Status and trend analysis of the production, export and import of wood and wood products in the G20 countries from 2004 to 2021

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Abstract: The aim of this work was to study the use of different types of wood products by the G20 countries. In the current scenario, every country is concerned about the severe exploitation of forests and the ensuing lack of markets for timber. Production and consumption of wood and wood products by the G20 countries account for 85% of global GDP and two-thirds of the world's population. Data for the study includes eight major categories of wood products in the G20 countries from 2004 to 2021: industrial raw wood, sawlogs and veneer logs, sawn wood, wood fuel, wood-based panels, paper and paperboard, pulp for paper, wood pellets, and other agglomerates. Autoregressive integrated moving average (ARIMA) models were used to predict the production, export, and import behaviour of wood and wood products from 2022 to 2030. According to the findings, the G20 countries would consume 1 644.6 million m³ of industrial raw wood in 2030, followed by 984.8 million m³ of sawlogs and veneer logs, 454.7 million m³ of sawn wood, 882.5 million m³ of wood fuel, 406.2 million t of paper and paperboard, 199.4 million t of pulp for paper, and 51.7 million t of wood pellets and other agglomerates. This study provides decision-makers with an analysis of the production and consumption of wood product markets in the G20 countries, which can be used for policy decisions.

Keywords: autoregressive integrated moving average model; forecast; time series; wood trade

Forests cover 31.2% of the global land area, i.e. 4 058.9 million ha (FAO, UNEP 2020; World Bank Group 2020), in which the G20 group of countries contributed 2 778.1 million ha, representing 68.4% (FAO 2020). Russia, Brazil, Canada, the United States, and China are the five wealthiest forest countries in the world, making up 78.8% of the forests of the G20 countries and more than half (53.9%) of the world's total forest area (FAO 2020). According to the Global Forest Goals Report (UN DESA, UNFF Secretariat 2021), 1.6 billion people, or 25% of the world's population, depend on forests for their sustenance requirements, livelihoods, jobs, and income, and 93% of the world's for-

ests are natural, while 7% were planted (UN DESA, UNFF Secretariat 2021). Plantations are now the main source of wood supply for wood products. The outlook for global wood production from planted forests by 2030 was estimated in 61 countries, representing about 95% of the global planted forest area (FAO 2006).

With the growing population and expanding consumer interest in wood and wood products after economic liberalization, the demand for wood and wood products has significantly increased (Sood 2014; Ghosh and Sinha 2016). Nowadays, there exists a rapidly increasing demand for wood fuels and a rising competition with paper and panel industries for logs and sawmill wood by-products in Europe (Pätäri 2010; Söderberg and Eckerberg 2013; Sosa et al. 2013). The demand and supply gap in wood and wood products is partially fulfilled by promoting trees outside forests (Pandey, Rangaraju 2008; Ghosh, Sinha 2016) and partially by raw material import (Woodzon 2016; Upadhyay et al. 2019). Demand and scarcity of domestic wood produce make the G20 countries the largest producers, importers and exporters of wood and wood products.

This study focused on the production, import and export of wood and wood products by the G20 group of countries because the G20 nations make up about 85% of global GDP, over 75% of global trade, and two-thirds of the world's total population. These nations also make up about half of the Earth's total land area (Sosa et al. 2015). The Group of Twenty (G20) comprises 19 countries (Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of Korea, Mexico, Russia, Saudi Arabia, South Africa, Türkiye, United Kingdom and the United States) and the European Union (Pätäri 2010; Sosa et al. 2015).

In this context, the analysis of production and trade in wood and wood products would facilitate the understanding of the current and future trends of G20 for better planning of the economy and industrial sector. Moreover, the knowledge of wood and wood product trade is of prime importance to the national economy (Upadhyay et al. 2019). The present study attempts to evaluate the production, import and export of wood/wood products and make a forecast using the autoregressive integrated moving average (ARIMA) models (Sivaram 2014; Upadhyay et al. 2017). Forecasting is intimately related to human planning activity, and it allows for the prediction of upcoming events, facilitates business decisions, and allows for the estimation of their impact on future economic development (Woodzon 2016). Models have been developed, and statistical analysis has been applied to assess (Upadhyay et al. 2019) the required characteristics such as minimum Bayesian information criterion (*BIC*), mean absolute percentage error (*MAPE*), root mean square error (*RMSE*), and highest R^2 value based on estimated export, import and production of wood-based produce by G20 by the year 2030.

