Consumption-Based Accounting for Environmental Impacts of the Russian Wood Industry

by

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Abstract

Russia covers more than a fifth of the world's forest, its wood industry is vital to both global carbon cycling and the Russian economy. In this research, a Mixed-Unit Input-Output (MUIO) model is developed using Russian wood product export data from Food and Agriculture Organization (FAO) and Multi-Regional Input-Output (MRIO) models from the World Input-Output Database (WIOD). The MUIO is applied to develop a consumption-based accounting for nine Russian wood products and associated environmental impacts. Structural Path Analysis (SPA) is then applied to identify important supply chains contributing to the consumption of Russian wood products as well as related environmental impacts.

Results show that the major final consumers of Russian wood products are China, Finland, Japan, Germany, USA, South Korea, Belarus, India and Turkey. The time-series SPA finds the dominant sectors driving the consumption of Russian wood products are Wood and Products of Wood and Cork sectors, Construction sectors, Rubber and Plastics sectors, Pulp, Paper, Printing and Publishing sectors, Agriculture, Hunting, Forestry and Fishing sectors in China, Japan, Belarus, Finland, Turkey and India.

Although USA, developed European countries and South Korea are not important direct consumers of Russian wood industry, they are the major final consumers that ultimately drive the consumption of Russian wood products and associated environmental impacts. It indicates that China, Finland, Belarus, Turkey and India import Russian wood products for producing goods that are finally consumed by developed countries like Western European countries, USA, Japan and South Korea.

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1. Introduction

Forests hold 90% of plant biomass carbon and 80% of soil carbon in terrestrial ecosystems (Landsberg et al., 1997). Annual loss of forests due to disturbance (such as harvesting, conversion, and insects) contributes as much as 20% of total global greenhouse gas (GHG) emission each year. Russia, which covers more than a fifth of the world's forests, is the largest wood production country in the world. In the economic perspective, wood-related industries in Russia worth around 20 billion dollars per year (FAO, 2010). While in the environmental perspective, the carbon storage of Russian forests is estimated to be 35.07 Pg, total annual carbon deposition is estimated to be 213.2 Tg (Isaev et al., 1995; Shvidenko and Nilsson, 2003). Therefore, studying the relationship between global trades and wood production in Russia will help us find the internal cause of Russian wood production consumed by global industry chains ,and lead to a better long term strategy for Russian wood industry in both economic and environmental perspectives (Wilson Rowe, 2013).

The exports of Russian wood products is in rapid growth between 1998 and 2008 (FAO, 2010). According to reports from Food and Agriculture Organization (FAO), China is the largest importer of Russian wood products. China’s huge natural resource demand, environmental pollution ,and energy use have long been criticized by the world (Guan et al., 2009; Lenzen, 2007; Lenzen et al., 2007). In traditional production-based accounting perspectives, China should take the major responsibility to the natural resource consumption and environmental pollution in Russian wood production.

According to life cycle theory (Finnveden et al., 2009), production activities have both direct and indirect economic and environmental effects through supply chains. Consumption-based accounting, which is based on the Multi-Regional Input-Output (MRIO) models, can calculate direct and indirect resource consumption and emission from final consumers (Matthews and Small, 2000; Suh and Huppes, 2002; Suh et al., 2004; Treloar, 1997; Wiedmann, 2009). Consumption-based accounting pointed out that the consumer of the products, rather than manufacturer, should take the major responsibility for the natural resource consumption and environmental pollution in commodity production. (Davis and Caldeira, 2010; Gregg et al.,

2008; Rothman, 1998). Consumption-based accounting is widely used in analyzing economic trades and environmental pressure in global supply chains (Davis and Caldeira, 2010; Davis et al., 2011).

By using consumption-based accounting, the major final consumption countries of Russian wood products can be revealed (Ferrao and Nhambiu, 2009; Lave et al., 1995; Lenzen, 2000; Suh et al., 2004). Furthermore, we can also estimate the influence of global economy on Russian wood industry.

Therefore, the research questions of this study are:

1. Which countries and industries are the most important final consumer and carry major responsibilities of environmental pollution in Russian wood industry?
2. Which countries and industries are the most important downstream supply chains for Russian wood products?
3. How the intermediate and final consumer of Russian wood industry change in the last two decades and what's the new trend?

To answer the research questions, several methods are introduced in this research.

MRIO model is the foundation of this research. However, it's better for analyzing the Russian wood export data in physical transactions rather than economic transactions since the sale price of Russian wood products is different from case to case. The Mixed-Unit Input-Output (MUIO) model can decompose the economic sectors in IO table and deduce the target physical and economic transactions from the original economic transactions in IO table (Hawkins et al., 2006; Liang et al., 2012b; Ming, 2010). MUIO model is widely used in environmental life cycle assessment and material flow analysis (Hawkins et al., 2006; Liang et al., 2013a; Liang et al., 2013b; Liang and Zhang, 2011; Qu et al., 2013; Zhang and Anadon, 2013). In this research, MUIO model is applied to analyze consumption-based accounting of Russian wood products as well as associated environmental impacts in Russian wood industry.

Furthermore, the important intermediate industries in downstream supply chains of Russian wood products are also very important factors. Structural Path Analysis (SPA) is introduced to find out the critical economic and physical flow in economic Input-Output model and social accounting matrix (Defourny, 1984; Roberts, 2005; Sonis and Hewings, 1998). SPA was used to analyze ecosystem network and environmental impact in previous researches as well (Lenzen, 2007; Wood and Lenzen, 2003). In this research, SPA is used to analyze the critical downstream supply chains of Russian wood products around the world.

In this study, MUIO model and SPA are implemented to investigate the intermediate and final consumer of Russian wood products in both economic and environmental perspectives.

2. Data

This research is deeply rooted in using Multi-Regional Input-Output (MRIO) table to construct MUIO model to investigate the consumption based accounting of Russian wood production and its environmental impact as well as finding critical supply chain by Structural Path Analysis. The monetary MRIO tables are from World Input-Output Database (WIOD), which contains national and global economic flow data in sector scale. WIOD database covers 27 EU countries and 13 other major countries in the world for the period from 1995 to 2011.The WIOD MRIO tables are represented in US 1,000 dollar.

The physical and economic transactions data of Russian wood products to the globe are from Food and Agriculture Organization of the United Nations (FAO). The monetary transactions of FAO are represented in US 1,000 dollar and physical transactions are represented in m^3 and tones.

The WIOD database also provides the satellite accounts including industry energy use, CO_2 emissions, land use, materials use and water use. In this research, only CO_2 emissions and energy use are analyzed. The units of energy use is in Tera joules (TJ), units of CO2 emissions are in Kilo tons (K tons).

3. Methodology

3.1 Input-Output Analysis basics

According to Input-Output (IO) theory (Leontief, 1936; Miller and Blair, 2009), let Z = $\{z_{ij}\}_{i,j=1,\cdots n}$ be a $n \times n$ matrix of economic flows from sector i to sector j, and Y = $\{y_i\}_{i,j=1,\cdots n}$ be a $n \times 1$ matrix of the final demand for the output of sector i.

Let X = $\{x_i\}_{i,j=1,\cdots n}$ be a $n \times 1$ matrix of the total output of each sectors, where

$$x_i = z_{i1} + z_{i2} + z_{i3} + \cdots + z_{in} + y_i = \sum_{j=1}^{n} z_{ij} + y_i \quad (1)$$

The entire economy can be presented as a series of n equations

$$x_1 = z_{11} + z_{12} + z_{13} + \cdots + z_{in} + y_1 = \sum_{j=1}^{n} z_{1j} + y_1$$

$$x_2 = z_{21} + z_{22} + z_{23} + \cdots + z_{2n} + y_2 = \sum_{j=1}^{n} z_{2j} + y_2$$

$$\vdots$$

$$x_n = z_{n1} + z_{n2} + z_{n3} + \cdots + z_{nn} + y_n = \sum_{j=1}^{n} z_{nj} + y_n \quad (2)$$

Let A=$\{a_{ij}\}_{i,j=1,\cdots n}$ be a $n \times n$ matrix of inter industry direct requirements from sector i to sector j, it represents how much material are required in sector i to produce one unit of products in sector j. That is

$$a_{ij} = \frac{z_{ij}}{x_j} \quad (3)$$

The equation (1) could be presented as

$$x_i = \frac{z_{i1}}{x_1} x_1 + \frac{z_{i2}}{x_2} x_2 + \frac{z_{i3}}{x_3} x_3 + \cdots + \frac{z_{in}}{x_n} x_1 + y_i \quad (4)$$

Therefore, x_i could be turned to

$$x_i = a_{i1}x_1 + a_{i2}x_2 + a_{i3}x_3 + \cdots + a_{in}x_n + y_i \quad (5)$$

In matrix form, the total output of an economy X is,

$$X = AX + Y, \tag{6}$$

By solving equation (4) the total output X could be obtained by existed directed requirement matrix A and final demand Y:

$$X = LY = (I - A)^{-1}Y, \tag{7}$$

where $L = (I - A)^{-1}$ is called Leontief inverse.

Let R = $\{r_i\}_{\mathrm{i,j=1,\cdots n}}$ be a $n \times 1$ matrix of multiply satellite indicators, E = $\{e_i\}_{\mathrm{i,j=1,\cdots n}}$ be a $n \times 1$ matrix of total impact of each sector (for example, energy use or water use), X $= \{x_i\}_{\mathrm{i,j=1,\cdots n}}$ is the total output of each sector. Then

$$r_i = \frac{e_i}{x_i} \tag{8}$$

The equation (7) could be converted to environmental impacts and factor requirements. As

$$E = RX = R(I - A)^{-1}Y, \tag{9}$$

3.2 MUIO model theory

The general idea of MUIO is to disaggregate sectors presented by monetary flow data into several sectors with physical mass flow data extracted from various data sources (Hawkins et al., 2006). In this way, the total output of disaggregate sectors in physical form could be calculated with existed IO economic flow data.

However, there was an assumption with disaggregating sectors in IO model (Liang et al., 2012a; Weisz and Duchin, 2006), that the products in disaggregated sectors imported and exported to other sectors were the same proportion as its original sector. This assumption is not consistent with reality, which causes error in analysis results.

The disaggregated physical sectors could be expressed as

$$\mathrm{x}_i^p = z_{i1}^p + z_{i2}^p + z_{i3}^p + \cdots + z_{in}^p + y_i^p \tag{10}$$

While the monetary sectors in original IO table are

$$x_i^m = z_{i1}^m + z_{i2}^m + z_{i3}^m + \cdots + z_{in}^m + y_i^m \quad (11)$$

A MUIO could be represented as a m+n-1 equations if we disaggregate one monetary sector into m physical sectors, where n is the original sector number:

$$x_1^p = z_{11}^p + z_{12}^p + z_{13}^p + \cdots + z_{1n}^p + y_1^p \text{ (Physical units)}$$

$$x_2^p = z_{21}^p + z_{12}^p + z_{13}^p + \cdots + z_{1n}^p + y_2^p \text{ (Physical units)}$$

$$\vdots$$

$$x_m^p = z_{m1}^p + z_{m2}^p + z_{m3}^p + \cdots + z_{mn}^p + y_m^p \text{ (Physical units)}$$

$$x_1^m = z_{11}^m + z_{12}^m + z_{13}^m + \cdots + z_{1n}^m + y_1^m \text{ (Monetary unites)}$$

$$x_2^m = z_{21}^m + z_{12}^m + z_{13}^m + \cdots + z_{1n}^m + y_2^m \text{(Monetary unites)}$$

$$\vdots$$

$$x_n^m = z_{n1}^m + z_{n2}^m + z_{n3}^m + \cdots + z_{nn}^m + y_n^m \text{ (Monetary unites)} \quad (12)$$

But when adding a physical flow sector to the equations, the monetary value of the added physical sector should be reduced from the disaggregated monetary sector which this flow previously belonged. This will prevent from double counting the same flow in monetary and physical units within the economy.

The key of building a MUIO model is to construct mixed direct technique coefficient matrix A^* with both physical and monetary terms. The structure A^* is shown in equation (13) and **Table 1**.

$$A^* = \begin{pmatrix} P & C_D \\ C_U & A' \end{pmatrix}, \quad (13)$$

where P is physical transactions, $a_{ij}^P = \frac{Z_{ij}^P}{X_j^P} = \frac{Physical\ output\ of\ sector\ i\ demanded\ by\ sector\ j}{Total\ physical\ output\ of\ sector\ j}$;

C_U is Upstream Requirements, $a_{ij}^U = \frac{Z_{ij}^M}{X_j^P} = \frac{Monetary\ output\ of\ sector\ i\ demanded\ by\ sector\ j}{Total\ physical\ output\ of\ sector\ j}$;

C_D is Downstream Requirements, $a_{ij}^D = \frac{Z_{ij}^P}{X_j^M} = \frac{Physical\ output\ of\ sector\ i\ demanded\ by\ sector\ j}{Total\ monetary\ output\ of\ sector\ j}$;

A' is monetary transactions, $a_{ij}^{A} = \frac{z_{ij}^{P}}{x_{j}^{P}} = \frac{Monetary\ output\ of\ sector\ i\ demanded\ by\ sector\ j}{Total\ monetary\ output\ of\ sector\ j}$.

A' is obtained by subtracting the value of each physical transaction from the sector in the monetary transactions matrix Z, which is used to calculate direct requirements (A).

Table 1. Conceptual structure of MUIO A^* table.

	Intermediate uses		
		Physical sectors	Monetary sectors
Intermediate inputs	Physical sectors	A_{pp} (P)	A_{pm} (C_D)
	Monetary sectors	A_{mp} (C_U)	A_{mm} (A')

Then the life cycle output could be obtained by equation 14-17.

Similar as equation (7), the total output (direct and indirect) of a MUIO model could be calculated as

$$X^* = (\mathrm{I} - A^*)^{-1} Y^*, \tag{14}$$

The total output including direct output and indirect output. The direct output is the products demanded by manufacturing sectors in the first-order of supply chain. The indirect outputs are products demanded by all sectors of the supply chains to provide the initial output demanded by manufacturing.

$$\text{Direct Output} = \mathrm{A}^* * Y^* \tag{15}$$

$$\text{Indirect Output} = (\mathrm{I} - A^*)^{-1} Y^* - A^* * Y^* \tag{16}$$

$$\text{Life cycle resource impacts} = (\mathrm{I} - A^*)^{-1} - I \tag{17}$$

Let R = $\{r_i\}_{\mathrm{i,j=1,\cdots n}}$ be a $\mathrm{n} \times 1$ matrix of multiply satellite indicators. The satellite indicators could be environmental impacts, water, energy and land use as shown in equation (8). Then equation (14) could be converted to impacts of total output driven by the final demand of each

sector. As

$$E^* = R^* X^* = R^*(\mathrm{I} - A^*)^{-1} Y^*, \tag{18}$$

By using equation (14) and (18), the final total output production in physical form of any sector driven by the final demand of each sector and its impacts.

3.3 Structural Path Analysis (SPA)

Structural Path Analysis (SPA) is used to analyze the critical downstream supply chains of Russian wood products around the world.

As in Equation (7), the inverse $(I - A)^{-1}$ could be expanded by Taylor expansion:

$$(I - A)^{-1} = \mathrm{I} + \mathrm{A} + A^2 + A^3 + \cdots + A^n + \cdots \tag{19}$$

As in Equation (8), the impacts could be expanded as

$$E = R(I - A)^{-1} Y = \mathrm{RY} + \mathrm{RAY} + \mathrm{R}A^2 Y + RA^3 Y + \cdots + RA^n Y + \cdots \tag{20}$$

It could be expanded as

$$\mathrm{E} = \sum_{i,j=1}^{n} R_i \left(1 + A_{ij} + \sum_{k=1}^{n} A_{ik} A_{kj} + \sum_{l=1}^{n} \sum_{k=1}^{n} A_{il} A_{lk} A_{kj} + \cdots\right) y_j \tag{21}$$

where the first-order path is $R_i A_{ij} y_j$, it represents the production rate of a path from sector i directly into sector j. The second-order path is $R_i A_{ik} A_{kj} y_j$, it represents the production rate of a path from sector i via sector k into sector j. The third-order path is $R_i A_{il} A_{lk} A_{kj} y_j$, it represents the production rate of a path from sector i via sector l and sector k into sector j, and so forth. Therefore, by searching all the paths in Taylor expansion, the critical paths in both economic and environmental perspectives could be detected.

If there are n sectors in A matrix, there will be n paths for first order, and n^2 paths for second order, and n^m paths for the mth order.

The pseudo-code of downstream SPA in the mth-order is shown in **Box 1**.

Box 1. Pseudo-code of Structural Path Analysis for mth-order

```
For i1 = 1 to n {
    For i2 = 1 to n {
        For i3 = 1 to n {
            …
                For im = 1 to n {
                    Cov = R(ind) ∗ A(ind, i1) ∗ A(i1, i2) ∗ ⋯ ∗ A(i(m − 1), im);
                }
        }
    }
}
```

where,
n is sector number,
m is the mth-order,
A is inter industry direct requirements matrix,
R is the satellite indicators vector,
ind is the index of sector to be analyzed,
Cov is the coverage of the supply chain.

4. Consumption-Based accounting of Russian wood industry by MUIO model

4.1 Data preparation for MUIO model

4.1.1 Dataset Selection in WIOD

WIOD classification is based on UN International Standard Industrial Classification of All Economic Activities (ISIC) Revision 4 (UNSD, 2008). There are unrelated industries in WIOD sectors. For example, Sector 1 of each country includes agriculture, hunting and fishing. Only wood products related parts in Sector 1 is useful to this study. Therefore, further disaggregation in WIOD tables is necessary. After investigation, only Sector 1, 6 and 7 of each country in WIOD are related to wood products. The detailed description for sector division in Sector 1, 6 and 7 of ISIC (Revision 4) are shown in **Table 2-4**.

Table 2. Description of Sector 1 (Division 02 in ISIC): Forestry and logging

Group	Class	Description
21	210	Silviculture and other forestry activities
22	220	Logging
23	230	Gathering of non-wood wood products
24	240	Support services to forestry

Table 3. Description of Sector 6 (Division 16 in ISIC): Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials.

Group	Class	Description
161	1610	Sawmilling and planning of wood
162		Manufacture of products of wood, cork, straw and plaiting materials
	1621	Manufacture of veneer sheets and wood-based panels
	1622	Manufacture of builders' carpentry and joinery
	1623	Manufacture of wooden containers
	1629	Manufacture of other products of wood; manufacture of articles of cork, straw and plaiting materials

Table 4. Description of Sector 7 (Division 17 in ISIC): Manufacture of Paper and Paper products.

Group	Class	Description
	1701	Manufacture of pulp, Paperand paperboard
	1702	Manufacture of corrugated Paperand paperboard and of containers of Paperand paperboard
	1709	Manufacture of other articles of Paperand paperboard

As the sector definition above, a further division of Sector 1, 6 and 7 of Russian wood

products related sectors in WIOD into specified Russian wood product sectors is possible.

4.1.2 Dataset Selection in FAO

In FAO, there are two datasets: **Forestry Production and Trade dataset** and **Forestry Trade Flows dataset**. Forestry Production and Trade dataset is not a good dataset to construct MUIO model since there is no detailed export data to each country. Forestry Trade Flows (FTF) dataset have detailed export data to each country for 9 wood products, it is very useful to construct MUIO model. Therefore, FTF dataset was selected to build MUIO model. The description of 9 Russian wood products from FAO is shown in **Table 5**.

Table 5. Description of 9 Russian wood products from FAO.

Russian Wood product	Description
Chips and Particles	Wood that has been deliberately reduced to small pieces from wood in the rough or from industrial residues, suitable for pulping, for particle board and fibreboard production, for fuelwood or for other purposes.
Roundwood (C)	The commodities included are sawlogs or veneer logs, pulpwood, and other industrial roundwood. (C) means products are from coniferous trees.
Roundwood (NC)	(NC) means products are from non-coniferous trees.
Particle Board	A sheet material manufactured from small pieces of wood or other ligno-cellulosic materials agglomerated by use of an organic binder together with one or more of the following agents: heat, pressure, humidity, a catalyst, etc.
Plywood	Plywood, veneer plywood, core plywood including veneered wood, blockboard, laminboard and battenboard.
Sawnwood (C)	Sawnwood, unplaned, planed, grooved, tongued, etc., sawn lengthwise, or produced by a profile-chipping process (e.g. planks, beams, joists, boards, rafters, scantlings, laths, boxboards, "lumber", sleepers, etc.) and planed wood which may also be finger jointed, tongued or grooved, chamfered, rabbeted, V-jointed, beaded, etc. (C) means products are from coniferous trees.
Sawnwood (NC)	(NC) means products are from non-coniferous trees.
Veneer Sheets	Thin sheets of wood of uniform thickness, rotary cut, sliced or sawn, for use in plywood, laminated construction, furniture, veneer containers, etc.
Newsprint	Uncoated paper, unsized (or only slightly sized), containing at least 60% (percentage of fibrous content) mechanical wood pulp, usually weighing not less than 40 g/square m and generally not more than 60 g/square m of the type used mainly for the printing of newspapers.

According to the sector division of FAO FTF dataset, the most proper way to incorporate FAO FTF and WIOD dataset is to add those 9 wood products as physical sectors into MUIO model and subtract the total monetary value of those 9 added wood products sectors from their original sectors in Russia. The physical and monetary export data structure of 9 wood products in FTF dataset and its relationship with WIOD is shown in **Table 6**.

Table 6. The associated sectors between FAO FTF and WIOD dataset.

Items	Associated sector in WIOD		
	Sector Name in ISIC	Sector # in WIOD	Description
Chips and Particles	Sector 6	1161	Wood and products of wood and cork
Roundwood (C)	Sector 1	1156	Agriculture, hunting, forestry and fishing
Roundwood (NC)	Sector 1	1156	Agriculture, hunting, forestry and fishing
Particle Board	Sector 6	1161	Wood and products of wood and cork
Plywood	Sector 6	1161	Wood and products of wood and cork
Sawnwood (C)	Sector 6	1161	Wood and products of wood and cork
Sawnwood (NC)	Sector 6	1161	Wood and products of wood and cork
Veneer Sheets	Sector 6	1161	Wood and products of wood and cork
Newsprint	Sector 7	1162	Pulp, paper, Paperproducts, printing and publishing

4.2 Building MUIO model

FAO FTF dataset contains export data to around 120 countries for 9 wood products. WIOD dataset includes detailed import/export data for the most important 40 countries with 35 sectors for each country. WIOD aggregate the rest of countries as one Rest Of World (ROW) region with 35 sectors. Therefore, we must incorporate the total export data to each country in FAO with the detailed sectoral import/export data in WIOD.

To incorporate FTF dataset to WIOD dataset in order to add new industry rows and columns in WIOD IO table, the total export to all countries in FTF dataset, should be split to export data to sectors of all countries. Since there is no detailed data of wood import/export data in sector scale, an assumption must be made, that the wood import and export distribution of each added Russian wood product sectors is the same as disaggregated wood related sectors in WIOD IO table.

The sector disaggregation process is introduced in the following steps, the matlab code is shown in **Appendix 4**:

Step 1. Find associated data for same countries between FAO and WIOD.

a) The FAO wood export data must be transferred to WIOD data structure.

b) Find Russian wood related sectors in WIOD.

The Russian wood related sectors are sector "Agriculture, hunting, forestry and fishing", "Wood and products of wood and cork" and "Pulp, paper, Paperproducts, printing and publishing". The sector numbers of those related sectors in WIOD are 1156, 1161, 1162.

Step 2. Calculate Russia Wood export data to sectors of each country in WIOD.

The data in FAO FTF dataset contains 9 wood products total export data to around 120 countries. Let us call those countries with detailed data in FAO as **Recorded Country**. The rest countries could be called **Unrecorded Country**. We can also infer the export data to Unrecorded Country by allocating the total export to Unrecorded Country according to the export proportion to each country in sector 1156, 1161 and 1162 of WIOD dataset, then the specified Russia Wood export data to sector scale could be obtained.

a) Copy wood product export data FAO dataset to Recorded Country in WIOD IO table.

b) Find the wood products total export to Unrecorded Country.

There are three sectors in FAO stands for the Unrecorded Country, "Unspecified", "Sudan (former)" and "Others (adjustment)". The sum of them would be the total export of Unknown country.

c) Split the wood product total export data to sectors of Unrecorded Country according to export proportion for each Unrecorded Country in sectors 1156, 1161 and 1162 of WIOD dataset.

The split dataset should be the WIOD economic flow data. Split Equation is,

$$w_i = \frac{\sum_j z_{i,j} + \sum_j y_{i,j}}{\sum_i \sum_j z_{i,j} + \sum_i \sum_j y_{i,j}} * W \quad (22)$$

where,

w_i is wood product export to Unrecorded country i in physical or monetary form,

$Z_{i,j}$ is economic flow in WIOD IO table from associated wood product sector to **industry** sector j of Unrecorded Country i,

$Y_{i,j}$ is economic flow in WIOD IO table from wood product to **final demand** sector j of Unrecorded Country i,

W is the total wood export to Unrecorded Country.

Step 3. Split Russia wood export to industry and final demand sectors of each country.

a) Load the total export data to each country of wood related sectors.

b) Split wood product export to industry and final demand sectors of each country in WIOD in monetary and physical form by the same proportion export data in wood product related sectors in WIOD. The split equation is:

$$Z^*_{ij,k,export} = \frac{Z_{ij,k}}{X_k} * w_{i,k} \quad (23)$$

where,

$Z^*_{ij,k,export}$ is the Russian wood product i's export to industry or final demand sector j of country k in physical or monetary form,

$w_{i,k}$ is the total Russian wood product i's export to country k in physical or monetary form,

$Z_{ij,k}$ is the monetary export from Russian wood product related sector i to industry and final demand sector j of country k,

X_k is the total monetary export to country k,

There are 9 wood products sectors to be added into MUIO model, as shown in **Table 6**. The split Russian wood exports are obtained by multiplying the proportion of Russian wood product related sector in WIOD IO table. For example, Chips and Particles sector is obtained by multiplying the proportion of sector 1156.

The split Russian wood sectors should be obtained in both monetary and physical form. Physical form is the sectors to be added to the MUIO table. The monetary form is mean to be reduced after adding physical sectors to avoid double counting in IO table.

c) Divide Russian wood export rows into industry parts and final demand parts

The Russian wood export includes exports to industry sectors of all countries and exports to final demand sectors of all countries. The industry sectors part is used to construct the MUIO model A^* matrix, the final demand part is used to construct new Y matrix.

Step 4. **Building $\mathbf{A}^*$ matrix**.

a) Add physical Russian wood export to IO table as new physical sector.

Add physical Russian wood sector's rows as the top 9 rows in IO table to form MUIO $\mathbf{A}^*$ matrix. Calculate import of physical Russian wood sectors from other sectors of all countries as physical Russian wood sector's columns. Adding physical Russian wood product sector's columns as the top 9 columns.

$$Z^*_{ij,import} = A_{ij} * X_i, \tag{24}$$

where,

$Z^*_{ij,import}$ is the import data from industry sector i to Russian wood product related sector j in physical form,

A_{ij} is technique coefficient of associated rows in original industry by industry IO table,

X_i is total output of Russian wood sector i.

Leave the first 9 by 9 fields of added rows and columns as zeros, since there is no import or export relationship among Russian wood products.

b) Subtract the monetary total export of Russian wood sector's from Russian wood related sectors (sectors 1156, 1161 and 1162 in WIOD A matrix) to avoid double counting.

c) Calculate the new final demand matrix Y^* for the MUIO model

The industry by industry Z matrix of WIOD dataset is a 1435×1435 matrix. After inserting

Russian wood physical sectors, the MUIO table (Z^*) is a 1444×1444 matrix. Sine Y^* includes 5 final demand sectors for each country or region, Y^* is a 1444×205 matrix. Therefore, the total output matrix X^* of each sector is also a 1444×205 vector.

Step 5. Calculate the total life-cycle consumption.

After constructing MUIO $\boldsymbol{A}^*$ matrix, the total life-cycle consumption of Russian wood products by sectors of each country could be calculated by equation (14).

The first 9 rows of X^* is the total export result. X_{ij}^* represents the total export from sector i to final demand sector j of all countries in both direct and indirect form. For the added Russian wood physical sectors, it could be interpreted as the total production of Russian wood product i caused by the final demand sector j in one country in direct and indirect form.

4.3 Consumption-based Accounting of Russian wood industry

After obtaining the MUIO model, the influence of final demand sectors around the world to Russia wood products could be obtained. The analysis results are discussed below.

4.3.1 Major Consumer Countries

Finding the major final consumer countries of Russian wood products is critical to Russian forestry industry. Taking the most recent data in 2011 as example, the main Russian wood products consumption countries are China, Finland, France, Italy, Japan, Germany, UK, USA, South Korea, India, Sweden, and Turkey. The top five consumption countries are shown in **Table 7**. The full analysis result is shown in **Appendix 1** and **Appendix 2**.

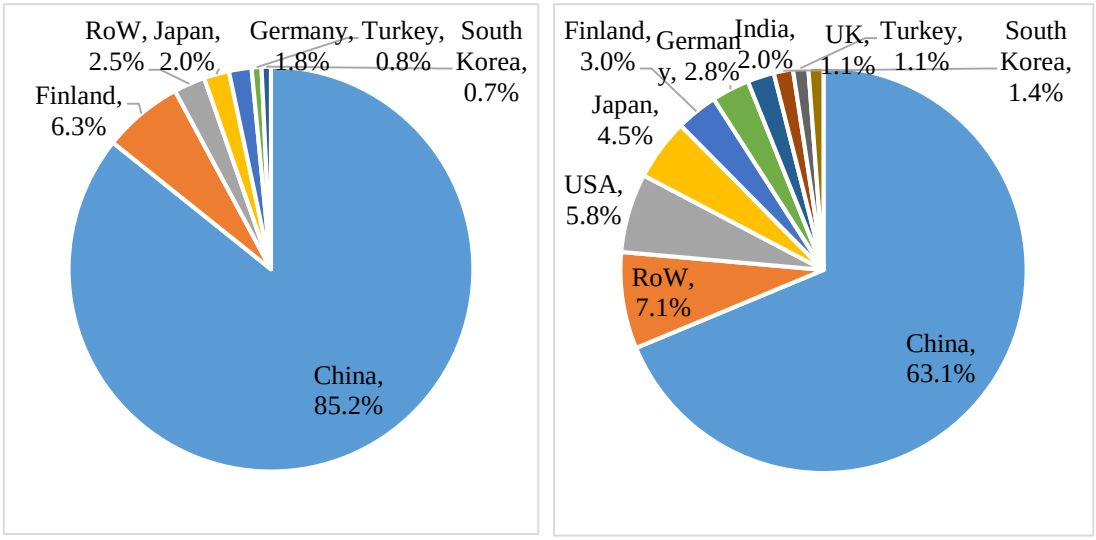
USA, with little wood products direct import from Russian, is a major final consumer of Russian wood products. China and Finland, as the major direct importer of Russian wood products, consumed much less than its direct import.

Roundwood is the most important exported wood product. The other wood products are products or byproducts of roundwood. Therefore, the consumption change of roundwood is critical to Russian forestry industry. Take Roundwood (C) and Roundwood (NC) as example,

the direct import and final consumption countries of Roundwood (C) and Roundwood (NC) in 2011 are compared in **Figure 1 and Figure 2**.

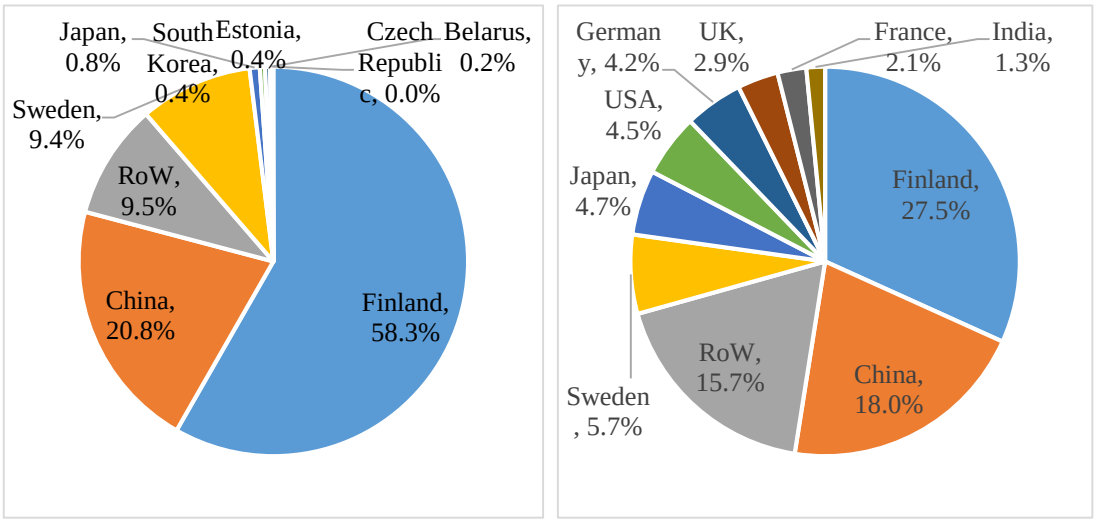
Table 7. Top five consumption countries of Russian wood products in 2011.

