French and German consumption are foreseen to increase by some four percent from 2010 to 2020, whereas UK consumption will remain stable (around one percent increase from 2010 to 2020). This is contrasted by Italian consumption, which is projected to decrease from 2010 to 2020 by as much as 9.5 percent (Figure 2).

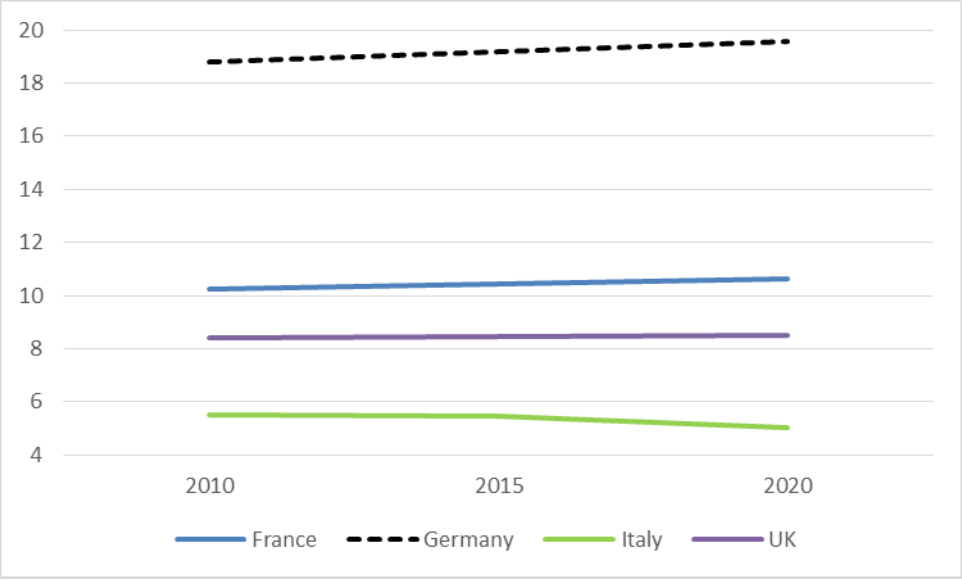

Figure 2 Projections for coniferous sawnwood consumption (million m^3) for the four largest consumers in EU

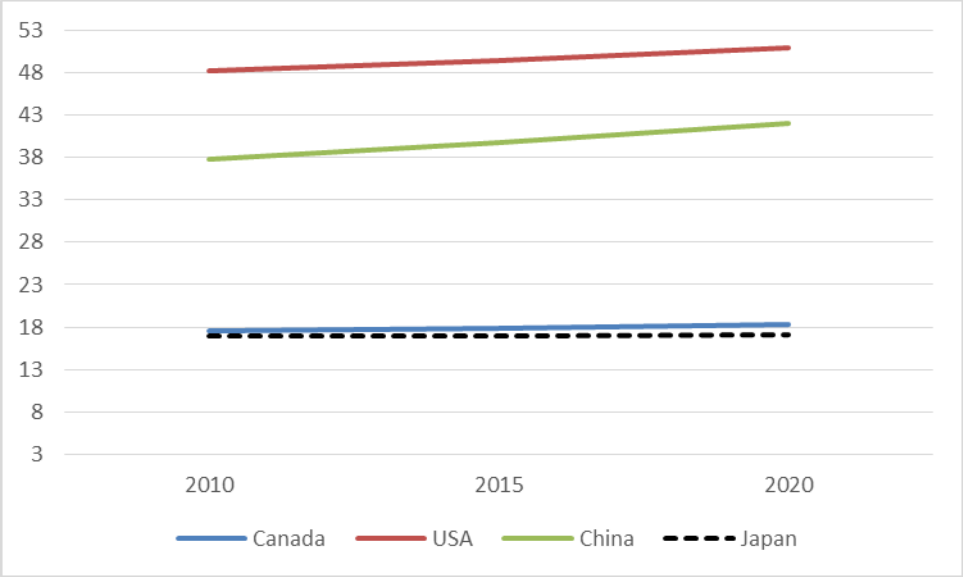

Figure 3 Projections for coniferous sawnwood consumption (million m^3) for the four largest consumers outside EU

Figure 3 depicts projected consumption of coniferous sawnwood for the four largest consumers outside EU28 in 2010; Canada. USA, China and Japan. Consumption of all these countries is foreseen to grow, most markedly in China and modestly in Canada and Japan.

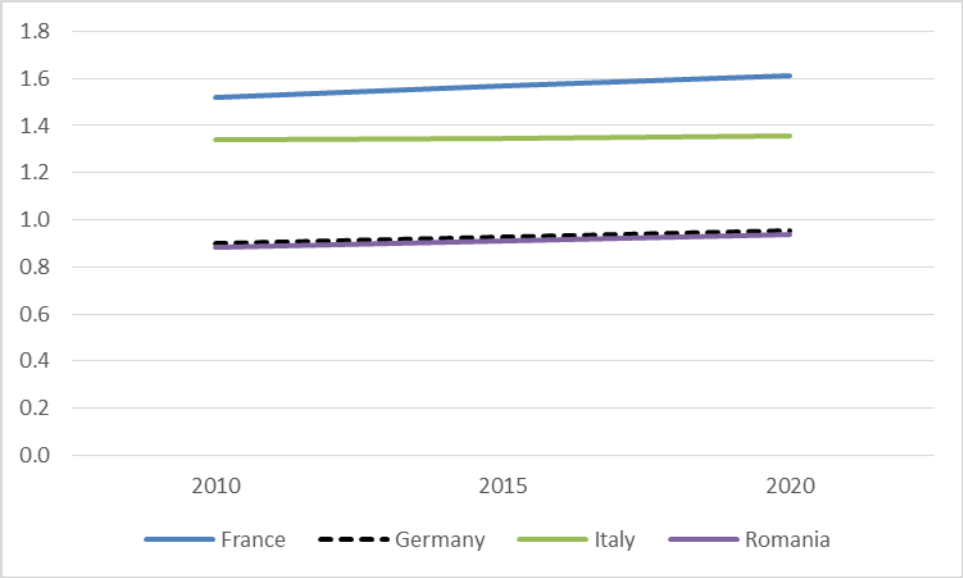

Figure 4 Projections for non-coniferous sawnwood consumption (million m^3) for the four largest consumers in EU

Figure 4 depicts projected consumption of non-coniferous sawnwood for the four largest consumers in EU28 in 2010, namely France, Germany, Italy, and Romania. Consumption of all these countries is foreseen to exhibit consistent, albeit, modest growth.

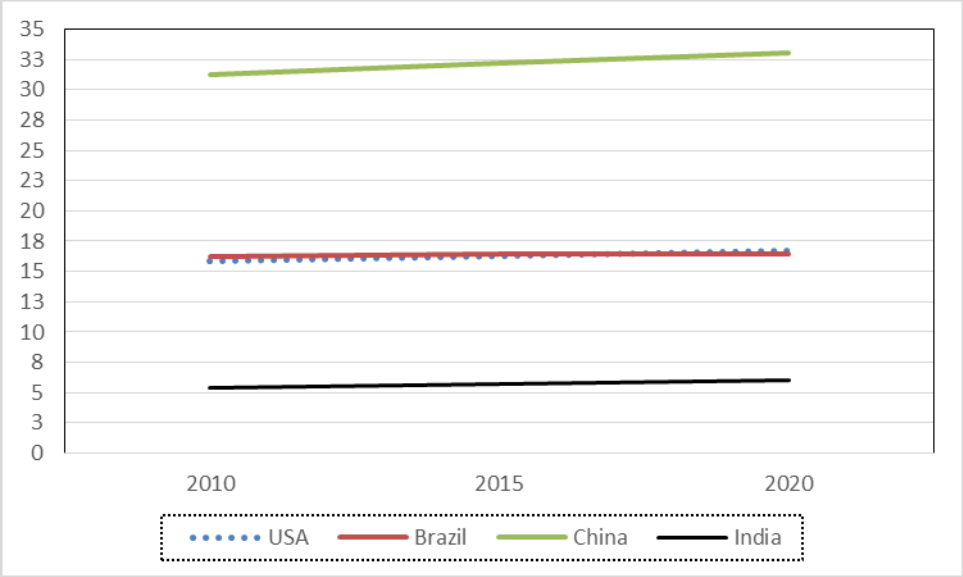

Figure 5 Projections for non-coniferous sawnwood consumption (million m^3) for the four largest consumers outside EU.

Figure 5 depicts projected consumption levels of non-coniferous sawnwood for the four largest consumers outside EU28; Brazil, China, India, USA. Consumption is projected to increase in all four countries, most markedly in China and India, with six and thirteen percent respectively.

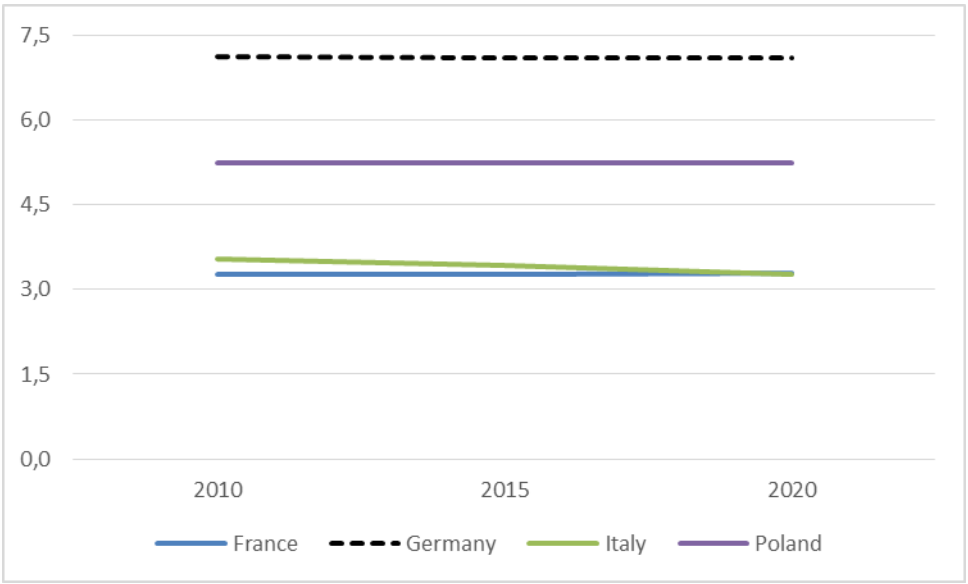

Figure 6 Projections for particle board consumption (million m^3) for the four largest consumers in the EU.

Figure 6 depicts projected consumption of particle board for the four largest consumers in EU28 in 2010, namely France, Germany, Italy, and Poland. With the exception of Italy, expected to register a decrease, consumption will remain largely constant.

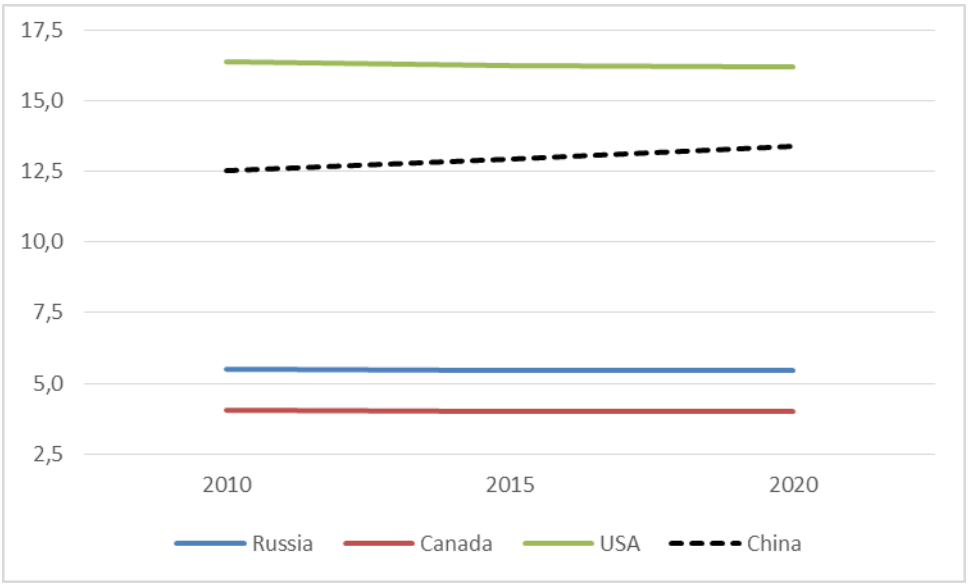

Figure 7 Projections for particle board consumption (million m^3) for the four largest consumers outside EU

Particle board consumption is expected to remain virtually unchanged in the four largest consumers outside the EU28, with the exception of China, where a steady growth is projected (Figure 7).