MATERIAL AND METHODS

The data on the volume and price value of wood and wood products consists of production, import and export of G20 nations during the years 2004 to 2021. Data was collected from the FAOSTAT-Forestry database as of January 2023. Wood and wood products for the present study comprise industrial roundwood (IRW), paper and paperboard (PB), pulp for paper (PP), sawlogs and veneer logs (SV), sawn wood (SW), wood fuel (WF), wood pellets and other agglomerates (WPO) (considering the years 2012–2021) and wood-based panels (WBP). The time series data was used for the estimation and evaluation of the trend and behaviour of wood products of the G20 countries with the help of statistical analysis such as descriptive statistics, autoregressive integrated moving average (ARIMA) model and compound annual growth rate (*CAGR*), calculated according to Equation (1):

$$CAGR = \left(\frac{\text{ending value}}{\text{beginning value}} \right)^{\left(\frac{1}{\text{No. of years}} \right)} - 1 \qquad (1)$$

Autoregressive integrated moving average (ARIMA). ARIMA models exploit information embedded in the autocorrelation pattern of stationary and non-stationary time series data in economic situations and control problems. An approach to the set of procedures for identifying and estimating time series models within the class of ARIMA models was discussed by Box and Jenkins (World Population Review 2023). ARIMA model is classified based on the parameters as ARIMA(*p*, *d*, *q*) (National Portal of India 2023).

The ARIMA model according to Box and Jenkins (1994) is usually denoted as ARIMA(*p*, *d*, *q*), which is expressed mathematically as shown by Equation (2):

$$z_t = \phi_1 z_{t-1} + ... + \phi_p z_{t-p} + a_t - \theta_1 a_{t-1} - \theta_2 a_{t-2} ... - \theta_q a_{t-q} \quad (2)$$

where:

z_t	– $\nabla^d y_t$;
$\phi_1, ..., \phi_p$	– parameters;
a_t	– residual error;
$\theta_1, \theta_2, ... , \theta_q$	– parameters;
$a_1, a_2, ..., a_{t-q}$	– previous values of the error;
p	– the order of the autoregressive process in which the current value of the process is expressed as a finite linear aggregate of previous values of the process and a shock a_t;
d	– the order of differencing involved to make the data series that contains a (non-stationary) trend to the stationary one by taking successive differences of the data;
q	– the order of the moving average process in which the dependent variable y_t depends on the values of the error term (a_t, a_{t-1}, ..., a_{t-p}) rather than on the variable itself.

Mathematically, *p* can be expressed by Equation (3):

$$y_t = \phi_1 y_{t-1} + \phi_2 y_{t-2} + ... + \phi_p y_{t-p} + a_t \quad (3)$$

where:

y_t – dependent variable.

Mathematically, *q* can be expressed by Equation (4):

$$y_t = a_t - \theta_1 a_{t-1} - \theta_2 a_{t-2} - \theta_3 a_{t-3} ... - \theta_q a_{t-q} \quad (4)$$

The order of *p* and *q* in an ARIMA model may be chosen on the basis of autocorrelation function (*ACF*) and partial autocorrelation function (*PACF*) graphs known as Box-Jenkins (1994) model identification process. In this approach, the number of lags in the autoregressive (AR) process is based on the *PACF* graph where the choice of *p* is measured so that the *PACF* value becomes zero (or is close to zero) at (*p* + 1) lags and the choice of *q* lags in the moving average (MA) process is chosen so that the *ACF* becomes zero at (*q* + 1) lags.

Forecasts follow from the form of the fitted model (FAO 2023). The selection of an ARIMA model with the minimum value of Bayesian information criterion (*BIC*), mean absolute percentage error (*MAPE*), root mean square error (*RMSE*) and high-est R^2 value is considered an appropriate model for the purpose of forecasting. The SPSS statistical software (Version 16.0, 2009) was used for statistical analysis.

