JRC TECHNICAL REPORT

# 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:

$$\sum_i \sum_{FP} \int_0^{q_{FP}^i} D^{-1}\left(q_{FP}^i\right) dq_{FP}^i - p_{FP}^i q_{FP}^i \qquad q_{FP}^i \geq 0, \forall i, FP \qquad (1)$$

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 $\theta^i_{FP}$ 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 $\theta^i_{PP}$ 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 $t$, $\Delta K_{IPt}$, 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 $\Delta Y_{IPt-i}$ 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 $\Delta K_{IPt}$ 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 $\pi^{i}_{IP}$ 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 $\varphi^i_{WP}$, $\varphi^i_{NP}$ and $\varphi^i_{OP}$, 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:

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

## ***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:

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

### *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:

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

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

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 $p_{PP}^{i} = a_{PP}^{i} {q_{PP}^{i}}^{\theta_{PP}^{i}}$, 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 $\theta_{PP}^{i}$, 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.

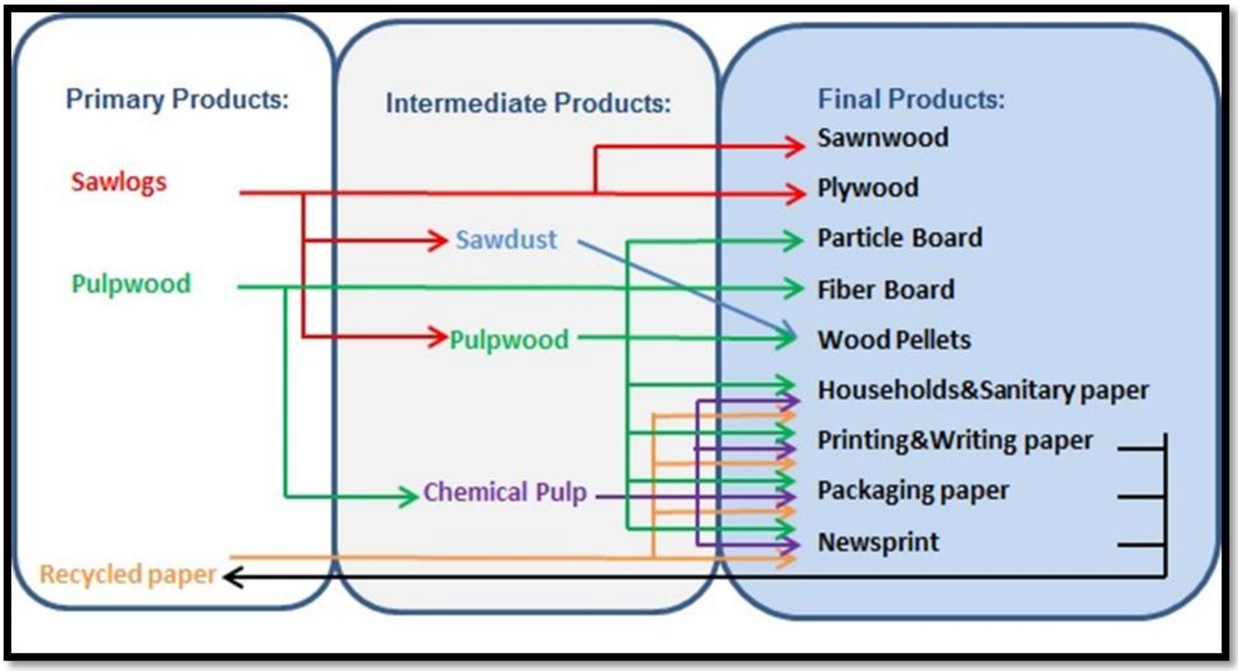


**Figure 1 Industry module of the GFTM**

### 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).

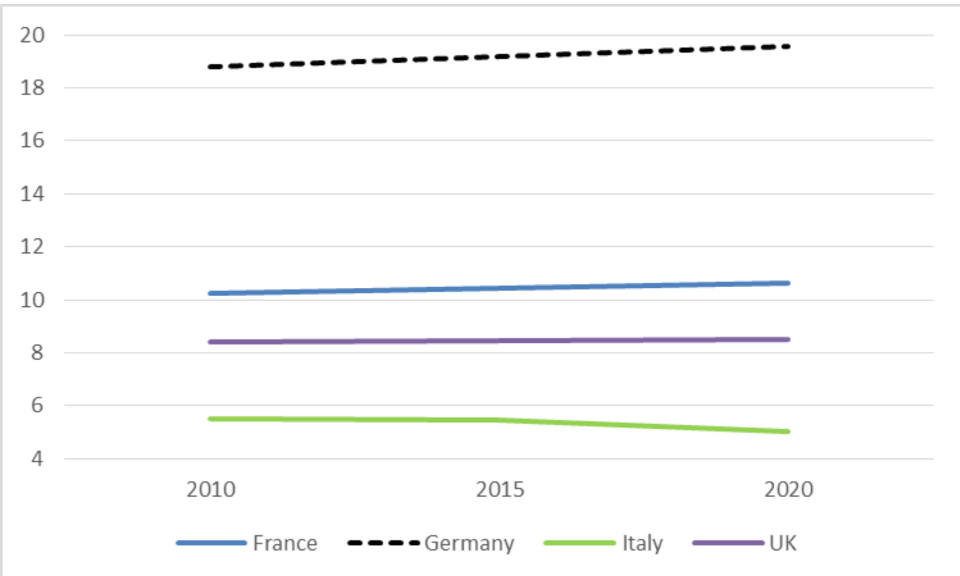


**Figure 2 Projections for coniferous sawnwood consumption (million $m^3$) for the four largest consumers in EU**

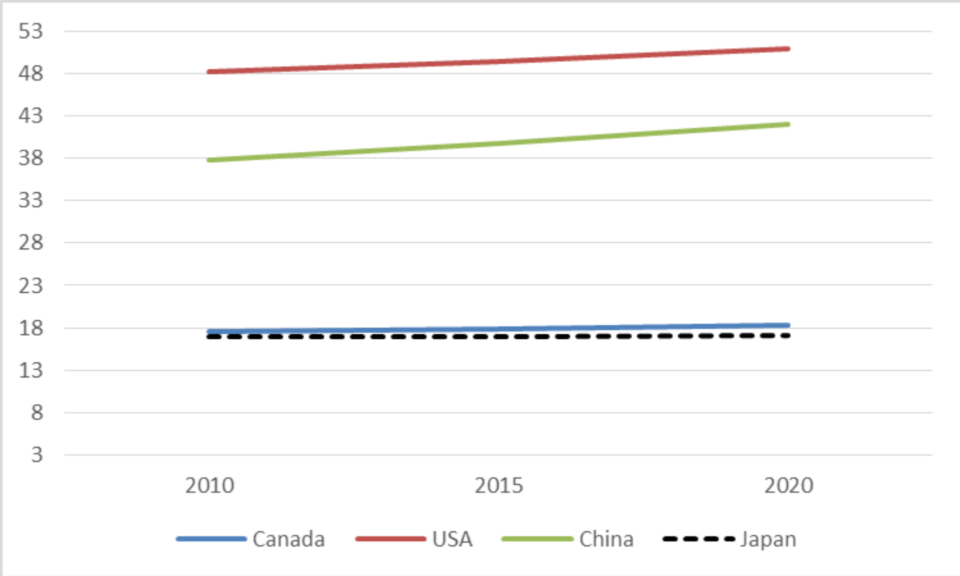


**Figure 3 Projections for coniferous sawnwood consumption (million m$^3$) for the four largest consumers outside EU**

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.

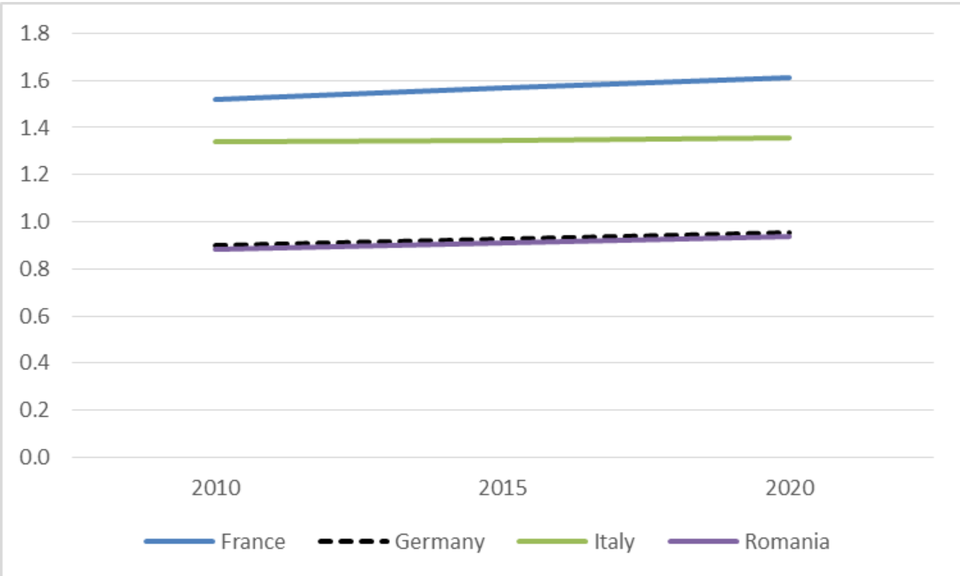


**Figure 4 Projections for non-coniferous sawnwood consumption (million m$^3$) for the four largest consumers in EU**

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.

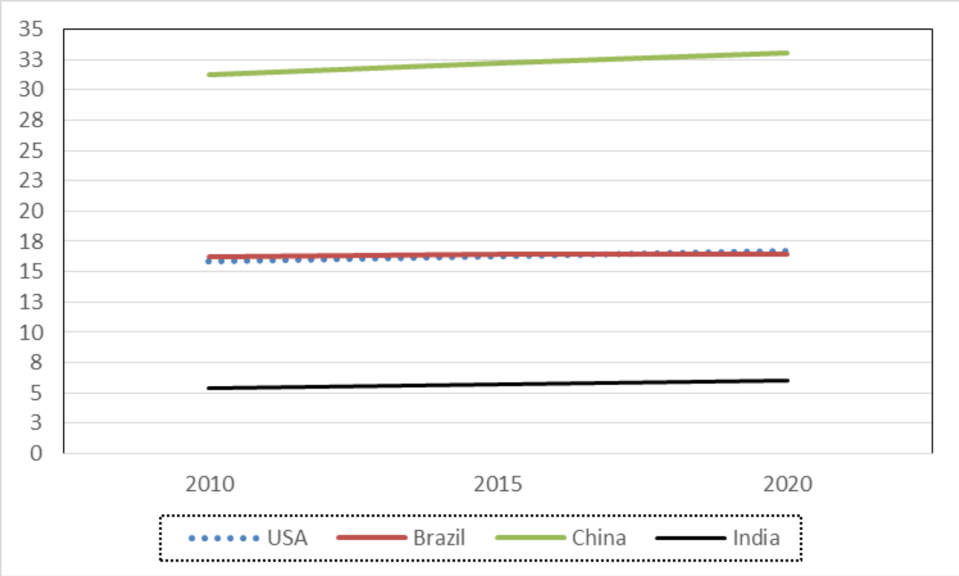


**Figure 5 Projections for non-coniferous sawnwood consumption (million $m^3$) for the four largest consumers outside EU.**

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.

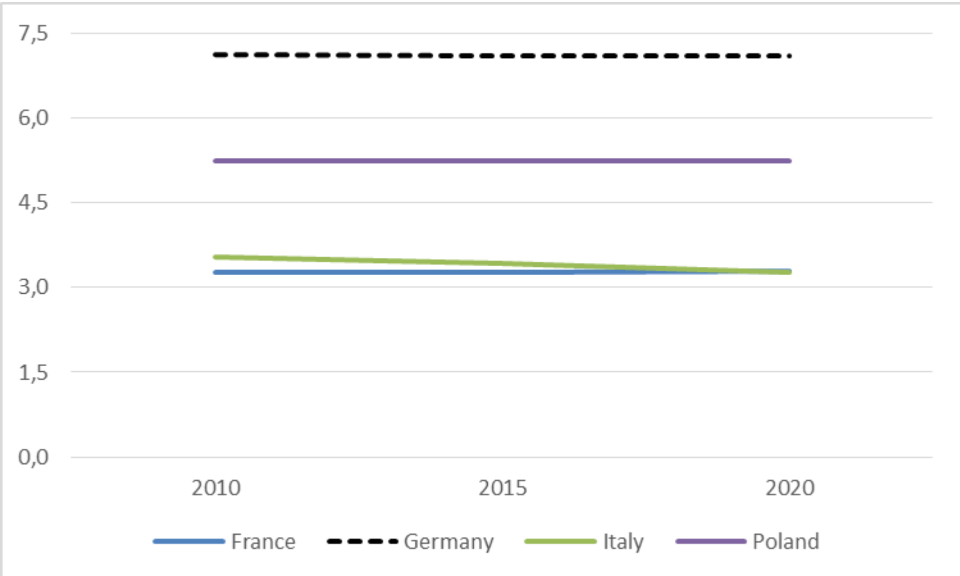


**Figure 6 Projections for particle board consumption (million $m^3$) for the four largest consumers in the EU.**

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.