Rank	1	2	3	4	5
Chips and Particles	Finland 71.1%	China 6.1%	Japan 3.0%	Germany 2.00%	Sweden 1.9%
Roundwood (C)	China 63.1%	USA 5.8%	Japan 4.5%	Finland 3.0%	Germany 2.8%
Roundwood (NC)	Finland 27.5%	China 18.0%	Sweden 5.7%	Japan 4.7%	USA 4.5%
Particle Board	Belarus 14.0%	China 11.1%	South Korea 9.6%	USA 4.1%	India 3.3%
Plywood	USA 15.2%	Germany 11.9%	UK 6.6%	Turkey 6.0%	Italy 3.8%
Sawnwood (C)	China 27.0%	Japan 6.3%	USA 4.1%	Germany 3.3%	India 3.0%
Sawnwood (NC)	China 69.6%	USA 4.9%	India 2.6%	Japan 2.6%	Germany 1.6%
Veneer Sheets	Japan 63.0%	China 9.5%	USA 2.3%	Italy 1.6%	Finland 1.2%
Newsprint	India 16.7%	Turkey 10.1%	Germany 7.4%	China 4.4%	UK 4.1%



(a) Direct import (b) Final consumption

Figure 1. Direct import and Final consumption of Roundwood (C) in 2011.



(a) Direct import (b) Final consumption

Figure 2. Direct import and Final consumption of Roundwood (NC) in 2011.

The results show around 22.1% of Russian Roundwood (C) exported to China are used to make products that serves developed countries like USA, Japan and European countries. China is still the largest final consumer of Russian Roundwood (C) due to its rapid development and high population. Around 20.8% of Russian Roundwood (NC) exported to Finland are also used to make products that serves developed countries.

4.3.2 Time Series Analysis of consumer change to Russian wood industries

Consumption of wood products is highly influenced by economy. Time series analysis of Russian wood products consumption change around the world will reveal economy and policy change in the world as well as the future consumption trend of Russian wood products. The time series analysis results of 9 Russian wood products are discussed in the following chapter. Roundwood is the most important exported wood product. The other wood products are products or byproducts of roundwood. Therefore, the consumption change of roundwood is critical to Russian forestry industry.

4.3.2.1 Roundwood (C)

Roundwood (C) consumption amount and percentage by top consumption countries are shown in **Figure 3** and **Figure 4**. The global consumption of roundwood (C) is generally increasing, although cyclical economic crisis, like in 2001 and 2008, decrease global Roundwood consumption. China has continuous growth for Roundwood (C) consumption since 1997 and still increasing. Japan used to be the largest consumer of Roundwood (C), but its dependence on Russian Roundwood (C) is continuously decreasing. It's probably because of Japan's strict Paper recycle policy. Final consumptions of Roundwood (C) by USA and major European countries are stable. It indicates developed countries, as final consumer, are important to Russian wood industry.

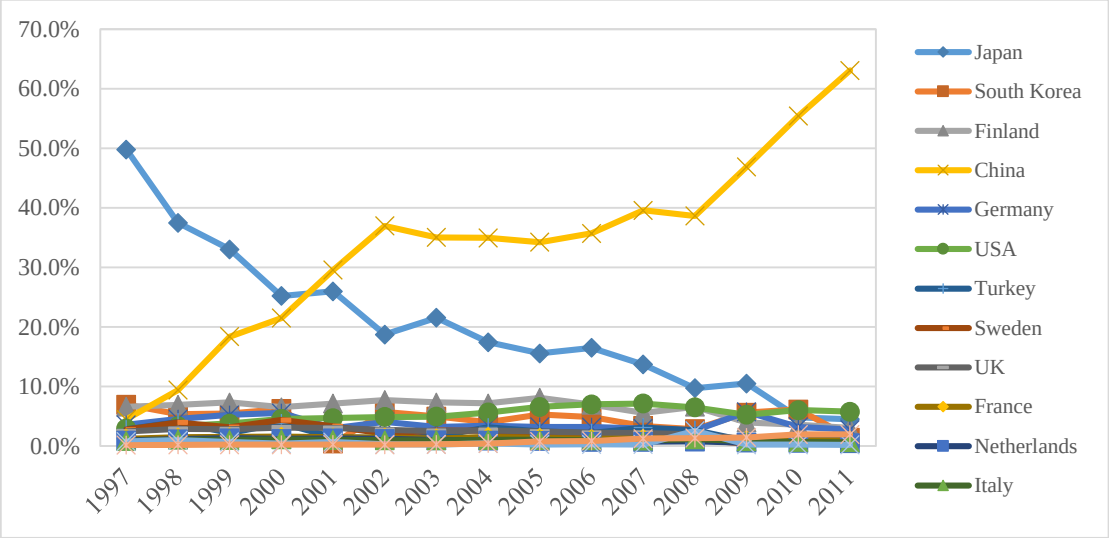


Figure 3. Roundwood (C) consumption percentage by major countries in 1997 - 2011

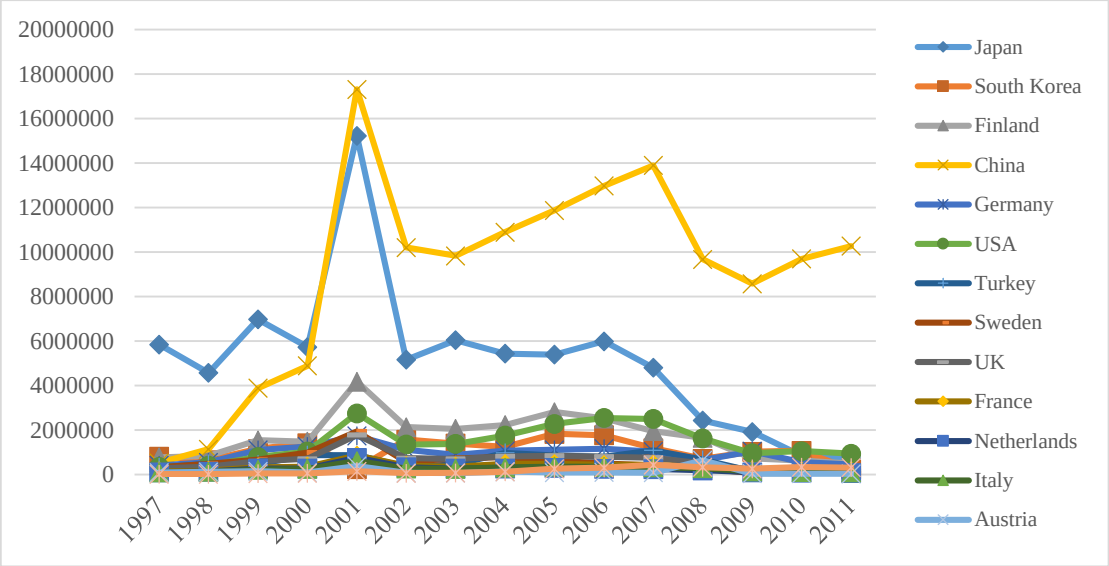


Figure 4. Roundwood (C) consumption amount by major countries in 1997 - 2011 (m^3)

4.3.2.2 Roundwood (NC)

Roundwood (NC) consumption amount and percentage by top consumption countries are shown in **Figure 5** and **Figure 6**. The global consumption of Russian roundwood (NC) was increasing from 1997-2006 then decreasing since then. Finland is the largest consumer of Roundwood (NC) throughout 1997-2011. China's consumption is generally increasing. Japan's consumption is generally decreasing after 2001. Final consumption of Roundwood (NC) by USA and major European countries are generally decreasing.

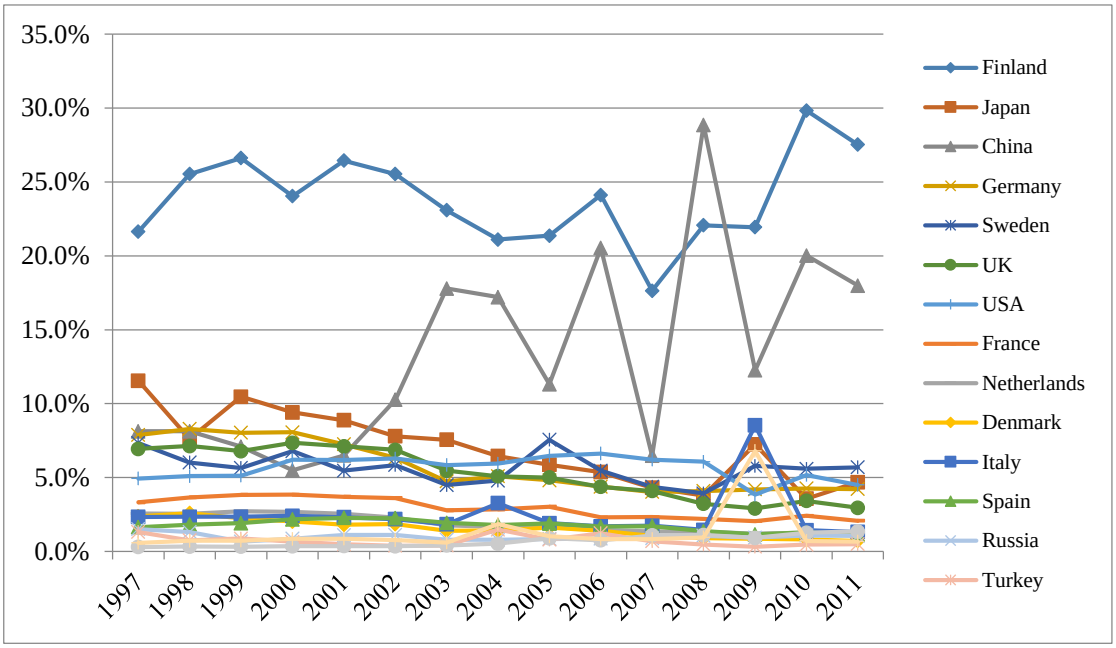


Figure 5. Roundwood (NC) consumption percentage by major countries in 1997 - 2011

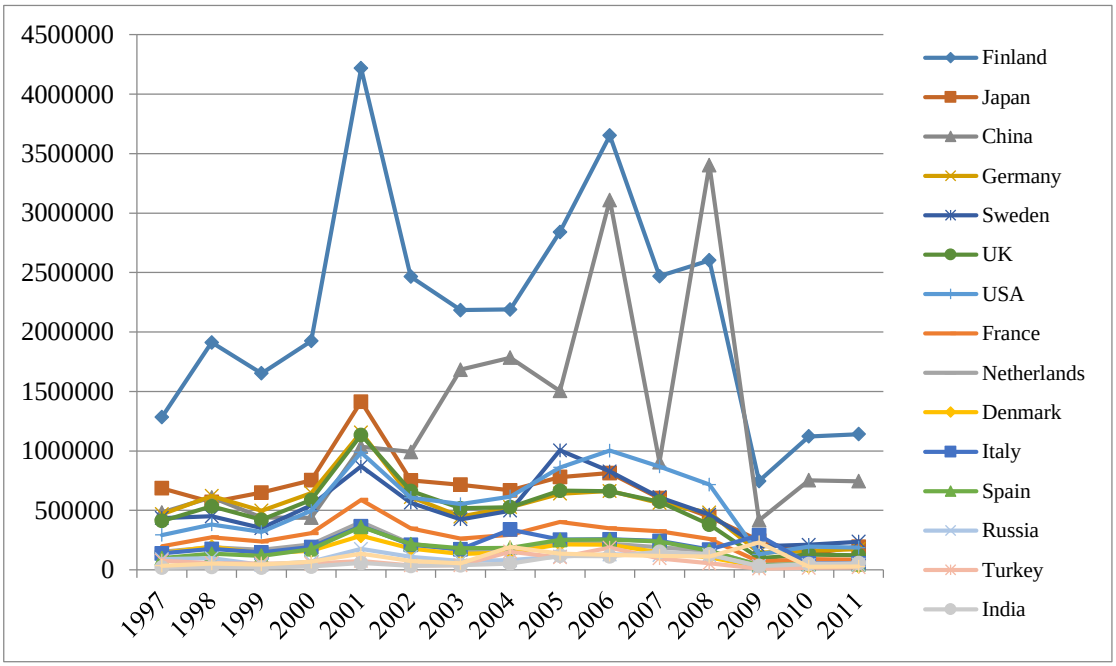


Figure 6. Roundwood (NC) consumption amount by major countries in 1997 - 2011 (m^3)

4.3.2.3 Chips and Particles

Chips and Particles consumption amount and percentage by top consumption countries are shown in **Figure 7** and **Figure 8**. Chips and Particles are byproducts of Roundwood. With roundwood production increase, the export of Chips and Particles are also rising. Finland is the largest final consumer of Russian Chips and Particles and its consumption is still rising. Japan was a big final consumer of Chips and Particles, but its consumption amount generally stays still.

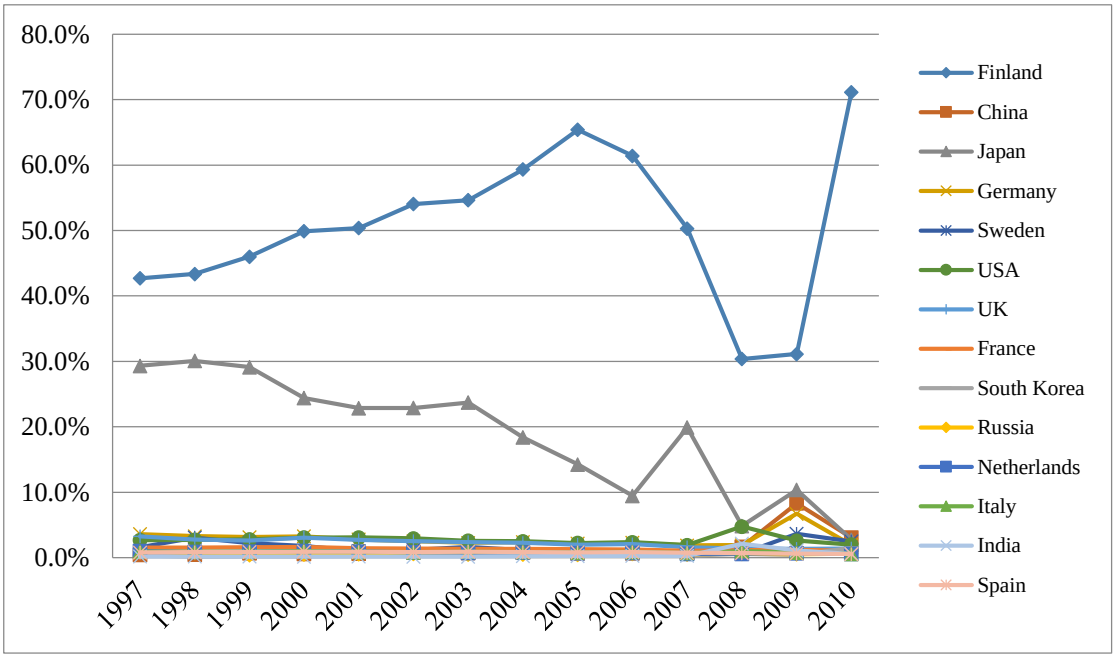


Figure 7. Chips and Particles consumption percentage by major countries in 1997 - 2011

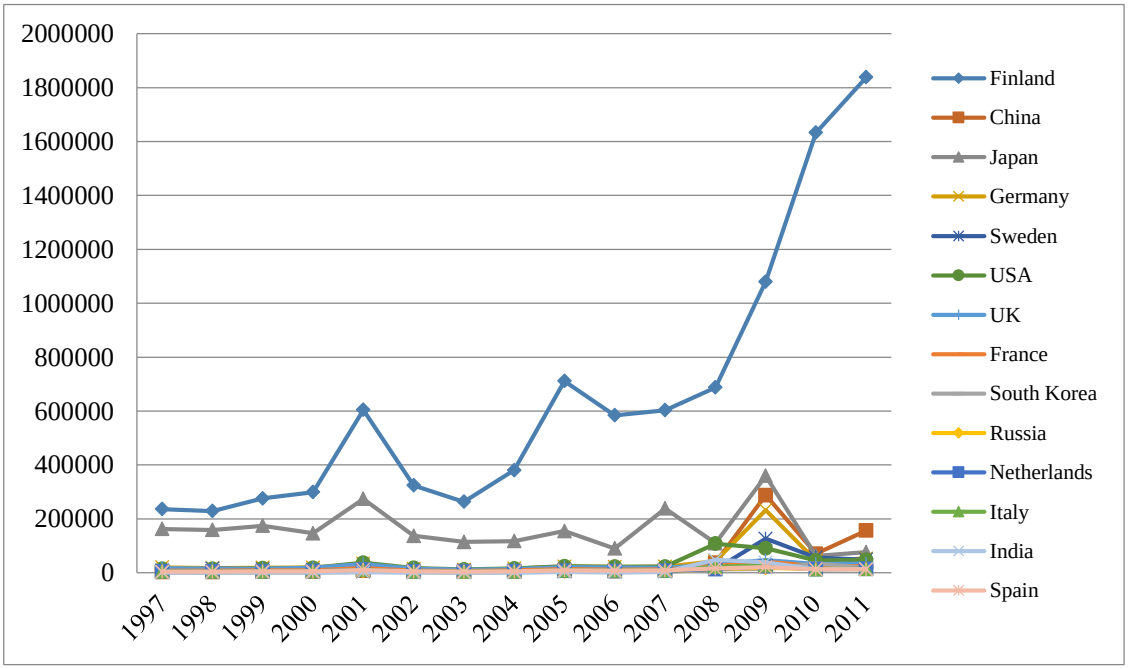


Figure 8. Chips and Particles consumption amount by major countries in 1997 - 2011 (m^3)

4.3.2.4 Particle Board

Particle Board consumption amount and percentage by top consumption countries are shown in **Figure 9** and **Figure 10**. The global consumption of Russian Particle Board is generally constant. Surprisingly, USA is a big final consumer of Particle Board. Belarus suddenly became the largest consumer in 1999-2001 and 2008-2011. The role of China and India is significantly increased since 2008. It's probably because of their big investment on infrastructure and construction. With their rapid economy growth, China and India may play more important role in Russian Particle Board consumption. South Korea also has a sudden increase in 2011. It also could be more important to Russian Particle Board industry in the future.

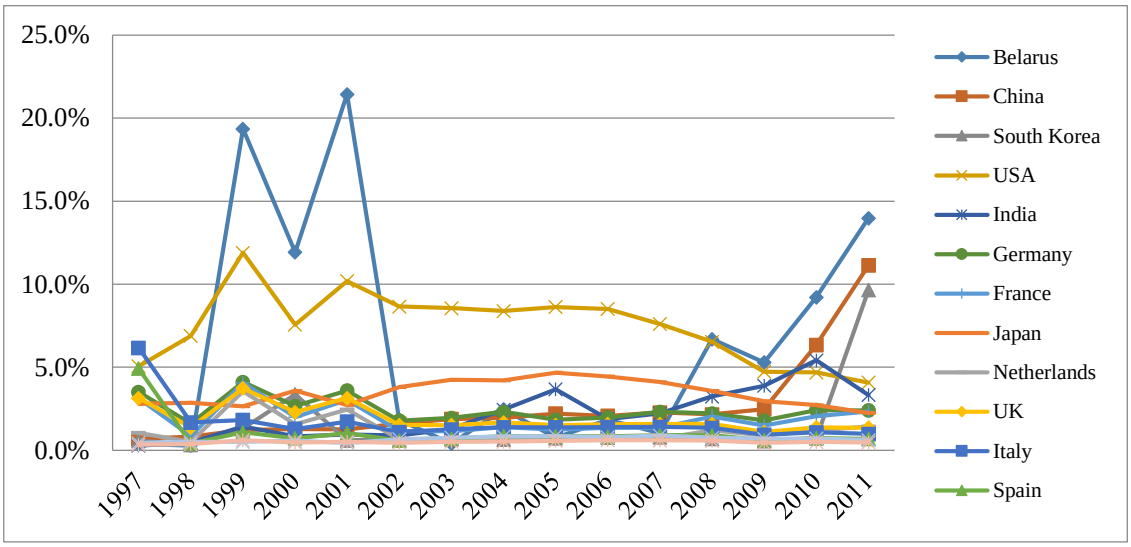


Figure 9. Particle Board consumption percentage by major countries in 1997 - 2011

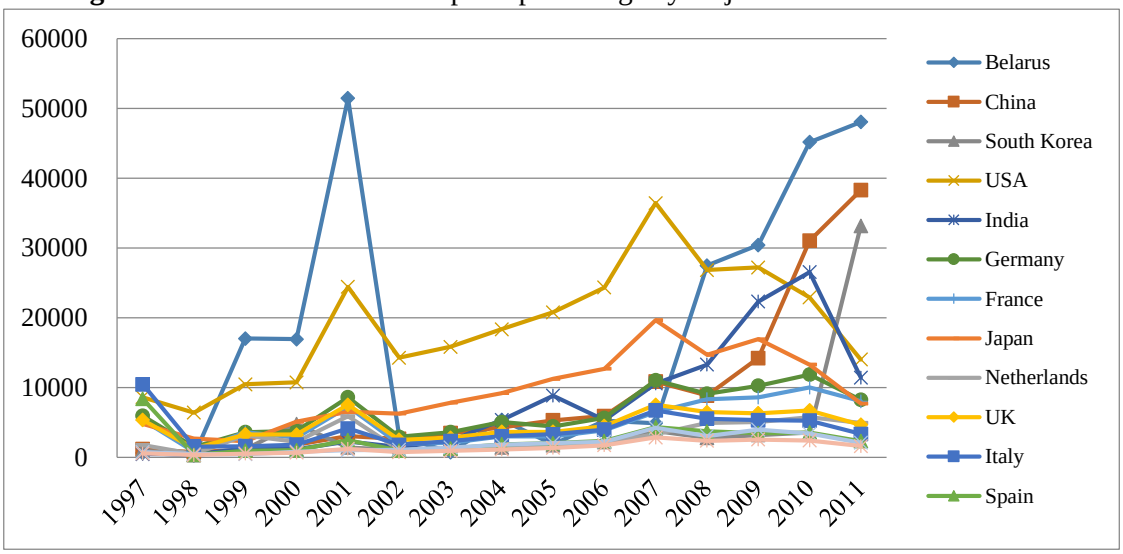


Figure 10. Particle Board consumption amount by major countries in 1997 - 2011 (m^3)

4.3.2.5 Plywood

Russian Plywood consumption amount and percentage by top consumption countries are shown in **Figure 11** and **Figure 12**. The global consumption of Russian Plywood is generally constant. USA is the largest final consumer of Plywood. Developed European countries are important consumers to Russian Plywood industry. Although China is an important consumer of Plywood, its role is relatively small compare to its role in other Russian wood products.

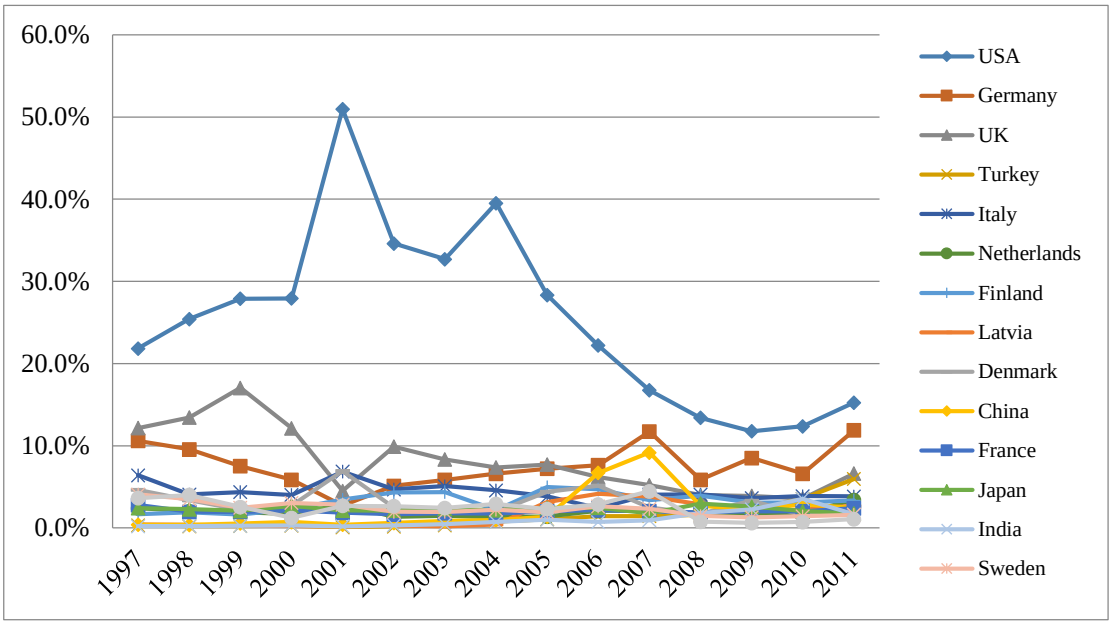


Figure 11. Plywood consumption percentage by major countries in 1997 - 2011

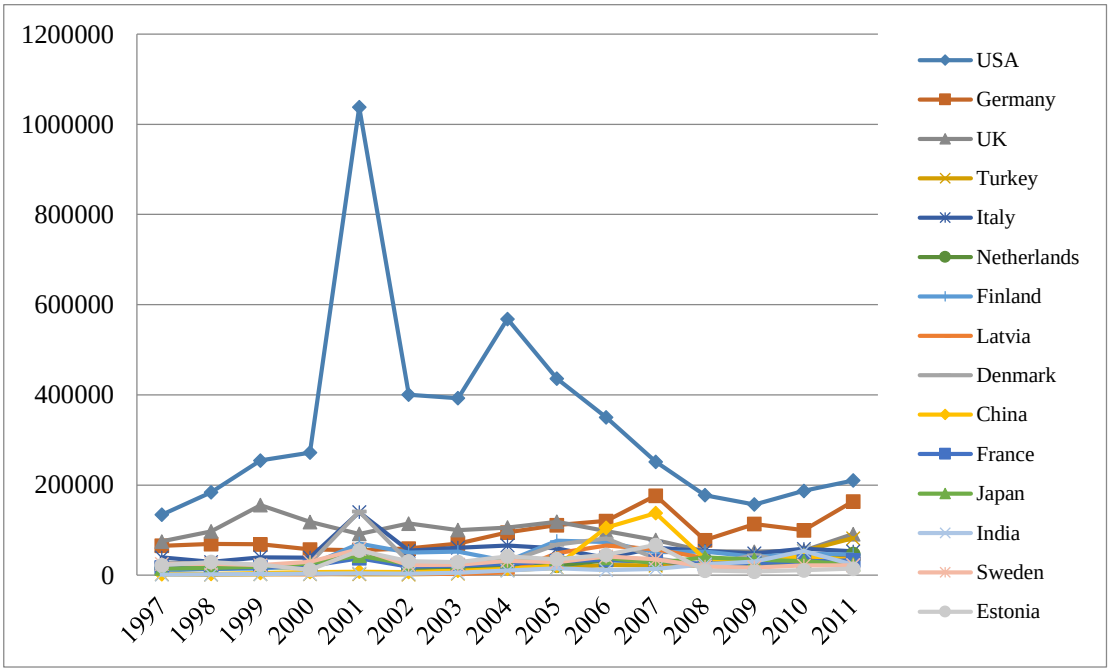


Figure 12. Plywood consumption amount by major countries in 1997 - 2011 (m^3)

4.3.2.6 Sawnwood (C)

Russian Sawnwood (C) consumption amount and percentage by top consumption countries are shown in **Figure 13** and **Figure 14**. The global consumption of Sawnwood (C) is generally increasing. USA, Italy and Finland play important role to Russian Sawnwood (C), but all have sudden decreased since 2009. Surprisingly, consumption by Japan is increasing dramatically since 2009. China's consumption is steadily increasing.

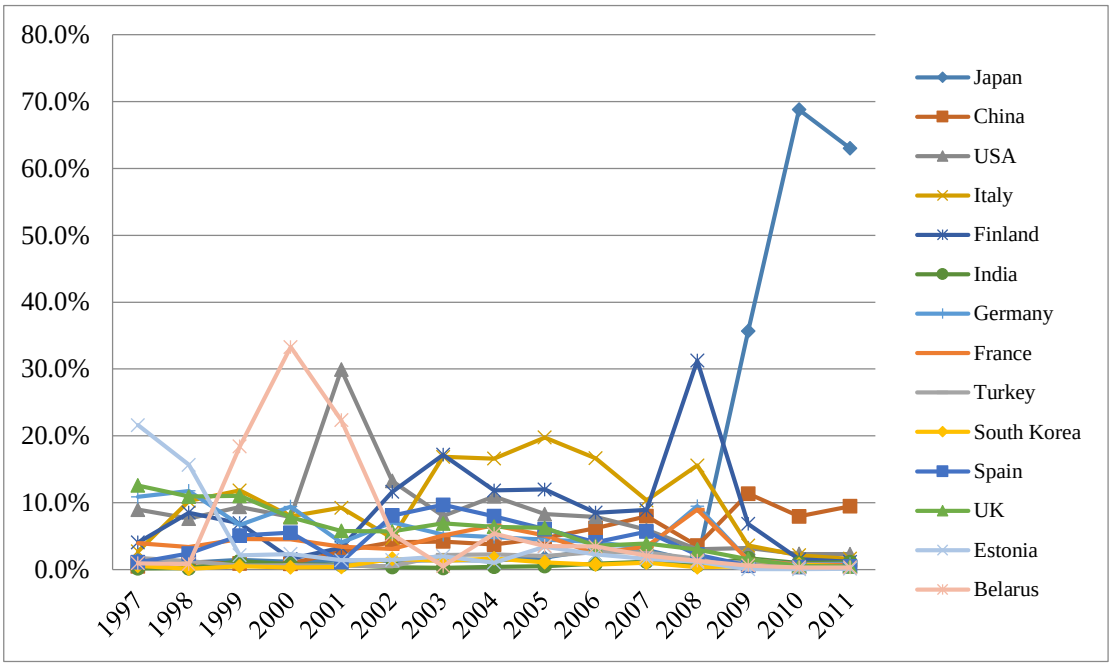


Figure 13. Sawnwood (C) consumption percentage by major countries in 1997 - 2011

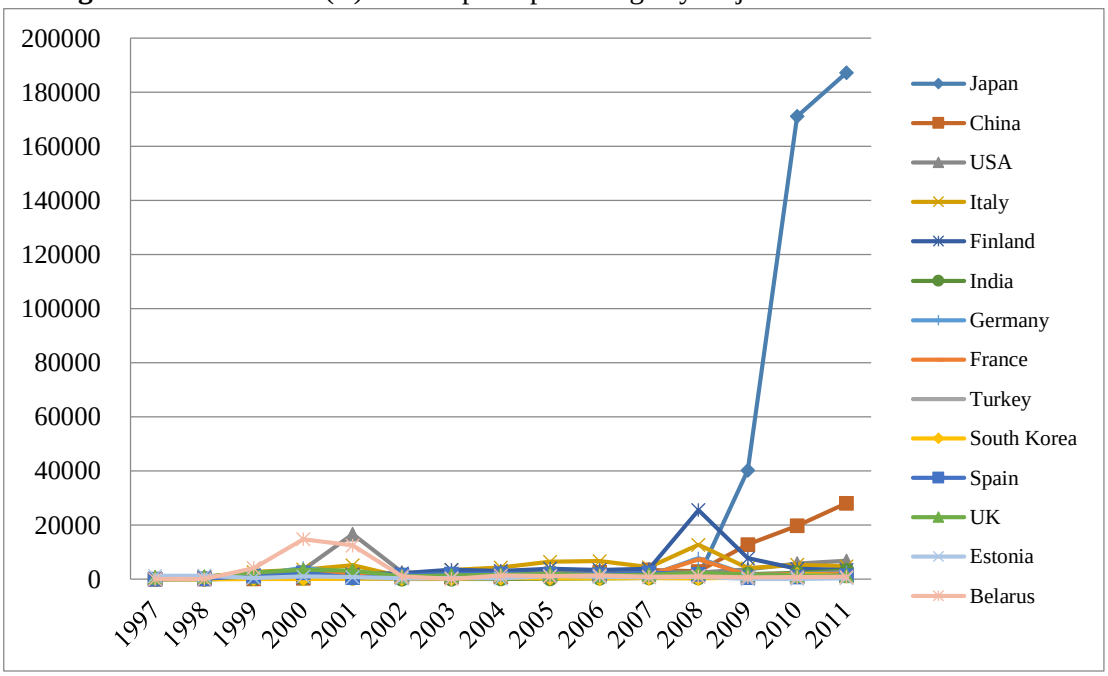


Figure 14. Sawnwood (C) consumption amount by major countries in 1997 - 2011 (m^3)

4.3.2.7 Sawnwood (NC)

Russian Sawnwood (NC) consumption amount and percentage by top consumption countries are shown in **Figure 15** and **Figure 16**. The global consumption of Russian Sawnwood (NC) is generally increasing. Consumption by China is increasing dramatically, especially after 2008. USA is second largest consumer of Russian Sawnwood (NC). Its role to Russian Sawnwood (NC) is steady throughout 1997-2011. The role of developed European countries stays the same, even decrease a little bit.