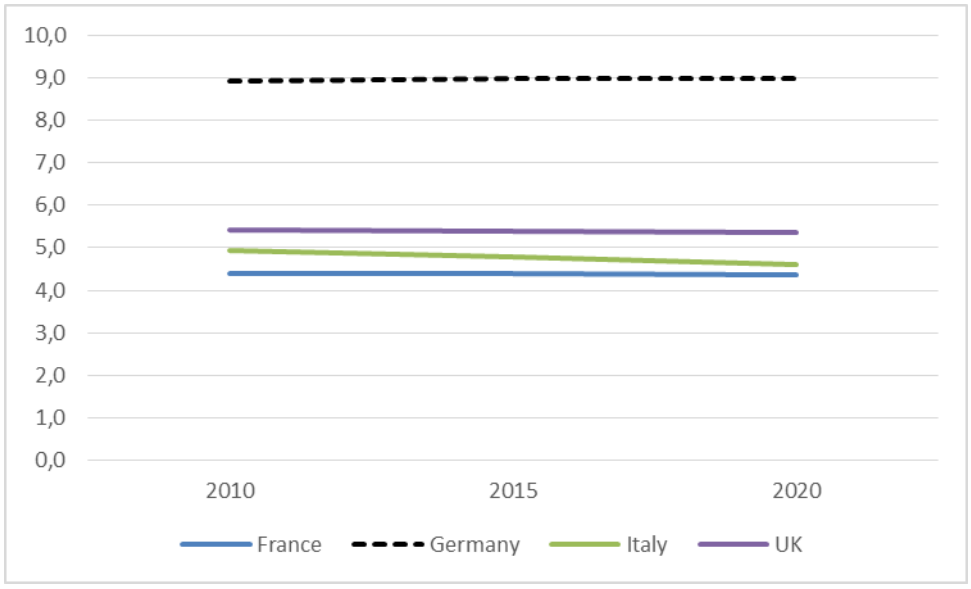

Figure 8 Projections for graphic paper consumption (million tonnes) for the four largest consumers in EU

Graphic paper (newsprint and printing & writing paper) consumption is expected to remain virtually unchanged in the four largest consumers inside the EU28, with the exception of Italy, which is projected to experience a steady decline (Figure 8).

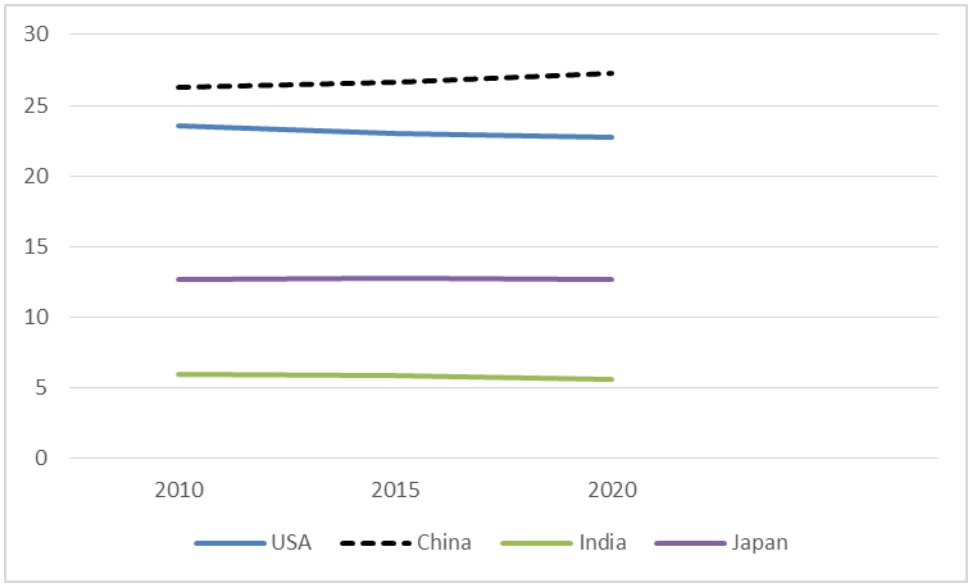

Figure 9 Projections for graphic paper consumption (million tonnes) for the four largest consumers outside EU.

Graphic paper consumption is projected to remain virtually unchanged in Japan and India, decrease in USA, and increase in China (Figure 9).

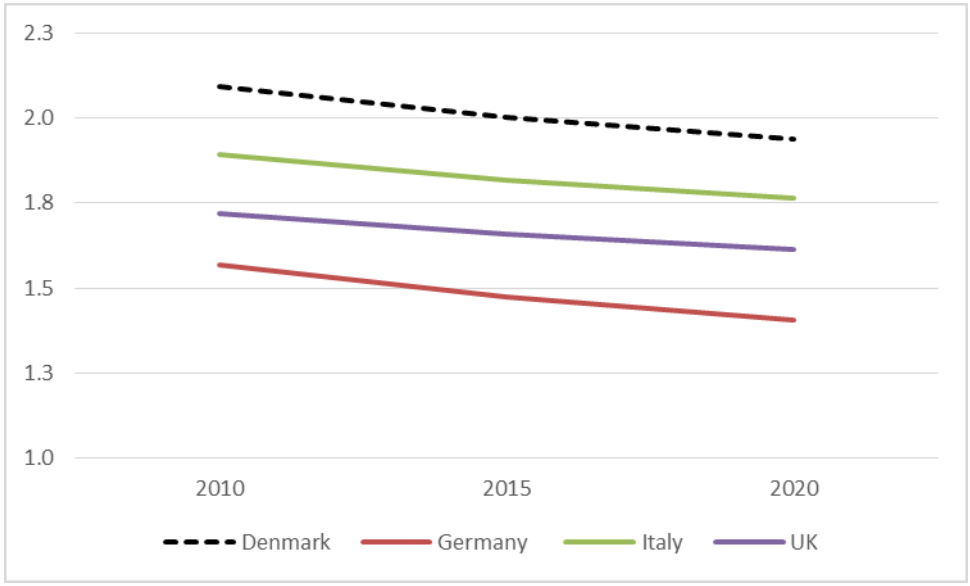

Figure 10 Projections of wood pellets consumption (million tonnes) for the four largest consumers in EU

Wood pellets consumption is projected to decrease in all the four largest consumers of EU28 (Figure 10). This is noteworthy, as one might have expected consumption to increase, and gives an indication that consumption is not driven strictly by economic

drivers, but perhaps rather by policy instruments such as, for example, feed-in tariffs

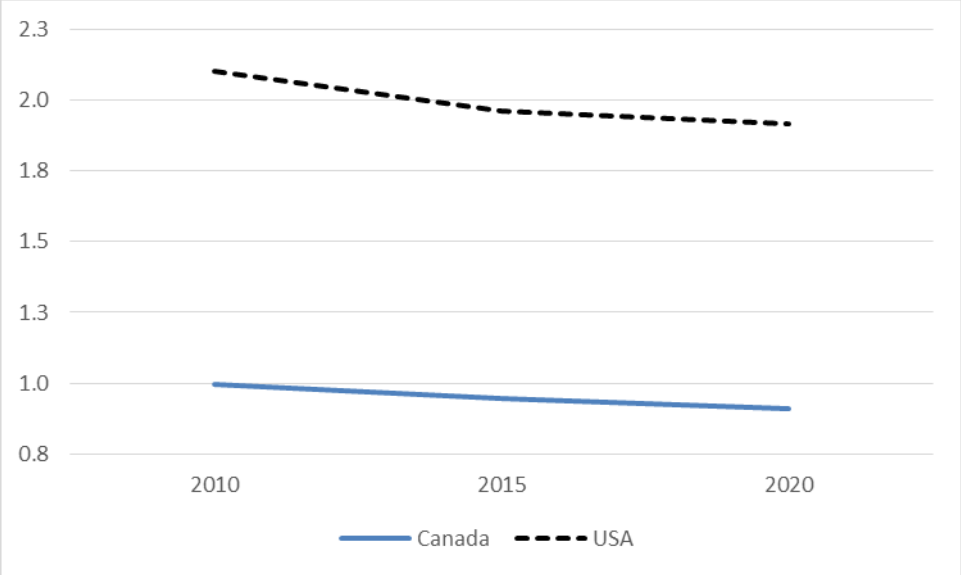

Figure 11 Projections of wood pellets consumption (million tonnes) for the two largest consumers outside EU

Canada and USA are the two only countries outside of EU28 that have a notable consumption of wood pellets. The same as for the four largest EU consumers, a bit counterintuitive, consumption is projected to decrease (Figure 11). Again, this implies that wood pellets consumption to a large extent is driven by other than strictly economic drivers.

Production

The general path followed by consumption is to a large extent mirrored in production data (Tables 12-21).

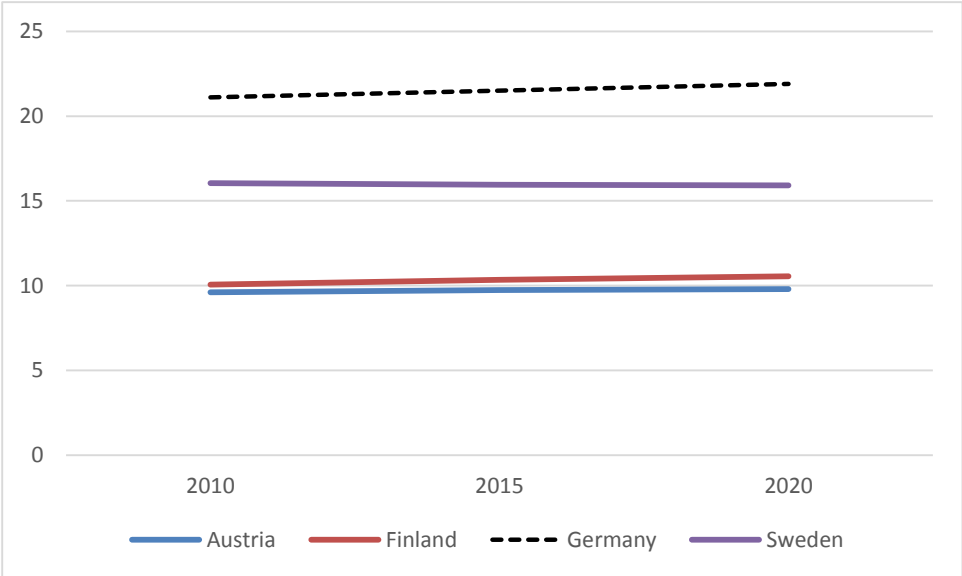

Figure 12 Production of coniferous sawnwood (million m^3) for the four largest producers in EU

Production of coniferous sawnwood is generally set to increase, albeit at a very modest rate, between 2010 and 2020 for the four largest EU producers, with the exception of Sweden, foreseen to observe a slight decline in production between 2010 and 2020 (Figure 12).