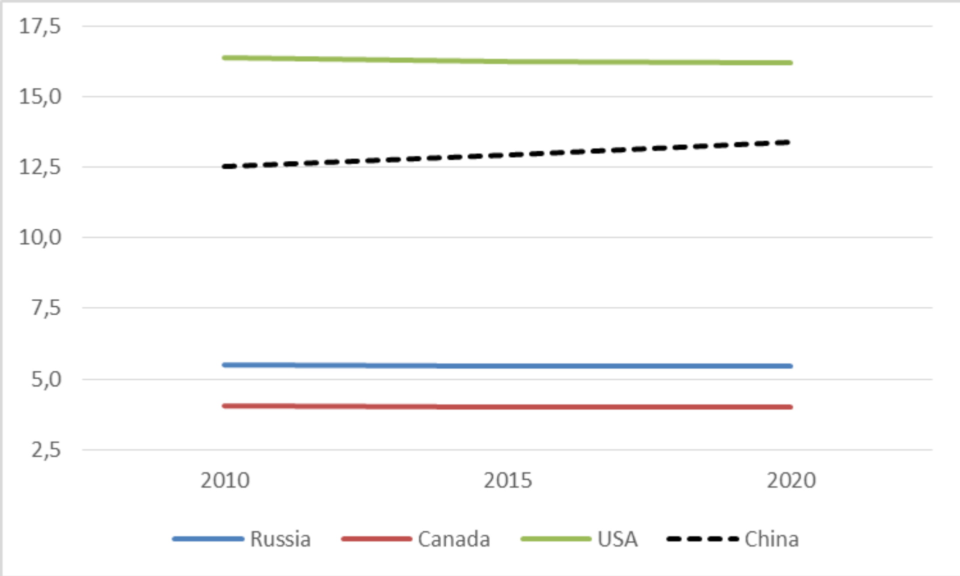


**Figure 7 Projections for particle board consumption (million m$^3$) for the four largest consumers outside EU**

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).

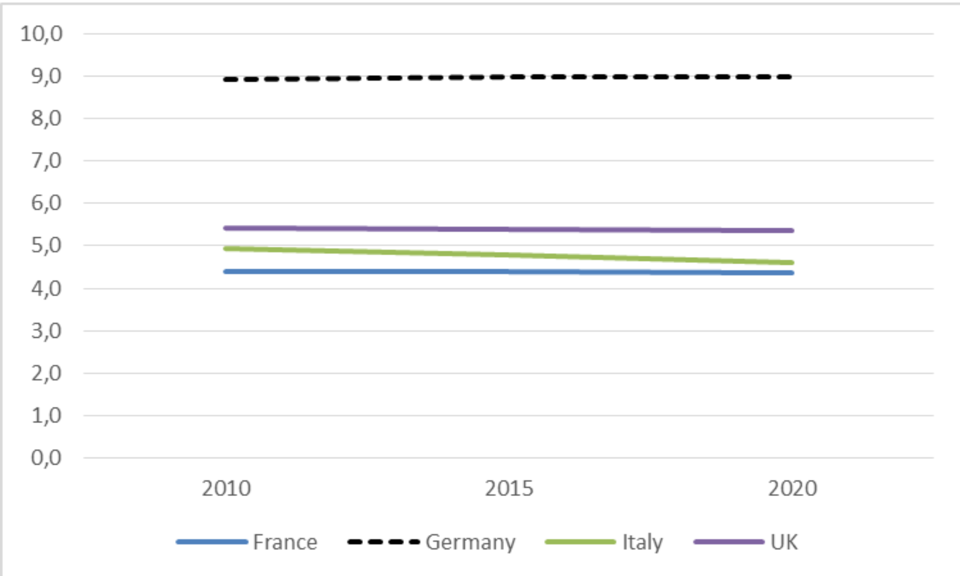


**Figure 8 Projections for graphic paper consumption (million tonnes) for the four largest consumers in EU**

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).