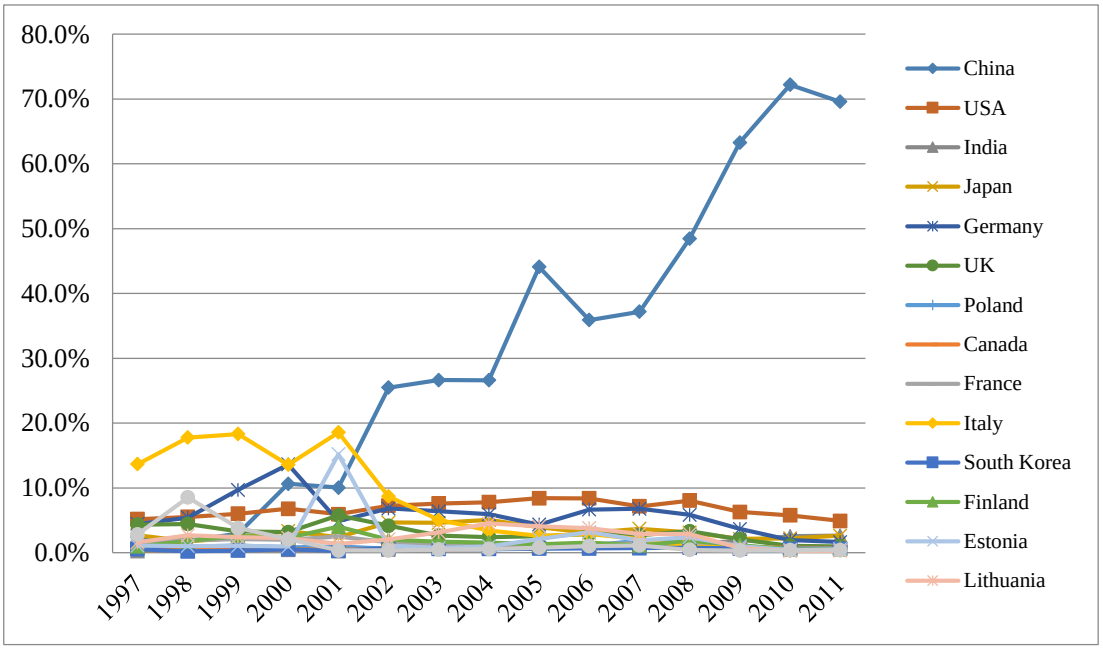


Figure 15. Sawnwood (NC) consumption percentage by major countries in 1997 - 2011

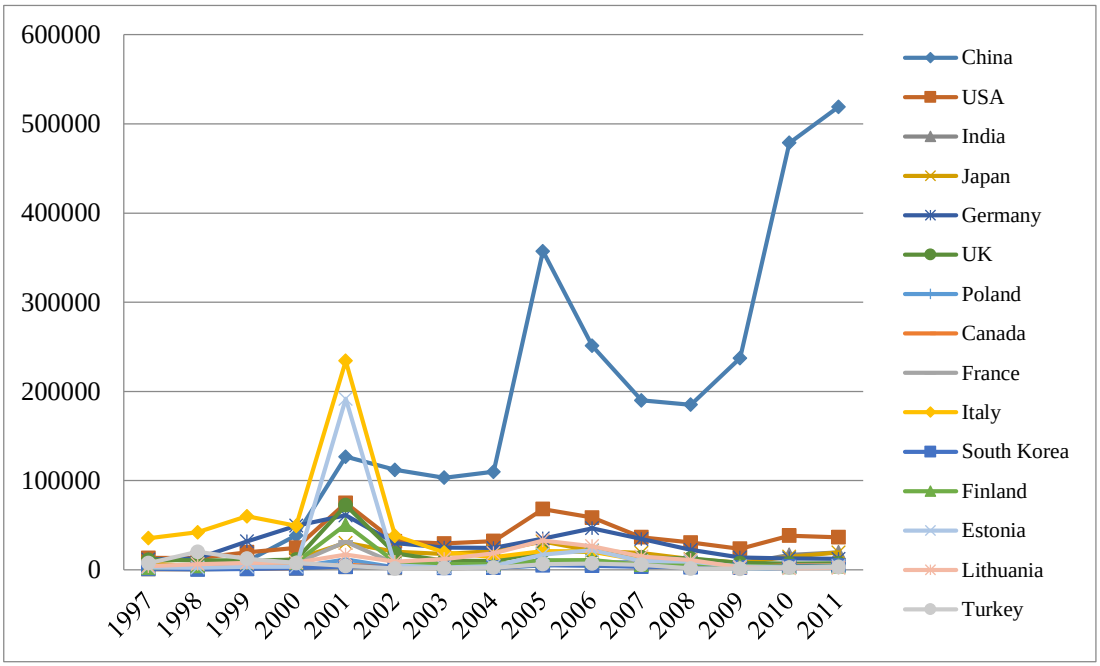


Figure 16. Sawnwood (NC) consumption amount by major countries in 1997 - 2011 (m^3)

4.3.2.8 Veneer Sheets

Russian veneer consumption amount and percentage by top consumption countries are shown in **Figure 17** and **Figure 18**. Japan became the largest final consumer of Russian Veneer Sheets since 2009 and still increasing. China is becoming to an important final consumer of Russian Veneer Sheets too. Interestingly, USA with little direct import of Russian Veneer Sheets, actually is an important final consumer of Russian Veneer Sheets. But USA is less and less important to Russian Veneer Sheets production after 2001.

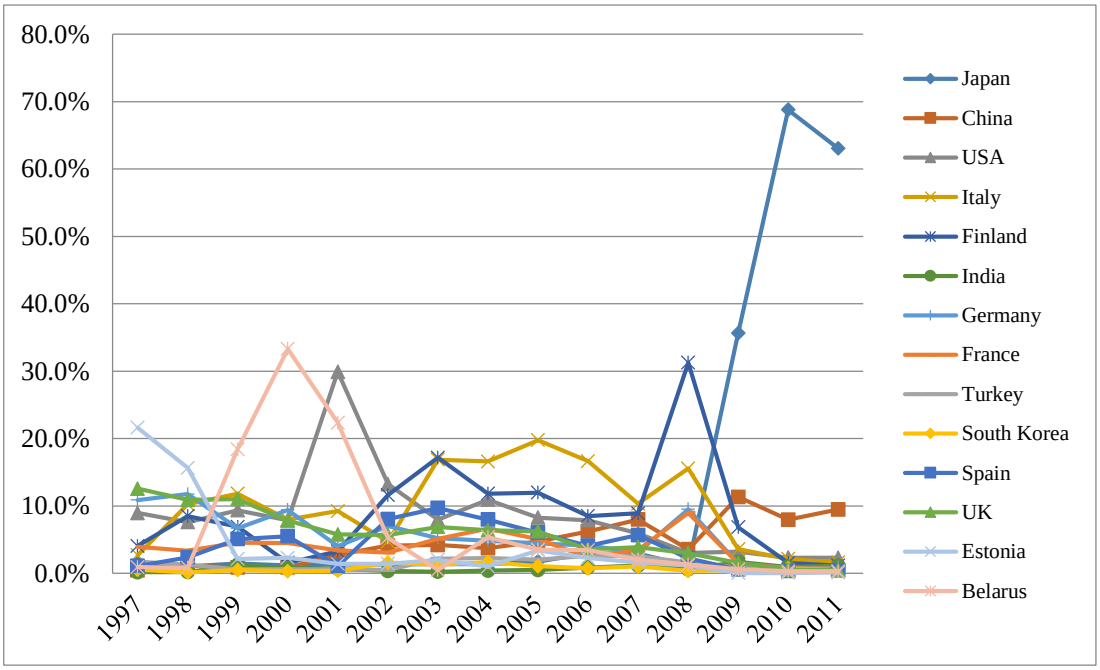


Figure 17. Veneer Sheets consumption percentage by major countries in 1997 - 2011

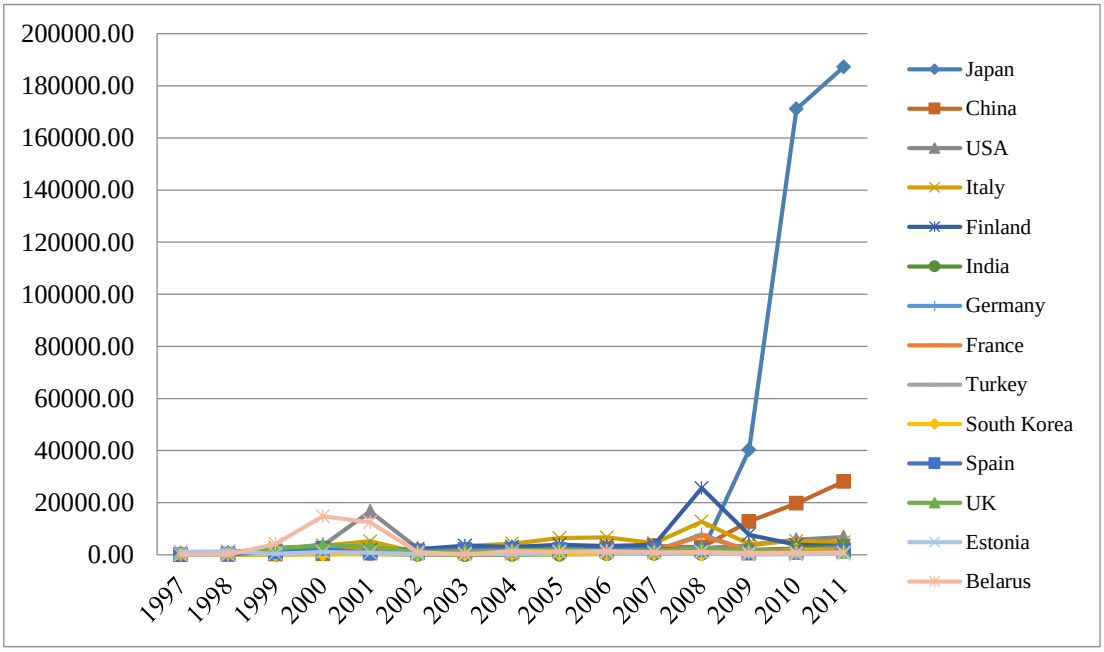


Figure 18. Veneer Sheets consumption amount by major countries in 1997 - 2011 (m^3)

4.3.2.9 Newsprint

Russian newsprint consumption amount and percentage by top consumption countries are shown in **Figure 19** and **Figure 20**.The global consumption of Russian Newsprint is generally constant. India, Turkey and Germany are the largest consumer of Russian Newsprint. Consumption by USA is steadily decreasing, while other developed countries stay the same. It may because of rapid development of internet and online information media. It may cause a global consumption reduction of Russian Newsprint in the future.

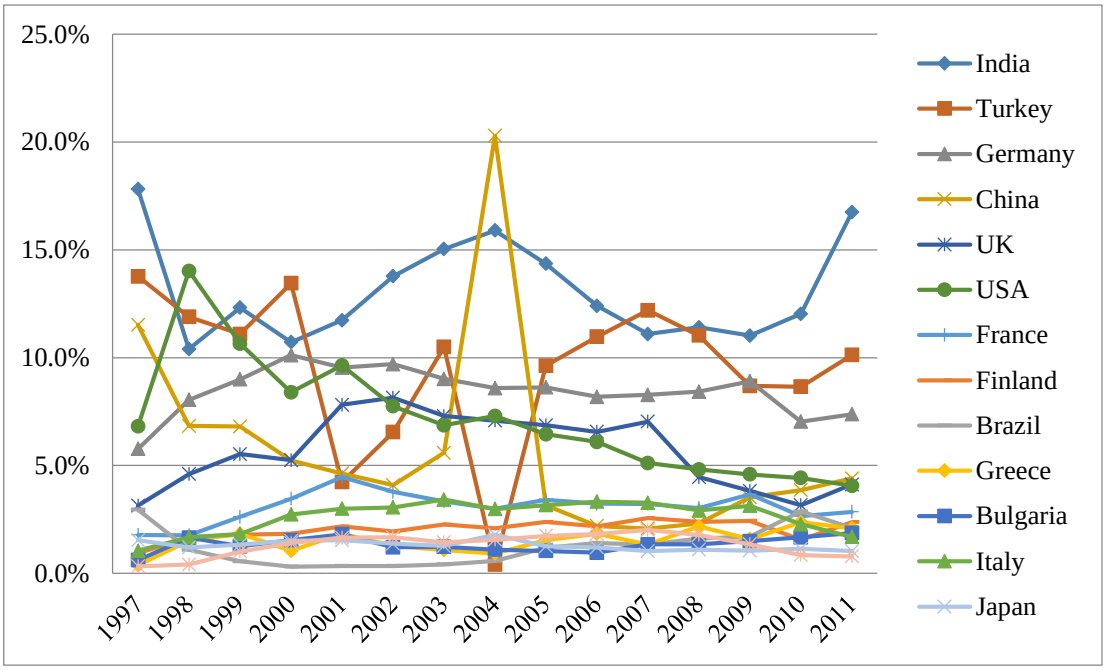


Figure 19. Newsprint consumption percentage by major countries in 1997 – 2011

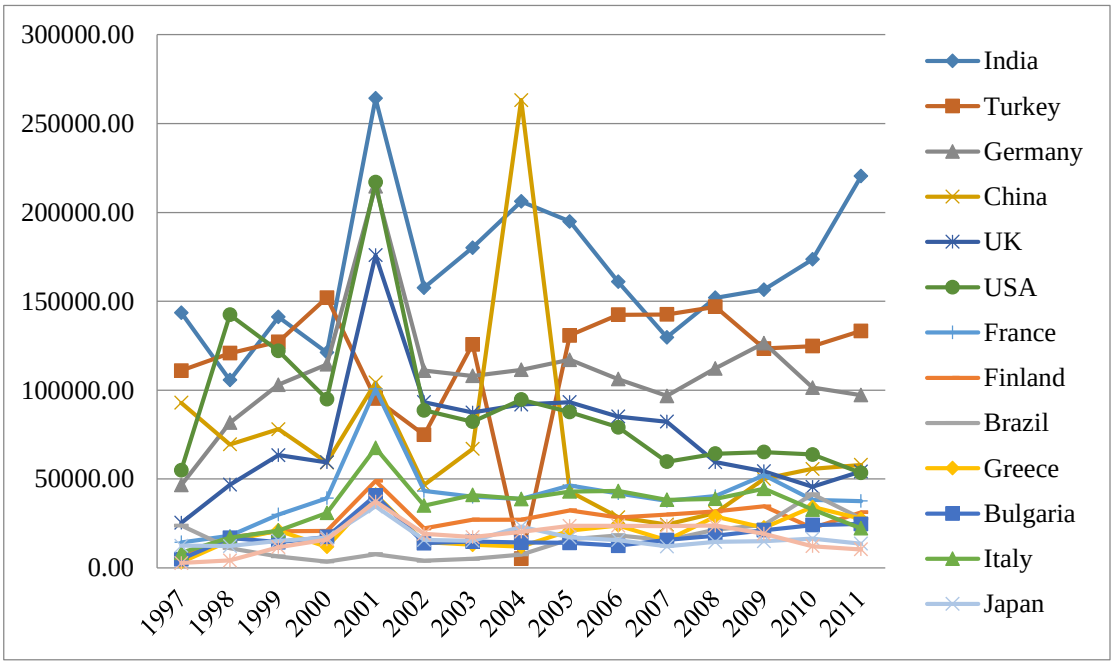


Figure 20. Newsprint consumption amount by major countries in 1997 - 2011 (tonnes)

4.4 Chapter summarization

By incorporate WIOD and FAO datasets, a MUIO model was built with physical Russian wood product sectors and monetary industry sectors around the world. The result indicates the major final consumer of Russian wood products are China, Finland, Japan, Germany, USA, South Korea, Belarus, India and Turkey.

China is the largest final consumer of Russian Roundwood (C) and Sawnwood (NC). Japan is the largest final consumer of Russian Sawnwood (C) and Veneer Sheets. Finland is the largest final consumer of Russian Chips and Particles and Roundwood (NC). Belarus is the largest final consumer of Russian Particle Board. USA is the largest final consumer of Russian Plywood. India is the largest final consumer of Russian Newsprint.

Interestingly, there is little direct export to USA and developed European countries, but they are important final consumers of Russian wood products. The final consumption by China, Finland and India are much smaller than their direct imports. It means a big proportion of Russian wood products direct export to China, Finland and India is used to manufacture products that serve developed European countries, USA, Japan and South Korea.

5. Environmental and energy impact analysis for Russian wood industry

The production and consumption of Russian wood products caused a lot of Green House Gas (GHG) emissions and energy use. Time series analysis of the CO_2 emission and energy use in Russian wood production will reveal the final consumer countries that are most responsible for CO_2 emission and energy use by consuming Russian wood products. It will also show the technology improvement to reduce GHG emissions as well as energy efficiency improvement during the last 2 decades.

5.1 Building A^* matrix in monetary form

To investigate CO_2 emission and energy use in Russian wood products, we also need to disaggregate Russian wood related sectors in WIOD MRIO table into A^* matrix with 9 Russian wood products in monetary form. In this way, it will be convenient to use equation (18) to do CO_2 emission and energy use analysis. The CO_2 emission and energy use impact data is from WIOD.

The process of building A^* matrix in monetary form is similar to build a MUIO A^* matrix in **Chapter 4.2** except the added 9 Russian wood product sectors are in monetary transaction rather than physical transaction.

5.1 CO_2 emission analysis for Russian wood industry

5.1.1 Chips and Particles

CO_2 emission amount and percentage of Russian Chips and Particles production caused by top 10 consumption countries are shown in **Figure 21** and **Figure 22**. The unit is in kilo tons (KT). The total CO_2 emission decreased gradually. Finland is responsible for most CO_2 emission by Russian Chips and Particles production from1997-2007, Japan gradually became the largest responsible country after 2007. Compare with the consumption amount of Chips and Particles in **Figure 8**, with dramatically increase in Chips and Particles consumption since 2005, the CO_2 emission caused by Finland gradually increased. It indicates great technique improvement of reducing CO_2 emission in Chips and Particles related production.

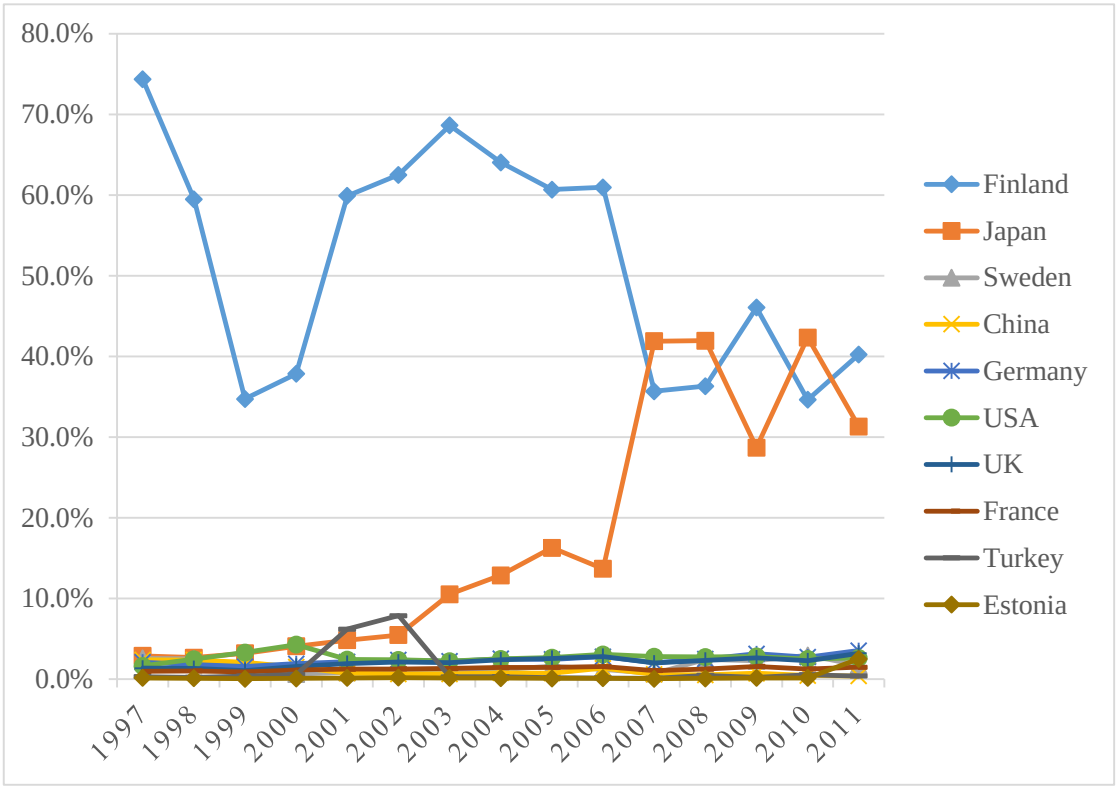


Table 21. CO_2 emission change in Chips and Particles consumption by major countries (%)

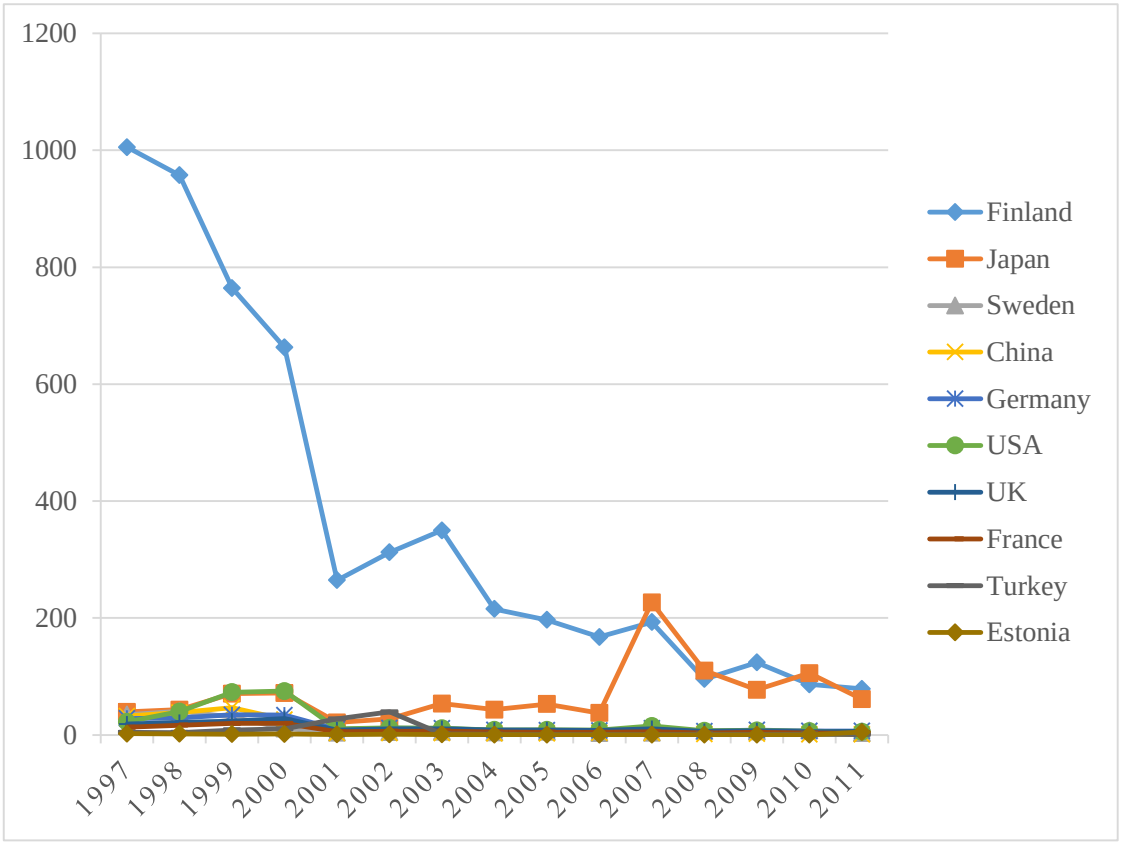


Figure 22. CO_2 emission change in Chips and Particles consumption by major countries (KT)

5.1.2 Roundwood (C)

CO_2 emission amount and percentage of Russian Roundwood (C) production caused by top 10 consumption countries are shown in **Figure 23** and **Figure 24**. The total CO_2 emission decreased gradually. China used to be the largest responsible country of CO_2 emission in Russian Roundwood (C) production, but its CO_2 emission gradually decreased since 1997. Compare with the consumption amount of Roundwood (C) by China in **Figure 4**, there is a big improvement in reducing CO_2 emission in the production and consumption after 1998. Japan and USA also took a large part of CO_2 emission. With dramatically decrease in Roundwood (C) consumption since 2001, the CO_2 emission caused by Japan actually slightly increased. It indicates Japan import more Roundwood (C) related products with big CO_2 emission in production to reduce domestic CO_2 emission.

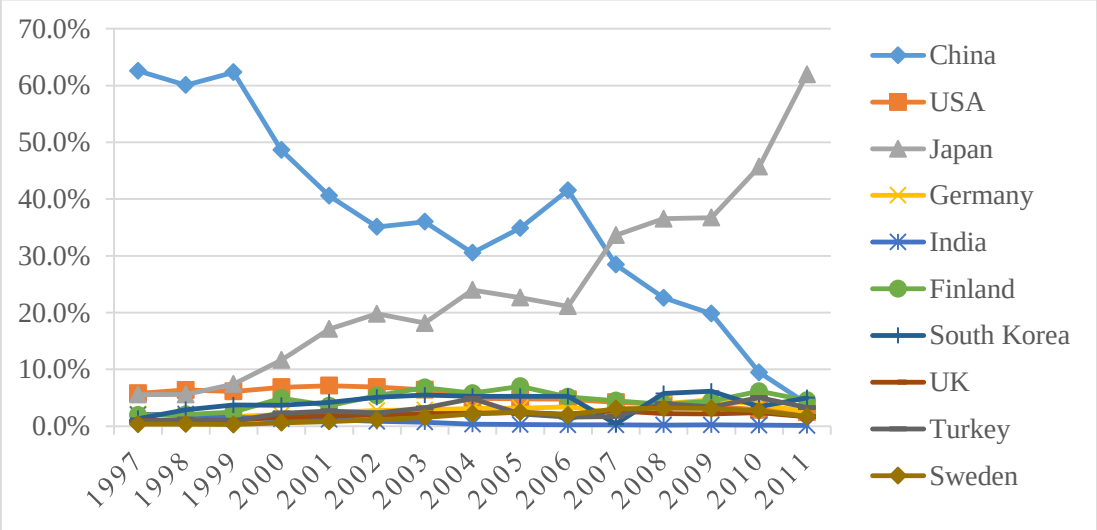


Figure 23. CO_2 emission change in Roundwood (C) consumption by major countries (%)

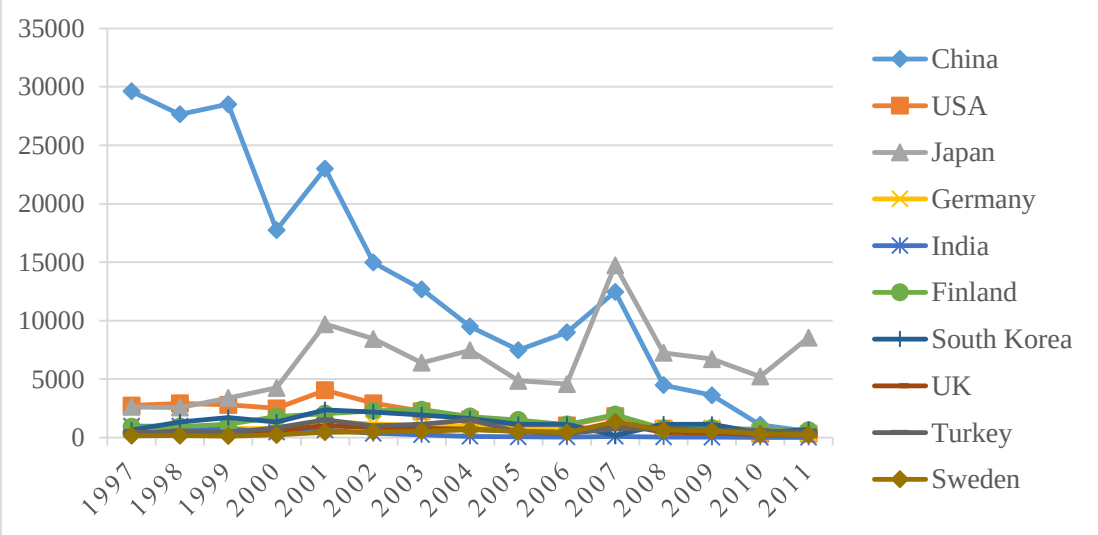


Figure 24. CO_2 emission change in Roundwood (C) consumption by major countries (KT)

5.1.3 Roundwood (NC)

CO_2 emission amount and percentage of Russian Roundwood (NC) production caused by top 10 consumption countries are shown in **Figure 25** and **Figure 26**. China, Finland and Japan are responsible for most CO_2 emission by Russian Roundwood (NC) production from1997-2011. The total CO_2 emission decreased gradually. Compare with consumption amount of Roundwood (NC) in **Figure 6**, with dramatically decrease in Roundwood (C) consumption since 2009, the CO_2 emission caused by Finland and Japan actually slightly increased. It indicates the Roundwood (NC) related products consumed by Finland and Japan were turning to high CO_2 emission products.

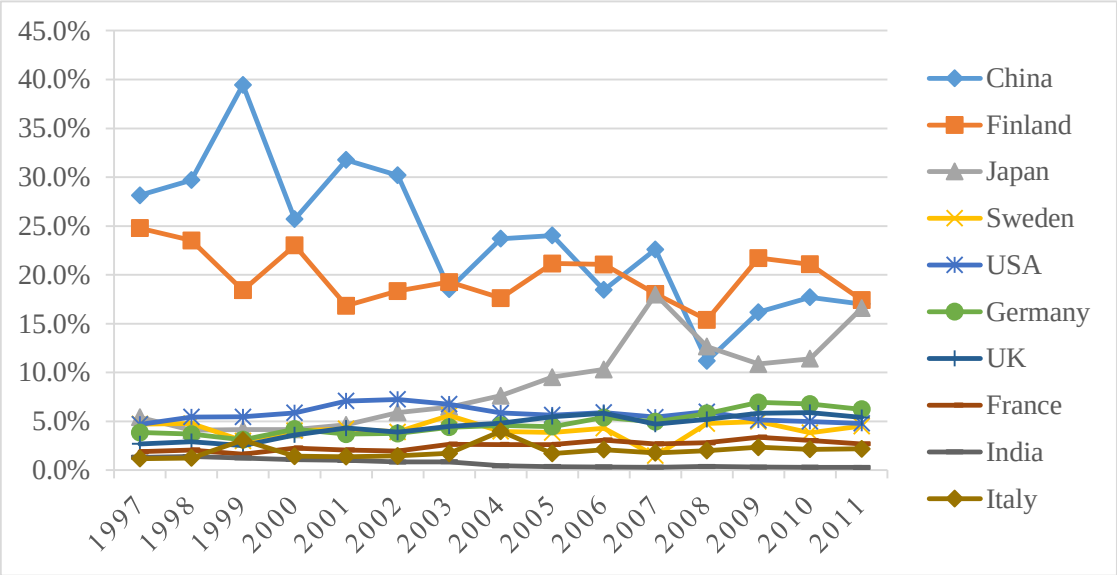


Figure 25. CO_2 emission change in Roundwood (NC) consumption by major countries (%)

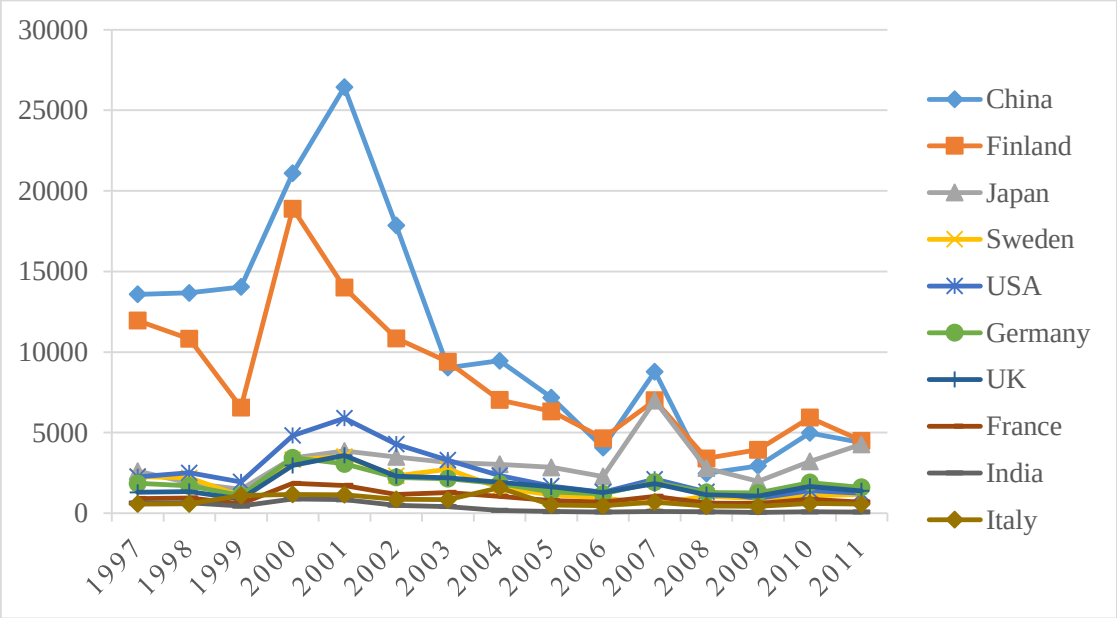


Figure 26. CO_2 emission change in Roundwood (NC) consumption by major countries (KT)

5.1.4 Particle Board

CO_2 emission amount and percentage of Russian Particle Board production caused by top 10 consumption countries are shown in **Figure 27** and **Figure 28**. The total CO_2 emission decreased gradually. Belarus and USA are responsible for most CO_2 emission by Russian Particle Board production from1997-2011. Compare with consumption amount of Particle Board in **Figure 10**, with increase of Particle Board consumption, the CO_2 emission caused by Belarus, China and USA were slowly decreasing. It indicates the gradually technique improvement for reducing CO_2 emission in Particle Board related production.