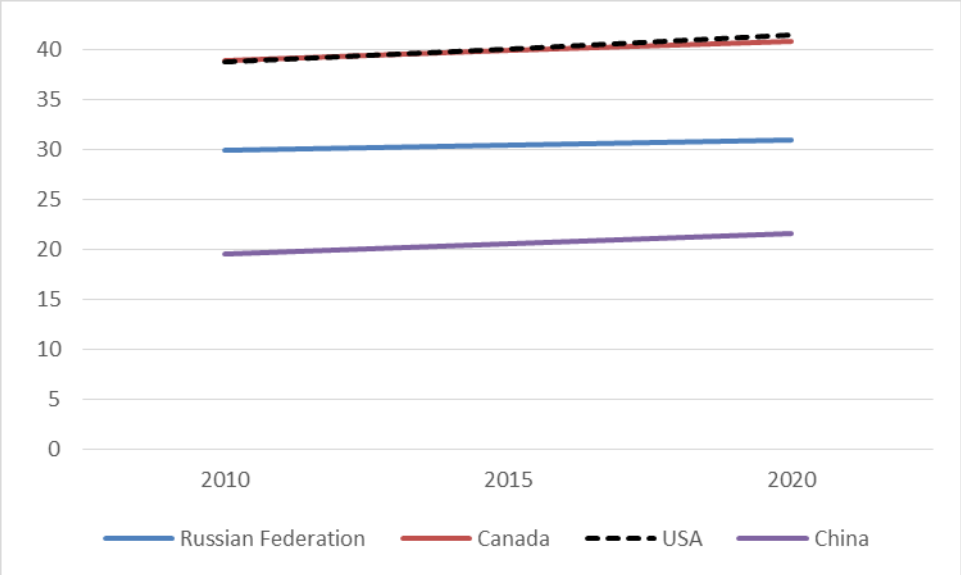

Figure 13 Production of coniferous sawnwood (million m3) for the four largest producers outside EU

Production of coniferous sawnwood is projected to increase for the four largest producers outside EU28, albeit at different rates. Hence, while Russian Federation is expected to exhibit sluggish growth, USA and China will grow considerably faster, with Canada growth rate somewhere in between (Figure 13).

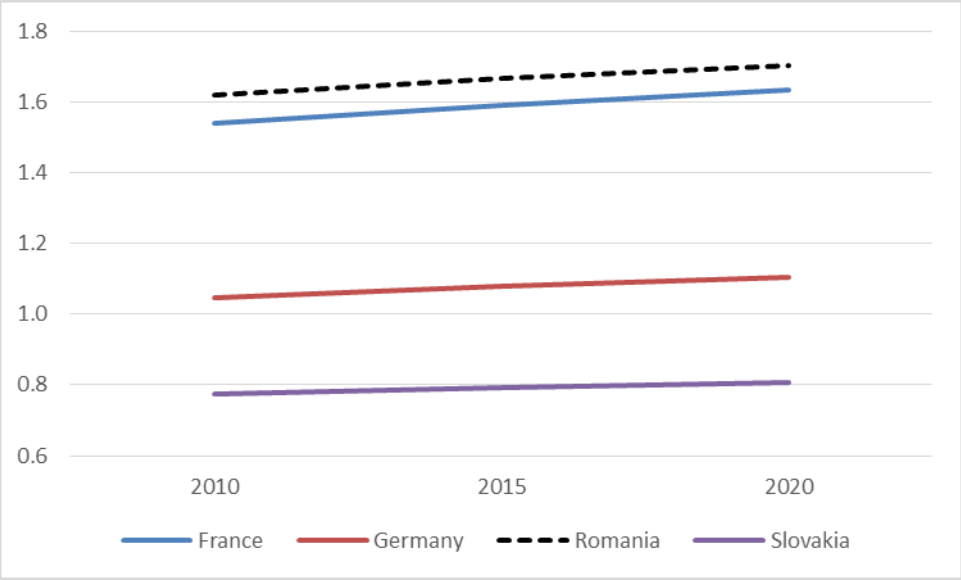

Figure 14 Production of non-coniferous sawnwood (million m3) for the four largest producers in EU

Production of non-coniferous sawnwood is set to increase in all of the four largest producer countries within the EU28 between 2010 and 2020 (Figure 14).

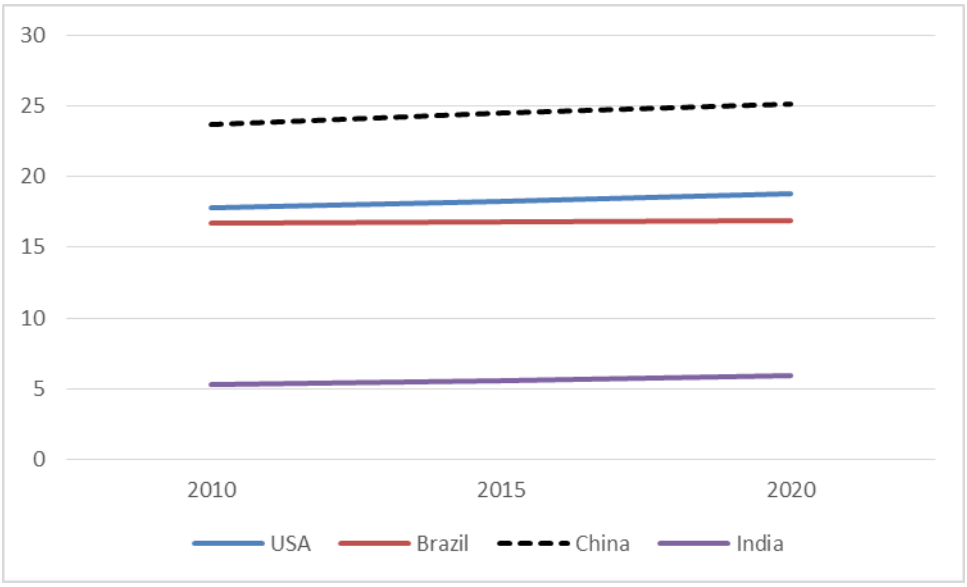

Figure 15 Production of non-coniferous sawnwood (million m3) for the four largest producers outside EU

Production of non-coniferous sawnwood outside the EU28 is projected to increase in all the four largest producers, though at very different rates, with India and China registering the highest growth from 2010 to 2020, with thirteen and six percent respectively (Figure 15).

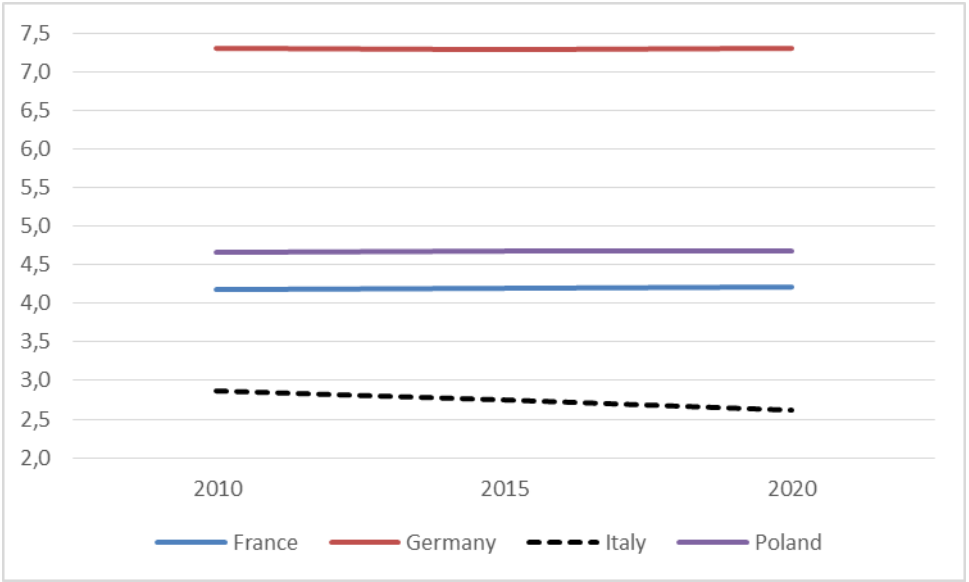

Figure 16 Production of particle board (million m^3) for the four largest producers in EU

The only noticeable projected development as regards particle board production in the four largest producers within the EU28 is a significant decrease in the Italian production (Figure 16).

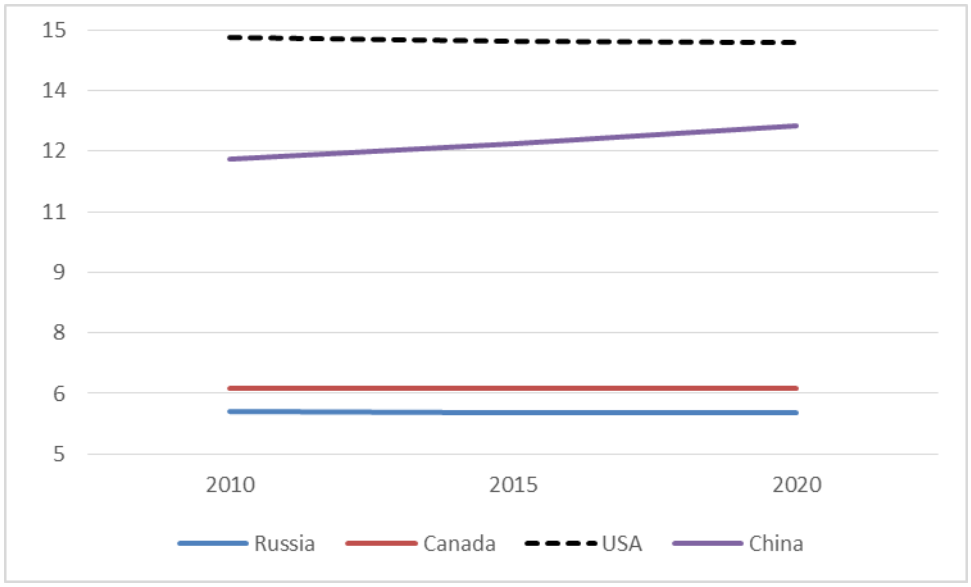

Figure 17 Production of particle board (million m^3) for the four largest producers outside EU

The notable projected development as regards particle board production in the four largest producers outside the EU28 is a marked increase in the Chinese production (Figure 17).

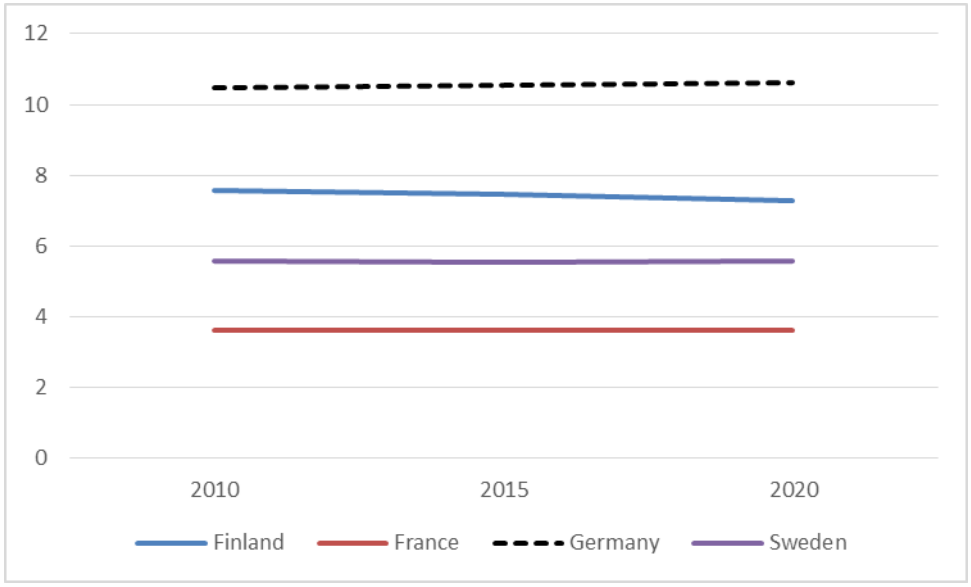

Figure 18 Production of graphic paper (million tonnes) for the four largest producers in EU

As for graphic paper, Germany is projected to register a small increase in production up to 2020, production in France and Sweden is foreseen to remain virtually unchanged, whereas Finnish production is projected to decrease slightly (Figure 18).