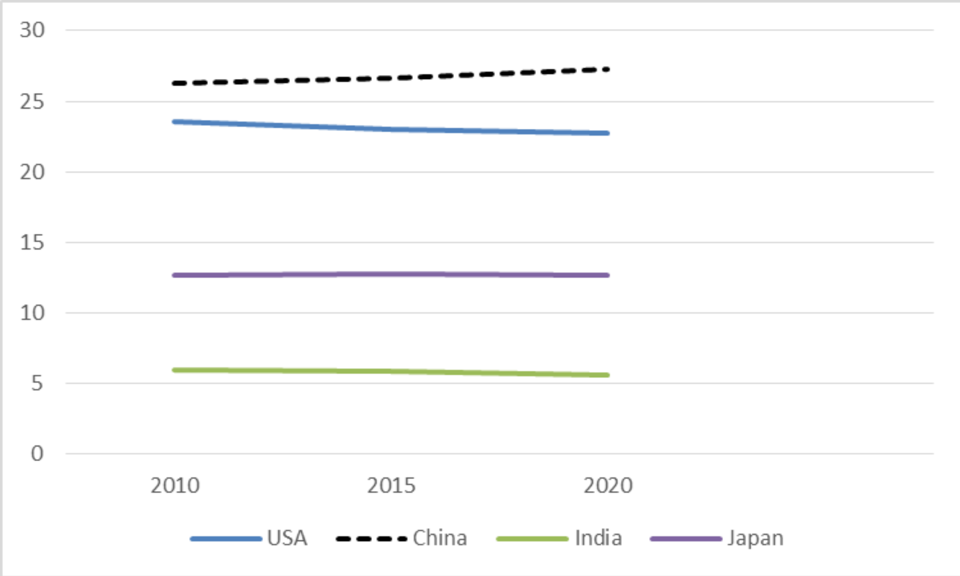


**Figure 9 Projections for graphic paper consumption (million tonnes) for the four largest consumers outside EU.**

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

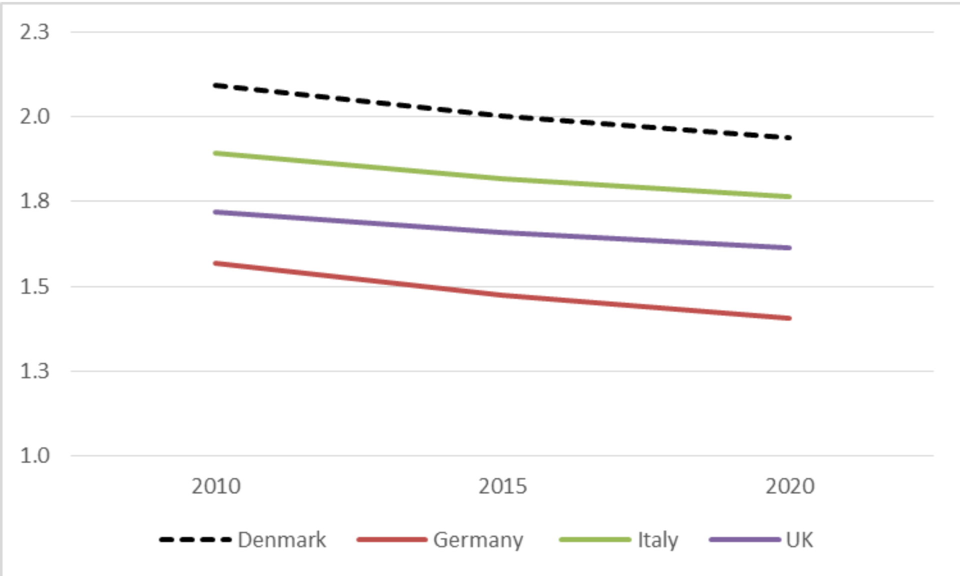


**Figure 10 Projections of wood pellets consumption (million tonnes) for the four largest consumers in EU**

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

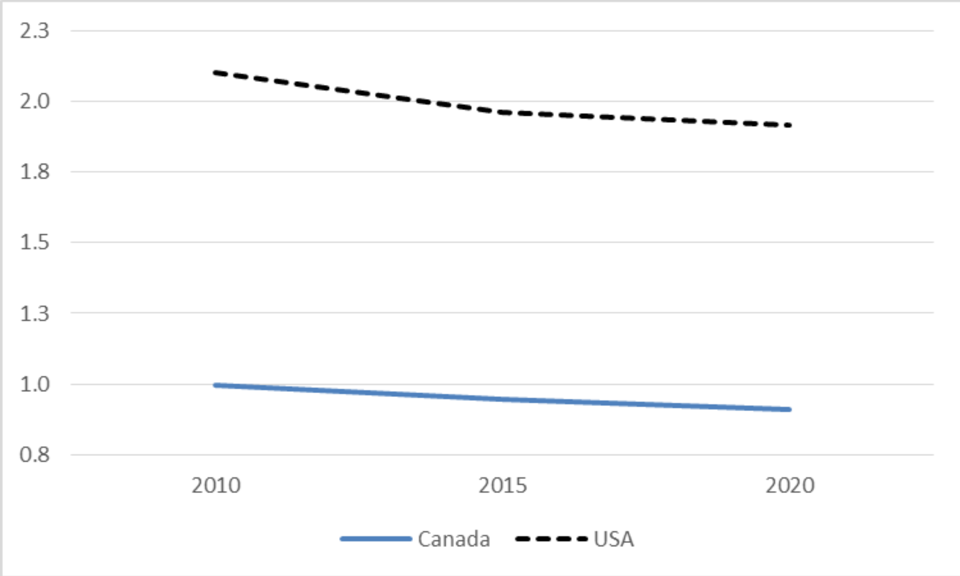


**Figure 11 Projections of wood pellets consumption (million tonnes) for the two largest consumers outside EU**

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).

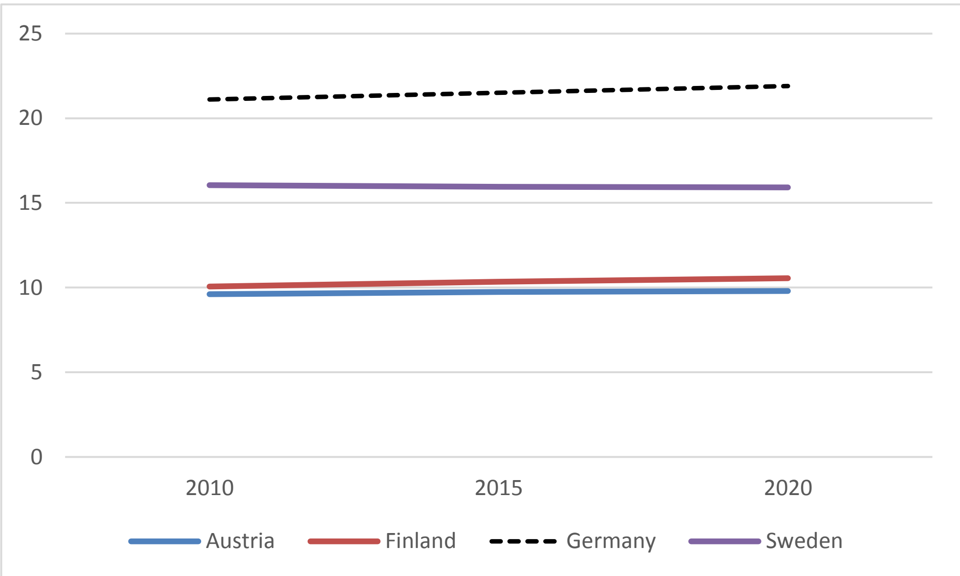


**Figure 12 Production of coniferous sawnwood (million $m^3$) for the four largest producers in EU**

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).