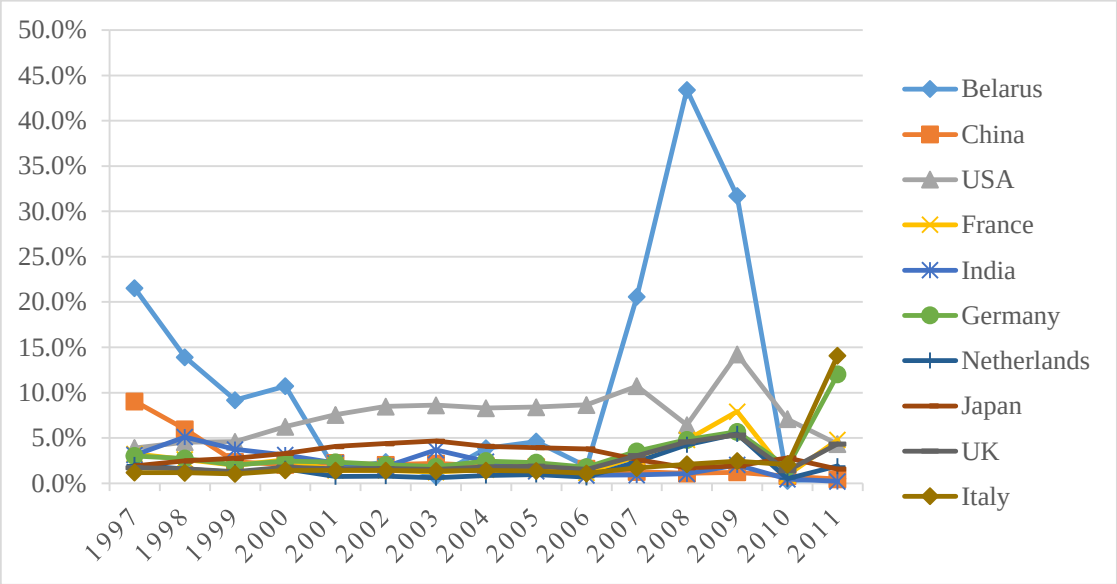


Figure 27. CO_2 emission change in Particle Board consumption by major countries (%)

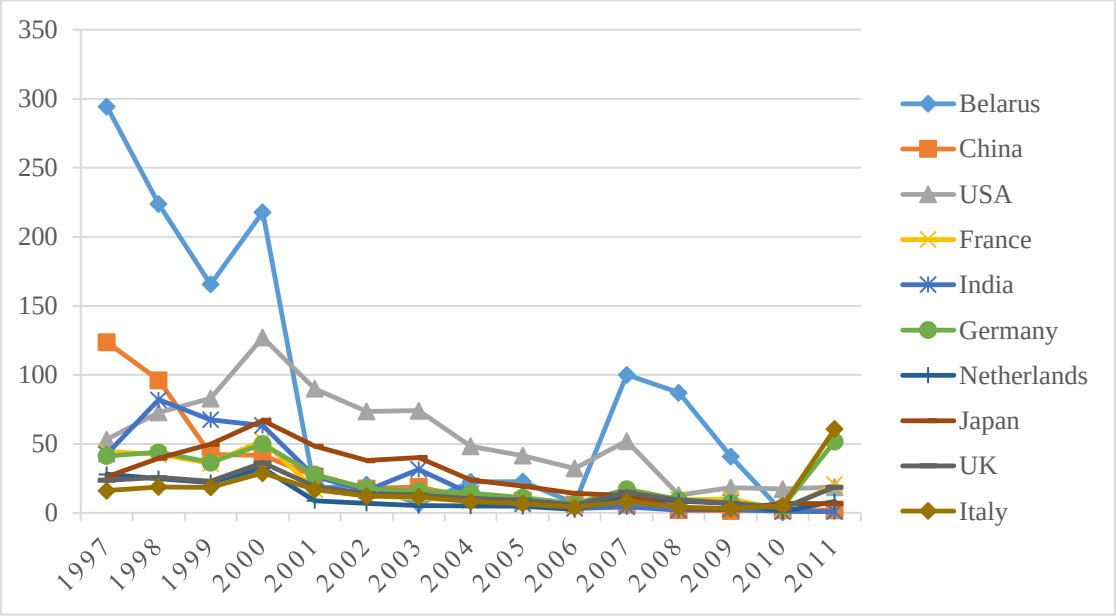


Figure 28. CO_2 emission change in Particle Board consumption by major countries (KT)

5.1.5 Plywood

CO_2 emission amount and percentage of Russian Plywood production caused by top 10 consumption countries are shown in **Figure 29** and **Figure 30**. The total CO_2 emission gradually decreased. USA, UK and Germany are responsible for most CO_2 emission by Russian Plywood production from1997-2011. Compare with consumption amount of Plywood in **Figure 12**, with dramatically decrease in Plywood consumption since 2001, the CO_2 emission caused by USA, UK and Germany slightly decreased. It indicates USA and Germany imported more Plywood related products with high CO_2 emission in production to reduce domestic CO_2 emission.

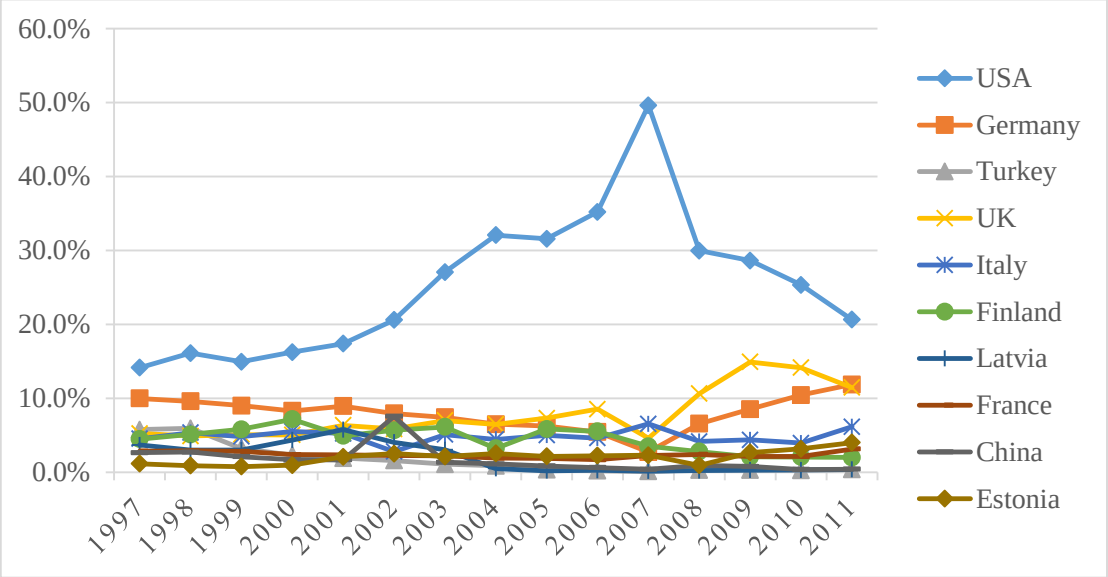


Figure 29. CO_2 emission change in Plywood consumption by major countries (%)

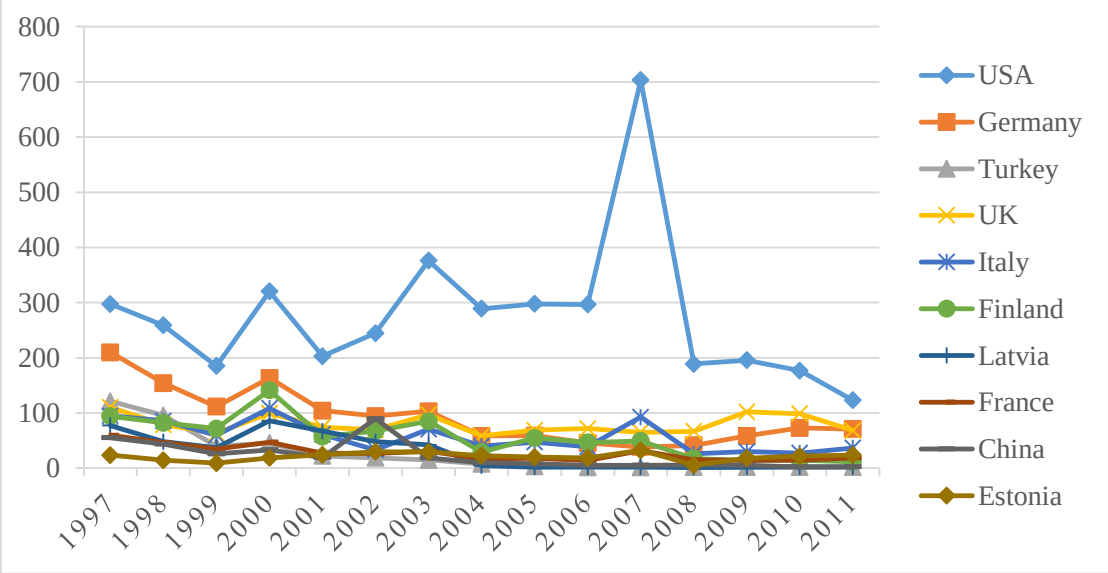


Figure 30. CO_2 emission change in Plywood consumption by major countries (KT)

5.1.6 Sawnwood (C)

CO_2 emission amount and percentage of Russian Sawnwood (C) production caused by top 10 consumption countries are shown in **Figure 31** and **Figure 32**. The total CO_2 emission gradually decreased. China and Japan are responsible for most CO_2 emission by Russian Sawnwood (C) production from1997-2011. China used to be the largest responsible country but CO_2 emission caused by China gradually decreased. Japan became the largest responsible country after 2006. Compare with consumption amount in **Figure 14**, with slightly increase in Sawnwood (C) consumption since 2007, the CO_2 emission caused by Japan greatly increased. It indicates Japan imported more Sawnwood (C) related products with high CO_2 emission in production to reduce domestic CO_2 emission.

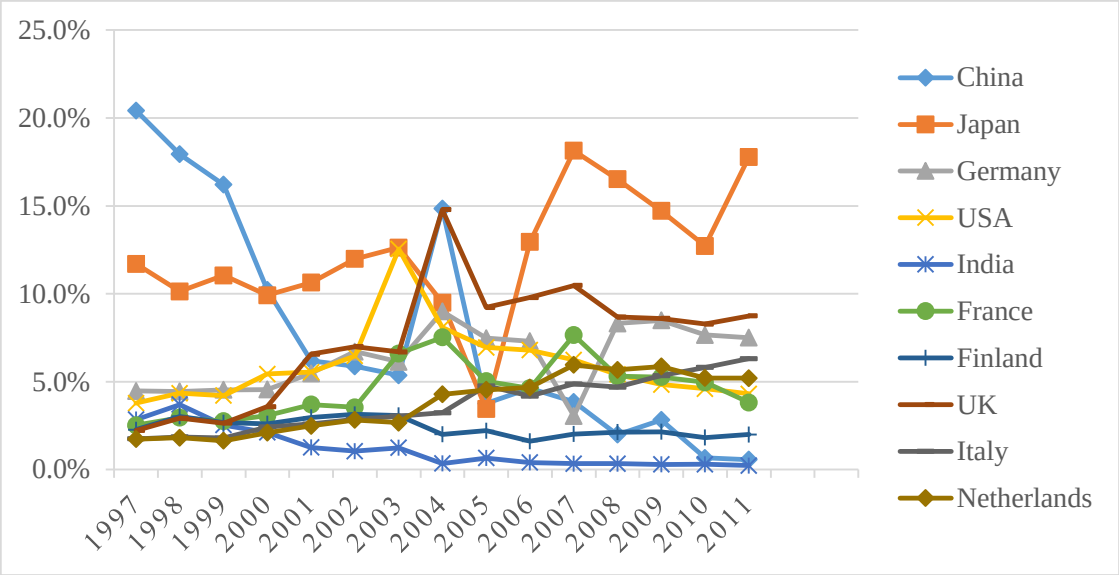


Figure 31. CO_2 emission change in Sawnwood (C) consumption by major countries (%)

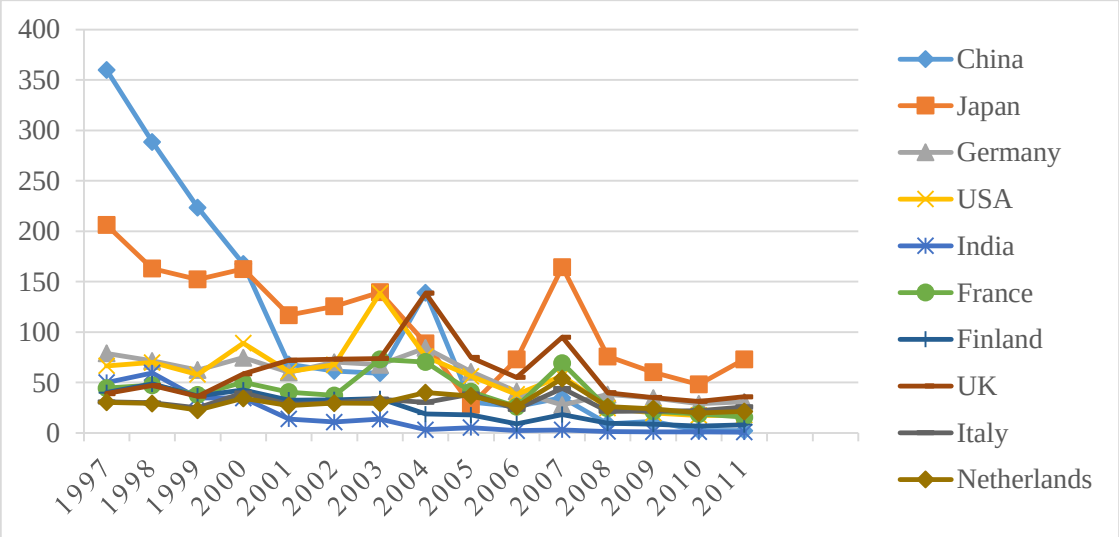


Figure 32. CO_2 emission change in Sawnwood (C) consumption by major countries (KT)

5.1.7 Sawnwood (NC)

CO_2 emission amount and percentage of Russian Sawnwood (NC) production caused by top 10 consumption countries are shown in **Figure 33** and **Figure 34**. The total CO_2 emission gradually decreased. China is responsible for most CO_2 emission by Russian Sawnwood (NC) production before 2003. After that, CO_2 emission caused by China gradually decreased. Compare with consumption amount in **Figure 16**, with dramatically increase in Sawnwood (NC) consumption since 2005, the CO_2 emission caused by China greatly decreased. It indicates the great technique improvement of reducing CO_2 emission in Sawnwood (NC) related production.

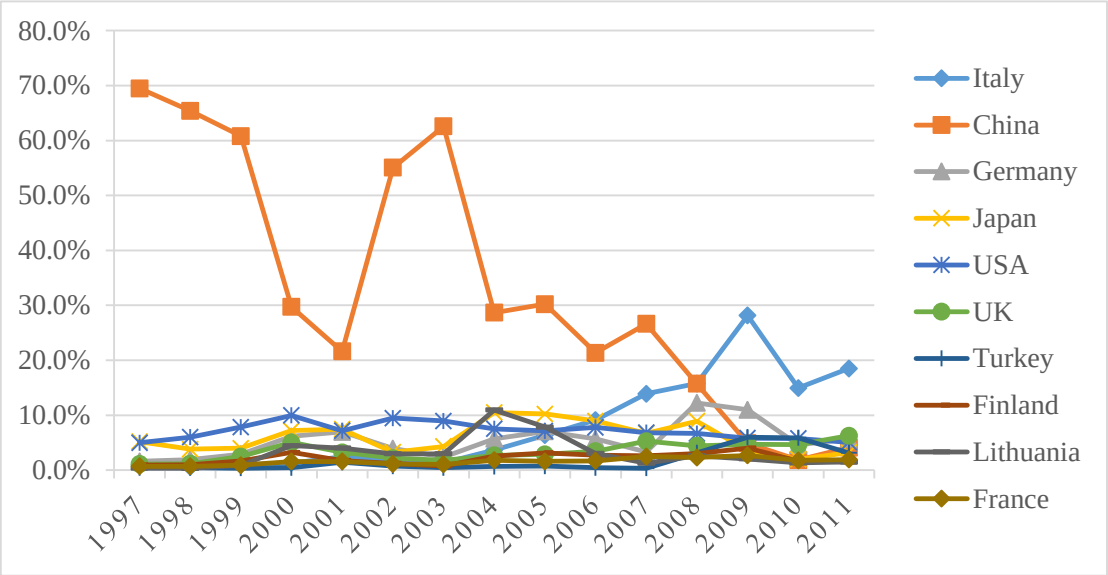


Figure 33. CO_2 emission change in Sawnwood (NC) consumption by major countries (%)

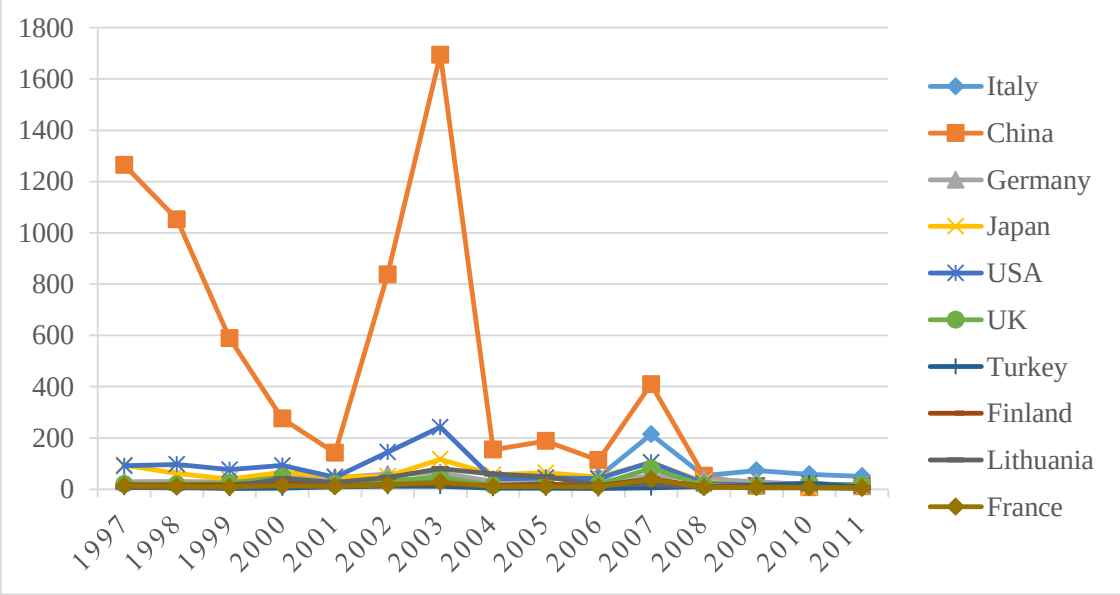


Figure 34. CO_2 emission change in Sawnwood (NC) consumption by major countries (KT)

5.1.8 Veneer Sheets

CO_2 emission amount and percentage of Veneer Sheets production caused by top 10 consumption countries are shown in **Figure 35** and **Figure 36**. The total CO_2 emission gradually decreased. Japan used to be the largest responsible country of CO_2 emission by Russian Veneer Sheets production before 2000. But the emission caused by Japan greatly decreased since 1998. Compare with consumption amount in **Figure 18**, with dramatically increase in Veneer Sheets consumption since 2008, the CO_2 emission caused by Japan greatly decreased. It indicates great technique improvement of reducing CO_2 emission in Veneer Sheets related production.

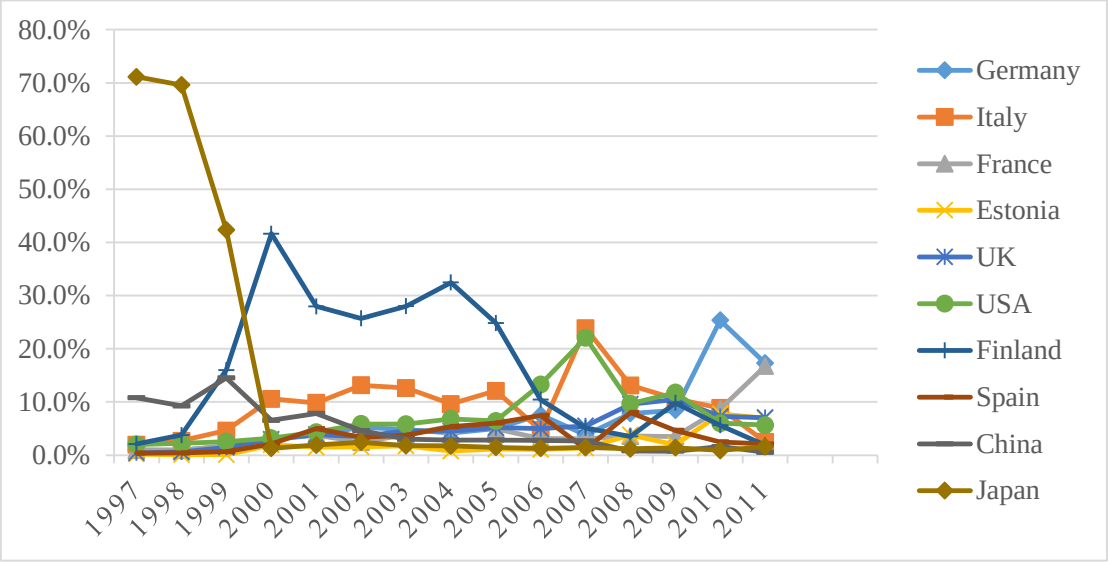


Figure 35. CO_2 emission change in Veneer Sheets consumption by major countries (%)

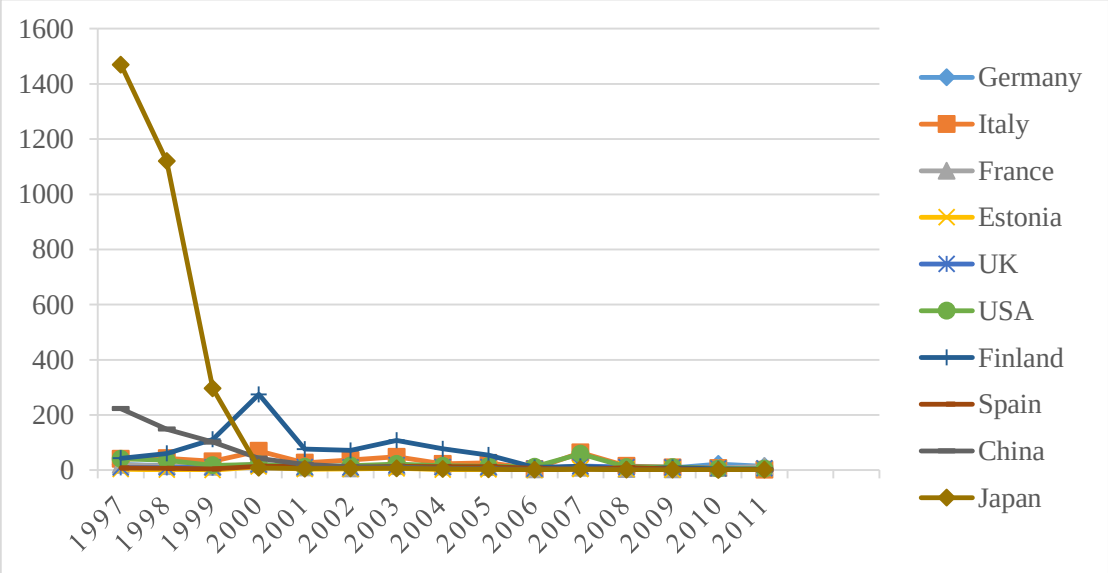


Figure 36. CO_2 emission change in Veneer Sheets consumption by major countries (KT)

5.1.9 Newsprint

CO_2 emission amount and percentage of Russian Newsprint production caused by top 10 consumption countries are shown in **Figure 37** and **Figure 38**. The total CO_2 emission gradually decreased. India, Turkey, Germany and China are responsible for most CO_2 emission by Russian Newsprint production from1997-2011. Compare with consumption amount in **Figure 20**, with gradual increase in Newsprint consumption since 2005, the CO_2 emission caused by India, Turkey and Germany decreased dramatically. It indicates the great technique improvement of reducing CO_2 emission in Newsprint related production.

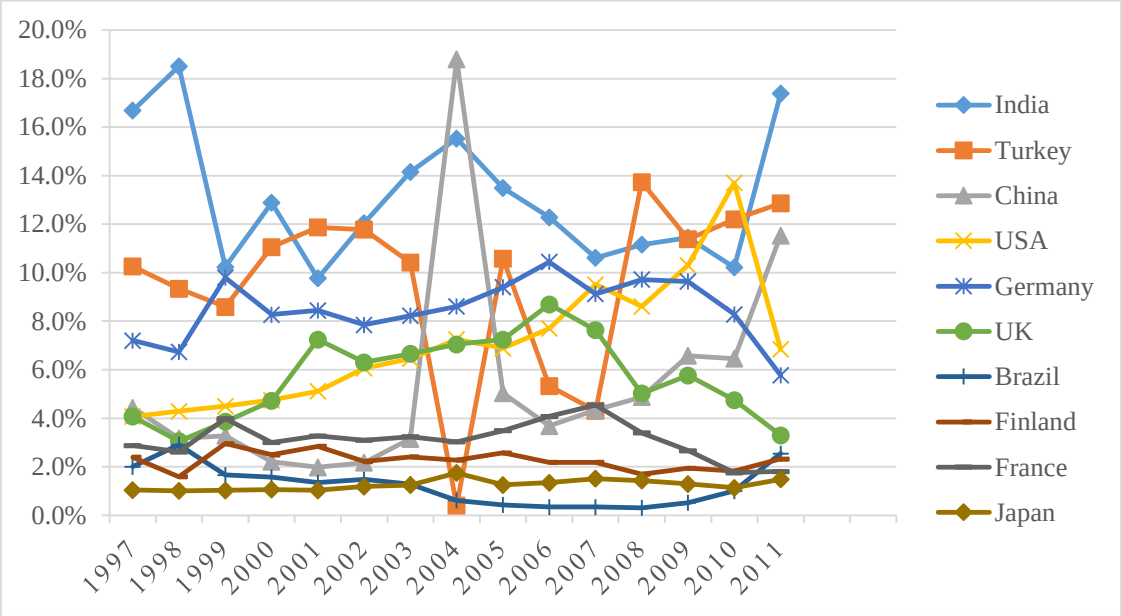


Figure 37. CO_2 emission change in Newsprint consumption by major countries (%)

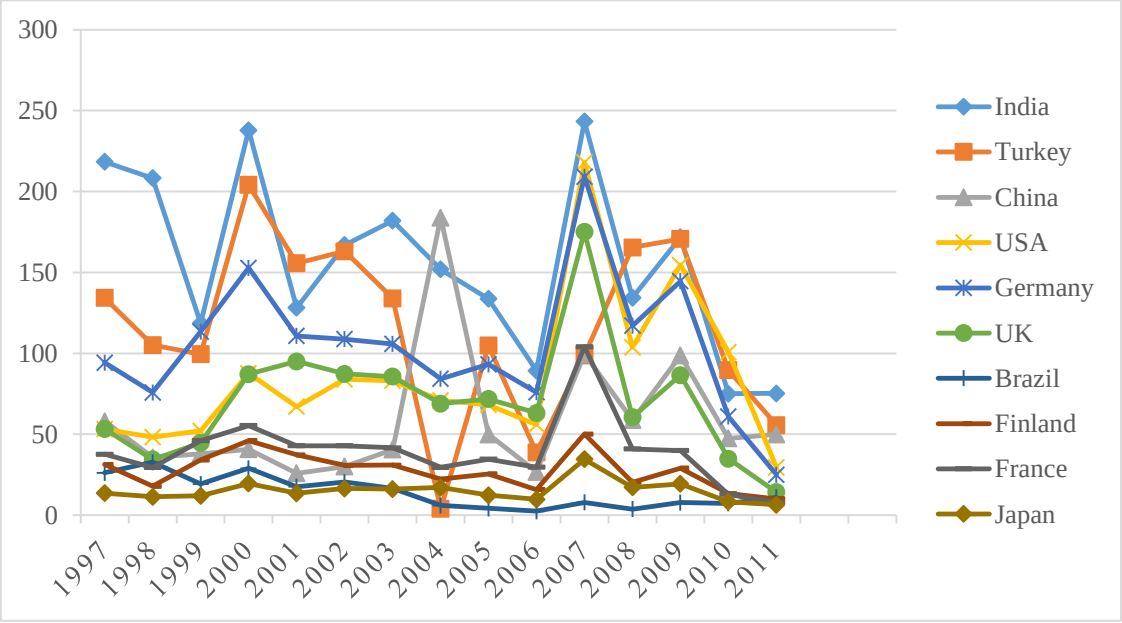


Figure 38. CO_2 emission change in Newsprint consumption by major countries (KT)

5.2 Energy use analysis for Russian wood industry

5.2.1 Chips and Particles

Energy use amount and percentage of Russian Chips and Particles production caused by top 10 consumption countries are shown in **Figure 39** and **Figure 40**. The unit is in kilo tons (TJ). The total energy use decreased gradually. Finland is responsible for most energy use by Russian Chips and Particles production from1997-2006, Japan gradually became the largest responsible country after 2007. Compare with the consumption amount of Chips and Particles in **Figure 8**, with dramatically increase in Chips and Particles consumption since 2005, the Energy use caused by Finland gradually increased. It indicates great technique improvement of reducing Energy use in Chips and Particles related production.