RESULTS AND DISCUSSION

The G20 countries contributed to the worldwide production of wood and wood products ranging from 75% to 94% of all products with the exception of only wood fuel, which accounted for 48% during the 18-year period (2004–2021). During the study period, they produced a great deal in the world output of PB (94.3%), PP (92.9%), WBP (91.1%), WPO (88.1%), SV (84.7%), IRW (75.8%), and WF (48.2%) (Figure 1). The percentage of the G20 countries that contributed to the worldwide import of wood and wood products ranged from 79% for paper pulp to 98% for wood pallets and other agglomerates in terms of both quantity and value (Figure 1). The export of wood and wood products globally also exhibits an increasing development trend. Figure 1 demonstrates that IRW made the least contribution, whereas paper and paperboard, sawn wood, and wood-based panels made the greatest wood commodity.

Status of wood and wood products during 2004–2021

The evaluation of available data from Tables S1–S3 in the Electronic Suplementary Material (ESM) reveals that the total production of industrial wood/wood products was 70 200.6 million m³, and of other associated wood products, it was 10 176.4 million t in the last 18 years (2004–2021). In addition to the 5 124.3 million m³ of industrial wood and wood products, 2 550.4 million t of other associated wood products were also imported from 2004 to 2021. Exports of industrial wood and wood products were 4 747.8 million m³ and 2 627.2 million t of other associated wood products in the study period.

Analysis of wood and wood products during 2004–2021

As indicated by the coefficient of variation, G20 production of wood and wood products varies from slightly over 1.5% in WPO to more than 25.1% in wood-based panels. During the 18 years, *CAGR* in WBP was 4.24% followed by WPO at 4.06%, PB at 0.93%, SW at 0.86%, IRW at 0.65% and much
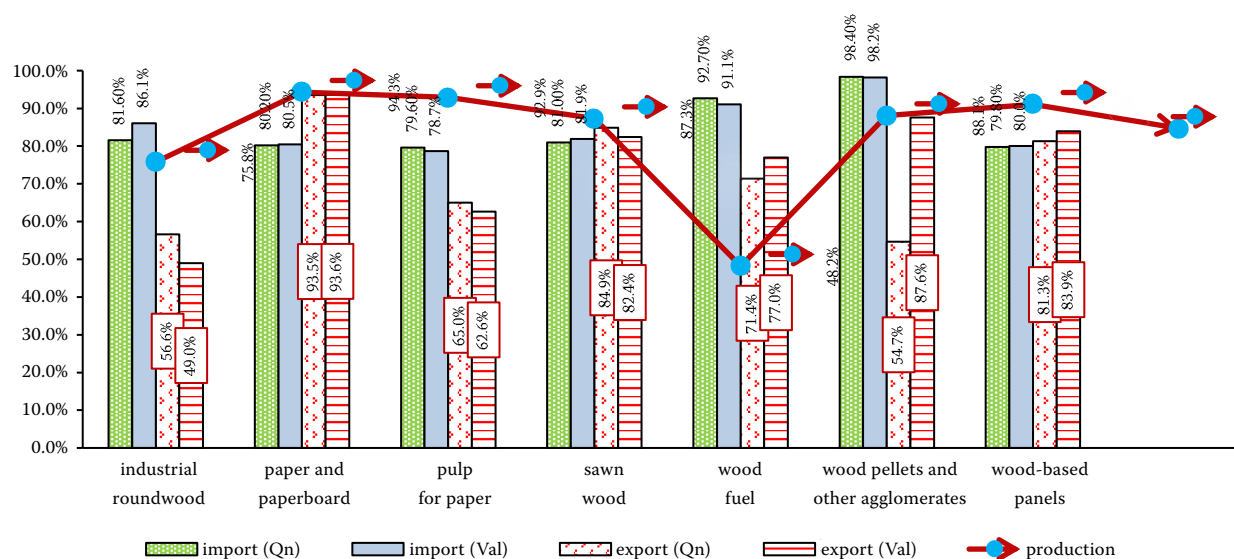
Figure 1. G20 percentage share in the global production, import, and export of wood and wood-derived products in the period 2004–2021

Qn – quantity; Val – value

lower growth in sawlogs and veneer logs at 0.15%, PP at 0.04%, and WF at −0.29% (Table S1 in the ESM).