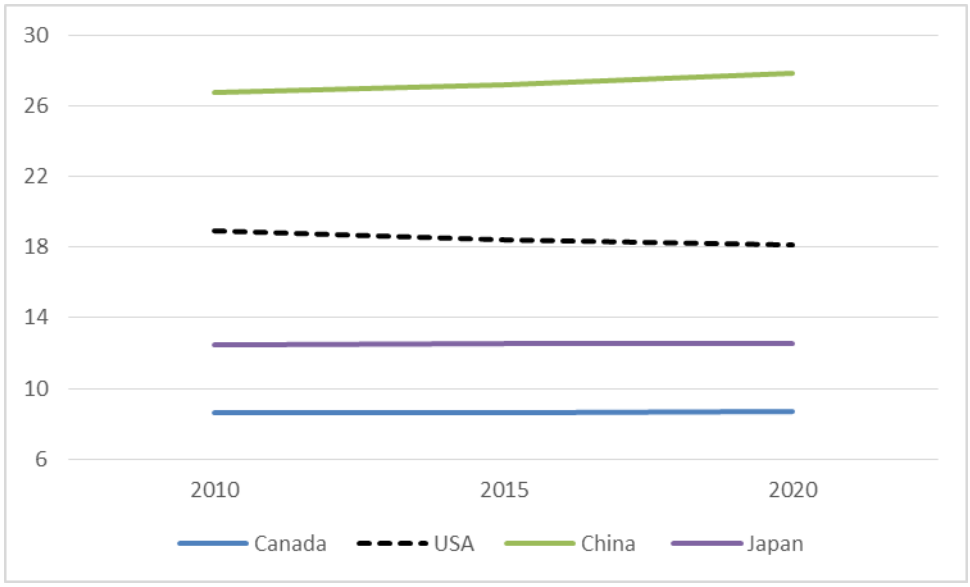

Figure 19 Production of graphic paper (million tonnes) for the four largest producers outside EU

Projected production of graphic paper for the four largest producers outside EU28 to a large extent mirrors projected consumption. Hence, while Chinese production is foreseen to increase by nearly four percent between 2010 and 2020, production in the USA is expected to contract by more than four percent. Canadian production is projected to increase by some 1.3 percent, while Japanese production will remain stable (Figure 19).

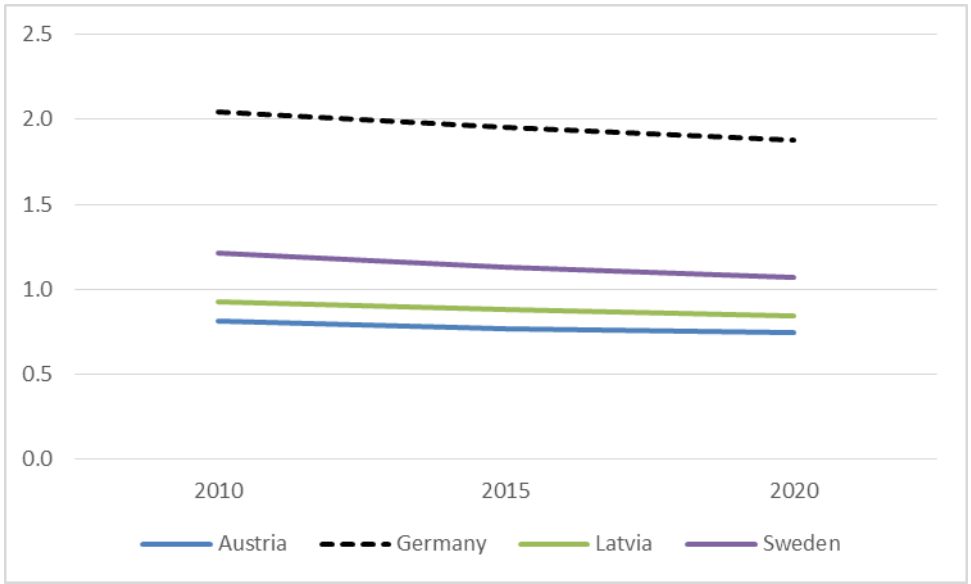

Figure 20 Production of wood pellets (million tonnes) for the four largest producers in EU

All the four largest producer countries as regards wood pellets in the EU are projected to decrease production between 2010 and 2020, from eight percent in Germany to some twelve percent in Sweden (Figure 20).

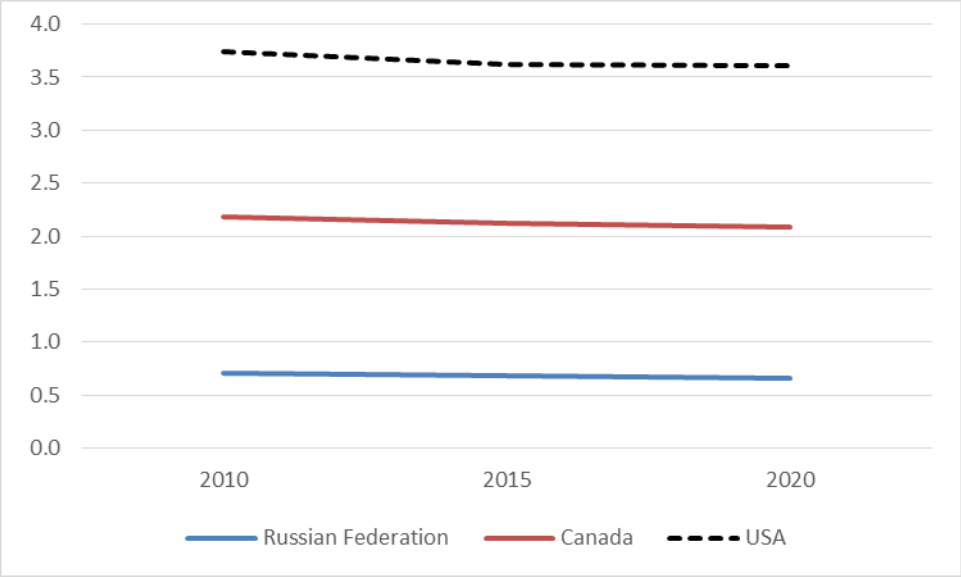

Figure 21 Production of wood pellets (million tonnes) for the four largest producers outside EU

Production of wood pellets is, with the exception of USA registering a modest decline, projected to be more or less stable for the four largest producer countries outside the EU28 between 2010 and 2020 (Figure 21).

Additional test of model robustness

In order to check the robustness of the model, also considering the linkage with a dedicated energy model, additional tests for wood pellets were performed. Thus, wood pellets consumption were set to increase by ten percent from 2010 to 2015 in the seven largest consumers within the EU28: Belgium, Denmark, Germany, Italy, Netherlands, Sweden and the United Kingdom, and by a further ten percent from 2015 to 2020. One would expect that such an increase in the consumption of wood pellets would affect trade (increased imports of wood pellets in test countries), as well as the production of wood pellets, sawnwood (increasing), reconstituted panels (decreasing) and paper products (decreasing) in test countries and major export partners (see, e.g., Jonsson 2011).

Looking at production projections in the test countries and major source countries for wood pellets—Canada, Russian Federation and the USA—interesting patterns emerge. Table 2 depicts projections for 2015 in the base setting and the setting with fixed (high) wood pellet consumption in the six EU countries in question. Interestingly, Italy is the only one of the five test countries with production of wood pellets that is foreseen to significantly increase production compared to the base setting. In the other countries, obviously in Belgium, which does not produce wood pellets, the increase in consumption is entirely met by increased net imports (or decreased net exports). Indeed, all seven countries increase net imports (or decrease net exports). In Italy, production of sawnwood (coniferous and non-coniferous alike) increases, in line with expectations (see, e.g., Jonsson 2011). Again logically consistent is the decrease in production of reconstituted panels, newsprint, printing paper, packaging paper and household & sanitary paper in the alternative setting, all these products suffering from increased competition for raw materials. In the other five EU countries with high fixed wood pellet consumption and domestic production, all except Netherlands increase the production of wood pellets, but quite conservatively. All of these four countries, with

the exception of Denmark, increase sawnwood production, though modestly. Denmark, like Italy, exhibits signs of crowding out of panels and paper production. For the other three 'test countries', there are no clear patterns of displacement of panel and paper production, and this also holds for the three 'source countries' of wood pellets. Canada, Russia and USA all increase production of wood pellets. However, the increase in net exports is projected to outpace the production increase in all three source countries, hence domestic consumption of wood pellets in these three source countries is displaced by increased consumption in the seven EU test countries (Table 2).

Table 2 Production of wood products and wood pellets and wood pellet net trade in 2015 (m^3/metric tonnes)

2015										
Base setting										
	Belgium	Denmark	Germany	Italy	Netherl.	Sweden	UK	Canada	Russia	USA
Sawnwood con.	1,078,009	271,950	21,564,312	751,337	145,114	15,916,337	3,467,218	39,940,209	30,586,033	40,222,792
Sawnwood non-con.	194,848	211,348	1,078,228	551,274	67,686	141,120	57,075	1,609,592	2,651,766	18,378,946
Particle board	1,740,082	309,304	7,291,483	2,746,762	0	492,491	2,521,970	6,126,993	5,522,868	14,773,645
Fibreboard	237,550	29,771	4,610,817	777,500	44,833	96,965	756,090	1,272,330	1,703,655	7,514,476
Newsprint	250,209	4,233	2,255,771	177,841	258,139	2,232,953	1,199,015	4,499,115	1,944,627	2,771,505
Printing paper	1,092,195	160,482	8,282,254	2,444,521	599,892	3,313,518	434,206	4,120,770	521,653	15,703,260
Packaging paper	440,815	280,841	11,649,303	4,269,176	1,563,720	5,532,096	1,786,912	3,480,064	2,898,866	62,406,829
Househ & Sanitary	173,052	74,804	1,293,676	1,310,984	69,986	341,853	738,465	518,273	308,926	6,443,756
Pellets prod	0	79,859	1,951,832	597,705	74,861	1,129,735	224,819	2,118,428	679,716	3,644,557
Pellet net export	-921,330	-1,925,087	476,627	-1,218,110	-791,225	-301,673	-1,434,909	1,173,527	617,356	1,668,783
Pellet test										
	Belgium	Denmark	Germany	Italy	Netherl.	Sweden	UK	Canada	Russia	USA
Sawnwood con.	1,076,888	274,177	21,732,020	799,508	146,415	16,164,945	3,530,616	39,985,494	31,303,559	40,102,571
Sawnwood non-con.	194,800	212,263	1,087,188	569,908	67,817	143,361	58,450	1,623,384	2,711,285	18,483,588
Particle board	1,737,373	308,658	7,267,259	2,711,640	0	492,560	2,533,221	6,118,830	5,523,288	14,781,104
Fibreboard	237,500	29,767	4,618,669	772,305	44,841	96,956	745,686	1,268,124	1,703,784	7,522,065
Newsprint	250,502	4,233	2,250,827	177,763	258,115	2,232,541	1,202,298	4,500,373	1,946,356	2,761,109
Printing paper	1,091,495	160,532	8,296,036	2,424,552	600,131	3,315,856	434,567	4,129,252	521,614	15,634,396
Packaging paper	441,434	280,957	11,630,828	4,261,310	1,559,902	5,527,293	1,772,024	3,483,979	2,895,529	62,407,046
Househ & Sanitary	172,987	74,791	1,288,155	1,308,562	69,981	341,806	737,723	518,242	308,923	6,459,932
Pellets prod	0	86,108	2,088,689	747,497	77,526	1,280,970	267,589	2,291,348	798,023	3,834,530
Pellet net export	-1,034,808	-2,217,146	365,510	-1,335,661	-898,116	-386,269	-1,624,378	1,386,697	738,206	1,912,566

The same pattern as identified for the projections of 2015 is repeated for the 2020 projections. Again, the main effects are increased net imports or decreased net exports in the seven 'test countries', and crowding out of wood pellets consumption in the main 'source countries' for EU wood pellets imports (Table 3).