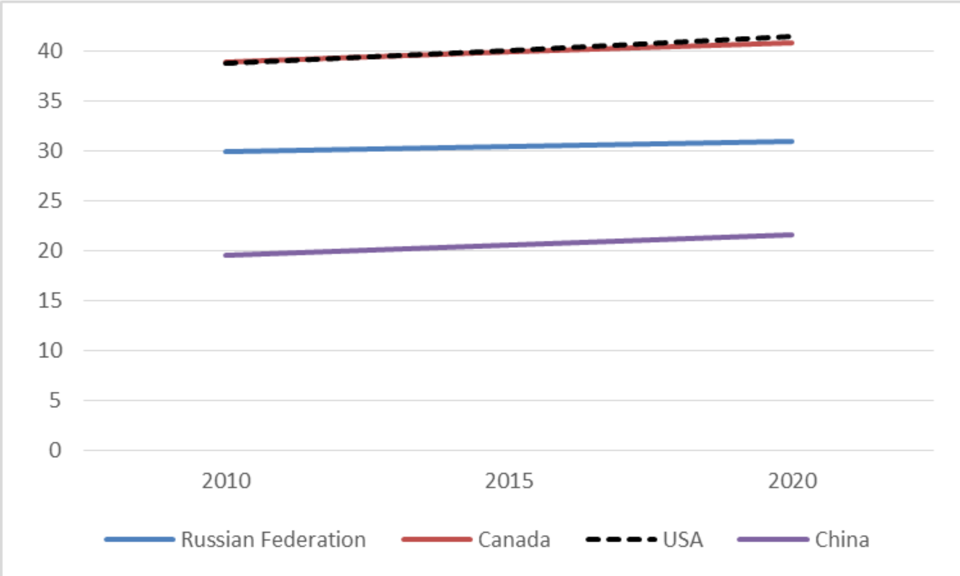


**Figure 13 Production of coniferous sawnwood (million m3) for the four largest producers outside EU**

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).

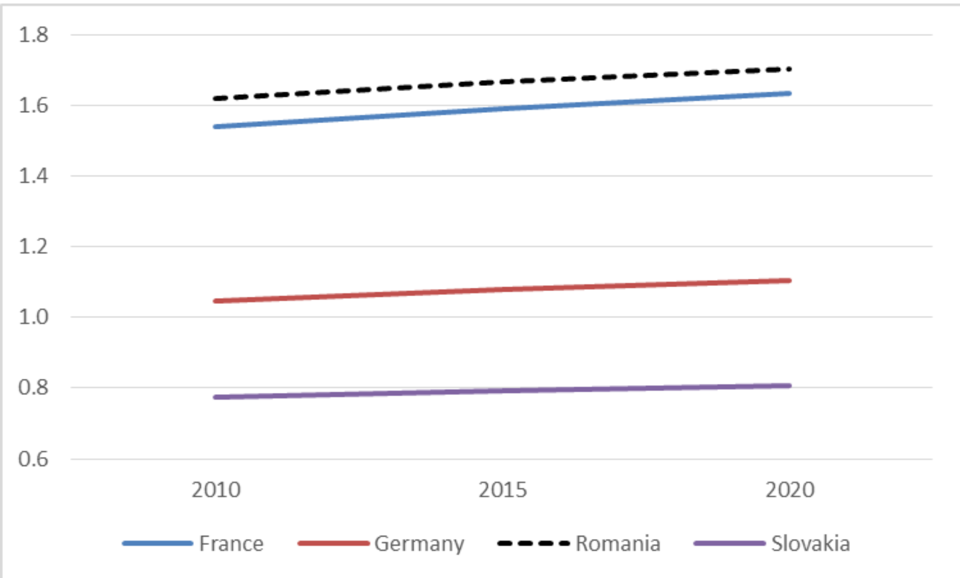


**Figure 14 Production of non-coniferous sawnwood (million m3) for the four largest producers in EU**

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).

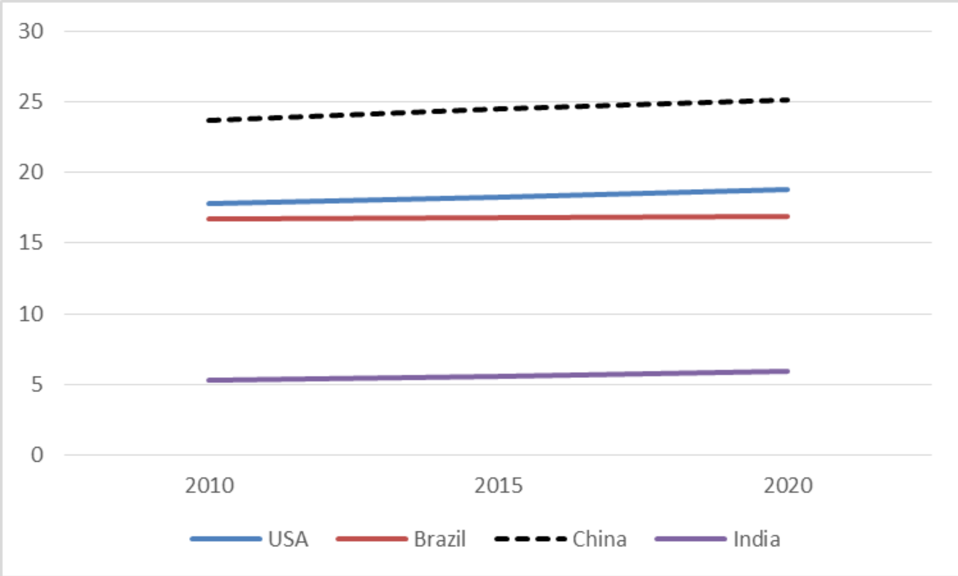


**Figure 15 Production of non-coniferous sawnwood (million m3) for the four largest producers outside EU**

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).