The import of wood/wood products showed that PB exhibited the lowest variability (5% and 8.4%) and the amount and value of WF showed the largest variability (36% and 47.7%). The *CAGR* was 6.63% and 6.29% for imports of WPO, followed by 5.86% and 10.12% for WF, 2.71% and 4.27% for WBP, 2.19% and 4% for PP, 0.87% and 3.23% for IRW, 0.53% and 3.1% for SW, and there was declining growth of −0.24% and 0.49% for PB (Table S3 in the ESM).

For exports, the coefficient of variation ranged from 3.3% in quantity and 8% in value to 38.9% in quantity and 55.1% in value for PB and WF, respectively. In terms of quantity and value, *CAGR* for exported wood products was 6.61% and 11.83% for WF, 6.17% and 5.38% for WPO, 3.51% and 5.36% for WBP, 2.47% and 3.85% for PP, 0.82% and 3.41% for SW, 0.44% and 2.03% for IRW, and declining growth of −0.03% and 0.98% for PB (Table S2 in the ESM). The other statistics for production, import and export (quantity and value) are also shown in Tables S1, S2 and S3 in the ESM, respectively, in terms of the mean, standard deviation, minimum and maximum.

Autoregressive integrated moving average (ARIMA) model

For the wood and wood products of the G20 group of countries, the model statistics are shown

in Table S4 in the ESM. The ARIMA model selection criteria satisfy the maximum criteria [highest R^2, lowest *RMSE*, *MAPE*, *MAE* (mean absolute error), and normalized *BIC*]. The results of ARIMA models were best suitable for the production of IRW(0, 1, 0) with $R^2 = 0.652$, followed by PB(0, 1, 0) with $R^2 = 0.464$, PP(0, 1, 0), SV(0, 1, 0), SW(0, 1, 0), WF(0, 0, 1), WPO(0, 1, 0) and WBP(0, 1, 0) with minimum *MAPE*, *MAE* and *BIC* with the highest R^2 value.

The best models for import were found for IRW(0, 1, 0), PB(0, 1, 0), PP(0, 1, 0), SW(0, 1, 0), WF(0, 1, 0), WPO(1, 0, 0), WBP(0, 1, 0) with minimum *MAPE*, *MAE* and *BIC* with the highest R^2 value. For export, a model with the lowest *MAPE*, *MAE*, and *BIC* values and the highest R^2 value was fitted for IRW(0, 1, 0), PB(0, 0, 1), PP(0, 1, 0), SW(0, 1, 0), WF(0, 1, 0), WPO(0, 1, 0), and WBP(0, 1, 0). The volume for the next nine years was predicted using the best-fit models, and the results are shown in Table S5 in the ESM. According to projections, the production and trade of wood and wood products will rise in future.