Table 3 Production of wood products and wood pellets and wood pellet net trade in 2020 (m^3/metric tonnes)

2020										
Base setting										
	Belgium	Denmark	Germany	Italy	Netherl.	Sweden	UK	Canada	Russia	USA
Sawnwood con.	1,097,795	272,995	21,940,752	727,955	125,333	16,047,716	3,511,985	40,672,079	31,071,001	41,543,493
Sawnwood non-con.	193,594	213,624	1,102,733	564,881	68,592	139,762	59,398	1,647,743	2,698,773	18,855,714
Particle board	1,688,060	293,484	7,296,263	2,618,450	0	492,240	2,543,479	6,153,094	5,511,297	14,695,137
Fibreboard	236,501	29,601	4,649,569	769,629	44,216	96,936	653,480	1,271,813	1,704,748	7,499,140
Newsprint	248,175	4,235	2,262,670	177,174	262,673	2,231,335	1,204,876	4,525,937	1,958,433	2,700,439
Printing paper	1,068,830	162,973	8,334,624	2,341,628	545,346	3,349,111	435,310	4,139,175	523,452	15,373,593
Packaging paper	440,214	280,793	11,679,649	4,208,901	1,468,980	5,559,550	1,685,673	3,494,767	2,892,209	65,517,908
Househ & Sanitary	161,035	62,589	1,253,488	1,286,942	67,395	329,527	734,941	449,268	307,994	6,420,419
Pellets prod	0	74,447	1,882,451	555,854	66,277	1,064,148	205,981	2,065,878	656,689	3,584,005
Pellet net export	-907,446	-1,866,421	477,318	-1,196,840	-783,505	-302,065	-1,404,695	1,160,636	594,759	1,694,941
Pellet test										
	Belgium	Denmark	Germany	Italy	Netherl.	Sweden	UK	Canada	Russia	USA
Sawnwood con.	1,115,114	279,737	22,733,019	844,956	128,082	16,820,047	3,631,420	41,819,191	32,223,684	42,310,081
Sawnwood non-con.	194,010	216,029	1,141,714	606,846	68,554	148,303	63,276	1,711,525	2,825,572	19,414,655
Particle board	1,672,015	296,622	7,237,751	2,613,113	0	491,851	2,536,159	6,136,243	5,498,156	14,706,110
Fibreboard	236,089	29,652	4,656,351	762,602	44,467	96,914	633,641	1,265,786	1,702,310	7,500,516
Newsprint	246,511	4,236	2,264,737	177,234	260,174	2,217,960	1,206,185	4,526,033	1,949,975	2,718,005
Printing paper	1,048,934	163,637	8,366,164	2,353,262	563,925	3,350,959	434,739	4,154,526	521,729	15,314,472
Packaging paper	441,262	281,697	11,712,311	4,190,473	1,487,904	5,473,928	1,661,908	3,506,674	2,876,836	65,515,813
Househ & Sanitary	162,830	62,807	1,242,381	1,277,328	67,797	331,125	731,481	449,269	307,941	6,438,132
Pellets prod	0	81,063	2,310,467	778,310	68,881	1,384,991	247,538	2,518,192	803,548	4,161,476
Pellet net export	-1,138,289	-2,452,516	414,971	-1,513,164	-1,004,325	-448,973	-1,833,626	1,716,630	745,044	2,435,435

Summary and conclusions

The importance of the forest-based sector in the Bioeconomy of the EU calls for the use of forest-based sector models, integrating dynamics of forest resources, timber markets, forest-based industry processes, and forest-based product market demand. As part of the integrated modelling framework for the Bioeconomy, the IES has developed the Global Forest Sector Model (GFTM) presented in this report. In order to be suitable for forest policy analysis, a forest sector model should ideally meet on the one hand the necessity to be as disaggregated as possible both in terms of geographical scope and products covered, and, on the other hand, the necessity to maintain a certain degree of aggregation in order to limit numerical problems.

Runs with GFTM, presented in this report, indicate that the model behaves well in line with what can be expected from economic theory and established knowledge regarding forest-based industry processes. Therefore, GFTM seems to have struck a reasonable balance between the objectives of disaggregation and computability respectively. It is true though, that, as other current forest-based sector models, GFTM does not, with the exception of wood pellets, deal with "new/emerging products", an obvious shortcoming. However, as there are very limited information as to demand functions, production techniques ("conversion factors"), and limited data as to production and trade for these products, they have yet to be dealt with in mainly a qualitative sense.

As the forest-based sector is highly globalized, GFTM focus on tradable products. In some cases, representation of bilateral trade flows might also turn out to be useful. This will certainly be a topic for future research. Finally, a valid model for the forest sector should represent the production process in a sufficiently accurate way to allow the traceability of the impact of policy from primary resources availability, through the industrial transformation process, and finally to consumption and trade. The industry module of the GFTM has been precisely constructed to this aim.

For what concerns the results presented in this reports, somewhat surprising is the (albeit modest) decrease in projected wood pellets consumption of EU countries. As pointed out earlier, this gives a clear indication that wood pellets consumption to a large extent is contingent upon other factors than pure economic drivers. In general, the results, as regards wood pellets projections, should be interpreted with a certain degree of caution, since the GFTM is not dealing with the energy sector. Thus, only the competition between pellets and other wood-based products is regarded as relevant for reaching the market equilibrium.

However, this issue will be resolved soon as the GFTM is planned to ingest demand for wood pellets exogenously, from a dedicated energy-model (see suggested modelling set up in Figure 22 below). Results of the test of arbitrarily fixing the wood pellets consumption levels for respective projected period indicate that GFTM behaves in a logically consistent way, thus allowing, e.g., the assessment of the effects of an increased demand for wood pellets in terms of the production (and consequently also consumption) of other wood-based commodities.

The GFTM model will soon become part of the integrated Bioeconomy modelling framework of the JRC. Indeed, besides the obvious link with the forest resource models used by JRC—the Carbon Budget Model (CBM) and the European Forestry Dynamics Model (EFDM)—the GFTM could also work in cooperation with dedicated energy models. Doing so, GFTM is well-poised for assessing competition as well as synergies

between material and energy uses of woody biomass. Next steps in the modelling development will entail testing these linkages.

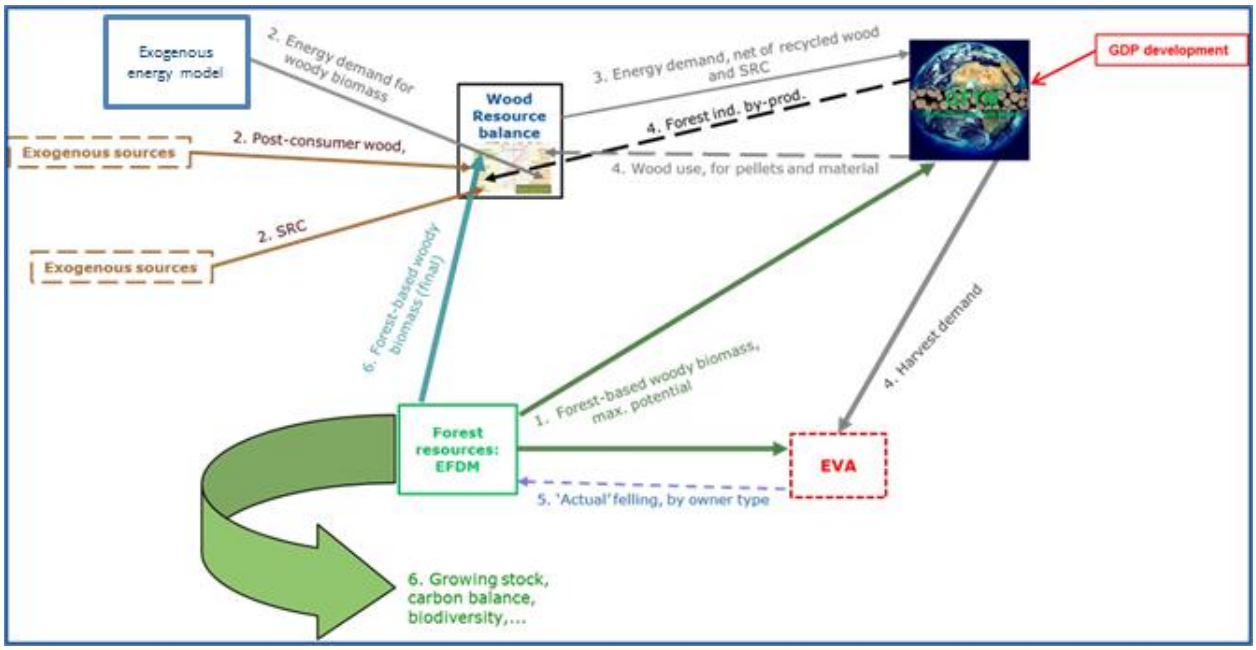

Figure 22 Suggested forest-based Bioeconomy modelling framework

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Acronyms

- AIEL: Associazione Italiana Energie Agroforestali
- CARMEN: Centrales Agrar-Rohstoff Marketing- und Energie-Netzwerk e.V.
- DEPI: Deutsches Pelletsinstitut
- DEPV: Deutscher Energieholz- und Pellet-Verband e.V.
- EFI-GTM: European Forest Institute Global Trade Model
- EFSOS: European Forest Sector Outlook
- EFTA: European Free Trade Association
- EU: European Union
- FAO: Food and Agriculture Organization of the United Nations
- FISE: Forest Information System for Europe
- FRA: (Global) Forest Resources Assessment
- GFTM: Global Forest Trade Model
- GFPM: Global Forest Products Model
- IIASA: International Institute of Applied System Analysis
- JRC: European Commission Joint Research Centre
- SVEBIO: Svenska Bioenergiföreningen
- UN: United Nations
- UNECE: United Nations Economic Commission for Europe

Appendix A

Per-year GDP growth rates from SSPs used in GFTM

per year GDP growth rates	2010-2015	2015-2020
Austria	0.0217	0.0178
Belarus	0.0415	0.0393
Belgium	0.0153	0.0162
Bulgaria	0.0208	0.0426
Croatia	0.0070	0.0206
Cyprus	0.0001	0.0190
Czech Republic	0.0281	0.0335
Denmark	0.0150	0.0173
Estonia	0.0449	0.0332
Finland	0.0227	0.0181
France	0.0126	0.0177
Germany	0.0182	0.0124
Greece	-0.0129	0.0237
Hungary	0.0093	0.0164
Ireland	0.0214	0.0239
Italy	0.0056	0.0121
Latvia	0.0409	0.0320
Lithuania	0.0376	0.0313
Luxembourg	0.0207	0.0265
Malta	0.0204	0.0237
Netherlands	0.0139	0.0178
Norway	0.0243	0.0234
Poland	0.0304	0.0319
Portugal	-0.0007	0.0190
Romania	0.0177	0.0324
Russian Federation	0.0398	0.0366
Serbia	0.0156	0.0242
Slovakia	0.0323	0.0320
Slovenia	0.0149	0.0215
Spain	0.0108	0.0121
Sweden	0.0283	0.0249
Switzerland	0.0186	0.0202
UK	0.0165	0.0247
Ukraine	0.0370	0.0352
NorAf	0.0350	0.0550
SouAf	0.0377	0.0440
Canada	0.0241	0.0250
USA	0.0243	0.0291
Oceania	0.0340	0.0326
Brazil	0.0329	0.0400
Chile	0.0488	0.0445
ReLaAm	0.0406	0.0373
China	0.0876	0.0798
India	0.0655	0.0680
Japan	0.0112	0.0094
SouEastAs	0.0528	0.0569
Turkey	0.0465	0.0430
ReWo	0.0471	0.0484

Appendix B

Results from time-series cross-sectional analysis (OLS) of apparent consumption of wood pellets

Multiple R	0.782373964
R Square	0.61210902
Adjusted R Square	0.586249621
Standard Error	0.599856776
Observations	49

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	25.552109	8.5173697	23.67065948	2.4033E-09
Residual	45	16.19226685	0.3598282		
Total	48	41.74437585			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	14.643	3.611	4.055	0.000	7.370	21.916	7.370	21.916
Y	**0.271**	0.095	2.851	0.007	0.080	0.463	0.080	0.463
P	**-0.980**	0.642	-1.526	0.134	-2.274	0.314	-2.274	0.314
t	**0.192**	0.036	5.399	0.000	0.120	0.264	0.120	0.264

Y: GDP

P: price

t: trend

Countries included: Aut, Ger, Swe, It

Appendix C

Demand elasticities for coniferous sawnwood

Country	GDP elastic	Price elastic	Country	GDP elastic	Price elastic
Austria	0.469	-0.5090	Romania	0.302	-0.1700
Belarus	0.302	-0.1700	Russia	0.302	-0.1700
Belgium	0.618	-0.3452	Serbia	0.302	-0.1700
Bulgaria	0.302	-0.1700	Slovakia	0.302	-0.1700
Croatia	0.302	-0.1700	Slovenia	0.302	-0.1700
Cyprus	0.245	-0.0120	Spain	0.449	-0.4821
Czech Rep.	0.302	-0.1700	Sweden	0.211	-0.0120
Denmark	0.093	-0.4190	Switzerland	0.085	-0.4622
Estonia	0.302	-0.1700	Turkey	0.365	-0.0120
Finland	0.469	-0.5090	Ukraine	0.302	-0.1700
France	0.302	-0.1106	UK	0.122	-0.2900
Germany	0.212	-0.1380	Canada	0.737	-0.4119
Greece	0.245	-0.0120	USA	0.399	-0.0454
Hungary	0.302	-0.1700	Brazil	0.153	-0.0001
Ireland	0.258	-0.0120	Chile	0.964	-0.1841
Italy	0.671	-0.0007	Rest of Latinamerica	0.964	-0.1841
Latvia	0.302	-0.1700	China	0.068	-0.1691
Lithuania	0.302	-0.1700	India	0.491	-0.2116
Luxembourg	0.618	-0.3452	Japan	0.550	-0.1156
Malta	0.245	-0.0120	SE Asia	0.068	-0.1834
Netherlands (NL)	0.102	-0.4190	Oceania	0.754	-0.1350
Norway	0.422	-0.1281	North Africa	0.739	-0.1438
Poland	0.302	-0.1700	South Africa	0.425	-0.1352
Portugal	0.266	-0.0120	RoW	0.692	-0.5219