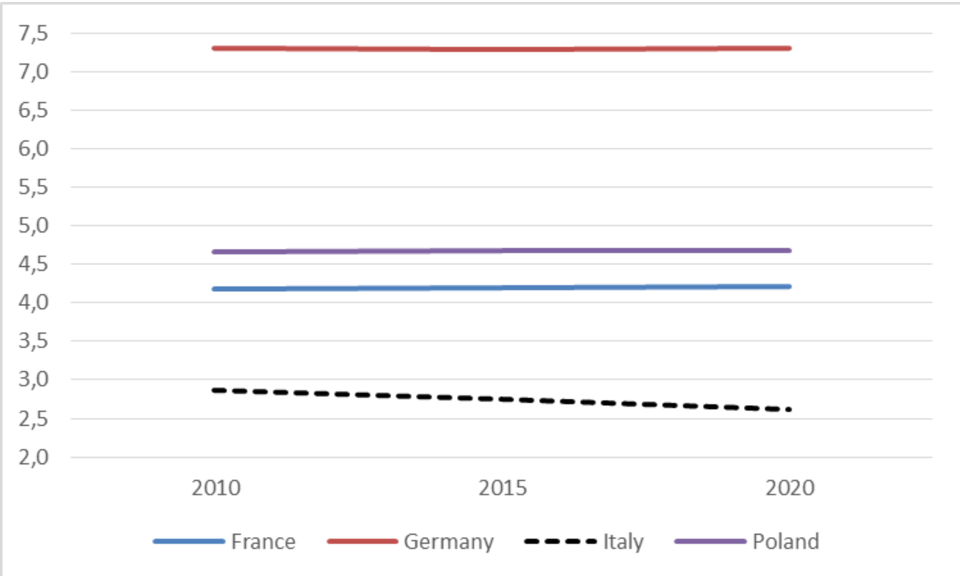


**Figure 16 Production of particle board (million $m^3$) for the four largest producers in EU**

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).

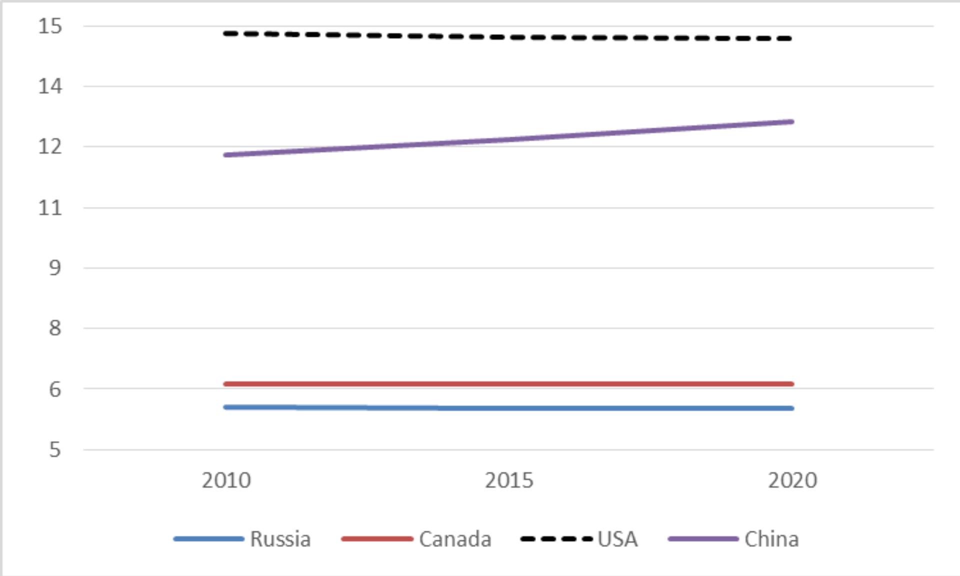


**Figure 17 Production of particle board (million m$^3$) for the four largest producers outside EU**

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).

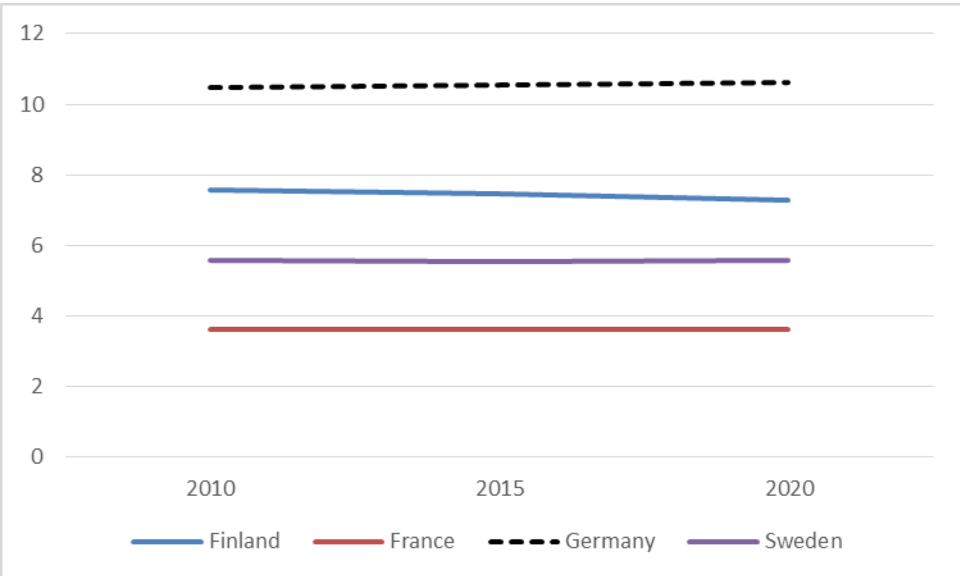


**Figure 18 Production of graphic paper (million tonnes) for the four largest producers in EU**

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).