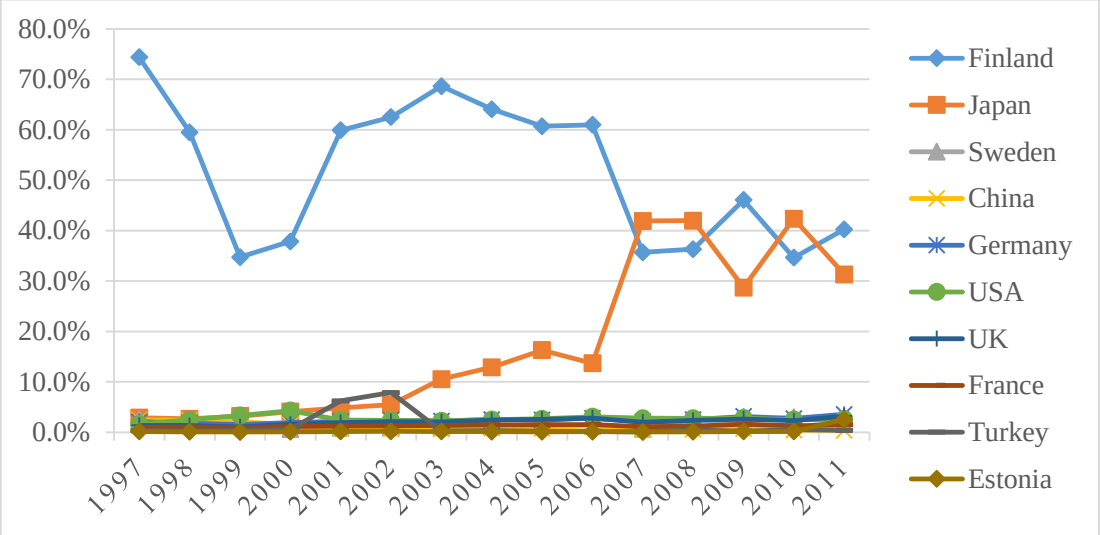


Figure 39. Energy use change in Chips and Particles consumption by major countries (%)

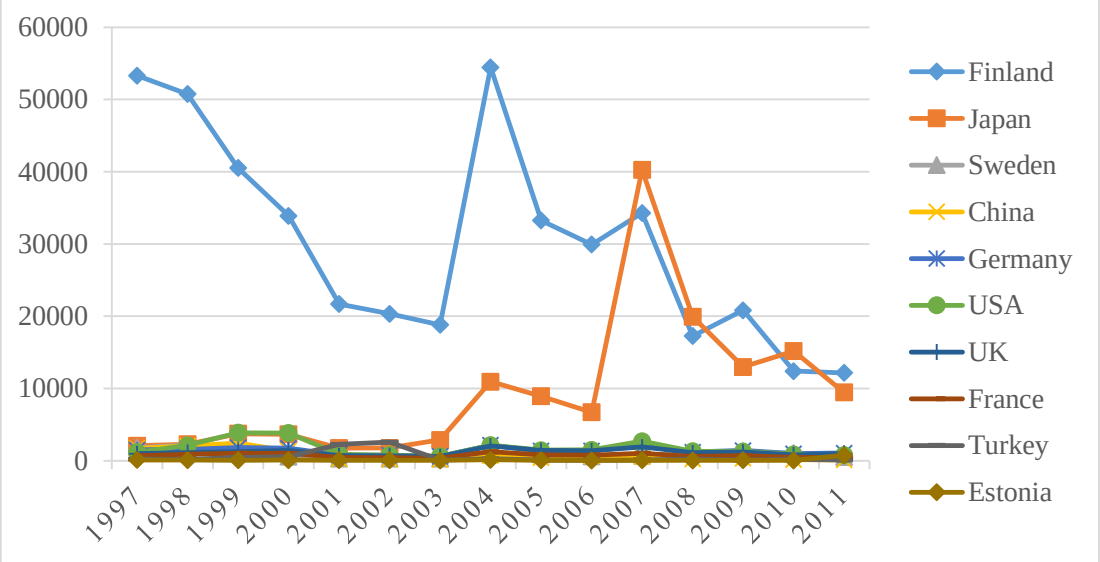


Figure 40. Energy use change in Chips and Particles consumption by major countries (TJ)

5.2.2 Roundwood (C)

Energy use amount and percentage of Russian Roundwood (C) production caused by top 10 consumption countries are shown in **Figure 41** and **Figure 42**. The total Energy use decreased gradually. China used to be the largest responsible country of Energy use in Russian Roundwood (C) production, but its energy use gradually decreased since 1997. Compare with the consumption amount of Roundwood (C) by China in **Figure 4**, there is a big improvement in reducing Energy use in the production and consumption after 1998. Japan took a large part of Energy use. With dramatically decrease in Roundwood (C) consumption since 2001, the Energy use caused by Japan greatly increased. It indicates Japan import more Roundwood (C) related products with big Energy use in production to reduce domestic energy use.

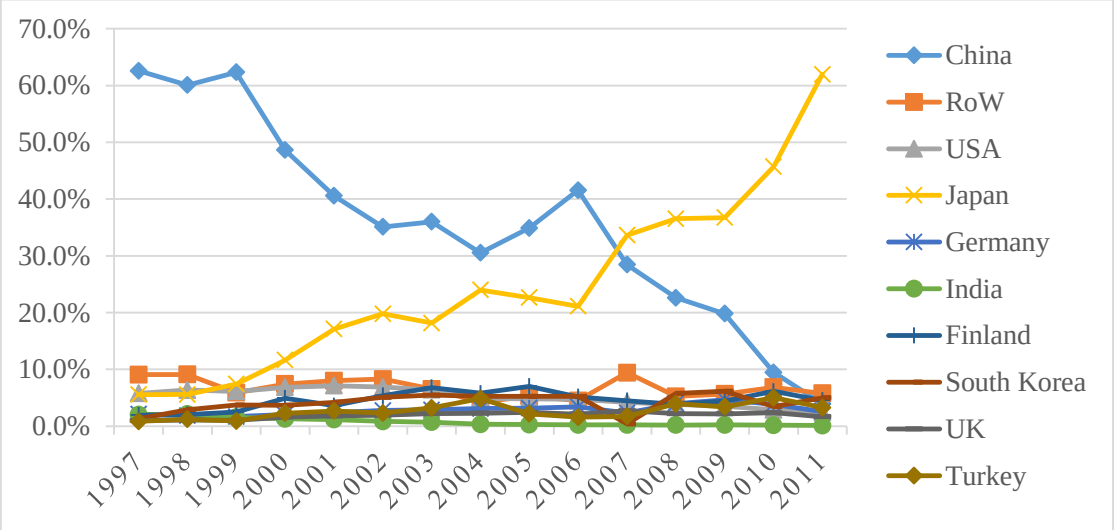


Figure 41. Energy use change in Roundwood (C) consumption by major countries (%)

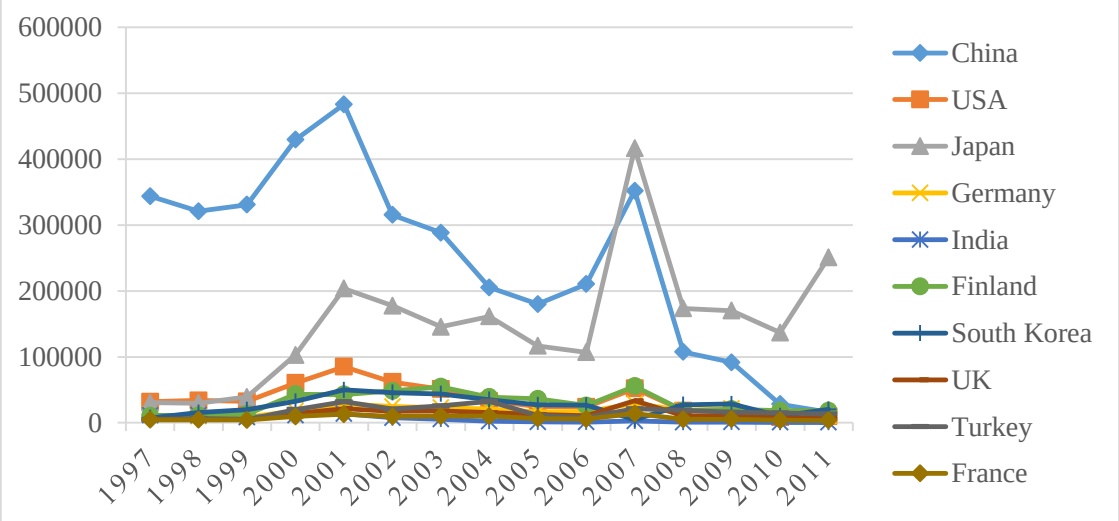


Figure 42. Energy use change in Roundwood (C) consumption by major countries (TJ)

5.2.3 Roundwood (NC)

Energy use amount and percentage of Russian Roundwood (NC) production caused by top 10 consumption countries are shown in **Figure 43** and **Figure 44**. China, Finland and Japan are responsible for most Energy use by Russian Roundwood (NC) production from1997-2011. The total Energy use decreased gradually. Compare with consumption amount of Roundwood (NC) in **Figure 6**, with dramatically decrease in Roundwood (C) consumption since 2009, the Energy use caused by Finland, Chian and Japan actually slightly increased. It indicates the Roundwood (NC) related products consumed by Finland and Japan were turning to high Energy use products.

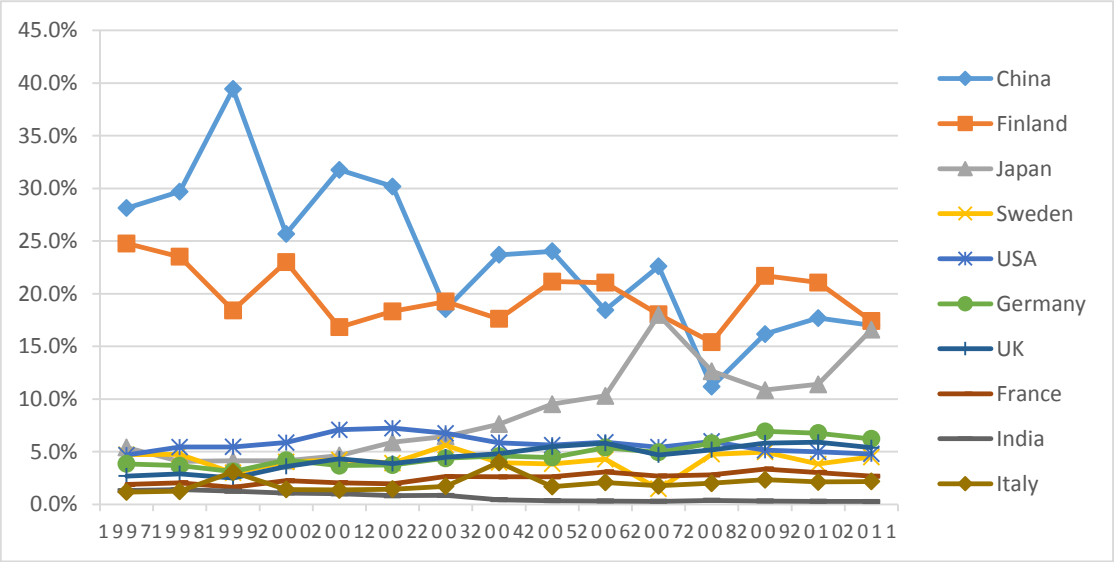


Figure 43. Energy use change in Roundwood (NC) consumption by major countries (%)

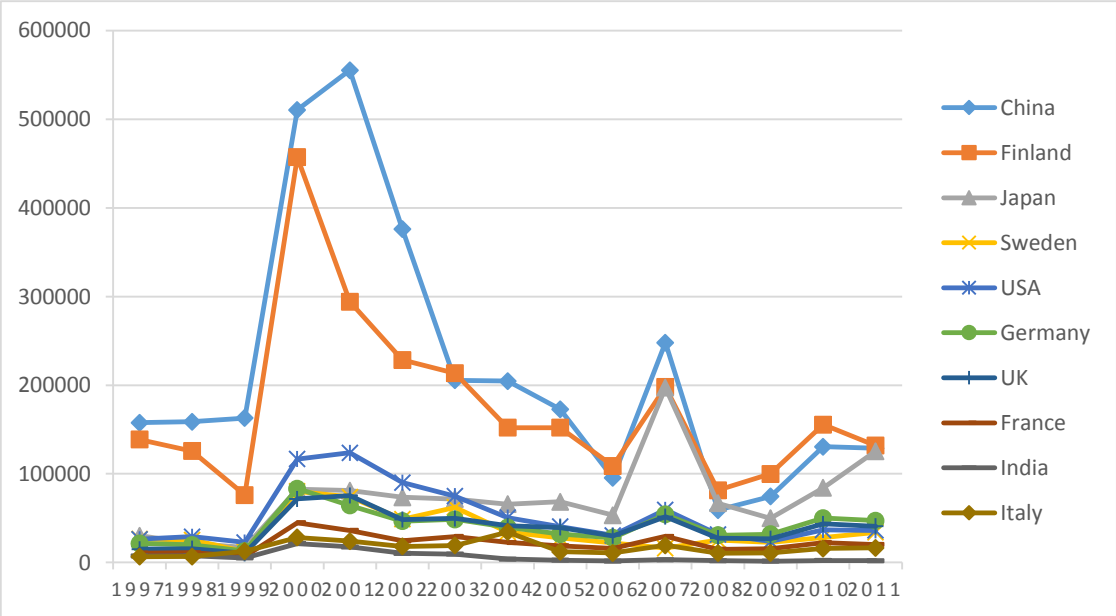


Figure 44. Energy use change in Roundwood (NC) consumption by major countries (m^3)

5.2.4 Particle Board

Energy use amount and percentage of Russian Particle Board production caused by top 10 consumption countries are shown in **Figure 45** and **Figure 46**. The total energy use decreased gradually. Belarus and USA are responsible for most Energy use by Russian Particle Board production from1997-2011. Compare with consumption amount of Particle Board in **Figure 10**, with increase of Particle Board consumption, the Energy use caused by Belarus, China and USA were slowly decreasing. It indicates the gradually technique improvement for reducing Energy use in Particle Board related production.

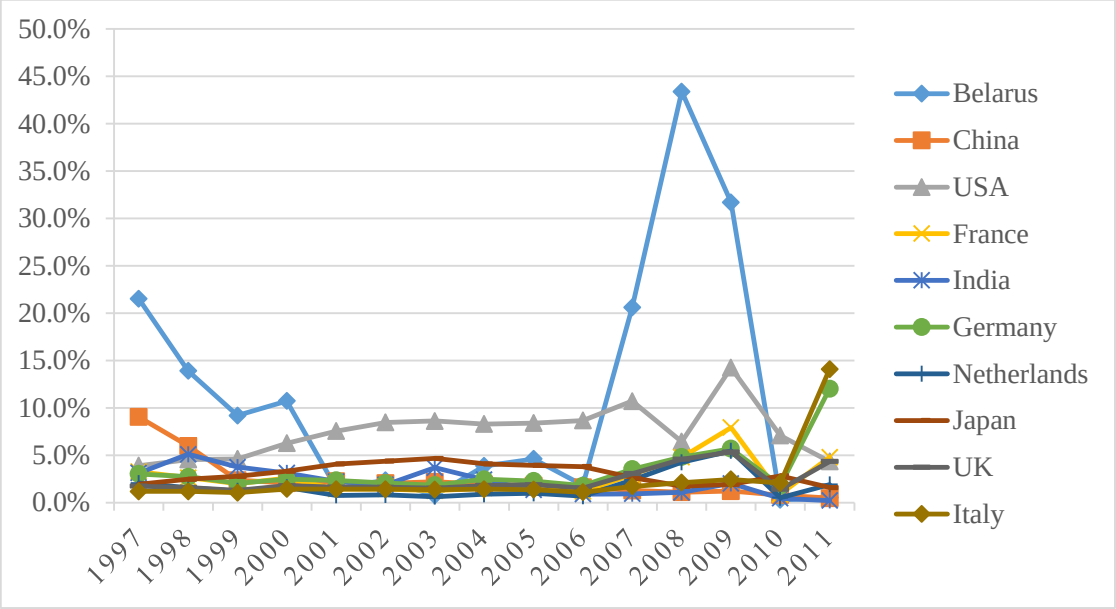


Figure 45. Energy Use change in Particle Board consumption by major countries (%)

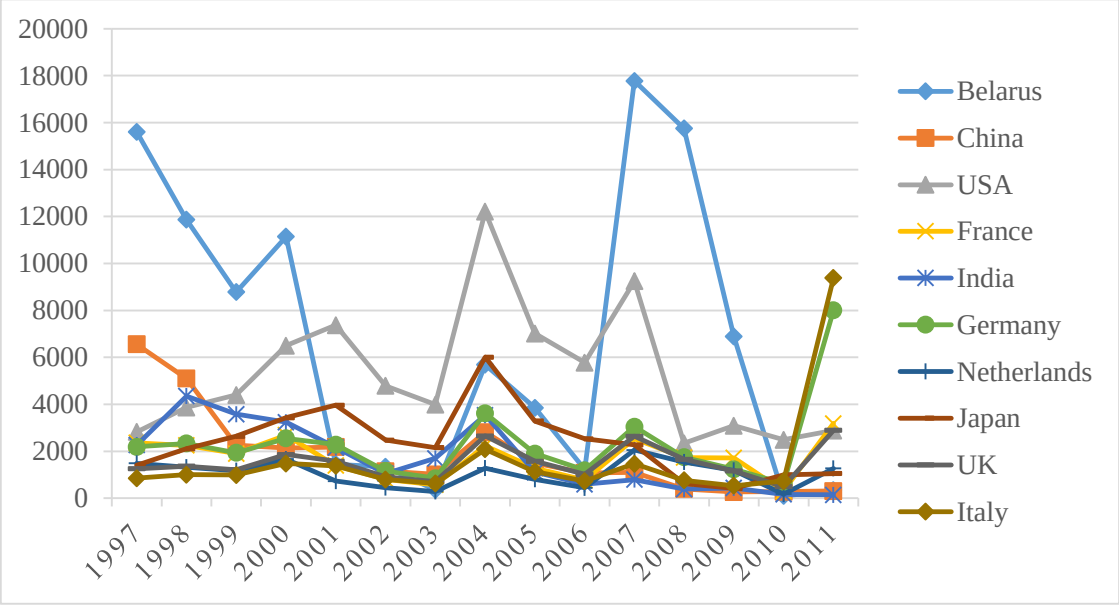


Figure 46. Energy Use change in Particle Board consumption by major countries (TJ)

5.2.5 Plywood

Energy use amount and percentage of Russian Plywood production caused by top 10 consumption countries are shown in **Figure 29** and **Figure 30**. USA, UK and Germany are responsible for most energy use by Russian Plywood production from1997-2011. Compare with consumption amount of Plywood in **Figure 12**, with dramatically decrease in Plywood consumption since 2001, the energy use caused by USA, UK and Germany dramatically increased. It indicates USA, UK and Germany import more Plywood related products with high energy use in production to reduce domestic energy use.

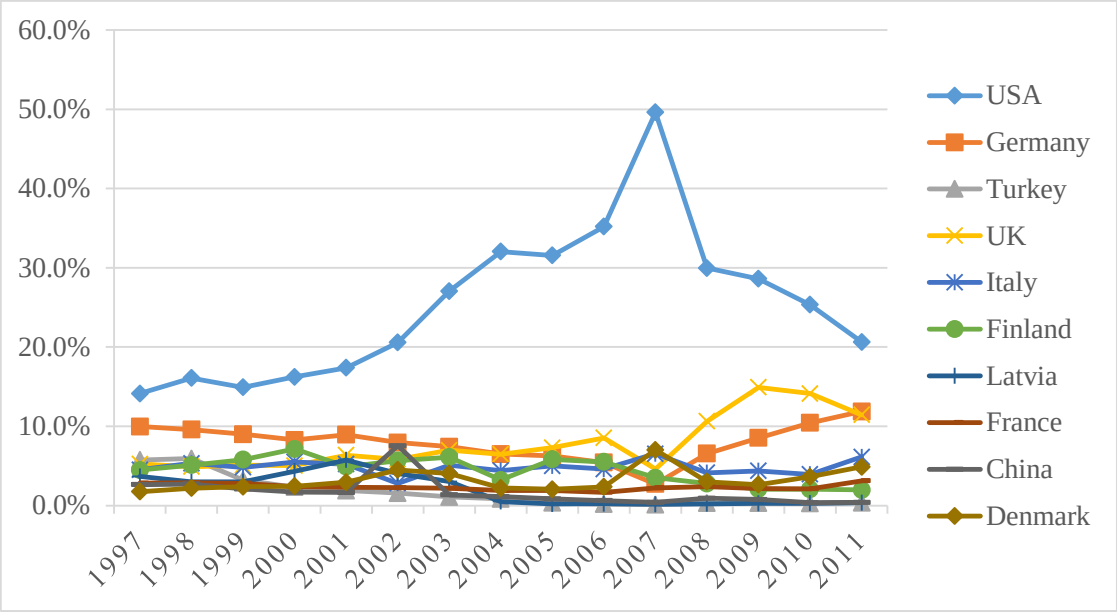


Figure 47. Energy Use change in Plywood consumption by major countries (%)

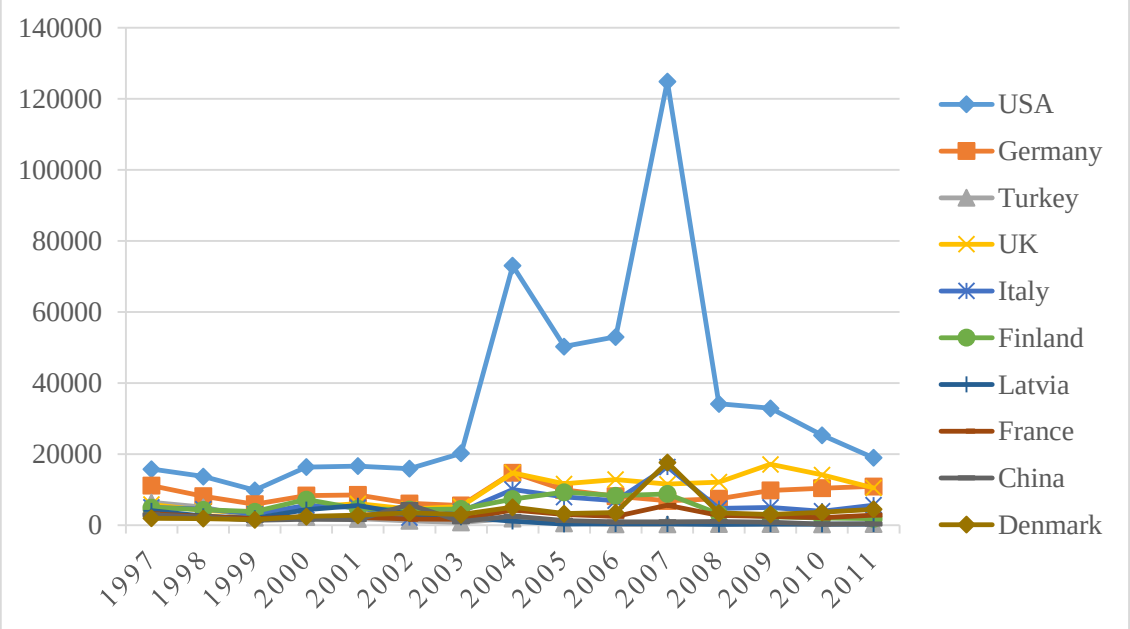


Figure 48. Energy Use change in Plywood consumption by major countries (TJ)

5.2.6 Sawnwood (C)

Energy use amount and percentage of Russian Sawnwood (C) production caused by top 10 consumption countries are shown in **Figure 47** and **Figure 48**. The total energy use gradually decreased. China and Japan are responsible for most Energy use by Russian Sawnwood (C) production from1997-2011. China used to be the largest responsible country but energy use caused by China gradually decreased. Japan became the largest responsible country after 2004. Compare with consumption amount in **Figure 14**, with slightly increase in Sawnwood (C) consumption since 2007, the energy use caused by Japan greatly increased. It indicates Japan imported more Sawnwood (C) related products with high energy use in production to reduce domestic energy use.

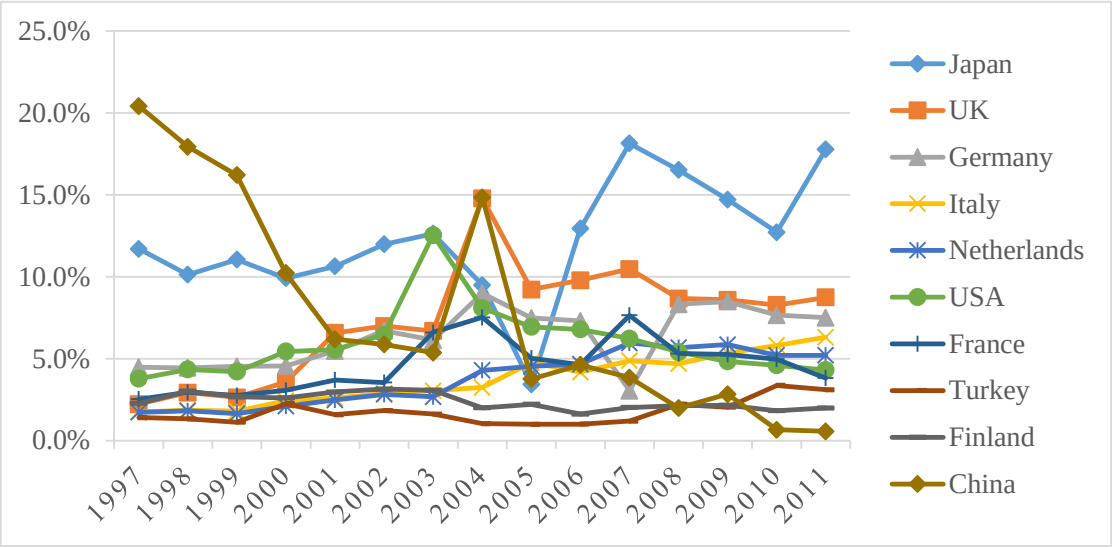


Figure 47. Energy Use change in Sawnwood (C) consumption by major countries (%)

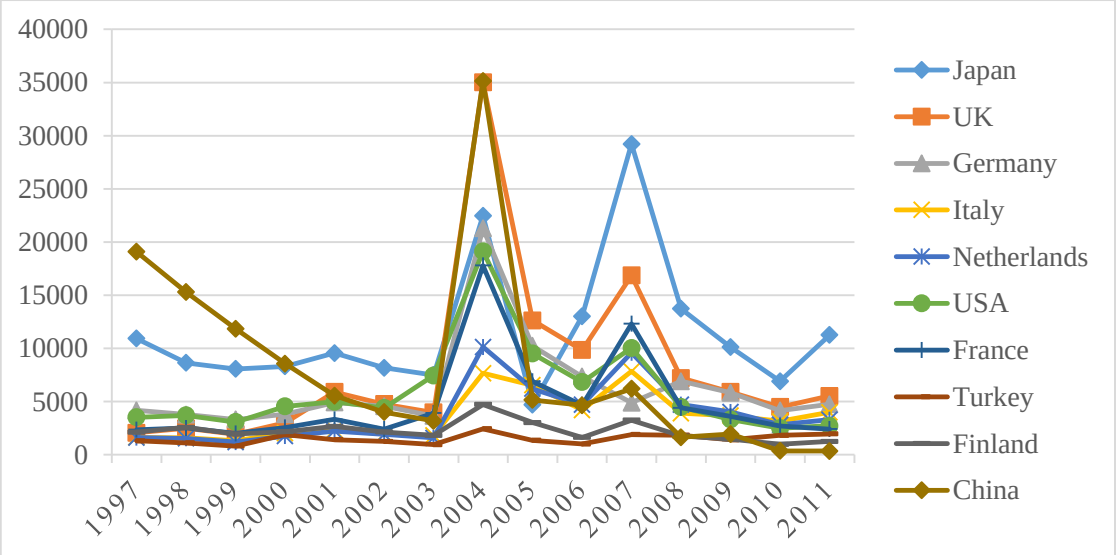


Figure 48. Energy Use change in Sawnwood (C) consumption by major countries (TJ)

5.2.7 Sawnwood (NC)

Energy use amount and percentage of Russian Sawnwood (NC) production caused by top 10 consumption countries are shown in **Figure 49** and **Figure 50**. The total energy use gradually decreased. China is responsible for most energy use by Russian Sawnwood (NC) production before 2008. After that, Energy use caused by China gradually decreased. Compare with consumption amount in **Figure 16**, with dramatically increase in Sawnwood (NC) consumption since 2003, the Energy use caused by China greatly decreased. It indicates the great technique improvement of reducing Energy use in Sawnwood (NC) related production.

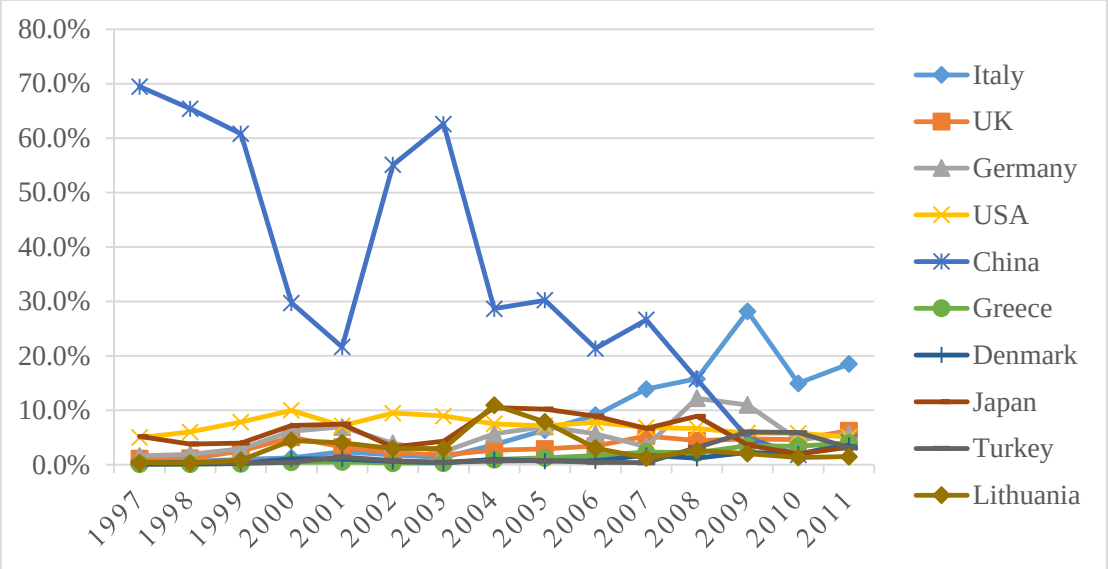


Figure 49. Energy Use change in Sawnwood (NC) consumption by major countries (%)

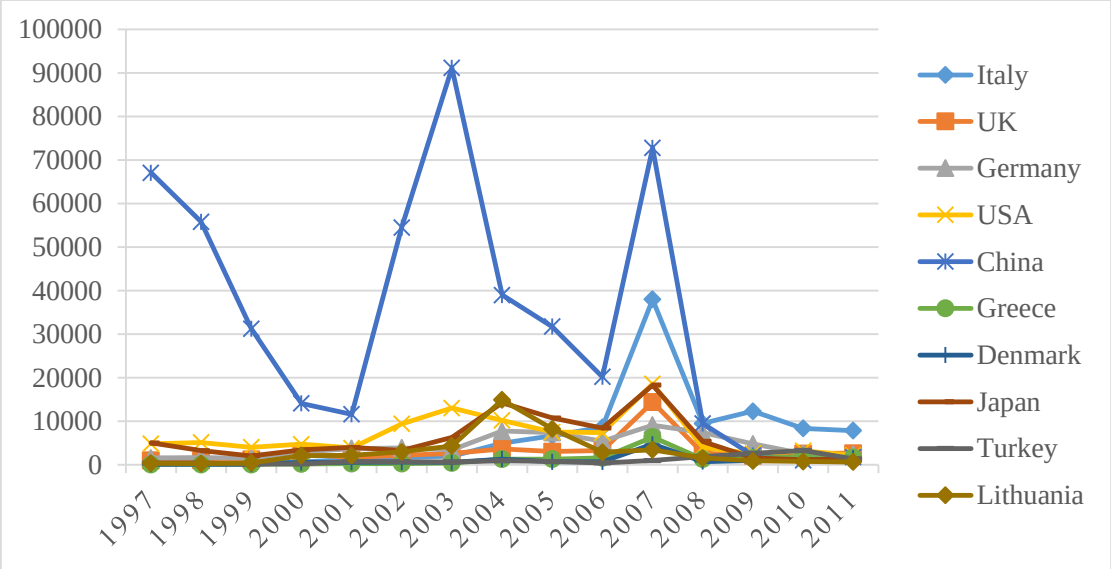


Figure 50. Energy Use change in Sawnwood (NC) consumption by major countries (TJ)

5.2.8 Veneer Sheets

Energy use amount and percentage of Veneer Sheets production caused by top 10 consumption countries are shown in **Figure 51** and **Figure 52**. The total Energy use gradually decreased. Japan used to be the largest responsible country of energy use by Russian Veneer Sheets production before 2000. But the emission caused by Japan greatly decreased since 1998. Compare with consumption amount in **Figure 18**, with dramatically increase in Veneer Sheets consumption since 2008, the Energy use caused by Japan greatly decreased. It indicates great technique improvement of reducing energy use in Veneer Sheets related production.