Appendix D

Demand elasticities for non-coniferous sawnwood

Country	GDP elastic	Price elastic	Country	GDP elastic	Price elastic
Austria	0.659	-0.2997	Romania	0.437	-0.1140
Belarus	0.437	-0.1140	Russia	0.437	-0.1140
Belgium	0.154	-0.4646	Serbia	0.437	-0.1140
Bulgaria	0.437	-0.1140	Slovakia	0.718	-0.2239
Croatia	0.437	-0.1140	Slovenia	0.437	-0.1140
Cyprus	0.679	-0.1810	Spain	0.574	-0.2427
Czech Rep.	0.877	-0.7782	Sweden	0.104	-0.1910
Denmark	0.154	-0.4646	Switzerland	0.154	-0.4646
Estonia	0.437	-0.1140	Turkey	0.813	-0.1810
Finland	0.662	-0.2540	Ukraine	0.437	-0.1140
France	0.113	-0.2471	UK	0.154	-0.4646
Germany	0.113	-0.2471	Canada	0.594	-0.0640
Greece	0.679	-0.1810	USA	0.594	-0.0640
Hungary	0.437	-0.1140	Brazil	0.409	-0.1482
Ireland	0.635	-0.1810	Chile	0.348	-0.3613
Italy	0.213	-0.3471	Rest of Latinamerica	0.490	-0.3313
Latvia	0.437	-0.1140	China	0.015	-0.0094
Lithuania	0.437	-0.1140	India	0.047	-0.0162
Luxembourg	0.154	-0.4646	Japan	0.012	-0.0144
Malta	0.679	-0.1810	SE Asia	0.565	-0.2540
Netherlands (NL)	0.154	-0.4646	Oceania	0.012	-0.0144
Norway	0.154	-0.4646	North Africa	0.638	-0.0286
Poland	0.923	-0.3219	South Africa	0.010	-0.0144
Portugal	1.094	-0.0780	RoW	0.226	-0.4850

Appendix E

Demand elasticities for Plywood

Country	GDP elastic	Price elastic	Country	GDP elastic	Price elastic
Austria	0.945	-0.7840	Romania	0.571	-0.5930
Belarus	0.571	-0.5930	Russia	0.571	-0.5930
Belgium	0.945	-0.7840	Serbia	0.571	-0.5930
Bulgaria	0.571	-0.5930	Slovakia	0.571	-0.5930
Croatia	0.571	-0.5930	Slovenia	0.571	-0.5930
Cyprus	0.817	-0.0460	Spain	0.837	-0.3634
Czech Rep.	0.571	-0.5930	Sweden	0.200	-0.3700
Denmark	0.054	-0.6610	Switzerland	0.945	-0.7840
Estonia	0.571	-0.5930	Turkey	0.609	-0.1860
Finland	0.200	-0.3700	Ukraine	0.571	-0.5930
France	0.368	-0.6368	UK	0.480	-0.4360
Germany	0.105	-0.2628	Canada	0.411	-0.2875
Greece	0.735	-0.6108	USA	0.411	-0.2875
Hungary	0.571	-0.5930	Brazil	0.361	-0.2911
Ireland	0.936	-1.5280	Chile	1.085	-0.4544
Italy	0.891	-0.3634	Rest of Latinamerica	0.870	-1.1805
Latvia	0.571	-0.5930	China	0.411	-0.2875
Lithuania	0.571	-0.5930	India	0.474	-1.1330
Luxembourg	0.945	-0.7840	Japan	0.358	-0.0002
Malta	0.817	-0.0460	SE Asia	0.364	-0.0403
Netherlands (NL)	0.945	-0.7840	Oceania	0.685	-0.0068
Norway	0.110	-0.2790	North Africa	0.571	-0.3625
Poland	0.571	-0.5930	South Africa	0.765	-1.3514
Portugal	0.776	-0.0460	RoW	0.411	-0.2875

Appendix F

Demand elasticities for Particle board

Country	GDP elastic	Price elastic	Country	GDP elastic	Price elastic
Austria	0.627	-0.1160	Romania	0.578	-0.4330
Belarus	0.578	-0.4330	Russia	0.578	-0.4330
Belgium	0.557	-0.0360	Serbia	0.578	-0.4330
Bulgaria	0.578	-0.4330	Slovakia	0.578	-0.4330
Croatia	0.578	-0.4330	Slovenia	0.578	-0.4330
Cyprus	1.369	-0.0390	Spain	0.646	-0.2980
Czech Rep.	0.578	-0.4330	Sweden	0.646	-0.2980
Denmark	0.598	-0.6490	Switzerland	0.481	-0.1770
Estonia	0.578	-0.4330	Turkey	0.545	-0.2878
Finland	0.646	-0.2980	Ukraine	0.578	-0.4330
France	0.482	-0.5330	UK	0.646	-0.2980
Germany	0.396	-0.2980	Canada	0.545	-0.2878
Greece	1.369	-0.0390	USA	0.545	-0.2878
Hungary	0.578	-0.4330	Brazil	0.196	-0.1021
Ireland	0.557	-0.0360	Chile	0.870	-0.0115
Italy	0.646	-0.2980	Rest of Latinamerica	0.452	-0.2454
Latvia	0.578	-0.4330	China	0.545	-0.2878
Lithuania	0.578	-0.4330	India	0.551	-0.1008
Luxembourg	0.557	-0.0360	Japan	0.545	-0.2878
Malta	1.369	-0.0390	SE Asia	1.114	-0.7826
Netherlands (NL)	0.488	-0.1770	Oceania	0.843	-0.0420
Norway	0.646	-0.2980	North Africa	0.457	-0.1952
Poland	0.578	-0.4330	South Africa	0.954	-0.0298
Portugal	0.557	-0.0360	RoW	0.545	-0.2878

Appendix G

Demand elasticities for Fibreboard

Country	GDP elastic	Price elastic	Country	GDP elastic	Price elastic
Austria	0.354	-0.4644	Romania	0.354	-0.4644
Belarus	0.354	-0.4644	Russia	0.354	-0.4644
Belgium	0.354	-0.4644	Serbia	0.354	-0.4644
Bulgaria	0.354	-0.4644	Slovakia	0.354	-0.4644
Croatia	0.354	-0.4644	Slovenia	0.354	-0.4644
Cyprus	0.354	-0.4644	Spain	0.354	-0.4644
Czech Rep.	0.354	-0.4644	Sweden	0.354	-0.4644
Denmark	0.354	-0.4644	Switzerland	0.354	-0.4644
Estonia	0.354	-0.4644	Turkey	0.354	-0.4644
Finland	0.354	-0.4644	Ukraine	0.354	-0.4644
France	-0.125	-0.3120	UK	0.354	-0.4644
Germany	0.354	-0.4644	Canada	0.354	-0.4644
Greece	0.354	-0.4644	USA	0.354	-0.4644
Hungary	0.354	-0.4644	Brazil	0.354	-0.4644
Ireland	0.354	-0.4644	Chile	0.354	-0.4644
Italy	0.354	-0.4644	Rest of Latinamerica	0.354	-0.4644
Latvia	0.354	-0.4644	China	0.354	-0.4644
Lithuania	0.354	-0.4644	India	0.354	-0.4644
Luxembourg	0.354	-0.4644	Japan	0.354	-0.4644
Malta	0.354	-0.4644	SE Asia	0.354	-0.4644
Netherlands (NL)	0.354	-0.4644	Oceania	0.354	-0.4644
Norway	0.354	-0.4644	North Africa	0.354	-0.4644
Poland	0.354	-0.4644	South Africa	0.354	-0.4644
Portugal	0.354	-0.4644	RoW	0.354	-0.4644

Appendix H

Demand elasticities for Newsprint

Country	GDP elastic	Price elastic	Country	GDP elastic	Price elastic
Austria	-0.186	-0.6850	Romania	0.576	-0.2548
Belarus	0.576	-0.2548	Russia	0.576	-0.2548
Belgium	-0.186	-0.6850	Serbia	0.576	-0.2548
Bulgaria	0.576	-0.2548	Slovakia	0.576	-0.2548
Croatia	0.576	-0.2548	Slovenia	0.576	-0.2548
Cyprus	0.576	-0.2548	Spain	-0.186	-0.6850
Czech Rep.	0.576	-0.2548	Sweden	0.327	-0.6240
Denmark	0.576	-0.2548	Switzerland	0.576	-0.2548
Estonia	0.576	-0.2548	Turkey	0.576	-0.2548
Finland	0.327	-0.6240	Ukraine	0.576	-0.2548
France	-0.186	-0.6850	UK	0.126	-0.2250
Germany	-0.186	-0.6850	Canada	-0.136	-0.1230
Greece	0.576	-0.2548	USA	-0.136	-0.1230
Hungary	0.576	-0.2548	Brazil	0.139	-0.0895
Ireland	0.576	-0.2548	Chile	0.139	-0.0895
Italy	-0.186	-0.6850	Rest of Latinamerica	0.139	-0.0895
Latvia	0.576	-0.2548	China	0.576	-0.2548
Lithuania	0.576	-0.2548	India	0.576	-0.2548
Luxembourg	-0.186	-0.6850	Japan	0.576	-0.2548
Malta	0.800	-1.1300	SE Asia	0.576	-0.2548
Netherlands (NL)	-0.186	-0.6850	Oceania	0.576	-0.2548
Norway	0.327	-0.6240	North Africa	0.576	-0.2548
Poland	0.576	-0.2548	South Africa	0.576	-0.2548
Portugal	0.576	-0.2548	RoW	0.576	-0.2548

Appendix I

Demand elasticities for printing & writing paper

Country	GDP elastic	Price elastic	Country	GDP elastic	Price elastic
Austria	0.660	-0.3500	Romania	0.410	-1.0900
Belarus	0.630	-0.3400	Russia	0.410	-1.0900
Belgium	0.660	-0.3500	Serbia	0.630	-0.3400
Bulgaria	0.630	-0.3400	Slovakia	0.630	-0.3400
Croatia	0.630	-0.3400	Slovenia	0.630	-0.3400
Cyprus	0.630	-0.3400	Spain	0.800	-1.1300
Czech Rep.	0.410	-1.0900	Sweden	0.280	-0.1500
Denmark	0.660	-0.3500	Switzerland	0.957	-1.3000
Estonia	0.630	-0.3400	Turkey	1.134	-0.4360
Finland	0.280	-0.1500	Ukraine	0.630	-0.3400
France	0.660	-0.3500	UK	0.660	-0.3500
Germany	0.660	-0.3500	Canada	0.454	-0.3699
Greece	0.800	-1.1300	USA	0.454	-0.3699
Hungary	0.410	-1.0900	Brazil	0.454	-0.3699
Ireland	0.800	-1.1300	Chile	0.454	-0.3699
Italy	0.800	-1.1300	Rest of Latinamerica	0.454	-0.3699
Latvia	0.630	-0.3400	China	0.454	-0.3699
Lithuania	0.630	-0.3400	India	0.454	-0.3699
Luxembourg	0.660	-0.3500	Japan	0.454	-0.3699
Malta	0.800	-1.1300	SE Asia	0.454	-0.3699
Netherlands (NL)	0.660	-0.3500	Oceania	0.454	-0.3699
Norway	0.830	-0.7000	North Africa	0.454	-0.3699
Poland	0.410	-1.0900	South Africa	0.454	-0.3699
Portugal	0.800	-1.1300	RoW	0.454	-0.3699