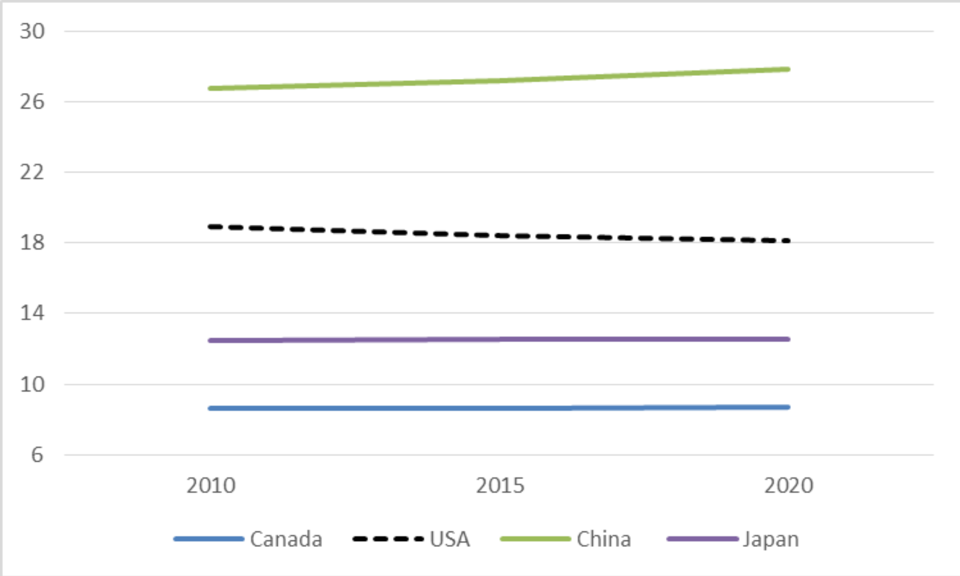


**Figure 19 Production of graphic paper (million tonnes) for the four largest producers outside EU**

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).

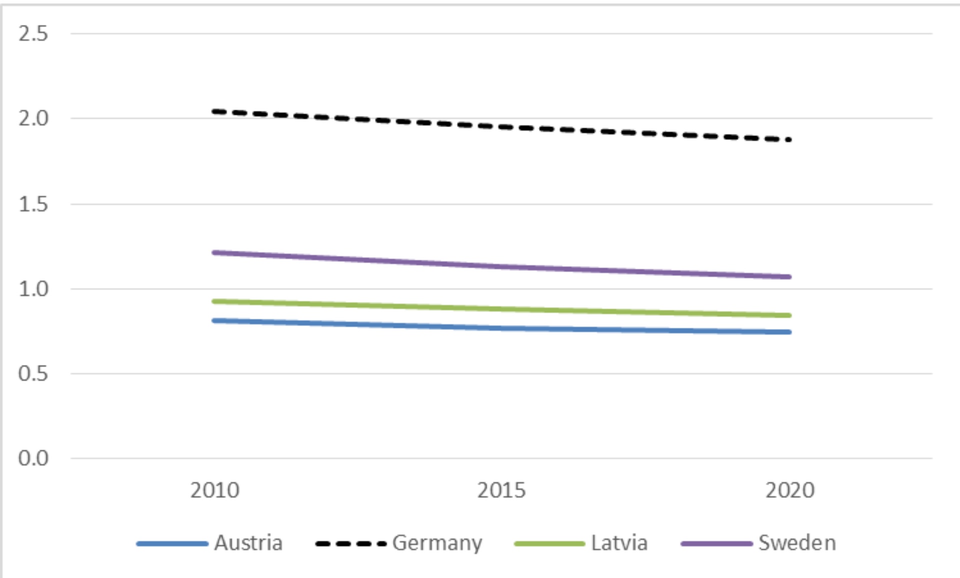


**Figure 20 Production of wood pellets (million tonnes) for the four largest producers in EU**

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).

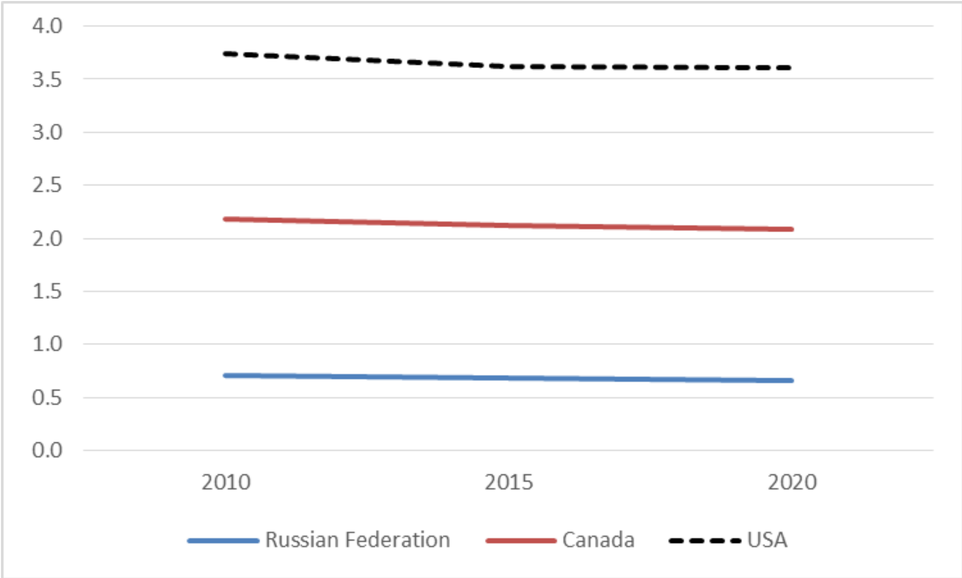


**Figure 21 Production of wood pellets (million tonnes) for the four largest producers outside EU**

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.