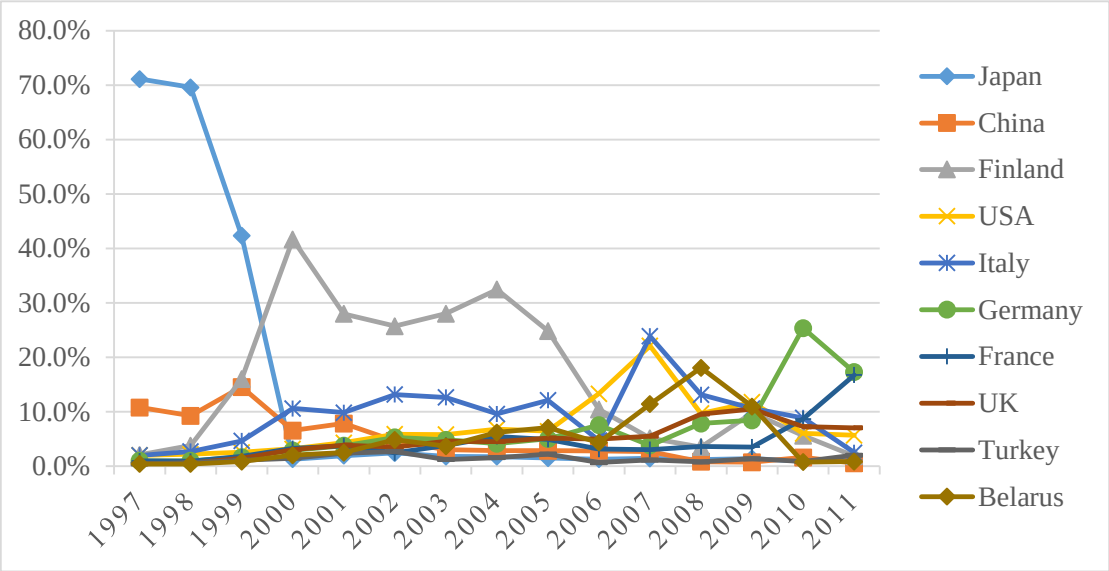


Figure 51. Energy Use change in Veneer Sheets consumption by major countries (%)

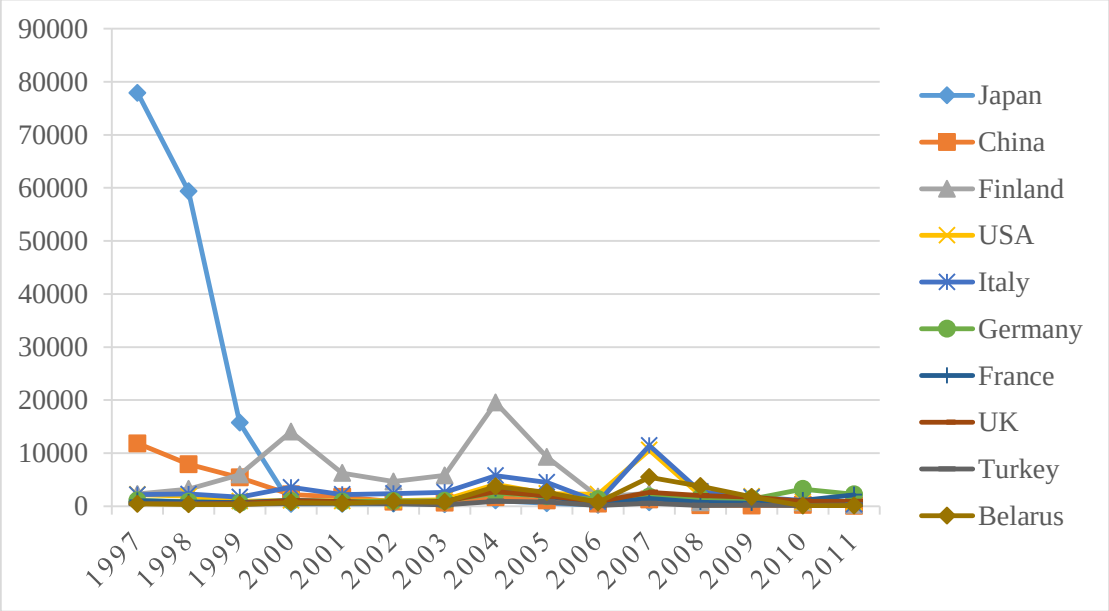


Figure 52. Energy Use change in Veneer Sheets consumption by major countries (TJ)

5.2.9 Newsprint

Energy use amount and percentage of Russian Newsprint production caused by top 10 consumption countries are shown in **Figure 53** and **Figure 54**. The total energy use gradually decreased. India, Turkey, Germany and China are responsible for most Energy use by Russian Newsprint production from1997-2011. Compare with consumption amount in **Figure 20**, with gradual increase in Newsprint consumption since 2005, the energy use caused by India, Turkey and Germany decreased dramatically. It indicates the great technique improvement of reducing energy use in Newsprint related production.

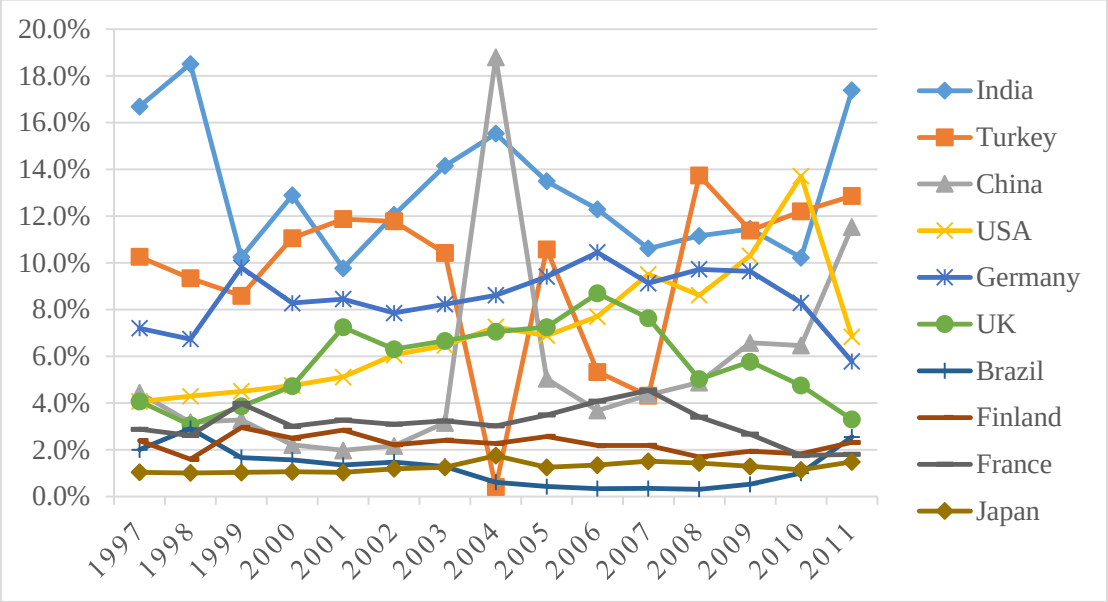


Figure 53. Energy Use change in Newsprint consumption by major countries (%)

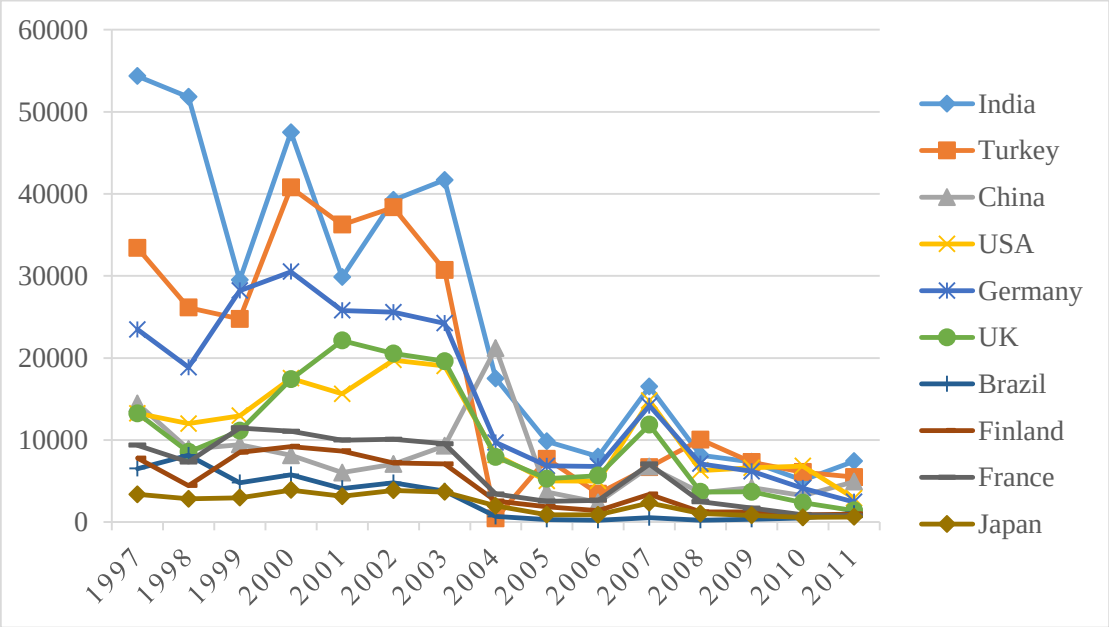


Figure 54. Energy Use change in Newsprint consumption by major countries (TJ)

5.4 Chapter summary

By incorporate WIOD and FAO datasets, a disaggregated A^* matrix with Russian wood product sectors and industry sectors around the world in monetary form was built. After consumption-based accounting analysis, the result indicates the major final responsible countrys of CO_2 emission and energy use in Russian wood products are China, Finland, Japan, Germany, USA, France, Belarus, India and Turkey.

The consumption-based accounting analysis result of CO_2 emission and energy use in Russian wood products is quite similar as final consumer analysis results in Chapter 4.4. The time series analysis of consumption accounting CO_2 emission and energy use in Russian wood products indicates the great technology improvement of reducing CO_2 emission and increase energy efficiency in Russian wood products related industry production around the world.

China used to be the largest final responsible country of CO_2 emission and energy use in Russian Roundwood (C), Roundwood (NC), Sawnwood (C) and Sawnwood (NC), but its impact greatly decreased. China is no longer the largest responsible country in those Russian wood products. Japan is the largest final responsible country in Russian Veneer Sheets, Roundwood (C), Chips and Particles and Sawnwood (C). Japan used to be the largest final responsible country in Veneer Sheets, but its impact greatly decreased. Now Germany is the largest responsible country in Veneer Sheets. Italy is the largest final responsible country in Russian Sawnwood (NC). Finland is the largest final responsible country in Russian Chips and Particles, Roundwood (NC). Belarus is the largest final responsible country in Russian Particle Board. USA is the largest final responsible country in Russian Plywood. India is the largest final responsible country in Russian Newsprint.

There is little direct export of Russian wood products to USA and developed European countries, but they are important final responsible country of CO_2 emission and energy use in Russian wood products.

6. Structural Path Analysis (SPA) of Russian Wood industry

In Chapter 4, the major final consumer countries as the driven force of Russian wood production are analyzed. In this chapter, the important intermediate industries in the supply chains of Russian wood products will be investigated by Structural Path Analysis.

6.1 Building models and calculation algorithm

The disaggregated A^* matrix with 9 Russian wood products in monetary form are obtained as the same way in Chapter 5.1. The calculation algorithm is shown in **Appendix 4**. The methodology for SPA is described by **equation 19-21** and **Box 1** in Chapter 3.3.

The calculation of SPA is time consuming and memory consuming. The computational complexity is $O(n^m)$, where n is the number of sectors in IO, m is the order of paths to calculate. Usually calculating the second-order SPA for a single sector in an IO table with 1,500 sectors will take 20 seconds with single CPU core, while calculating the third-order SPA in this 1,500 sector IO table will take 8.33 hours for single CPU core. For the fifth-order, it will be 521 days! In IO network, the substance through the paths will decrease as the number of orders increase in the path. Usually the most critical paths are all within the first-order to the third-order paths. Seldom critical paths are in fourth-order path. Therefore, if not specially mentioned, the SPA in this research will only calculate by the third order.

Usually, the full calculation result in a 1,500 sector IO table to 3rd-order will take 50 GB of memory, and 51500GB of memory for 4th-order! That is out of range of contemporary computer! Luckily we don't need to record all the results. A SPA algorithm with much fewer memory cost was programmed to do the calculation in this research. The code is shown in **Appendix 3**.

6.2 Structural Path Analysis (SPA) in single year

First we need to find the most important supply chains for Russian wood products for single year. Taking the most recent data year 2011 as example. The analysis results are discussed in the following.

6.2.1 Russian Roundwood (C)

Top 10 downstream supply chain SPA results of Russian Roundwood (C) in 2011 is shown in **Table 8**. The major downstream demanders of Russian Roundwood (C) are Wood and Products of Wood and Cork sector, Rubber and Plastics sector, Pulp, Paper, Printing and Publishing sector in China. Sectors in China covered over 57% of Russian Roundwood (C) direct export.

The second-order supply chain from Wood and Products of Wood and Cork sector in China to itself and supply chain from Wood and Products of Wood and Cork sector to Manufacturing, Recycling sector in China are also very important supply chains to Russian Roundwood (C). Therefore the wood industry in China is critical to Russian Roundwood (C) production.

Table 8. Top 10 downstream supply chain of Russian Roundwood (C) in 2011.

Rank	Supply chain Coverage (%)	Downstream supply chain
1	38.7%	Roundwood (C) ->Wood and Products of Wood and Cork (CHN)
2	14.4%	Roundwood (C) ->Wood and Products of Wood and Cork (CHN) ->Wood and Products of Wood and Cork (CHN)
3	14.0%	Roundwood (C) ->Rubber and Plastics (CHN)
4	5.4%	Roundwood (C) ->Wood and Products of Wood and Cork (CHN) ->Wood and Products of Wood and Cork (CHN) ->Wood and Products of Wood and Cork (CHN)
5	5.2%	Roundwood (C) ->Pulp, Paper, Paper , Printing and Publishing (CHN)
6	3.0%	Roundwood (C) ->Wood and Products of Wood and Cork (RoW)
7	2.3%	Roundwood (C) ->Wood and Products of Wood and Cork (CHN) ->Manufacturing, Nec; Recycling (CHN)
8	2.0%	Roundwood (C) ->Wood and Products of Wood and Cork (FIN)
9	1.9%	Roundwood (C) ->Manufacturing, Nec; Recycling (CHN)
10	1.4%	Roundwood (C) ->Pulp, Paper, Paper , Printing and Publishing (FIN)

6.2.2 Roundwood (NC)

Top 10 downstream supply chain SPA results of Russian Roundwood (NC) in 2011 is shown in **Table 9**. The major downstream demanders of Russian Roundwood (NC) are Wood and Products of Wood and Cork sector in Finland and China, Pulp, Paper, Printing and Publishing sector and Agriculture, Hunting, Forestry and Fishing sector in Finland, along with Wood and Products of Wood and Cork sector and Pulp, Paper, Paper , Printing and Publishing sector in

Sweden.

Sectors in Finland covered over 50% of Russian Roundwood (NC) supply chain, China is about 16.7%, while Sweden took about 2.6%. The second-order supply chain from Wood and Products of Wood and Cork sector in Finland to Construction sector in Finland and supply chain from Wood and Products of Wood and Cork sector in Finland to itself are also very important. Therefore the wood industry of China, Finland and Sweden are critical to Russian Roundwood (NC) production.

Table 9. Top 10 downstream supply chain of Russian Roundwood (NC) in 2011.

Rank	Supply chain Coverage (%)	Downstream supply chain
1	24.4%	Roundwood (NC) ->Wood and Products of Wood and Cork (FIN)
2	17.0%	Roundwood (NC) ->Pulp, Paper, Paper , Printing and Publishing (FIN)
3	16.7%	Roundwood (NC) ->Wood and Products of Wood and Cork (CHN)
4	9.3%	Roundwood (NC) ->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)
5	8.8%	Roundwood (NC) ->Agriculture, Hunting, Forestry and Fishing (FIN)
6	3.6%	Roundwood (NC) ->Wood and Products of Wood and Cork (SWE)
7	2.7%	Roundwood (NC) ->Wood and Products of Wood and Cork (FIN) ->Wood and Products of Wood and Cork (FIN)
8	2.6%	Roundwood (NC) ->Pulp, Paper, Paper , Printing and Publishing (SWE)
9	2.1%	Roundwood (NC) ->Pulp, Paper, Paper , Printing and Publishing (FIN) ->Pulp, Paper, Paper , Printing and Publishing (FIN)
10	1.6%	Roundwood (NC) ->Agriculture, Hunting, Forestry and Fishing (FIN) ->Wood and Products of Wood and Cork (FIN)

6.2.3 Chips and Particles

Top 10 downstream supply chain SPA results of Russian Chips and Particles in 2011 is shown in **Table 10**. The major downstream demander sectors of Russian Chips and Particles are all from Finland. They are Construction sector, Pulp, Paper, Printing and Publishing sector, Manufacturing, Recycling sector and Electricity, Gas and Water Supply sector.

The second-order supply chain from Construction sector in Finland to Real Estate Activities

sector in Finland and supply chain from Wood and Products of Wood and Cork sector in Finland to Construction sector in Finland are also very important. Therefore the wood industry, construction industry and paper industry in Finland are critical to Russian Chips and Particles production.

Table 10. Top 10 downstream supply chain of Russian Chips and Particles in 2011.

Rank	Supply chain Coverage (%)	Downstream supply chain
1	59.5%	Chips and Particles ->Construction (FIN)
2	17.6%	Chips and Particles ->Wood and Products of Wood and Cork (FIN)
3	6.9%	Chips and Particles ->Construction (FIN) ->Real Estate Activities (FIN)
4	6.7%	Chips and Particles ->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)
5	6.0%	Chips and Particles ->Pulp, Paper, Paper , Printing and Publishing (FIN)
6	3.1%	Chips and Particles ->Manufacturing, Nec; Recycling (FIN)
7	2.3%	Chips and Particles ->Electricity, Gas and Water Supply (FIN)
8	2.0%	Chips and Particles ->Wood and Products of Wood and Cork (FIN) ->Wood and Products of Wood and Cork (FIN)
9	0.6%	Chips and Particles ->Mining and Quarrying (FIN)
10	0.4%	Chips and Particles ->Wood and Products of Wood and Cork (FIN) ->Manufacturing, Nec; Recycling (FIN)

6.2.4 Particle Board

Top 10 downstream supply chain SPA results of Russian Particle Board in 2011 is shown in **Table 11**. The major downstream demander sectors of Russian Particle Board is mainly from Belarus. They are Construction Sector, Wood and Products of Wood and Cork sector, Real Estate Activities sector and Manufacturing, Recycling sector in Belarus. Sectors in Belarus covered over 19% of Russian Particle Board supply chain. The second-order supply chain from Wood and Products of Wood and Cork sector in Belarus to itself and Construction sector in Belarus to itself are also very important. Therefore, the wood industry, construction industry and paper industry of Belarus are critical to Russian Particle Board production.

6.2.5 Plywood

Top 10 downstream supply chain SPA results of Russian Plywood in 2011 are shown in **Table 12**. The export of Russian Plywood is scattered to sectors around the world. The major

downstream demanders of Russian Plywood are Wood and Products of Wood and Cork sector in Latvia, UK, Turkey, Finland and Estonia, and Construction sector in Latvia and Estonia. Therefore, wood industry in Latvia, Turkey, Finland and Estonia and construction industry in Latvia are important to Russian Plywood industry.

Table 11. Top 10 downstream supply chain of Particle Board in 2011.

Rank	Supply chain Coverage (%)	Downstream supply chain
1	26.7%	Particle Board ->Wood and Products of Wood and Cork (RoW)
2	9.2%	Particle Board ->Construction (BEL)
3	7.5%	Particle Board ->Wood and Products of Wood and Cork (BEL)
4	5.7%	Particle Board ->Wood and Products of Wood and Cork (RoW) ->Wood and Products of Wood and Cork (RoW)
5	4.4%	Particle Board ->Manufacturing, Nec; Recycling (RoW)
6	2.4%	Particle Board ->Construction (BEL) ->Construction (BEL)
7	1.5%	Particle Board ->Real Estate Activities (BEL)
8	1.3%	Particle Board ->Manufacturing, Nec; Recycling (BEL)
9	1.1%	Particle Board ->Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies (BEL)
10	1.1%	Particle Board ->Wood and Products of Wood and Cork (POL)

Table 12. Top 10 downstream supply chain of Plywood in 2011.

Rank	Coverage (%)	Downstream supply chain
1	2.7%	Plywood ->Wood and Products of Wood and Cork (LVA)
2	1.9%	Plywood ->Construction (LVA)
3	1.4%	Plywood ->Wood and Products of Wood and Cork (TUR)
4	1.1%	Plywood ->Wood and Products of Wood and Cork (GBR)
5	0.9%	Plywood ->Wood and Products of Wood and Cork (FIN)
6	0.9%	Plywood ->Wood and Products of Wood and Cork (EST)
7	0.8%	Plywood ->Manufacturing, Nec; Recycling (LVA)
8	0.8%	Plywood ->Construction (EST)
9	0.5%	Plywood ->Wood and Products of Wood and Cork (LVA) ->Wood and Products of Wood and Cork (LVA)
10	0.4%	Plywood ->Manufacturing, Nec; Recycling (EST)

6.2.6 Sawnwood (C)

Top 10 downstream supply chain SPA results of Russian Sawnwood (C) in 2011 is shown in **Table 13**. The export of Russian Plywood is scattered to sectors around the world. The major downstream demanders of Russian Sawnwood (C) are Construction sector in Finland and Estonia, and Wood and Products of Wood and Cork in China, Germany and Estonia.

Therefore, wood industry in Germany and Estonia, and construction industry in Finland and Estonia are important to Russian Sawnwood (C).

Table 13. Top 10 downstream supply chain of Sawnwood (C) in 2011.

Rank	Coverage (%)	Downstream supply chain
1	17.3%	Sawnwood (C) ->Wood and Products of Wood and Cork (RoW)
2	9.4%	Sawnwood (C) ->Wood and Products of Wood and Cork (CHN)
3	1.6%	Sawnwood (C) ->Construction (FIN)
4	1.1%	Sawnwood (C) ->Wood and Products of Wood and Cork (EST)
5	1.1%	Sawnwood (C) ->Wood and Products of Wood and Cork (DEU)
6	1.0%	Sawnwood (C) ->Construction (EST)
7	0.5%	Sawnwood (C) ->Wood and Products of Wood and Cork (FIN)
8	0.4%	Sawnwood (C) ->Manufacturing, Nec; Recycling (EST)
9	0.4%	Sawnwood (C) ->Wood and Products of Wood and Cork (KOR)
10	0.4%	Sawnwood (C) ->Wood and Products of Wood and Cork (GBR)

6.2.7 Sawnwood (NC)

Top 10 downstream supply chain SPA results of Russian Sawnwood (NC) in 2011 is shown in **Table 14**. The major downstream demander sectors of Russian Sawnwood (NC) are mainly from Wood and Products of Wood and Cork sector and Manufacturing, Recycling sector in China. China covered over 40% of Russian Sawnwood (NC) supply chain. The second-order supply chain from Wood and Products of Wood and Cork sector in China to itself is also very important. Therefore wood industry and manufacturing industry in China are important to Russian Plywood production.

Table 14. Top 10 downstream supply chain of Sawnwood (NC) in 2011.

Rank	Coverage (%)	Downstream supply chain
1	35.5%	Sawnwood (NC) ->Wood and Products of Wood and Cork (CHN)
2	13.2%	Sawnwood (NC) ->Wood and Products of Wood and Cork (CHN) ->Wood and Products of Wood and Cork (CHN)
3	5.8%	Sawnwood (NC) ->Manufacturing, Nec; Recycling (CHN)
4	0.5%	Sawnwood (NC) ->Wood and Products of Wood and Cork (EST)
5	0.4%	Sawnwood (NC) ->Construction (EST)
6	0.3%	Sawnwood (NC) ->Wood and Products of Wood and Cork (POL)
7	0.2%	Sawnwood (NC) ->Wood and Products of Wood and Cork (BEL)
8	0.2%	Sawnwood (NC) ->Manufacturing, Nec; Recycling (EST)
9	0.1%	Sawnwood (NC) ->Wood and Products of Wood and Cork (LVA)
10	0.1%	Sawnwood (NC) ->Manufacturing, Nec; Recycling (LTU)

6.2.8 Veneer Sheets

Top 10 downstream supply chain SPA results of Russian Veneer Sheets in 2011 is shown in **Table 15**. The major downstream demander sectors of Russian Veneer Sheets are Construction sector, Wood and Products of Wood and Cork sector, Pulp, Paper, Printing and Publishing sector and Manufacturing, Recycling sector in Japan and Construction sector in Finland. Japan covered over 28.6% of Russian Veneer Sheets supply chain. Therefore wood industry, construction industry and paper industry in Japan are critical to Russian Veneer Sheets production.

Table 15. Top 10 downstream supply chain of Veneer Sheets in 2011.

Rank	Coverage (%)	Downstream supply chain
1	15.0%	Veneer Sheets ->Construction (JPN)
2	9.2%	Veneer Sheets ->Wood and Products of Wood and Cork (JPN)
3	4.4%	Veneer Sheets ->Manufacturing, Nec; Recycling (JPN)
4	4.3%	Veneer Sheets ->Construction (FIN)
5	2.1%	Veneer Sheets ->Wood and Products of Wood and Cork (ITA)
6	1.5%	Veneer Sheets ->Wood and Products of Wood and Cork (FIN)
7	0.9%	Veneer Sheets ->Wood and Products of Wood and Cork (AUT)
8	0.8%	Veneer Sheets ->Wood and Products of Wood and Cork (CZE)
9	0.7%	Veneer Sheets ->Wood and Products of Wood and Cork (BEL)
10	0.2%	Veneer Sheets ->Wood and Products of Wood and Cork (EST)

Table 16. Top 10 downstream supply chain of Newsprint in 2011.

Rank	Coverage (%)	Downstream supply chain
1	15.0%	Newsprint ->Pulp, Paper, Paper , Printing and Publishing (RoW)
2	9.2%	Newsprint ->Pulp, Paper, Paper , Printing and Publishing (IND)
3	4.4%	Newsprint ->Pulp, Paper, Paper , Printing and Publishing (DEU)
4	4.3%	Newsprint ->Pulp, Paper, Paper , Printing and Publishing (TUR)
5	2.1%	Newsprint ->Pulp, Paper, Paper , Printing and Publishing (IND) ->Pulp, Paper, Paper , Printing and Publishing (IND)
6	1.5%	Newsprint ->Pulp, Paper, Paper , Printing and Publishing (FIN)
7	0.9%	Newsprint ->Pulp, Paper, Paper , Printing and Publishing (BGR)
8	0.8%	Newsprint ->Pulp, Paper, Paper , Printing and Publishing (TUR) ->Pulp, Paper, Paper , Printing and Publishing (TUR)
9	0.7%	Newsprint ->Pulp, Paper, Paper , Printing and Publishing (GRC)
10	0.2%	Newsprint ->Pulp, Paper, Paper , Printing and Publishing (ROU)

6.2.9 Newsprint

Top 10 downstream supply chain SPA results of Russian Newsprint from 1996 to 2011 are shown in **Table 16**. The major downstream demander sectors of Russian Newsprint are Pulp,

Paper, Printing and Publishing in India, Turkey, Finland and Germany. Therefore the Paper, Printing and Publishing industry in India, Turkey, Finland and Germany are critical to Russian Newsprint production.

6.3 Structural Path Analysis (SPA) of time series data

By analyzing the supply chain change in the last two decades will help us understand the critical supply chains and the developing trend in the future. The results are shown bellow.

6.3.1 Russian Chips and Particles

Top 10 downstream supply chain SPA result of Russian Chips and Particles from 1997 to 2011 is shown in **Table 17-20**. The major downstream demander sectors of Russian Chips and Particles are all from Finland. They are Construction sector, Pulp, Paper, Printing and Publishing sector, Manufacturing, Recycling sector and Electricity, Gas and Water Supply sector. The coverage of Construction sector increase from 27.9% in 1997 to 46.0% in 2002, then reach to 50.9% in 2005. In 2008 and 2009 suddenly dropped below 30% then reached to new max as 59.5% in 2011. Pulp, Paper, Printing and Publishing sector shrunk from 14.6% in 1997 to 2.6% in 2009 then revered to 6.0% in 2011. Pulp, Paper, Printing and Publishing sector remained around 14% in from 1997 to 2003 then raised over 18.0% until 2008. In 2009 it shrunk to 7.1% then recovered to 17.6% in 2011. Manufacturing, Recycling sector and Electricity, Gas and Water Supply sector remained in around 3.3% and 2.0%. The supply chain of Construction sector -> Real Estate Activities sector and Wood and Products of Wood and Cork sector -> Construction sector are also very important. Therefore, the wood industry, construction industry and paper industry of Finland is critical to Russian Chips and Particles production.

Table 17. Top 10 downstream supply chain change of Russian Chips and Particles during 1997-2000.

Rank	1997		1998		1999		2000	
	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain
1	27.9%	->Construction (FIN)	24.7%	->Construction (FIN)	34.6%	->Construction (FIN)	27.1%	->Construction (FIN)
2	14.6%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	11.0%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	14.0%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	12.1%	->Wood and Products of Wood and Cork (FIN)
3	10.4%	->Wood and Products of Wood and Cork (FIN)	8.6%	->Wood and Products of Wood and Cork (FIN)	10.0%	->Wood and Products of Wood and Cork (FIN)	7.4%	->Pulp, Paper, Paper , Printing and Publishing (FIN)
4	2.8%	->Manufacturing, Nec; Recycling (FIN)	6.8%	->Wood and Products of Wood and Cork (JPN)	4.3%	->Construction (FIN) ->Real Estate Activities (FIN)	3.3%	->Construction (FIN) ->Real Estate Activities (FIN)
5	1.6%	->Construction (EST)	3.1%	->Construction (FIN) ->Real Estate Activities (FIN)	2.3%	->Manufacturing, Nec; Recycling (FIN)	2.9%	->Manufacturing, Nec; Recycling (FIN)
6	1.4%	->Wood and Products of Wood and Cork (EST)	2.2%	->Manufacturing, Nec; Recycling (FIN)	1.4%	->Electricity, Gas and Water Supply (FIN)	2.6%	->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)
7	1.1%	->Manufacturing, Nec; Recycling (EST)	1.2%	->Electricity, Gas and Water Supply (FIN)	0.8%	->Other Non-Metallic Mineral (FIN)	1.5%	->Electricity, Gas and Water Supply (FIN)
8	0.8%	->Other Non-Metallic Mineral (FIN)	0.6%	->Other Non-Metallic Mineral (FIN)	0.4%	->Transport Equipment (FIN)	1.2%	->Wood and Products of Wood and Cork (FIN) ->Wood and Products of Wood and Cork (FIN)
9	0.1%	->Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods (EST)	0.4%	->Transport Equipment (FIN)	0.4%	->Wood and Products of Wood and Cork (BEL)	0.4%	->Other Non-Metallic Mineral (FIN)
10	0.0%	->Other Non-Metallic Mineral (EST)	0.3%	->Rubber and Plastics (FIN)	0.3%	->Rubber and Plastics (FIN)	0.3%	->Wood and Products of Wood and Cork (FIN) ->Manufacturing, Nec; Recycling (FIN)

Table 18. Top 10 downstream supply chain change of Russian Chips and Particles during 2001-2004.

Rank	2001		2002		2003		2004	
	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain
1	26.8%	->Construction (FIN)	46.0%	->Construction (FIN)	27.9%	->Construction (FIN)	47.3%	->Construction (FIN)
2	11.5%	->Wood and Products of Wood and Cork (FIN)	15.6%	->Wood and Products of Wood and Cork (FIN)	14.6%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	18.0%	->Wood and Products of Wood and Cork (FIN)
3	5.7%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	9.9%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	10.4%	->Wood and Products of Wood and Cork (FIN)	8.3%	->Pulp, Paper, Paper , Printing and Publishing (FIN)
4	3.1%	->Construction (FIN) ->Real Estate Activities (FIN)	5.4%	->Construction (FIN) ->Real Estate Activities (FIN)	3.7%	->Construction (FIN) ->Real Estate Activities (FIN)	5.3%	->Construction (FIN) ->Real Estate Activities (FIN)
5	2.6%	->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)	4.7%	->Manufacturing, Nec; Recycling (FIN)	2.8%	->Manufacturing, Nec; Recycling (FIN)	4.7%	->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)
6	2.4%	->Manufacturing, Nec; Recycling (FIN)	3.6%	->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)	1.6%	->Construction (EST)	3.9%	->Manufacturing, Nec; Recycling (FIN)
7	1.1%	->Wood and Products of Wood and Cork (FIN) ->Wood and Products of Wood and Cork (FIN)	2.3%	->Electricity, Gas and Water Supply (FIN)	1.4%	->Electricity, Gas and Water Supply (FIN)	3.5%	->Construction (FIN) ->Construction (FIN)
8	1.1%	->Electricity, Gas and Water Supply (FIN)	1.2%	->Wood and Products of Wood and Cork (FIN) ->Wood and Products of Wood and Cork (FIN)	1.4%	->Wood and Products of Wood and Cork (EST)	2.7%	->Electricity, Gas and Water Supply (FIN)
9	0.3%	->Other Non-Metallic Mineral (FIN)	0.4%	->Other Non-Metallic Mineral (FIN)	1.1%	->Manufacturing, Nec; Recycling (EST)	1.8%	->Wood and Products of Wood and Cork (FIN) ->Wood and Products of Wood and Cork (FIN)
10	0.2%	->Wood and Products of Wood and Cork (FIN) ->Manufacturing, Nec; Recycling (FIN)	0.4%	->Wood and Products of Wood and Cork (FIN) ->Manufacturing, Nec; Recycling (FIN)	0.8%	->Other Non-Metallic Mineral (FIN)	0.4%	->Wood and Products of Wood and Cork (FIN) ->Manufacturing, Nec; Recycling (FIN)

Table 19. Top 10 downstream supply chain change of Russian Chips and Particles during 2005-2008.