Appendix J

Demand elasticities for packaging paper

Country	GDP elastic	Price elastic	Country	GDP elastic	Price elastic
Austria	0.860	-0.5600	Romania	0.540	-0.3500
Belarus	0.540	-0.3500	Russia	0.540	-0.3500
Belgium	0.920	-0.4400	Serbia	0.540	-0.3500
Bulgaria	0.540	-0.3500	Slovakia	0.540	-0.3500
Croatia	0.540	-0.3500	Slovenia	0.540	-0.3500
Cyprus	0.910	-0.3300	Spain	0.930	-0.3700
Czech Rep.	0.540	-0.3500	Sweden	0.670	-0.0500
Denmark	0.920	-0.4400	Switzerland	0.920	-0.4400
Estonia	0.540	-0.3500	Turkey	0.790	-0.4900
Finland	0.670	-0.0500	Ukraine	0.540	-0.3500
France	0.930	-0.3700	UK	0.330	-0.0500
Germany	0.930	-0.3700	Canada	0.651	-0.3688
Greece	0.770	-0.4900	USA	0.475	-0.0001
Hungary	0.540	-0.3500	Brazil	0.428	-0.2300
Ireland	0.770	-0.4900	Chile	0.428	-0.2300
Italy	0.930	-0.3700	Rest of Latinam.	0.428	-0.2300
Latvia	0.540	-0.3500	China	0.428	-0.2300
Lithuania	0.540	-0.3500	India	0.428	-0.2300
Luxembourg	0.920	-0.4400	Japan	0.428	-0.2300
Malta	0.910	-0.3300	SE Asia	0.428	-0.2300
Netherlands (NL)	0.920	-0.4400	Oceania	0.428	-0.2300
Norway	0.670	-0.0500	North Africa	0.428	-0.2300
Poland	0.540	-0.3500	South Africa	0.428	-0.2300
Portugal	0.770	-0.4900	RoW	0.428	-0.2300

Appendix K

Demand elasticities for Household and sanitary paper

Country	GDP elastic	Price elastic	Country	GDP elastic	Price elastic
Austria	0.329	-0.052	Romania	0.329	-0.052
Belarus	0.532	-0.350	Russia	0.532	-0.350
Belgium	0.329	-0.052	Serbia	0.532	-0.350
Bulgaria	0.329	-0.052	Slovakia	0.329	-0.052
Croatia	0.329	-0.052	Slovenia	0.329	-0.052
Cyprus	0.329	-0.052	Spain	0.329	-0.052
Czech Rep.	0.329	-0.052	Sweden	0.329	-0.052
Denmark	0.329	-0.052	Switzerland	0.329	-0.052
Estonia	0.329	-0.052	Turkey	0.915	-0.329
Finland	0.329	-0.052	Ukraine	0.532	-0.350
France	0.329	-0.052	UK	0.329	-0.052
Germany	0.329	-0.052	Canada	0.475	0.000
Greece	0.329	-0.052	USA	0.475	0.000
Hungary	0.329	-0.052	Brazil	0.548	-0.259
Ireland	0.329	-0.052	Chile	0.548	-0.259
Italy	0.329	-0.052	Rest of Latinam.	0.548	-0.259
Latvia	0.329	-0.052	China	0.933	-0.656
Lithuania	0.329	-0.052	India	1.228	-0.728
Luxembourg	0.329	-0.052	Japan	0.364	-0.056
Malta	0.329	-0.052	SE Asia	1.228	-0.728
Netherlands (NL)	0.329	-0.052	Oceania	0.553	-0.051
Norway	0.329	-0.052	North Africa	1.018	-0.316
Poland	0.329	-0.052	South Africa	0.994	-0.947
Portugal	0.329	-0.052	RoW	1.149	-0.654

Appendix L

Demand elasticities for Wood pellets

Country	GDP elastic	Price elastic	Country	GDP elastic	Price elastic
Austria	0.271	-0.9802	Romania	0.271	-0.9802
Belarus	0.271	-0.9802	Russia	0.271	-0.9802
Belgium	0.220	-0.4900	Serbia	0.271	-0.9802
Bulgaria	0.271	-0.9802	Slovakia	0.271	-0.9802
Croatia	0.271	-0.9802	Slovenia	0.271	-0.9802
Cyprus	0.271	-0.9802	Spain	0.271	-0.9802
Czech Rep.	0.271	-0.9802	Sweden	0.220	-0.4900
Denmark	0.220	-0.4900	Switzerland	0.271	-0.9802
Estonia	0.271	-0.9802	Turkey	0.271	-0.9802
Finland	0.271	-0.9802	Ukraine	0.271	-0.9802
France	0.271	-0.9802	UK	0.220	-0.4900
Germany	0.271	-0.9802	Canada	0.226	-0.1000
Greece	0.271	-0.9802	USA	0.226	-0.1000
Hungary	0.271	-0.9802	Brazil	0.271	-0.9802
Ireland	0.271	-0.9802	Chile	0.271	-0.9802
Italy	0.271	-0.9802	Rest of Latinam.	0.271	-0.9802
Latvia	0.271	-0.9802	China	0.271	-0.9802
Lithuania	0.271	-0.9802	India	0.271	-0.9802
Luxembourg	0.220	-0.4900	Japan	0.271	-0.9802
Malta	0.271	-0.9802	SE Asia	0.271	-0.9802
Netherlands (NL)	0.220	-0.4900	Oceania	0.271	-0.9802
Norway	0.271	-0.9802	North Africa	0.271	-0.9802
Poland	0.271	-0.9802	South Africa	0.271	-0.9802
Portugal	0.271	-0.9802	RoW	0.271	-0.9802

Appendix M

Exogenous production costs

Country/sub-region	Sawnwood C (US$/m^3)	Sawnwood NC (US$/m^3)	Plywood (US$/m^3)	Particle board (US$/m3)	Fibreboard (US$/m3)	Newsprint (US$/ton)	Printing paper (US$/ton)	Packaging paper (US$/ton)	Househ.&sani (US$/ton)	Chem. pulp (US$/ton)	Recov.paper (US$/ton)
Austria	157,01	269,54	394,36	323,70	448,74	325,78	436,99	778,73	770,67	683,63	132,00
Belarus	87,19	177,21	336,04	211,37	259,31	499,53	769,27	734,01	1162,18	716,00	153,10
Belgium	197,40	334,62	531,96	356,09	391,40	358,12	302,34	200,87	504,16	708,67	115,84
Bulgaria	81,83	190,62	404,59	212,86	265,49	378,89	600,49	535,86	526,15	634,87	148,12
Croatia	106,46	225,65	369,21	241,10	361,07	458,02	862,18	866,67	1182,83	675,77	125,01
Cyprus	120,32	200,53	425,83	217,23	331,70	357,06	694,26	603,97	819,70	639,95	105,08
Czech Rep.	135,18	184,52	475,77	242,09	295,49	373,83	499,37	228,66	664,87	614,21	126,90
Denmark	201,29	356,32	552,64	315,17	367,75	435,03	777,86	618,95	768,76	653,74	123,00
Estonia	163,34	321,80	466,50	195,69	336,19	467,15	864,95	752,40	828,88	643,81	138,62
Finland	168,26	394,45	550,94	328,33	386,08	310,81	759,77	701,61	547,41	667,75	129,00
France	200,21	296,47	373,13	340,90	451,14	339,03	575,09	635,89	871,76	745,73	115,00
Germany	166,14	310,29	468,47	305,29	446,16	315,43	564,92	750,65	773,06	684,88	111,00
Greece	94,03	294,70	457,14	246,62	321,25	319,14	686,55	567,76	635,64	538,73	122,35
Hungary	160,45	252,11	414,40	217,47	302,94	369,95	545,00	573,24	850,00	635,88	147,27
Ireland	129,35	263,64	290,13	239,37	317,82	296,52	643,05	848,49	779,18	609,96	187,59
Italy	116,73	377,62	345,17	293,84	357,38	207,27	482,90	284,25	564,55	879,57	115,00
Latvia	157,82	231,20	327,18	206,27	316,02	486,72	910,66	722,66	1097,45	622,69	132,01
Lithuania	148,91	154,09	365,61	210,43	309,35	455,31	843,04	294,03	508,50	636,69	138,22
Luxemb.	177,08	354,64	466,71	299,36	356,15	379,55	714,94	840,48	1232,67	731,73	112,00
Malta	133,06	211,88	375,21	191,72	311,71	229,88	978,41	713,02	1160,20	548,15	126,00
Netherlands	178,67	279,25	616,02	275,62	379,85	12,56	273,64	230,58	445,41	650,05	113,00
Norway	174,48	373,13	489,50	368,94	457,32	393,98	925,27	614,61	528,05	717,15	136,00
Poland	128,46	267,41	434,66	223,43	283,96	334,97	373,40	657,01	624,75	642,05	133,00
Portugal	136,46	360,63	448,03	309,13	419,10	23,26	424,26	631,41	803,76	653,89	126,00
Romania	167,78	178,11	348,73	200,79	271,21	305,25	564,89	496,33	712,43	707,78	155,32
Russia	54,90	150,10	258,30	196,66	255,11	241,67	229,43	192,30	715,08	636,61	153,00
Serbia	127,98	163,41	469,59	273,22	305,14	345,58	780,47	871,17	1000,67	693,89	150,00
Slovakia	102,29	217,72	375,88	230,07	260,31	314,46	244,84	357,87	627,27	624,07	125,00
Slovenia	129,22	403,56	495,91	256,74	347,90	154,47	430,70	587,52	565,79	627,25	111,41
Spain	145,00	454,01	559,92	313,88	437,43	262,26	497,24	624,28	990,60	719,83	117,00
Sweden	185,52	404,70	574,96	326,76	420,81	417,09	306,17	435,33	550,89	691,24	129,47
Switzerland	132,37	293,93	490,33	274,89	406,18	198,68	653,40	785,69	786,77	647,49	125,00
UK	208,60	369,65	399,92	302,54	413,18	375,62	586,75	759,95	824,74	677,95	112,00
Ukraine	98,83	210,07	384,48	257,12	279,35	434,15	735,78	749,49	1001,78	692,57	151,00
Africa	59,46	173,71	367,79	197,96	209,02	322,46	531,87	497,39	601,92	510,86	159,48
Africa	47,79	220,13	438,93	281,41	285,54	246,23	526,79	368,43	741,18	554,33	121,66
Canada	68,48	297,64	311,26	235,33	353,44	421,90	611,39	611,79	508,73	603,01	133,45
USA	75,39	158,22	346,93	238,42	346,22	209,95	977,58	510,00	712,04	546,75	130,35
Oceania	199,67	78,93	233,08	230,76	358,54	378,82	335,28	180,26	550,96	572,78	156,20
Brazil	96,75	351,41	427,73	258,22	349,66	472,66	369,89	510,98	724,59	398,19	142,81
Chile	143,00	308,55	315,24	186,69	312,17	186,40	54,61	224,61	516,59	474,41	204,15
Rest of Latinam.	53,15	256,25	331,41	291,68	281,80	187,50	341,31	539,79	911,60	367,04	204,25
China	167,33	274,84	360,82	280,52	443,95	189,32	477,71	453,99	728,65	645,00	190,69
India	52,36	13,51	7,54	215,05	549,08	215,43	637,01	719,91	894,51	281,97	200,07
Japan	126,89	291,99	511,73	275,40	556,61	408,84	750,61	577,23	1084,27	537,00	119,70
SE Asia	257,77	198,29	104,02	198,71	315,43	353,34	472,36	400,60	722,84	438,08	190,93
Turkey	61,36	140,59	342,18	185,20	274,87	400,48	586,86	253,85	286,44	693,99	141,49
RoW	143,00	149,60	237,33	177,06	261,85	278,57	58,03	510,00	394,01	471,04	131,09

Appendix N

Transportation costs (US$ per unit)