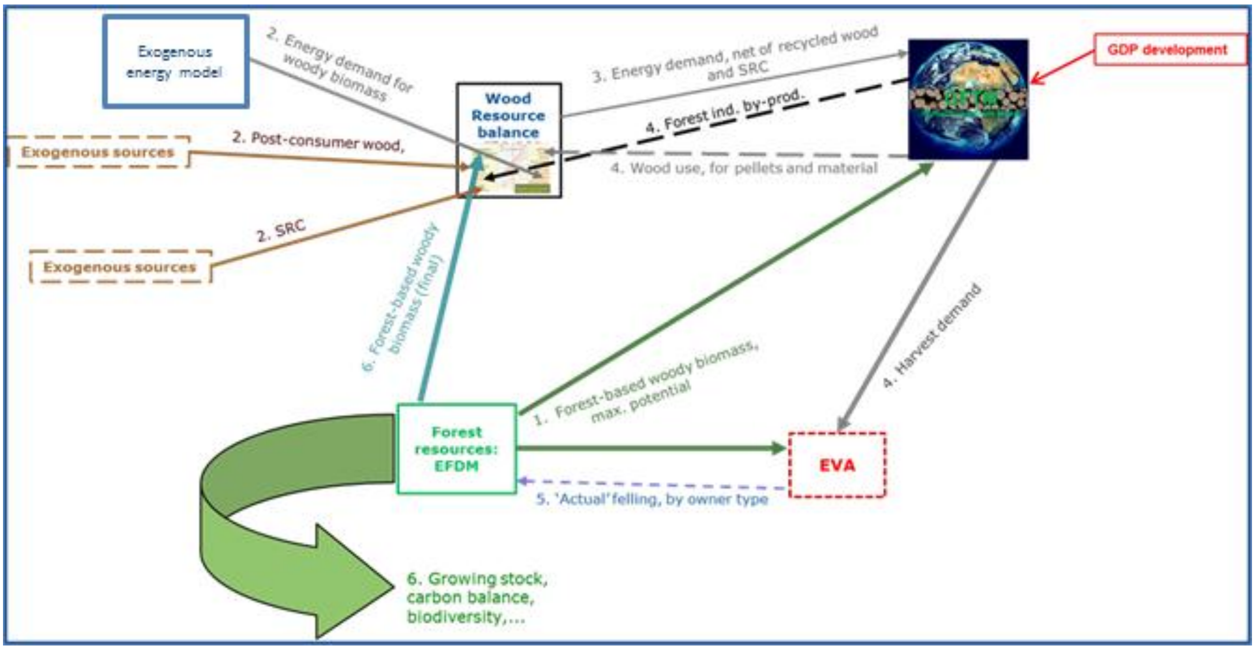

**Figure 22 Suggested forest-based Bioeconomy modelling framework**

## References


- European Commission 2013. *A new EU Forest Strategy: for forests and the forest-based sector*, COM(2013) 659 final, European Union Official Journal C 056 , 26/02/1999 P. 0001 – 0004.
- Fonseca, M. 2010. *Forest product conversion factors for the UNECE region*. Geneva Timber and Forest Discussion Paper 49; UNECE/FAO: Geneva, Switzerland. ISSN 1020 7228.
- Jonsson, R. 2011. Trends and Possible Future Developments in Global Forest-Product Markets—Implications for the Swedish Forest Sector. *Forests* 2, 147-167.
- Jonsson, R. 2012. *Econometric modelling and projections of wood products demand, supply and trade in Europe*. Geneva Timber and Forest Discussion Paper 59; UNECE/FAO: Geneva, Switzerland. ISSN 1020 7228.
- Jonsson R, Whiteman A. 2008. Global forest product projections. Food and Agricultural Organization of the United Nations, Rome, Italy.
- Kurz, W.A., Dymond, C.C., White, T. M., Stinson, G., Shaw, C.H., Rampley, G.J., Smyth, C., Simpson, B.N., Neilson, E.T., Trofymow, J.A., Metsaranta, J., Apps, M.J. 2009. CBM-CFS3: A model of carbon-dynamics in forestry and land-use change implementing IPCC standards. *Ecol. Model*. 220, 480-504.
- Mantau, U. et al. 2010. *EUwood - Real potential for changes in growth and use of EUforests. Final report*. Hamburg/Germany, June 2010.
- M'barek, R., Philippidis, G., Ferrari, E. 2015. Integrated Modelling Platform for Agro-economic Commodity and Policy Analysis. AgriFood2030 - Pathways for the European agriculture and food sector towards 2030. Progress report on the global model approach; Joint Research Centre (JRC), Seville, Spain.
- Packalen, T., Sallnäs, O., Sirkiä, S., Korhonen, K.T., Salminen, O., Vidal, C., Robert, N., Colin, A., Belouard, T., Schadauer, K., Berger, A., Rego, F., Louro, G., Camia, A., Räty, M., San-Miguel, J. 2014. The European Forestry Dynamics Model (EFDM). JRC Scientific and Policy Reports; European Commission Joint Research Centre, Ispra (VA), Italy.
- Rinaldi, F., Jonsson, R., Sallnäs, O., Trubins, R. 2015. Behavioral Modelling in a Decision Support System. *Forests* 6, 311-327.
- Samuelson, P A. 1952. Spatial price equilibrium and linear programming. *American Economic Review* 42, 283-303.
- Sikkema, R., Steiner, M., Junginger, M., Hiegl, W., Hansen, M. T., Faaij, A. 2011. The European wood pellet markets: current status and prospects for 2020. *Biofuels, Bioproducts and Biorefining* 5, 250-278.
- UN 2011. *The European Forest Sector Outlook Study II – 2010-203*. UNECE/FAO: Geneva, Switzerland.

## Internet sources

- AIEL: http://aiel.cia.it/en/
- CARMEN : http://www.carmen-ev.de/
- DEPI: http://www.depi.de/
- DEPV: http://www.depv.de/
- EFI-GTM: http://www.efi.int/files/attachments/publications/ir_15.pdf
- EFSOS II: http://www.unece.org/fileadmin/DAM/timber/publications/sp-28.pdf
- EFDAC: http://forest.jrc.ec.europa.eu/efdac/
- Energimyndigheten: http://www.energimyndigheten.se/
- Eurostat: http://ec.europa.eu/eurostat
- FAOSTAT: http://faostat.fao.org/
- GFPM: http://labs.russell.wisc.edu/buongiorno/welcome/gfpm/
- FRA: http://www.fao.org/forestry/fra/fra2010/en/
- IIASA website: http://www.iiasa.ac.at/
- Pelletsförbundet: http://pelletsforbundet.se/
- SoEF: http://www.unece.org/forests/fr/outputs/soef2011.html
- SVEBIO: https://www.svebio.se/english
- UN COMTRADE: http://comtrade.un.org/

# 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 elasticicities 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 $Aeq \times xjvec=0$, where *Aeq* is precisely the matrix to be constructed. *sbeq* is the vector of *0*s from the equation $Aeq \times xjvec=0$, 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 $Aineq \times xjvec \leq 0$, where *Aineq* is the matrix to be constructed. *sbineq* is the vector of *0*s from the equation $Aineq \times xjvec \leq 0$, 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 Tr^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,:),xjvec(881:920,:),xjvec(921:960,:),xjvec(961:1000,:),xjvec(1001:1040,:),xjvec(1041:1080,:),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,:),xjvec(1521:1560,:),xjvec(1561:1600,:),xjvec(1601:1640,:),xjvec(1641:1680,:),xjvec(1681:1720,:),xjvec(1721:1760,:),xjvec(1761:1800,:),xjvec(1801:1840,:),xjvec(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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