Rank	2005		2006		2007		2008	
	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain
1	50.9%	->Construction (FIN)	48.4%	->Construction (FIN)	47.5%	->Construction (FIN)	30.8%	->Construction (FIN)
2	18.0%	->Wood and Products of Wood and Cork (FIN)	19.1%	->Wood and Products of Wood and Cork (FIN)	17.8%	->Wood and Products of Wood and Cork (FIN)	20.8%	->Wood and Products of Wood and Cork (RoW)
3	6.6%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	6.5%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	5.9%	->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)	8.9%	->Wood and Products of Wood and Cork (FIN)
4	5.4%	->Construction (FIN) ->Real Estate Activities (FIN)	3.4%	->Manufacturing, Nec; Recycling (FIN)	5.3%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	3.3%	->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)
5	5.1%	->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)	2.8%	->Electricity, Gas and Water Supply (FIN)	4.4%	->Construction (FIN) ->Real Estate Activities (FIN)	3.1%	->Pulp, Paper, Paper , Printing and Publishing (FIN)
6	4.2%	->Manufacturing, Nec; Recycling (FIN)	2.4%	->Wood and Products of Wood and Cork (FIN) ->Wood and Products of Wood and Cork (FIN)	2.7%	->Manufacturing, Nec; Recycling (FIN)	2.8%	->Construction (FIN) ->Real Estate Activities (FIN)
7	3.0%	->Electricity, Gas and Water Supply (FIN)	1.8%	->Wood and Products of Wood and Cork (TUR)	2.2%	->Wood and Products of Wood and Cork (FIN) ->Wood and Products of Wood and Cork (FIN)	1.7%	->Manufacturing, Nec; Recycling (FIN)
8	1.8%	->Wood and Products of Wood and Cork (FIN) ->Wood and Products of Wood and Cork (FIN)	0.7%	->Wood and Products of Wood and Cork (LTU)	1.4%	->Wood and Products of Wood and Cork (TUR)	0.9%	->Wood and Products of Wood and Cork (FIN) ->Wood and Products of Wood and Cork (FIN)
9	0.6%	->Mining and Quarrying (FIN)	0.5%	->Manufacturing, Nec; Recycling (LTU)	1.2%	->Electricity, Gas and Water Supply (FIN)	0.9%	->Electricity, Gas and Water Supply (FIN)
10	0.4%	->Wood and Products of Wood and Cork (FIN) ->Manufacturing, Nec; Recycling (FIN)	0.2%	->Pulp, Paper, Paper , Printing and Publishing (LTU)	0.3%	->Mining and Quarrying (FIN)	0.2%	->Mining and Quarrying (FIN)

Table 20. Top 10 downstream supply chain change of Russian Chips and Particles during 2009-2011.

Rank	2009		2010		2011	
	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain
1	28.4%	->Construction (FIN)	47.5%	->Construction (FIN)	59.5%	->Construction (FIN)
2	22.2%	->Wood and Products of Wood and Cork (RoW)	14.3%	->Wood and Products of Wood and Cork (FIN)	17.6%	->Wood and Products of Wood and Cork (FIN)
3	7.1%	->Wood and Products of Wood and Cork (FIN)	5.7%	->Construction (FIN) ->Real Estate Activities (FIN)	6.9%	->Construction (FIN) ->Real Estate Activities (FIN)
4	3.1%	->Construction (FIN) ->Real Estate Activities (FIN)	5.6%	->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)	6.7%	->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)
5	2.9%	->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)	5.1%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	6.0%	->Pulp, Paper, Paper , Printing and Publishing (FIN)
6	2.6%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	2.4%	->Manufacturing, Nec; Recycling (FIN)	3.1%	->Manufacturing, Nec; Recycling (FIN)
7	1.4%	->Manufacturing, Nec; Recycling (FIN)	2.1%	->Electricity, Gas and Water Supply (FIN)	2.3%	->Electricity, Gas and Water Supply (FIN)
8	1.0%	->Electricity, Gas and Water Supply (FIN)	1.7%	->Wood and Products of Wood and Cork (FIN) ->Wood and Products of Wood and Cork (FIN)	2.0%	->Wood and Products of Wood and Cork (FIN) ->Wood and Products of Wood and Cork (FIN)
9	0.7%	->Wood and Products of Wood and Cork (FIN) ->Wood and Products of Wood and Cork (FIN)	0.4%	->Mining and Quarrying (FIN)	0.6%	->Mining and Quarrying (FIN)
10	0.2%	->Mining and Quarrying (FIN)	0.3%	->Wood and Products of Wood and Cork (FIN) ->Manufacturing, Nec; Recycling (FIN)	0.4%	->Wood and Products of Wood and Cork (FIN) ->Manufacturing, Nec; Recycling (FIN)

6.3.2 Roundwood (C)

Top 10 downstream supply chain SPA results of Russian Roundwood (C) from 1997 to 2011 are shown in **Table 21**. Wood and Products of Wood and Cork sector in Japan used to be the largest supply chain for Russian Roundwood (C) from 1997 to 2001, but dropped below 1.4% after 2006. Wood and Products of Wood and Cork sector in China became the largest supply chain for Russian Roundwood (C) after 2001. Its coverage increased from 6.2% in 2001 to 38.7% in 2011. Rubber and Plastics sector in China was below 1.2% until 2006, then it suddenly raised to 14.0% after 2006. Wood and Products of Wood and Cork sector in Finland increased its coverage from 1.2% in 1997 to 6.0% in 2006, then dropped below to 2.0% in 2011. Therefore wood industry and paper industry in China and Finland is critical to Russian Roundwood (C) production.

6.3.3 Roundwood (NC)

Top 10 downstream supply chain SPA result of Russian Roundwood (NC) from 1997 to 2011 is shown in **Table 22**. The major downstream demanders of Russian Roundwood (NC) are Wood and Products of Wood and Cork sector in Finland and China, Pulp, Paper, Printing and Publishing sector and Agriculture, Hunting, Forestry and Fishing sector in Finland, and Wood and Products of Wood and Cork sector in Sweden. The coverage of Wood and Products of Wood and Cork sector in Finland remained around 24%-26% during 1997-2011. Wood and Products of Wood and Cork sector in China increased from 4.6% to 16.7%. Pulp, Paper, Printing and Publishing sector in Finland increased from 15.1% to 17.0%. Agriculture, Hunting, Forestry and Fishing sector in Finland increased from 7.4% to 8.8%, while Wood and Products of Wood and Cork sector in Sweden increased from below 1.2% to 3.6%. Therefore the wood industry and paper industry of China, Finland and Sweden is critical to Russian Roundwood (NC) production.

6.3.4 Particle Board

Top 10 downstream supply chain SPA result of Russian Particle Board from 1996 to 2011 is shown in **Table 23**. The export of Russian Particle Board is scattered to sectors around the world. Wood and Products of Wood and Cork sector in Latvia used to be the largest downstream supply chain, it covered 7.2% in 1997 then dropped below 1.3% after then. Construction sector in Belarus gradually increased from below 0.9% in 1997 suddenly to 16.8% in 2001, then dropped below 1.5% and recovered to 9.2% in 2011. Wood and Products of Wood and Cork sector in Belarus gradually increased from below 0.9% in 1997 suddenly to 10.2% in 2001, then dropped below 1.5% and recovered to 7.5% in 2011. Real Estate Activities sector in Belarus gradually raised to 1.5%. Therefore, the economy condition of Belarus is critical to Russian Particle Board production.

6.3.5 Plywood

Top 10 downstream supply chain SPA result of Russian Plywood from 1997 to 2011 is shown in **Table 24**. The export of Russian Plywood is scattered to sectors around the world. The major downstream demanders of Russian Plywood are Wood and Products of Wood and Cork sector in Latvia, Estonia and UK, and Construction sector in Latvia, Finland and Estonia. The coverage of Wood and Products of Wood and Cork sector in UK shrunk from 3.0% in 1997 to below 0.4% in 2011. Wood and Products of Wood and Cork sector in Latvia increased from 0.3% to 2.7%. Manufacturing Recycling sector in Latvia increased from below 0.2% to 0.8%. Construction sector in Finland raised from below 0.2% in 1997 to 2.7% in 2006 then dropped below 0.4%. Therefore, Wood and Products of Wood and Cork sector, Manufacturing, Recycling sector and Construction sectors in Turkey and Latvia are critical to Russian Plywood production. Construction sector in Latvia is getting more and more important.

6.3.6 Sawnwood (C)

Top 10 downstream supply chain SPA result of Russian Sawnwood (C) from 1996 to 2011 is shown in **Table 25**. The major downstream demanders of Russian Sawnwood (C) are Wood and Products of Wood and Cork sector in China, Estonia, Germany and Finland, and Construction sector in Finland and Estonia.

The coverage of Wood and Products of Wood and Cork sector in China was below 0.2% until 2006 then suddenly increased to 9.4%. Construction sector in Finland raised from below 0.2% in 1996 to 1.6% in 2011. Wood and Products of Wood and Cork sector in Estonia remained in around 1%. Wood and Products of Wood and Cork sector in Germany suddenly raised from below 0.2% to 1.1%.

Therefore, with the big demand drop from Wood and Products of Wood and Cork sector in China, Construction sector in Finland, Wood and Products of Wood and Cork sector in Germany and Estonia are critical to Russian Sawnwood (C) production.

6.3.7 Sawnwood (NC)

Top 10 downstream supply chain SPA results of Russian Veneer Sheets from 1997 to 2011 are shown in **Table 26**. The major downstream demander sectors of Russian Sawnwood (NC) are mainly from China, Estonia and Italy. Manufacturing, Recycling sector in China suddenly increased from below 0.3% before 2006 to 5.8% in 2011. Therefore, Wood and Products of Wood and Cork sector and Manufacturing, Recycling sector in China are critical to Russian Sawnwood (NC) production.

6.3.8 Veneer Sheets

Top 10 downstream supply chain SPA results of Russian Veneer Sheets from 1997 to 2011 are shown in **Table**

27. The major downstream demand sectors of Russian Veneer Sheets are Wood and Products of Wood and Cork sector and Construction sector in Japan and Construction sector in Finland. Construction sector in Japan suddenly raised from below 0.2% in 1997 to 15.0% in 2011. Wood and Products of Wood and Cork sector in Japan s suddenly raised from below 0.2% in 1997 to 9.2% in 2011. Construction sector in Finland suddenly raised from below 0.2% to 15.1% in 2006 then dropped to 4.3% in 2011. Therefore wood industry and construction industry in Japan and Finland are critical to Russian Veneer Sheets production. It seems Japan's dependence on Russian Veneer Sheets production is increasing.

6.3.9 Newsprint

Top 10 downstream supply chain SPA results of Russian Veneer Sheets from 1997 to 2011 are shown in **Table 28**. The major downstream demander sectors of Russian Veneer Sheets are Pulp, Paper, Printing and Publishing in India, Turkey, Finland and Germany. Pulp, Paper, Printing and Publishing sector in India shrunk from 10.2% in 1996 to 9.2% in 2011. Turkey decreased from 5.3% to 4.3%. Germany suddenly raised from below 0.2% to 4.4% after 2006. Therefore, Pulp, Paper, Printing and Publishing sector in India, Germany and Turkey are critical to Russian Newsprint production.

Table 21. Top 10 downstream supply chain change of Russian Roundwood (C) during 1997-2011.

Rank	1997		2001		2006		2011	
	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain
1	21.5%	->Wood and Products of Wood and Cork (JPN)	9.0%	->Wood and Products of Wood and Cork (JPN)	21.4%	->Wood and Products of Wood and Cork (CHN)	38.7%	->Wood and Products of Wood and Cork (CHN)
2	6.7%	->Wood and Products of Wood and Cork (FIN)	6.3%	->Wood and Products of Wood and Cork (FIN)	7.7%	->Wood and Products of Wood and Cork (CHN) ->Wood and Products of Wood and Cork (CHN)	14.4%	->Wood and Products of Wood and Cork (CHN) ->Wood and Products of Wood and Cork (CHN)
3	6.4%	->Agriculture, Hunting, Forestry and Fishing (JPN)	6.2%	->Wood and Products of Wood and Cork (CHN)	6.0%	->Wood and Products of Wood and Cork (FIN)	14.0%	->Rubber and Plastics (CHN)
4	3.9%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	4.3%	->Wood and Products of Wood and Cork (SWE)	5.3%	->Wood and Products of Wood and Cork (JPN)	5.4%	->Wood and Products of Wood and Cork (CHN) ->Wood and Products of Wood and Cork (CHN) ->Wood and Products of Wood and Cork (CHN)
5	3.0%	->Wood and Products of Wood and Cork (JPN) ->Wood and Products of Wood and Cork (JPN)	4.2%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	3.1%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	5.2%	->Pulp, Paper, Paper , Printing and Publishing (CHN)
6	2.5%	->Wood and Products of Wood and Cork (SWE)	2.4%	->Pulp, Paper, Paper , Printing and Publishing (SWE)	2.4%	->Wood and Products of Wood and Cork (EST)	3.0%	->Wood and Products of Wood and Cork (RoW)
7	2.1%	->Wood and Products of Wood and Cork (KOR)	1.9%	->Agriculture, Hunting, Forestry and Fishing (FIN)	2.0%	->Agriculture, Hunting, Forestry and Fishing (FIN)	2.3%	->Wood and Products of Wood and Cork (CHN) ->Manufacturing, Nec; Recycling (CHN)
8	1.9%	->Agriculture, Hunting, Forestry and Fishing (FIN)	1.4%	->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)	1.1%	->Wood and Products of Wood and Cork (LVA)	2.0%	->Wood and Products of Wood and Cork (FIN)
9	1.2%	->Pulp, Paper, Paper , Printing and Publishing (SWE)	0.6%	->Wood and Products of Wood and Cork (TUR)	0.9%	->Wood and Products of Wood and Cork (TUR)	1.9%	->Manufacturing, Nec; Recycling (CHN)
10	1.2%	->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)	0.6%	->Wood and Products of Wood and Cork (EST)	0.8%	->Wood and Products of Wood and Cork (SWE)	1.4%	->Pulp, Paper, Paper , Printing and Publishing (FIN)

Table 22. Top 10 downstream supply chain change of Russian Roundwood (NC) during 1997-2011.

Rank	1997		2001		2006		2011	
	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain
1	25.9%	->Wood and Products of Wood and Cork (FIN)	26.0%	->Wood and Products of Wood and Cork (FIN)	21.7%	->Wood and Products of Wood and Cork (FIN)	24.4%	->Wood and Products of Wood and Cork (FIN)
2	15.1%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	17.7%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	18.2%	->Wood and Products of Wood and Cork (CHN)	17.0%	->Pulp, Paper, Paper , Printing and Publishing (FIN)
3	7.4%	->Agriculture, Hunting, Forestry and Fishing (FIN)	7.7%	->Agriculture, Hunting, Forestry and Fishing (FIN)	11.1%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	16.7%	->Wood and Products of Wood and Cork (CHN)
4	6.0%	->Wood and Products of Wood and Cork (SWE)	5.8%	->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)	7.2%	->Agriculture, Hunting, Forestry and Fishing (FIN)	9.3%	->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)
5	4.6%	->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)	4.8%	->Wood and Products of Wood and Cork (CHN)	6.9%	->Wood and Products of Wood and Cork (FIN) ->Construction (FIN)	8.8%	->Agriculture, Hunting, Forestry and Fishing (FIN)
6	4.6%	->Wood and Products of Wood and Cork (CHN)	2.5%	->Wood and Products of Wood and Cork (FIN) ->Wood and Products of Wood and Cork (FIN)	4.3%	->Wood and Products of Wood and Cork (SWE)	3.6%	->Wood and Products of Wood and Cork (SWE)
7	2.9%	->Pulp, Paper, Paper , Printing and Publishing (SWE)	2.2%	->Pulp, Paper, Paper , Printing and Publishing (FIN) ->Pulp, Paper, Paper , Printing and Publishing (FIN)	2.7%	->Wood and Products of Wood and Cork (FIN) ->Wood and Products of Wood and Cork (FIN)	2.7%	->Wood and Products of Wood and Cork (FIN) ->Wood and Products of Wood and Cork (FIN)
8	2.7%	->Pulp, Paper, Paper , Printing and Publishing (FIN) ->Pulp, Paper, Paper , Printing and Publishing (FIN)	1.7%	->Agriculture, Hunting, Forestry and Fishing (FIN) ->Food, Beverages and Tobacco (FIN)	1.3%	->Agriculture, Hunting, Forestry and Fishing (FIN) ->Food, Beverages and Tobacco (FIN)	2.6%	->Pulp, Paper, Paper , Printing and Publishing (SWE)
9	2.7%	->Wood and Products of Wood and Cork (FIN) ->Pulp, Paper, Paper , Printing and Publishing (FIN)	1.4%	->Agriculture, Hunting, Forestry and Fishing (FIN) ->Wood and Products of Wood and Cork (FIN)	1.3%	->Agriculture, Hunting, Forestry and Fishing (FIN) ->Wood and Products of Wood and Cork (FIN)	2.1%	->Pulp, Paper, Paper , Printing and Publishing (FIN) ->Pulp, Paper, Paper , Printing and Publishing (FIN)
10	1.7%	->Wood and Products of Wood and Cork (FIN) ->Wood and Products of Wood and Cork (FIN)	1.3%	->Agriculture, Hunting, Forestry and Fishing (FIN) ->Agriculture, Hunting, Forestry and Fishing (FIN)	1.2%	->Wood and Products of Wood and Cork (LVA)	1.6%	->Agriculture, Hunting, Forestry and Fishing (FIN) ->Wood and Products of Wood and Cork (FIN)

Table 23. Top 10 downstream supply chain change of Russian Particle Board during 1997-2011.

Rank	1997		2001		2006		2011	
	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain
1	7.2%	->Wood and Products of Wood and Cork (LVA)	16.8%	->Construction (BEL)	38.3%	->Wood and Products of Wood and Cork (RoW)	26.7%	->Wood and Products of Wood and Cork (RoW)
2	2.2%	->Wood and Products of Wood and Cork (POL)	16.4%	->Wood and Products of Wood and Cork (RoW)	20.8%	->Construction (RoW)	9.2%	->Construction (BEL)
3	2.0%	->Manufacturing, Nec; Recycling (POL)	10.2%	->Wood and Products of Wood and Cork (BEL)	7.6%	->Wood and Products of Wood and Cork (RoW) ->Wood and Products of Wood and Cork (RoW)	7.5%	->Wood and Products of Wood and Cork (BEL)
4	1.8%	->Manufacturing, Nec; Recycling (LVA)	3.1%	->Manufacturing, Nec; Recycling (BEL)	7.0%	->Manufacturing, Nec; Recycling (RoW)	5.7%	->Wood and Products of Wood and Cork (RoW) ->Wood and Products of Wood and Cork (RoW)
5	1.7%	->Manufacturing, Nec; Recycling (ROU)	3.1%	->Construction (BEL) ->Construction (BEL)	4.5%	->Basic Metals and Fabricated Metal (RoW)	4.4%	->Manufacturing, Nec; Recycling (RoW)
6	1.4%	->Construction (LVA)	2.6%	->Wood and Products of Wood and Cork (RoW) ->Wood and Products of Wood and Cork (RoW)	3.1%	->Pulp, Paper, Paper , Printing and Publishing (RoW)	2.4%	->Construction (BEL) ->Construction (BEL)
7	1.2%	->Wood and Products of Wood and Cork (LVA) ->Wood and Products of Wood and Cork (LVA)	1.5%	->Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies (BEL)	2.7%	->Wood and Products of Wood and Cork (RoW) ->Manufacturing, Nec; Recycling (RoW)	1.5%	->Real Estate Activities (BEL)
8	1.2%	->Wood and Products of Wood and Cork (ROU)	1.4%	->Other Community, Social and Personal Services (BEL)	2.4%	->Other Non-Metallic Mineral (RoW)	1.3%	->Manufacturing, Nec; Recycling (BEL)
9	1.1%	->Wood and Products of Wood and Cork (CYP)	1.4%	->Transport Equipment (BEL)	1.7%	->Machinery, Nec (RoW)	1.1%	->Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies (BEL)
10	0.9%	->Manufacturing, Nec; Recycling (CYP)	1.3%	->Construction (TUR)	1.5%	->Wood and Products of Wood and Cork (RoW) ->Wood and Products of Wood and Cork (RoW) ->Wood and Products of Wood and Cork (RoW)	1.1%	->Wood and Products of Wood and Cork (POL)

Table 24. Top 10 downstream supply chain change of Russian Plywood during 1997-2011.

Rank	1997		2001		2006		2011	
	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain
1	3.0%	->Wood and Products of Wood and Cork (GBR)	5.4%	->Construction (DNK)	2.7%	->Construction (FIN)	2.7%	->Wood and Products of Wood and Cork (LVA)
2	2.7%	->Construction (EST)	3.1%	->Wood and Products of Wood and Cork (ITA)	1.9%	->Wood and Products of Wood and Cork (LVA)	1.9%	->Construction (LVA)
3	2.3%	->Wood and Products of Wood and Cork (EST)	2.7%	->Wood and Products of Wood and Cork (EST)	1.4%	->Wood and Products of Wood and Cork (EST)	1.4%	->Wood and Products of Wood and Cork (TUR)
4	1.9%	->Manufacturing, Nec; Recycling (EST)	2.0%	->Manufacturing, Nec; Recycling (DNK)	1.1%	->Construction (LVA)	1.1%	->Wood and Products of Wood and Cork (GBR)
5	1.4%	->Manufacturing, Nec; Recycling (DNK)	1.4%	->Wood and Products of Wood and Cork (DNK)	0.9%	->Construction (EST)	0.9%	->Wood and Products of Wood and Cork (FIN)
6	1.0%	->Wood and Products of Wood and Cork (DNK)	1.2%	->Construction (EST)	0.9%	->Wood and Products of Wood and Cork (FIN)	0.9%	->Wood and Products of Wood and Cork (EST)
7	0.8%	->Wood and Products of Wood and Cork (POL)	1.1%	->Manufacturing, Nec; Recycling (EST)	0.8%	->Manufacturing, Nec; Recycling (LVA)	0.8%	->Manufacturing, Nec; Recycling (LVA)
8	0.3%	->Wood and Products of Wood and Cork (LVA)	0.9%	->Wood and Products of Wood and Cork (FIN)	0.8%	->Manufacturing, Nec; Recycling (EST)	0.8%	->Construction (EST)
9	0.3%	->Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles (EST)	0.4%	->Wood and Products of Wood and Cork (NLD)	0.5%	->Manufacturing, Nec; Recycling (DNK)	0.5%	->Wood and Products of Wood and Cork (LVA) ->Wood and Products of Wood and Cork (LVA)
10	0.2%	->Agriculture, Hunting, Forestry and Fishing (EST)	0.2%	->Wood and Products of Wood and Cork (GRC)	0.4%	->Wood and Products of Wood and Cork (DNK)	0.4%	->Manufacturing, Nec; Recycling (EST)

Table 25. Top 10 downstream supply chain change of Russian Sawnwood (C) during 1997-2011.

Rank	1997		2001		2006		2011	
	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain
1	10.0%	->Wood and Products of Wood and Cork (RoW)	2.8%	->Wood and Products of Wood and Cork (GBR)	15.9%	->Wood and Products of Wood and Cork (RoW)	17.3%	->Wood and Products of Wood and Cork (RoW)
2	2.4%	->Wood and Products of Wood and Cork (GBR)	1.8%	->Wood and Products of Wood and Cork (FRA)	1.6%	->Wood and Products of Wood and Cork (GBR)	9.4%	->Wood and Products of Wood and Cork (CHN)
3	1.3%	->Wood and Products of Wood and Cork (TUR)	1.1%	->Wood and Products of Wood and Cork (NLD)	1.6%	->Wood and Products of Wood and Cork (EST)	1.6%	->Construction (FIN)
4	1.1%	->Wood and Products of Wood and Cork (NLD)	1.1%	->Wood and Products of Wood and Cork (EST)	1.1%	->Construction (EST)	1.1%	->Wood and Products of Wood and Cork (EST)
5	0.4%	->Wood and Products of Wood and Cork (HUN)	0.7%	->Wood and Products of Wood and Cork (GRC)	1.1%	->Wood and Products of Wood and Cork (LVA)	1.1%	->Wood and Products of Wood and Cork (DEU)
6	0.4%	->Manufacturing, Nec; Recycling (ROU)	0.6%	->Wood and Products of Wood and Cork (LTU)	0.8%	->Wood and Products of Wood and Cork (FIN)	1.0%	->Construction (EST)
7	0.3%	->Wood and Products of Wood and Cork (GRC)	0.6%	->Construction (LTU)	0.6%	->Construction (LVA)	0.5%	->Wood and Products of Wood and Cork (FIN)
8	0.3%	->Wood and Products of Wood and Cork (LVA)	0.5%	->Wood and Products of Wood and Cork (LVA)	0.6%	->Manufacturing, Nec; Recycling (EST)	0.4%	->Manufacturing, Nec; Recycling (EST)
9	0.2%	->Wood and Products of Wood and Cork (ROU)	0.5%	->Manufacturing, Nec; Recycling (GRC)	0.4%	->Wood and Products of Wood and Cork (NLD)	0.4%	->Wood and Products of Wood and Cork (KOR)
10	0.2%	->Construction (EST)	0.5%	->Construction (EST)	0.4%	->Wood and Products of Wood and Cork (LTU)	0.4%	->Wood and Products of Wood and Cork (GBR)

Table 26. Top 10 downstream supply chain change of Russian Sawnwood (NC) during 1997-2011.

Rank	1997		2001		2006		2011	
	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain
1	8.5%	->Wood and Products of Wood and Cork (ITA)	8.4%	->Wood and Products of Wood and Cork (EST)	31.1%	->Wood and Products of Wood and Cork (CHN)	35.5%	->Wood and Products of Wood and Cork (CHN)
2	1.0%	->Wood and Products of Wood and Cork (GRC)	6.8%	->Wood and Products of Wood and Cork (ITA)	11.3%	->Wood and Products of Wood and Cork (CHN) ->Wood and Products of Wood and Cork (CHN)	13.2%	->Wood and Products of Wood and Cork (CHN) ->Wood and Products of Wood and Cork (CHN)
3	0.7%	->Manufacturing, Nec; Recycling (GRC)	3.7%	->Construction (EST)	5.5%	->Manufacturing, Nec; Recycling (CHN)	5.8%	->Manufacturing, Nec; Recycling (CHN)
4	0.7%	->Wood and Products of Wood and Cork (LVA)	3.5%	->Manufacturing, Nec; Recycling (EST)	1.5%	->Wood and Products of Wood and Cork (EST)	0.5%	->Wood and Products of Wood and Cork (EST)
5	0.6%	->Construction (EST)	0.6%	->Wood and Products of Wood and Cork (GRC)	1.1%	->Wood and Products of Wood and Cork (LTU)	0.4%	->Construction (EST)
6	0.6%	->Construction (LTU)	0.5%	->Real Estate Activities (EST)	1.1%	->Construction (EST)	0.3%	->Wood and Products of Wood and Cork (POL)
7	0.5%	->Wood and Products of Wood and Cork (EST)	0.4%	->Wood and Products of Wood and Cork (LTU)	1.1%	->Construction (LTU)	0.2%	->Wood and Products of Wood and Cork (BEL)
8	0.5%	->Wood and Products of Wood and Cork (CYP)	0.4%	->Wood and Products of Wood and Cork (EST) ->Wood and Products of Wood and Cork (EST)	0.8%	->Manufacturing, Nec; Recycling (LTU)	0.2%	->Manufacturing, Nec; Recycling (EST)
9	0.5%	->Wood and Products of Wood and Cork (SVN)	0.4%	->Wood and Products of Wood and Cork (CYP)	0.7%	->Wood and Products of Wood and Cork (LVA)	0.2%	->Wood and Products of Wood and Cork (FIN)
10	0.4%	->Manufacturing, Nec; Recycling (EST)	0.3%	->Manufacturing, Nec; Recycling (LTU)	0.6%	->Manufacturing, Nec; Recycling (EST)	0.1%	->Construction (LTU)

Table 27. Top 10 downstream supply chain change of Russian Veneer Sheets during 1997-2011.

Rank	1997		2001		2006		2011	
	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain
1	9.6%	->Construction (EST)	10.0%	->Wood and Products of Wood and Cork (ITA)	15.1%	->Construction (FIN)	15.0%	->Construction (JPN)
2	5.3%	->Wood and Products of Wood and Cork (EST)	4.0%	->Wood and Products of Wood and Cork (BEL)	9.2%	->Wood and Products of Wood and Cork (FIN)	9.2%	->Wood and Products of Wood and Cork (JPN)
3	2.2%	->Wood and Products of Wood and Cork (CZE)	2.2%	->Manufacturing, Nec; Recycling (BEL)	4.1%	->Wood and Products of Wood and Cork (ITA)	4.4%	->Manufacturing, Nec; Recycling (JPN)
4	0.8%	->Manufacturing, Nec; Recycling (EST)	1.1%	->Wood and Products of Wood and Cork (EST)	2.2%	->Wood and Products of Wood and Cork (BEL)	4.3%	->Construction (FIN)
5	0.5%	->Wood and Products of Wood and Cork (BGR)	0.7%	->Wood and Products of Wood and Cork (CYP)	1.7%	->Manufacturing, Nec; Recycling (FIN)	2.1%	->Wood and Products of Wood and Cork (ITA)
6	0.5%	->Manufacturing, Nec; Recycling (CZE)	0.7%	->Construction (EST)	0.9%	->Wood and Products of Wood and Cork (EST)	1.5%	->Wood and Products of Wood and Cork (FIN)
7	0.4%	->Construction (BGR)	0.4%	->Manufacturing, Nec; Recycling (CYP)	0.7%	->Wood and Products of Wood and Cork (POL)	0.9%	->Wood and Products of Wood and Cork (AUT)
8	0.3%	->Manufacturing, Nec; Recycling (BGR)	0.3%	->Manufacturing, Nec; Recycling (EST)	0.2%	->Electricity, Gas and Water Supply (FIN)	0.8%	->Wood and Products of Wood and Cork (CZE)
9	0.3%	->Wood and Products of Wood and Cork (SVN)	0.2%	->Construction (CYP)	0.2%	->Construction (EST)	0.7%	->Wood and Products of Wood and Cork (BEL)
10	0.2%	->Manufacturing, Nec; Recycling (SVN)	0.2%	->Wood and Products of Wood and Cork (LTU)	0.2%	->Wood and Products of Wood and Cork (LTU)	0.2%	->Wood and Products of Wood and Cork (EST)

Table 28. Top 10 downstream supply chain change of Russian Newsprint during 1997-2011.

Rank	1997		2001		2006		2011	
	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain	Cov	Supply chain
1	9.6%	->Pulp, Paper, Paper , Printing and Publishing (IND)	10.0%	->Pulp, Paper, Paper , Printing and Publishing (IND)	15.1%	->Pulp, Paper, Paper , Printing and Publishing (RoW)	15.0%	->Pulp, Paper, Paper , Printing and Publishing (RoW)
2	5.3%	->Pulp, Paper, Paper , Printing and Publishing (TUR)	4.0%	->Pulp, Paper, Paper , Printing and Publishing (TUR)	9.2%	->Pulp, Paper, Paper , Printing and Publishing (IND)	9.2%	->Pulp, Paper, Paper , Printing and Publishing (IND)
3	2.2%	->Pulp, Paper, Paper , Printing and Publishing (IND) ->Pulp, Paper, Paper , Printing and Publishing (IND)	2.2%	->Pulp, Paper, Paper , Printing and Publishing (IND) ->Pulp, Paper, Paper , Printing and Publishing (IND)	4.1%	->Pulp, Paper, Paper , Printing and Publishing (TUR)	4.4%	->Pulp, Paper, Paper , Printing and Publishing (DEU)
4	0.8%	->Pulp, Paper, Paper , Printing and Publishing (HUN)	1.1%	->Pulp, Paper, Paper , Printing and Publishing (BGR)	2.2%	->Pulp, Paper, Paper , Printing and Publishing (IND) ->Pulp, Paper, Paper , Printing and Publishing (IND)	4.3%	->Pulp, Paper, Paper , Printing and Publishing (TUR)
5	0.5%	->Pulp, Paper, Paper , Printing and Publishing (BGR)	0.7%	->Pulp, Paper, Paper , Printing and Publishing (GRC)	1.7%	->Pulp, Paper, Paper , Printing and Publishing (FIN)	2.1%	->Pulp, Paper, Paper , Printing and Publishing (IND) ->Pulp, Paper, Paper , Printing and Publishing (IND)
6	0.5%	->Pulp, Paper, Paper , Printing and Publishing (EST)	0.7%	->Pulp, Paper, Paper , Printing and Publishing (TUR) ->Pulp, Paper, Paper , Printing and Publishing (TUR)	0.9%	->Pulp, Paper, Paper , Printing and Publishing (BGR)	1.5%	->Pulp, Paper, Paper , Printing and Publishing (FIN)
7	0.4%	->Food, Beverages and Tobacco (EST)	0.4%	->Pulp, Paper, Paper , Printing and Publishing (CZE)	0.7%	->Pulp, Paper, Paper , Printing and Publishing (GRC)	0.9%	->Pulp, Paper, Paper , Printing and Publishing (BGR)
8	0.3%	->Pulp, Paper, Paper , Printing and Publishing (LVA)	0.3%	->Food, Beverages and Tobacco (BGR)	0.2%	->Food, Beverages and Tobacco (BGR)	0.8%	->Pulp, Paper, Paper , Printing and Publishing (TUR) ->Pulp, Paper, Paper , Printing and Publishing (TUR)
9	0.3%	->Food, Beverages and Tobacco (LTU)	0.2%	->Pulp, Paper, Paper , Printing and Publishing (ROU)	0.2%	->Pulp, Paper, Paper , Printing and Publishing (ROU)	0.7%	->Pulp, Paper, Paper , Printing and Publishing (GRC)
10	0.2%	->Pulp, Paper, Paper , Printing and Publishing (LTU)	0.2%	->Pulp, Paper, Paper , Printing and Publishing (LVA)	0.2%	->Pulp, Paper, Paper , Printing and Publishing (LVA)	0.2%	->Pulp, Paper, Paper , Printing and Publishing (ROU)

6.4 Chapter summary

After Structural Path Analysis of time series data, the most important downstream supply chains of Russian wood products are

a. Wood and Products of Wood and Cork sector;

b. Construction sector;

c. Rubber and Plastics sector;

d. Pulp, Paper, Printing and Publishing sector;

e. Agriculture, Hunting, Forestry and Fishing sector,

in China, Japan, Belarus, Finland, Turkey and India.