	Sawnw C	Sawnw NC	Plyw	Part. Board	Fiberboard	Newsprint	P&W paper	Packaging	HH & Sanitary	wood pellets	Sawlogs C	Sawlogs NC	Pulpwood C	Pulpwood NC	Chem.pulp	Recov. paper
Austria	28.00	29.00	22.00	11.00	16.00	31.00	58.00	54.00	70.00	23.00	17.00	17.50	17.00	17.50	48.00	30.00
Belarus	28.00	29.00	22.00	11.00	16.00	25.00	58.00	55.00	71.00	25.00	20.00	21.00	20.00	21.00	48.00	30.00
Belgium	28.00	29.00	22.00	11.00	16.00	25.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Bulgaria	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	23.00	17.00	17.50	17.00	17.50	48.00	30.00
Croatia	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	23.00	17.00	17.50	17.00	17.50	48.00	30.00
Cyprus	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	23.00	17.00	17.50	17.00	17.50	48.00	30.00
Czech Republic	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	23.00	17.00	17.50	17.00	17.50	48.00	30.00
Denmark	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Estonia	28.00	29.00	22.00	11.00	16.00	25.00	58.00	55.00	71.00	21.00	20.00	21.00	20.00	21.00	48.00	30.00
Finland	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
France	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Germany	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Greece	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Hungary	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Ireland	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Italy	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Latvia	28.00	29.00	22.00	11.00	16.00	25.00	58.00	55.00	71.00	21.00	20.00	21.00	20.00	21.00	48.00	30.00
Lithuania	28.00	29.00	22.00	11.00	16.00	25.00	58.00	55.00	71.00	21.00	20.00	21.00	20.00	21.00	48.00	30.00
Luxembourg	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Malta	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Netherlands	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Norway	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Poland	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Portugal	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Romania	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Russia	28.00	29.00	22.00	11.00	16.00	25.00	58.00	55.00	71.00	21.00	20.00	21.00	20.00	21.00	48.00	30.00
Serbia	28.00	29.00	22.00	11.00	16.00	25.00	58.00	55.00	71.00	21.00	20.00	21.00	20.00	21.00	48.00	30.00
Slovakia	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Slovenia	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Spain	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Sweden	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Switzerland	28.00	29.00	22.00	11.00	16.00	25.00	58.00	55.00	71.00	22.00	20.00	21.00	20.00	21.00	48.00	30.00
UK	28.00	30.00	22.00	11.00	16.00	25.00	58.00	50.00	74.00	22.00	20.00	21.00	20.00	21.00	48.00	30.00
Ukraine	28.00	29.00	22.00	11.00	16.00	25.00	58.00	55.00	71.00	21.00	20.00	21.00	20.00	21.00	48.00	30.00
NorAf	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	23.00	17.00	17.50	17.00	17.50	48.00	30.00
SouAf	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	23.00	17.00	17.50	17.00	17.50	48.00	30.00
Canada	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
USA	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
Oceania	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	23.00	17.00	17.50	17.00	17.50	48.00	30.00
Brazil	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.50	17.00	17.50	17.00	17.50	48.00	30.00
Chile	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.50	17.00	17.50	17.00	17.50	48.00	30.00
ReLaAm	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.50	17.00	17.50	17.00	17.50	48.00	30.00
China	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.50	17.00	17.50	17.00	17.50	48.00	30.00
India	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.50	17.00	17.50	17.00	17.50	48.00	30.00
Japan	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.50	17.00	17.50	17.00	17.50	48.00	30.00
SouEastAs	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.50	17.00	17.50	17.00	17.50	48.00	30.00
Turkey	28.00	29.00	22.00	11.00	16.00	31.00	58.00	55.00	71.00	22.00	17.00	17.50	17.00	17.50	48.00	30.00
ReWo	28.00	29.00	22.00	11.00	16.00	25.00	58.00	55.00	71.00	23.00	20.00	21.00	20.00	21.00	48.00	30.00

Appendix O

The code explained

The GFTM currently runs in MatLab, making intensive use of the optimization package of said software. The algorithm used for the optimization is *fmincon-Interior point*. The total number of variables that represent the equilibrium solution of GFTM is 2064, and their starting values are collected in a vector labelled *xjvec.*

The maximization problem is then set as:

fmincon*(*objfun*, sxjvec, Aeq, sbeq, Aineq, sbineq,slb,sub,[],options);*

Since the variance of the vector *xjvec* is extremely high, the problem is first rescaled through standard normalization to facilitate convergence. The vector *sxjvec* is nothing but *xjvec* rescaled*. Objfun* is a function handle to the function to be minimized, namely the opposite of the total welfare. Such function is called *scpwelfareJ* and it is the core of GFTM. The function handle is necessary since *scpwelfareJ* also includes a number of parameters which are not variables for the optimization process.

Aeq is a full rank matrix that deals with all the equilibrium condition presented above. In particular, a preliminary stage consists in transforming equations (4d)-(4g), (4i) so that they can alternatively be written as *Aeq× xjvec=0*, where *Aeq* is precisely the matrix to be constructed. *sbeq* is the vector of *0*s from the equation *Aeq× xjvec=0*, rescaled into *sbeq* in order to take into account of the rescaling of *xjvec*.

Similarly*, Aineq* is a full rank matrix that deals with all the feasibility condition for pellets production (4h). Thus, a preliminary stage consists in transforming equations (4h) so that they can alternatively be written as *Aineq× xjvec≤0*, where *Aineq* is the matrix to be constructed. *sbineq* is the vector of *0*s from the equation *Aineq× xjvec≤0*, rescaled into *sbineq* in order to take into account of the rescaling of *xjvec*.

Finally, *slb* and *sub* are rescaled upper and lower bounds in which inequalities (4a)-(4c) are transformed (eventually integrated by other bounds aimed at speeding up convergence and/or doing additional tests).

Next, we present the function *scpwelfareJ*. As it is customary in MatLab programming, we insert comments directly within the code in green and pre-posing the percentage sign %. The code of this function is presented in Appendix A

```
function
wJ=scpwelfareJ(xjvec,ela_f,ref_q_f,ref_p_f,ela_w,D_ijJ,cinput_l_i,v,phi,alp
ha_w,m,M)

%wJ is the output of the function, namely total welfare

%xjvec is the vector of variables introduced above, that is, quantity
consumed, produced, harvested and traded for all products in all regions

%ela_f is a matrix whose columns –one for each country- are vectors
representing the elasticity of the demand with respect to prices, that is,
vectors with components θ^i_FP in the theoretical formulation presented above

%ref_q_f and ref_p_f are matrices whose columns –one for each country- are
vectors representing respectively reference quantity and reference price
vectors for the consumption function, that is, vectors with components q^0i_FP
and p^0i_FP
```

%D_ijJ is a matrix whose columns –one for each country- are vectors representing average net trade cost vectors, that is, vectors with components the average of T_r^{ij}

%cinput_l_i is a matrix whose columns –one for each country- are vectors representing the cost vector for production, namely a vector with components c^i_{IP}

%phi,v are cost vectors for recovered paper and recovery rate, respectively, that is, vectors with components φ^i_{WP}, φ^i_{NP} and φ^i_{OP}, and g^i_{WP}, g^i_{NP} and g^i_{OP}

%alpha_w is a matrix whose columns –one for each country- are vectors representing the shift parameters in the supply function, that is, vectors with components a^i_{PP} in the theoretical formulation presented above

%ela_w is a matrix whose columns –one for each country- are vectors representing the inverse of the supply elasticity, that is, vectors with components θ^i_{PP} in the theoretical formulation presented above

%m,M are standard variation and mean of xjvec used for the rescaling

```
xJ=[xjvec(1:40,:),xjvec(41:80,:),xjvec(81:120,:),xjvec(121:160,:),xjvec(161
:200,:),xjvec(201:240,:),xjvec(241:280,:),xjvec(281:320,:),xjvec(321:360,:)
,xjvec(361:400,:),xjvec(401:440,:),xjvec(441:480,:),xjvec(481:520,:),xjvec(
521:560,:),xjvec(561:600,:),xjvec(601:640,:),xjvec(641:680,:),xjvec(681:720
,:),xjvec(721:760,:),xjvec(761:800,:),xjvec(801:840,:),xjvec(841:880,:),xjv
ec(881:920,:),xjvec(921:960,:),xjvec(961:1000,:),xjvec(1001:1040,:),xjvec(1
041:1080,:),xjvec(1081:1120,:),xjvec(1121:1160,:),xjvec(1161:1200,:),xjvec(
1201:1240,:),xjvec(1241:1280,:),xjvec(1281:1320,:),xjvec(1321:1360,:),xjvec
(1361:1400,:),xjvec(1401:1440,:),xjvec(1441:1480,:),xjvec(1481:1520,:),xjve
c(1521:1560,:),xjvec(1561:1600,:),xjvec(1601:1640,:),xjvec(1641:1680,:),xjv
ec(1681:1720,:),xjvec(1721:1760,:),xjvec(1761:1800,:),xjvec(1801:1840,:),xj
vec(1841:1880,:),xjvec(1881:1920,:)];

xJpellet=[xjvec(1921:1968,:)';xjvec(1969:2016,:)';xjvec(2017:2064,:)'];

%The vector xjvec is transformed into a matrix of size 40 x 48, one column
for each regions

q_f=[xJ(1:9,:);xJpellet(1,:)];%q_f is a matrix 10 x 48 that gathers
consumption quantities of the 10 final products for the 48 regions.

q_w=xJ(10:13,:);% q_w is a matrix 4 x 48 that gathers harvested quantities
of the 4 primary products for the 48 regions

y_l=[xJ(14:25,:);xJpellet(2,:)];% y_l is a matrix 13 x 48 that gathers
produced quantities of the 13 produced products (10 final products,
pulpwood coniferous and non-coniferous, chemical pulp) for the 48 regions

q_rp=q_f(6:8,:);% q_rp is a matrix 3 x 48 that gathers consumption
quantities of paper products that can be recycled for the 48 regions

e_ijJ=[xJ(26:34,:);xJpellet(3,:);xJ(35:40,:)]; e_ijJ is a matrix 16 x 48
that gathers net trade of the 16 products (10 final products, 4 primary
products, chemical pulp and recovered paper) for the 48 regions

w_d=(ref_p_f./(ela_f.*ref_q_f)).*((((M*q_f+m).*(M*q_f+m))./2)-((1-ela_f).*
ref_q_f.*(M*q_f+m))); %This is the first term of equation (7) above, that
is, the term concerning welfare of final products consumers

w_s=(alpha_w./(1.+ela_w)).*((M*q_w+m).^(1.+ela_w)).*((1/1000000).^ela_w);
%This is the third term of equation (4) above, that is, the term dealing
with welfare of primary products suppliers

cost_industry=cinput_l_i.*(M*y_l+m); %This is the second term of equation
(7) above, that is, total production cost
```

```
cost_paper=v.*phi.*(M*q_rp+m); %This is the fourth term of equation (4) above, that is, total paper recycling cost

trade_cost=D_ijJ.*(M*e_ijJ+m);

w_trader=sum(trade_cost(:));This is the fifth term of equation (4) above, that is, total cost of trade

w1=-(sum(w_d(:))-sum(w_s(:))-sum(cost_industry(:))-sum(cost_paper(:))-
w_trader); %w1 is total welfare

w1=w1*(10^(-15)); %This is a multiplicative scaling aimed at speeding up convergence

wJ=w1;

end
```

The next piece of code needed concerns updating of parameters:

```
ratio=Gt./Gt_1;%Gt and Gt_1 have to be provided by the forest resource model and they are matrices 48x2 containing for each region the undifferentiated (meaning pulpwood and logs undifferentiated) maximum harvestable level for coniferous and non-coniferous in the current period and in the previous one.

ratio=[ratio(:,1),ratio(:,1),ratio(:,2),ratio(:,2)];

ratio=ratio';

denominator=(ratio).^ela_w;

alpha_w0=alpha_w;

alpha_w=alpha_w0./denominator; % this is the updated alpha_w, namely a matrix whose columns –one for each country- are vectors representing the inverse of the supply elasticity, that is vectors with components θ^i_PP in the theoretical formulation presented above

ref_q_f0=ref_q_f;

ref_q_f=ref_q_f0.*(1+elaGDP.*GDP); % this is the updated ref_q_f, namely a matrix whose columns –one for each country- are vectors representing the reference quantity for the consumption function, that is, vectors with components q^0i_FP.

for t=1:48

a=10+(40*(t-1));

b=11+(40*(t-1));

c=12+(40*(t-1));

d=13+(40*(t-1));

ub(a,1)=GTpiu(t,1);

ub(b,1)=GTpiu(t,2);

ub(c,1)=GTpiu(t,3);

ub(d,1)=GTpiu(t,4);

end% GTpiu is a matrix 48x4 containing the new maximum harvestable level (splitted in coniferous sawlogs, non-coniferous sawlogs, coniferous pulpwood, non-coniferous pulpwood). Hence, this part of the code allows setting the maximum harvestable level for each region as constraint for the optimization problem.
```

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