Sectors in China are the dominant downstream supply chains for Russian Roundwood (C), Roundwood (NC), Sawnwood (C) and Sawnwood (NC). Sectors in Finland are the dominant downstream supply chains for Russian Roundwood (NC), Chips and Particles. Sectors in Belarus are the dominant downstream supply chains for Russian Particle Board. Sectors in Latvia are the dominant downstream supply chains for Russian Plywood.

Sectors in Japan are the dominant downstream supply chains for Russian Veneer Sheets. Pulp, Paper, Printing and Publishing sector in India and Turkey, Finland and Germany are the major downstream supply chains for Russian Newsprint.

Wood and Products of Wood and Cork sector in China became the dominant downstream supply chains for Russian Roundwood (C), Sawnwood (NC) after 2006. It indicates China's dependency of wood products from Russia is increasing. Japan is getting more and more dependency in Russian Veneer Sheets supply.

The time-series SPA of Russian wood products reveals USA, developed European countries and South Korea are not important downstream supply chains. But according to consumption accounting analysis in Chapter 4, they are the major final consumers. It indicates that China as manufacturer of the world, import Russian wood products to manufacture products that serves

final demand in developed countries like Western European countries, USA, Japan and South Korea.

7. Conclusion

This research focuses on investigating the final consumer and important downstream supply chains of nine Russian wood products and major responsible countries of CO_2 emission and energy use in Russian wood production. By incorporating FAO and WIOD dataset to build MUIO model both in physical and monetary form, the consumption-based accounting analysis from 1995 to 2011 of nine Russian wood products are investigated.

The result indicates the major final consumers of Russian wood products are China, Finland, Japan, Germany, USA, South Korea, Belarus, India, and Turkey. China is the largest final consumer of Russian Roundwood (C) and Sawnwood (NC). Japan is the largest final consumer of Russian Sawnwood (C) and Veneer Sheets. Finland is the largest final consumer of Russian Chips and Particles and Roundwood (NC). Belarus is the largest final consumer of Russian Particle Board. USA is the largest final consumer of Russian Plywood. India is the largest final consumer of Russian Newsprint.

The time-series analysis of CO_2 emission and energy use in Russian wood products indicates the great technology improvement of reducing CO_2 emission and increasing energy efficiency in Russian wood product related industries around the world. China used to be the largest final responsible country of CO_2 emission and energy use in Russian Roundwood (C), Roundwood (NC), Sawnwood (C) and Sawnwood (NC), but its impact has greatly decreased. China is no longer the largest responsible country of environmental pollution in Russian wood industry. Japan is the largest final responsible country in Russian Veneer Sheets, Roundwood (C), Chips and Particles, and Sawnwood (C). Japan used to be the largest final responsible country in Veneer Sheets, but its impact has greatly decreased. Now Germany is the largest responsible country in Veneer Sheets. Italy is the largest final responsible country in Russian Sawnwood (NC). Finland is the largest final responsible country in Russian Chips and Particles, and Roundwood (NC). Belarus is the largest final responsible country in Russian Particle Board. USA is the largest final responsible country in Russian Plywood. India is the largest final responsible country in Russian Newsprint.

Structural Path Analysis is also applied in this research to find out the most important supply

chains of nine Russian wood products. The time-series SPA of Russian wood products indicates the dominant supply chains are Wood and Products of Wood and Cork sector, Construction sector, Rubber and Plastics sector, Pulp, Paper, Printing and Publishing sector, and Agriculture, Hunting, Forestry and Fishing sector from China, Japan, Belarus, Finland, Turkey and India.

Sectors in China are the dominant downstream supply chains of Russian Roundwood (C), Roundwood (NC), Sawnwood (C) and Sawnwood (NC). Sectors in Finland are the dominant downstream supply chains of Russian Roundwood (NC), Chips and Particles. Sectors in Belarus are the dominant downstream supply chains of Russian Particle Board. Sectors in Latvia are the dominant downstream supply chains of Russian Plywood.

Sectors in Japan are the dominant downstream supply chains of Russian Veneer Sheets. Pulp, Paper, Printing and Publishing sector in India and Turkey, Finland and Germany are the major downstream supply chains of Russian Newsprint.

Wood and Products of Wood and Cork sector in China has been the dominant downstream supply chains for Russian Roundwood (C), Sawnwood (NC) since 2006. This result indicates that China's dependency of wood products from Russia is increasing. Japan is getting more and more dependency in Russian Veneer Sheets supply.

Combining the results from the three analyses, we can find that Although USA, developed European countries and South Korea are not important direct consumers of Russian wood industry, they are the major final consumers that ultimately drive the consumption of Russian wood products and associated environmental impacts. It indicates that China, Finland, Belarus, Turkey and India import Russian wood products for producing goods that are finally consumed by developed countries like Western European countries, USA, Japan and South Korea.

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Appendix

Appendix 1. Consumption volume of Russian wood products by each country in 2011.

	Chips and Particles	Round wood (C)	Round wood (NC)	Particle Board	Plywood	Sawnwood (C)	Sawnwood (NC)	Veneer Sheets	Newsprint
Australia	7181	120508	27257	2094	6943	110978	4216	953	9277
Austria	5361	35666	17854	832	12929	199266	1189	880	6260
Belarus	7560	40361	27913	48061	11017	56836	3046	900	10375
Bulgaria	516	3580	1814	102	2217	6117	116	320	24652
Brazil	7093	76078	24487	1458	4442	65463	2392	560	27776
Canada	6594	123490	23117	1611	19373	89208	5192	838	6289
China	156814	10268289	745447	38291	33443	5097696	519216	28117	57933
Cyprus	540	2607	1845	57	1799	3034	182	19	455
Czech Republic	2452	17411	9383	489	10993	29712	710	604	6158
Germany	52962	450317	174574	8244	163747	624887	12223	2578	97177
Denmark	10999	24112	29204	602	35962	30731	2199	207	2985
Spain	12520	75929	46166	2325	14240	84557	2307	1345	11028
Estonia	3867	4756	16960	99	14669	93458	3871	382	2270
Finland	1838178	495240	1140951	532	46214	217611	3943	3422	31282
France	24295	145914	85736	8042	33095	478429	5159	2088	37551
UK	33944	178876	122101	4656	91133	501264	7307	1327	54210
Greece	3172	17968	12266	624	6362	28678	622	187	27577
Hungary	1965	9574	6948	320	5872	20468	457	104	6096
Indonesia	3497	69419	14069	1600	2864	66772	2598	801	4983
India	14045	318477	55572	11430	22911	567412	19685	3290	220444
Ireland	1608	13618	6087	314	2426	16067	414	76	1775
Italy	14250	102410	54579	3359	52896	340058	4735	4786	22292
Japan	76511	731906	193969	7715	24282	1194521	19559	187229	13634
South Korea	18898	229057	40587	33166	11655	310133	4584	1379	5368
Lithuania	1464	3928	5186	108	8853	28022	2158	704	6124
Luxembourg	453	2109	1493	420	816	3973	86	27	626
Latvia	1291	4902	4205	58	37362	19837	1033	66	4193
Mexico	3273	65144	13775	1072	4136	52891	2018	519	3697
Malta	119	696	315	27	183	1295	24	11	141
Netherlands	14599	78038	47195	4933	47063	313415	2995	600	13130
Poland	7681	42218	27428	991	29369	50872	5843	831	17182
Portugal	1429	8199	5240	413	7593	13996	270	111	1677
Romania	1598	11172	5531	344	4355	16343	537	122	16957
Russia	15618	108438	43281	2389	11738	101206	3896	1012	12233
Slovakia	1113	7820	4250	280	3519	13787	327	132	1567
Slovenia	443	3294	1613	128	2551	8275	121	52	1188
Sweden	48469	81188	235763	1079	22046	57339	1579	361	5535
Turkey	6547	181173	20452	1848	82078	470826	3064	1416	133321
Taiwan	2801	41880	11335	1013	2646	51687	1567	938	2641
USA	47221	939550	186400	14009	209977	765523	36568	6816	53442
RoW	127398	1148684	652593	138864	271771	6643355	57992	40902	355121

Appendix 2. Consumption percentage of Russian wood products by each country in 2011.

	Chips and Particles	Round wood (C)	Round wood (NC)	Particle Board	Plywood	Sawnwood (C)	Sawnwood (NC)	Veneer Sheets	Newsprint
Australia	0.3%	0.7%	0.7%	0.6%	0.5%	0.6%	0.6%	0.3%	0.7%
Austria	0.2%	0.2%	0.4%	0.2%	0.9%	1.1%	0.2%	0.3%	0.5%
Belarus	0.3%	0.2%	0.7%	14.0%	0.8%	0.3%	0.4%	0.3%	0.8%
Bulgaria	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.1%	1.9%
Brazil	0.3%	0.5%	0.6%	0.4%	0.3%	0.3%	0.3%	0.2%	2.1%
Canada	0.3%	0.8%	0.6%	0.5%	1.4%	0.5%	0.7%	0.3%	0.5%
China	6.1%	63.1%	18.0%	11.1%	2.4%	27.0%	69.6%	9.5%	4.4%
Cyprus	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
Czech Republic	0.1%	0.1%	0.2%	0.1%	0.8%	0.2%	0.1%	0.2%	0.5%
Germany	2.0%	2.8%	4.2%	2.4%	11.9%	3.3%	1.6%	0.9%	7.4%
Denmark	0.4%	0.1%	0.7%	0.2%	2.6%	0.2%	0.3%	0.1%	0.2%
Spain	0.5%	0.5%	1.1%	0.7%	1.0%	0.4%	0.3%	0.5%	0.8%
Estonia	0.1%	0.0%	0.4%	0.0%	1.1%	0.5%	0.5%	0.1%	0.2%
Finland	71.1%	3.0%	27.5%	0.2%	3.4%	1.2%	0.5%	1.2%	2.4%
France	0.9%	0.9%	2.1%	2.3%	2.4%	2.5%	0.7%	0.7%	2.9%
UK	1.3%	1.1%	2.9%	1.4%	6.6%	2.7%	1.0%	0.4%	4.1%
Greece	0.1%	0.1%	0.3%	0.2%	0.5%	0.2%	0.1%	0.1%	2.1%
Hungary	0.1%	0.1%	0.2%	0.1%	0.4%	0.1%	0.1%	0.0%	0.5%
Indonesia	0.1%	0.4%	0.3%	0.5%	0.2%	0.4%	0.3%	0.3%	0.4%
India	0.5%	2.0%	1.3%	3.3%	1.7%	3.0%	2.6%	1.1%	16.7%
Ireland	0.1%	0.1%	0.1%	0.1%	0.2%	0.1%	0.1%	0.0%	0.1%
Italy	0.6%	0.6%	1.3%	1.0%	3.8%	1.8%	0.6%	1.6%	1.7%
Japan	3.0%	4.5%	4.7%	2.2%	1.8%	6.3%	2.6%	63.0%	1.0%
South Korea	0.7%	1.4%	1.0%	9.6%	0.8%	1.6%	0.6%	0.5%	0.4%
Lithuania	0.1%	0.0%	0.1%	0.0%	0.6%	0.1%	0.3%	0.2%	0.5%
Luxembourg	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%
Latvia	0.0%	0.0%	0.1%	0.0%	2.7%	0.1%	0.1%	0.0%	0.3%
Mexico	0.1%	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%	0.2%	0.3%
Malta	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Netherlands	0.6%	0.5%	1.1%	1.4%	3.4%	1.7%	0.4%	0.2%	1.0%
Poland	0.3%	0.3%	0.7%	0.3%	2.1%	0.3%	0.8%	0.3%	1.3%
Portugal	0.1%	0.1%	0.1%	0.1%	0.6%	0.1%	0.0%	0.0%	0.1%
Romania	0.1%	0.1%	0.1%	0.1%	0.3%	0.1%	0.1%	0.0%	1.3%
Russia	0.6%	0.7%	1.0%	0.7%	0.9%	0.5%	0.5%	0.3%	0.9%
Slovakia	0.0%	0.0%	0.1%	0.1%	0.3%	0.1%	0.0%	0.0%	0.1%
Slovenia	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.1%
Sweden	1.9%	0.5%	5.7%	0.3%	1.6%	0.3%	0.2%	0.1%	0.4%
Turkey	0.3%	1.1%	0.5%	0.5%	6.0%	2.5%	0.4%	0.5%	10.1%
Taiwan	0.1%	0.3%	0.3%	0.3%	0.2%	0.3%	0.2%	0.3%	0.2%
USA	1.8%	5.8%	4.5%	4.1%	15.2%	4.1%	4.9%	2.3%	4.1%
RoW	4.9%	7.1%	15.7%	40.4%	19.7%	35.3%	7.8%	13.8%	27.0%

Appendix 3. Matlab code to calculate downstream SPA

```
% function FastSPA_DownStream_Max4 is used to calculate downstream SPA in
% the 4th-order as maximum.
% Input:
% A: Inter industry direct requirement matrix
% R: The satellite indicators vector
% X: Total output of each sector
% ind: The index of sector to be analyzed
% coverage: The coverage to be reached as the stop loop
% SelectedNO: The number of most important paths to keep
% step: the maximum order of path to be calculated
% Output:
% SelectedList: the matrix of coverage and paths of most important supply chain

function SelectedList = FastSPA_DownStream_Max4(A,R,X,ind,coverage,SelectedNO,step)

    n=length(A);
    y=zeros(n,1);
    y(ind)=1;

    adjMax = max(max(A));
    if adjMax < 1
        total=R*inv(eye(n)-A)*y;

        step=0;
        cov=R*y;
        while cov<=(coverage*total)
            step=step+1;
            cov=cov+R*A^step*y;
        end
    end

    SelectedList = zeros(SelectedNO,step+1);

    if step<=2 && step~=0
        for i1=n:-1:1
            for i2=n:-1:0
                if i2 == 0
                    temp = R(ind)*A(ind,i1);
                    SelectedList = Compare_2(SelectedList,temp,i1,i2);
                    break;
                end

                temp = R(ind)*A(ind,i1)*A(i1,i2);
                SelectedList = Compare_2(SelectedList,temp,i1,i2);

            end
        end
    end

    if step == 3
        SelectedList = zeros(SelectedNO,4);

        for i1=n:-1:1
            for i2=n:-1:0
                if i2 == 0
                    temp = R(ind)*A(ind,i1);
```

```
                    SelectedList = Compare_3(SelectedList,temp,i1,i2,0);
                    break;
                end
                for i3=n:-1:0
                    if i3 == 0
                        temp = R(ind)*A(ind,i1)*A(i1,i2);
                        SelectedList = Compare_3(SelectedList,temp,i1,i2,i3);
                        break;
                    end

                    temp = R(ind)*A(ind,i1)*A(i1,i2)*A(i2,i3);
                    SelectedList = Compare_3(SelectedList,temp,i1,i2,i3);

                end
            end
        end
    end

if step >=4
    for i1=n:-1:1
        for i2=n:-1:0
            if i2 == 0
                temp = R(ind)*A(ind,i1);
                SelectedList = Compare_3(SelectedList,temp,i1,i2,0);
                break;
            end
            for i3=n:-1:0
                if i3 == 0
                    temp = R(ind)*A(ind,i1)*A(i1,i2);
                    SelectedList = Compare_3(SelectedList,temp,i1,i2,i3);
                    break;
                end

                for i4=n:-1:0

                    if i4 == 0
                        temp = R(ind)*A(ind,i1)*A(i1,i2)*A(i2,i3);
                        SelectedList = Compare_4(SelectedList,temp,i1,i2,i3,i4);
                        break;

                    end

                    temp = R(ind)*A(ind,i1)*A(i1,i2)*A(i2,i3)*A(i3,i4);
                    SelectedList = Compare_4(SelectedList,temp,i1,i2,i3,i4);
                end
            end
        end
    end
end

SelectedList = sortrows(SelectedList,-1);

[Srow, ~] = size(SelectedList);
for i = 1:Srow
    temp = 1;
    pathStep = sum(SelectedList(i,:)>0) - 1;
    for j = 1+1:pathStep+1
```

```
            if j == 2 && j < pathStep+1
                temp = R(ind)*A(ind,SelectedList(i,j));
            elseif j == 2 && j == pathStep+1
                temp = R(ind)*A(ind,SelectedList(i,j))*X(SelectedList(i,j));
            elseif j<pathStep+1
                temp = temp*A(SelectedList(i,j-1),SelectedList(i,j));
            elseif j == pathStep+1 && j~=2
                temp = temp*A(SelectedList(i,j-1),SelectedList(i,j))*X(SelectedList(i,j));
            end
        end

        SelectedList(i,1) = temp/X(ind);
    end
    SelectedList = sortrows(SelectedList,-1);
end

function SelectedList = Compare_4(SelectedList,temp,i1,i2,i3,i4)
    if temp > SelectedList(1,1)
        SelectedList(1,1) = temp;
        SelectedList(1,2) = i1;
        SelectedList(1,3) = i2;
        SelectedList(1,4) = i3;
        SelectedList(1,5) = i4;
    end

    SelectedList = sortrows(SelectedList,1);
end

function SelectedList = Compare_3(SelectedList,temp,i1,i2,i3)
    if temp > SelectedList(1,1)
        SelectedList(1,1) = temp;
        SelectedList(1,2) = i1;
        SelectedList(1,3) = i2;
        SelectedList(1,4) = i3;
    end

    SelectedList = sortrows(SelectedList,1);
end

function SelectedList = Compare_2(SelectedList,temp,i1,i2)
    if temp > SelectedList(1,1)
        SelectedList(1,1) = temp;
        SelectedList(1,2) = i1;
        SelectedList(1,3) = i2;
    end

    SelectedList = sortrows(SelectedList,1);
end
```

Appendix 4. Matlab code to calculate disaggregated A^* matrix

```
% Fuction MUIO_Monetary is used to calculate the disaggregating sector A* matrix
% Z matrix: Original MRIO economic flow table
% X matrix: Total output vector of each sector
% Y matrix: Final demand sectors of each country
% Z_Final matrix: MRIO economic flow matrix with disaggregated sector
% X_Final matrix: Total output vector of each sector with disaggregated sector
% A_Final matrix: Direct requirement A* matrix with disaggregated sector
% Y_Final matrix: Final demand sectors of each country with disaggregated sector
% Y_Final_ByCountry matrix: Sum of final demand by each country with disaggregated sector
% WIODCName: Country Name Matrix for WIOD
% FAOdata: Data read from FAO dataset
% FAOCountryNO: Country number with record data
% DivisionSectorNO: The Russian sector number to be disaggregated
% CorrespondingNO: Original sector type for disaggregated sector
% AddSectorNO: The sector number of Russian wood sector to be disaggregated

function [Z_Final,X_New,A_Final,Y_Final,Y_Final_ByCountry] = MUIO_Physical(Z,X,Y,WIODCName,FAOdata,
FAOCountryNO,DivisionSectorNO,CorrespondingNO,AddSectorNO)
%% 1.1 Associate Country Name and # between FAO and WIOD

WIODUniqueCName = unique(WIODCName);

% FAOSTAT # to WIOD
WIODCountryNO = 41;
countryNO = WIODCountryNO; % WIOD country NO

q = countryNO; % WIOD country NO
p = FAOCountryNO; % FAOSTAT country NO

EoraAsoName = zeros(q,1);
for i = 1:q
    changeFlag = 0;
    for j = 1:p
        if strcmp(FAOdata{i+2,2}, FAOdata{j+2,5}) == 1
            EoraAsoName(i,1) = FAOdata{j+2,4};
            FAOdata{i+2,3} = FAOdata{j+2,4};
            changeFlag = 1;
        end
    end
    if changeFlag == 0
        FAOdata{i+2,3} = 0;
    end
end

% FAOSTAT # to WIOD
FAOAsoName = zeros(p,1);
for i = 1:p
    changeFlag = 0;
    for j = 1:q
        if strcmp(FAOdata{i+2,5}, FAOdata{j+2,2}) == 1
            FAOAsoName(i,1) = FAOdata{j+2,1};
            FAOdata{i+2,6} = FAOdata{j+2,1};
            changeFlag = 1;
        end
    end
    if changeFlag == 0
        FAOdata{i+2,6} = 0;
```

```
    end
end


%% 2. Assign Russia Wood data to all countries

% Split FAO data to countries in WIOD
CountryIO = zeros(countryNO,2*AddSectorNO);

for i = 1:FAOCountryNO
    rowInEora = FAOdata{i+2,6};

    if rowInEora == 0
        continue;
    end

    for j = 1:2*AddSectorNO
        CountryIO(rowInEora,j) = FAOdata{i+2,j+6};
    end
end

FAOTotal = zeros(1,2*AddSectorNO);
for i = 1:FAOCountryNO+2
    if strcmp(FAOdata{i,5},'Total FAO') == 1
        FAOTotalRowNO = i;
        break;
    end
end

for i = 1:2*AddSectorNO
    FAOTotal(1,i) = FAOdata{FAOTotalRowNO,i+6};
end
KnownTotal = sum(CountryIO);

ROW = zeros(1,2*AddSectorNO);
for i = 1:2*AddSectorNO
    temp = FAOTotal(i) - KnownTotal(i);
    if temp > 0
        ROW(i) = temp;
    else
        ROW(i) = 0;
    end
end

CountryIO(WIODCountryNO,:) = ROW(:);

%% 2.4 Calculate Russia wood export in economic form and physical form

% Russian wood export to each country in economic form
WIODSectorNO = (35+5)*WIODCountryNO;
SectorMExport = zeros(AddSectorNO,WIODSectorNO);
Position = 0;
for i = 1:WIODCountryNO
    CountrySectorLength = 35 + 5;
    ExportInf = CountryIO(i,1:AddSectorNO);
    for j = Position + 1: Position + CountrySectorLength
        SectorMExport(:,j) = ExportInf';
    end
```

```
    Position = Position + CountrySectorLength;
end

% Russian wood export to each country in phisical form
SectorPExport = zeros(AddSectorNO,WIODSectorNO);
Position = 0;
for i = 1:WIODCountryNO
    CountrySectorLength = 35 + 5;
    ExportInf = CountryIO(i,AddSectorNO+1:2*AddSectorNO);
    for j = Position + 1: Position + CountrySectorLength
        SectorPExport(:,j) = ExportInf';
    end
    Position = Position + CountrySectorLength;
end


%% 3. Split Russia Wood export rows in physical and economic form as proportion to Eora Z matrix in associated rows
%% 3.1 Read Associated rows in Z matrix

AssociatedZRows = zeros(3,WIODSectorNO);

%% 3.2 Calculate the total export by each country in Eora Z matrix Associated rows

SectorZTotalByCountry = zeros(3,WIODSectorNO);

ZConvertedSector = AssociatedZRows;
for i = 1:3
%       RowNO = DivisionSectorNO(i,1);

    SectorCount = 0;
    for j = 1:WIODCountryNO
        countryIndustryStart = SectorCount+1;
        countryFDEnd = SectorCount+35+5;
        countryZSectors = ZConvertedSector(i,countryIndustryStart:countryFDEnd);

        countryX = sum(countryZSectors);
        for k = countryIndustryStart:countryFDEnd
            SectorZTotalByCountry(i,k) = countryX;
        end
        SectorCount = SectorCount + 35 + 5;
    end
end

%% 3.3 Calculate splited Russia wood exports in economic and physical form to other sectors in Eora
SectorExportProportion = zeros(3,WIODSectorNO);
for i = 1:3
    for j = 1:WIODSectorNO
        if SectorZTotalByCountry(i,j) ~= 0
            SectorExportProportion(i,j) = AssociatedZRows(i,j)/SectorZTotalByCountry(i,j);
        else
            SectorExportProportion(i,j) = 0;
        end
    end
end

% Russian wood export to each sectors in economic form
MMatrix = zeros(AddSectorNO,WIODSectorNO);
for i = 1:AddSectorNO
```

```
    for j = 1:WIODSectorNO
        MMatrix(i,j) = SectorMExport(i,j)*SectorExportProportion(CorrespondingNO(i),j);
    end
end

MMatrix = zeros(AddSectorNO,WIODSectorNO);
for i = 1:AddSectorNO
    for j = 1:WIODSectorNO
        MMatrix(i,j) = SectorMExport(i,j)*SectorExportProportion(CorrespondingNO(i),j);
    end
end

% Russian wood export to each sectors in physical form
PMatrix = zeros(AddSectorNO,WIODSectorNO);
for i = 1:AddSectorNO
    for j = 1:WIODSectorNO
        PMatrix(i,j) = SectorPExport(i,j)*SectorExportProportion(CorrespondingNO(i),j);
    end
end

%% 3.4 Split Russia wood exports to industry parts and Final Demand parts

% Set MMtrix as result of Add row
IndustryLength = 35;
FDLength = 5;
M = zeros(AddSectorNO,WIODCountryNO*IndustryLength);
MFD = zeros(AddSectorNO,WIODCountryNO*FDLength);
% Mbycountry = zeros(AddSectorNO,WIODCountryNO);
% MFDbycountry = zeros(AddSectorNO,WIODCountryNO);

for i = 1:AddSectorNO

    M(i,:) = Z(DivisionSectorNO(CorrespondingNO(i)),:);
    MFD(i,:) = Y(DivisionSectorNO(CorrespondingNO(i)),:);

end

TotalM = zeros(AddSectorNO,WIODCountryNO);

for i = 1:WIODCountryNO

    TempM = M(:,(i-1)*IndustryLength+1:i*IndustryLength);
    TotalM(:,i) = sum(TempM,2);

    TempMFD = MFD(:,(i-1)*FDLength+1:i*FDLength);
    TotalM(:,i) = TotalM(:,i) + sum(TempMFD,2);

end


temp = CountryIO(:,1:AddSectorNO)';
MFactor = zeros(AddSectorNO,WIODCountryNO);
for i = 1:AddSectorNO
    for j = 1:WIODCountryNO
        if TotalM(i,j) ~= 0
            MFactor(i,j) = temp(i,j)/TotalM(i,j);
        else
            MFactor(i,j) = 0;
```

```
            end
        end
end

M_Final =    zeros(AddSectorNO,WIODCountryNO*IndustryLength);
MFD_Final = zeros(AddSectorNO,WIODCountryNO*FDLength);

for i = 1:WIODCountryNO

        for j = 1:IndustryLength
            M_Final(:,(i-1)*IndustryLength+j) = M(:,(i-1)*IndustryLength+j).*MFactor(:,i);
        end

        for j = 1:FDLength
            MFD_Final(:,(i-1)*FDLength+j) = MFD(:,(i-1)*FDLength+j).*MFactor(:,i);
        end

end

M_Integral = [M_Final MFD_Final];
X_Add_M = sum(M_Integral,2);



% PFactor = CountryIO(:,10:18)'./TotalM;
[p, q] = size(TotalM);
temp = CountryIO(:,10:18)';
PFactor = zeros(p,q);
for i = 1:p
        for j = 1:q
            if TotalM(i,j) ~= 0
                PFactor(i,j) = temp(i,j)/TotalM(i,j);
            else
%                   PFactor(i,j) = temp(i,j);
                PFactor(i,j) = 0;
            end
        end
end

P_Final =    zeros(AddSectorNO,WIODCountryNO*IndustryLength);
PFD_Final = zeros(AddSectorNO,WIODCountryNO*FDLength);

for i = 1:WIODCountryNO

        for j = 1:IndustryLength
            P_Final(:,(i-1)*IndustryLength+j) = M(:,(i-1)*IndustryLength+j).*PFactor(:,i);
        end

        for j = 1:FDLength
            PFD_Final(:,(i-1)*FDLength+j) = MFD(:,(i-1)*FDLength+j).*PFactor(:,i);
        end

end

P_Integral = [P_Final PFD_Final];
X_Add_P = sum(P_Integral,2);
```

```
%% 4 Russian Wood MUIO
%% 4.1 Calculate Z and X

WIODSectorNO = WIODCountryNO*IndustryLength;
WIODFDNO = WIODCountryNO*FDLength;
% Ruduce Associated rows in Z and Y
ReductionRows = zeros(3,WIODSectorNO);
Z_Modify = Z;
Y_Modify = Y;

for i = 1:AddSectorNO
    RowNO = CorrespondingNO(i);
    for j = 1:WIODSectorNO
        ReductionRows(RowNO,j) = ReductionRows(RowNO,j) + M_Final(i,j);
    end
end

ReductionRows_Y = zeros(3,WIODFDNO);
for i = 1:AddSectorNO
    RowNO = CorrespondingNO(i);
    for j = 1:WIODFDNO
        ReductionRows_Y(RowNO,j) = ReductionRows_Y(RowNO,j) + MFD_Final(i,j);
    end
end

for i = 1:3
    RowNO = DivisionSectorNO(i);
    for j = 1:WIODSectorNO
        Z_Modify(RowNO,j) = Z_Modify(RowNO,j) - ReductionRows(i,j);
    end
end

for i = 1:3
    RowNO = DivisionSectorNO(i);
    for j = 1:WIODFDNO
        Y_Modify(RowNO,j) = Y_Modify(RowNO,j) - ReductionRows_Y(i,j);
    end
end

Y_New = insertRow(Y_Modify,PFD_Final,1);
Y_ByCountry = CalYByCountry(Y_New, length(Y_New), WIODCountryNO);

%% 4.2 Add Physical Cols to Eora Z matrix
AddSectorRows = P_Final;
AddSectorCols = zeros(WIODSectorNO,AddSectorNO);

X_Modify = sum(Z_Modify,2)+sum(Y_Modify,2);

A = CalualteAmatrix(Z_Modify,X_Modify);
for i = 1:AddSectorNO
    sectorNO = DivisionSectorNO(CorrespondingNO(i));
    DivisionSectorInputA = A(:,sectorNO);
    AddSectorCols(:,i) = DivisionSectorInputA*X_Add_P(i);
end

X_New = insertRow(X_Modify,X_Add_P,1);

%% 4.3 Ruduce Associated cols in Z and X
```

```
ReduceSectorCols = zeros(WIODSectorNO,AddSectorNO);
A = CalualteAmatrix(Z_Modify,X_Modify);
for i = 1:AddSectorNO
    sectorNO = DivisionSectorNO(CorrespondingNO(i));
    DivisionSectorInputA = A(:,sectorNO);
    ReduceSectorCols(:,i) = DivisionSectorInputA*X_Add_P(i);
end

ReductionCols = zeros(WIODSectorNO,3);
for j = 1:AddSectorNO
    ColNO = CorrespondingNO(j);
    for i = 1:WIODSectorNO
        ReductionCols(i,ColNO) = ReductionCols(i,ColNO) + ReduceSectorCols(i,j);
    end
end

for j = 1:3
    ColNO = DivisionSectorNO(j);
    for i = 1:WIODSectorNO
        if ((i ~= 1156) && (i ~= 1161) && (i ~= 1162))
            Z_Modify(i,ColNO) = Z_Modify(i,ColNO) - ReductionCols(i,j);
        end
    end
end

%% 4.4 Calculating direct requirement matrix A and Leontief inverse L

InsertSectorPosition = 1; % Add sectors at beginning
Z_New = insertRow(Z_Modify,AddSectorRows,InsertSectorPosition);
NewSectorsMatrix = zeros(AddSectorNO);
AddSectorCols_New = insertRow(AddSectorCols,NewSectorsMatrix,InsertSectorPosition);

Z_Final = insertCol(Z_New,AddSectorCols_New,InsertSectorPosition);
A_Final = CalualteAmatrix(Z_Final,X_New);
Y_Final = Y_New;
Y_Final_ByCountry = Y_ByCountry;
```