Residual diagnostics

ACF and *PACF* values were within the 95% zero-bound, see Figures 2–4, and they showed that there is no association between the residuals. This results in the independence of residuals. The *ACF* and *PACF*
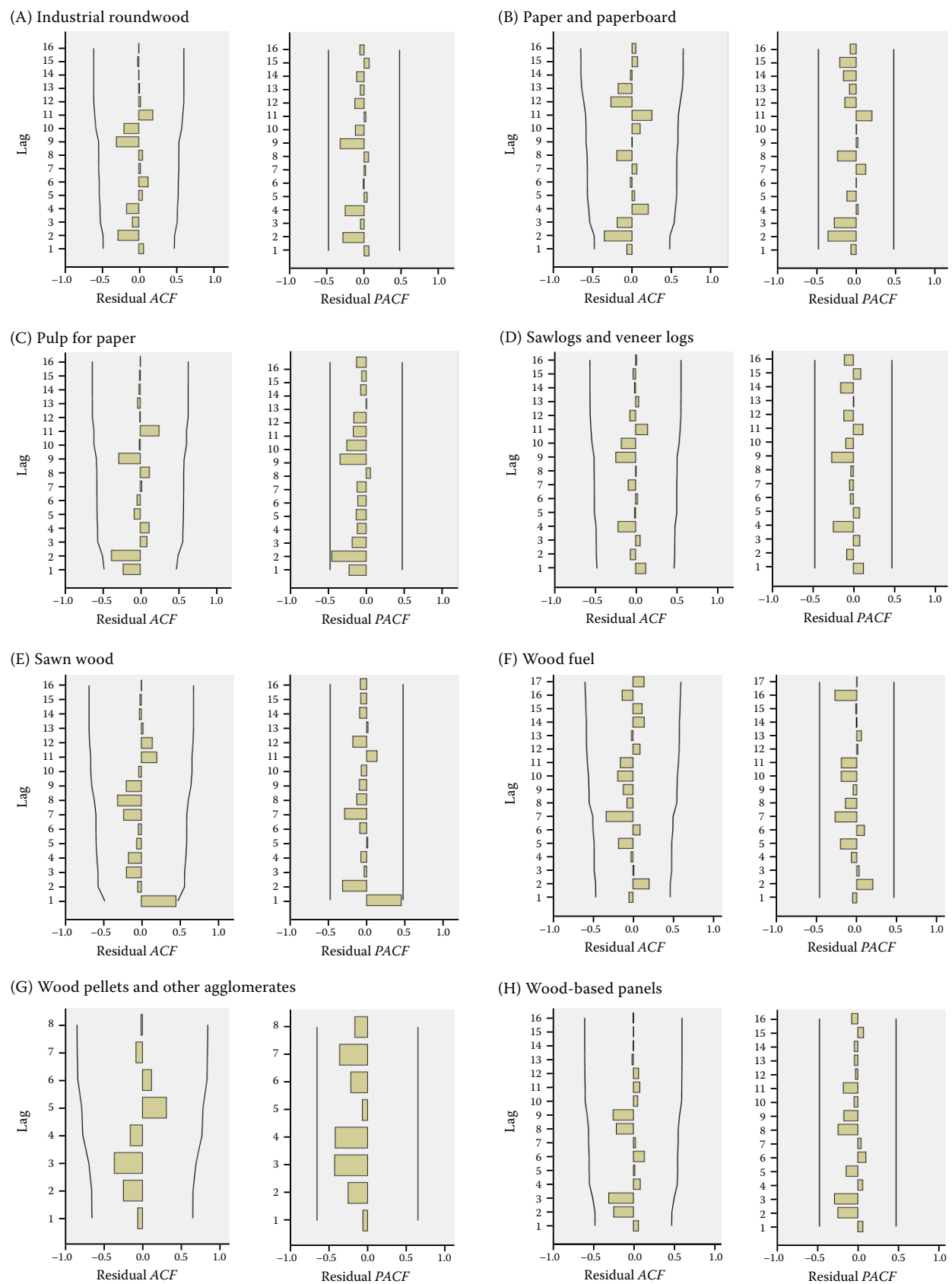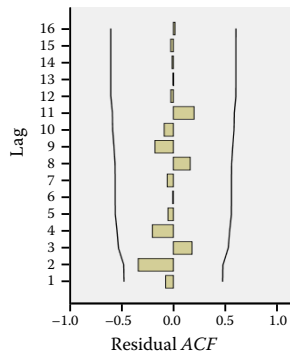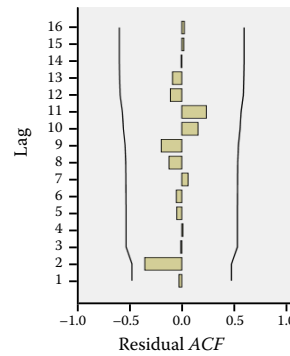
Figure 2. (A–H) Residual diagnostics *ACF* and *PACF* for the production of wood and wood products

ACF – autocorrelation function; *PACF* – partial autocorrelation function

Figure 3. (A–G) Residual diagnostics *ACF* and *PACF* for the import of wood and wood products

ACF – autocorrelation function; *PACF* – partial autocorrelation function
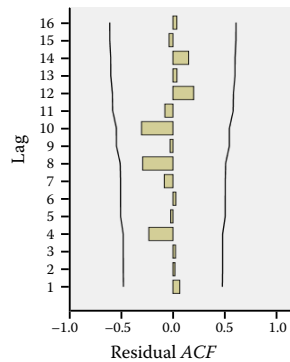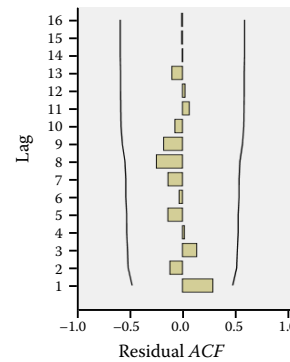
(A) Industrial roundwood
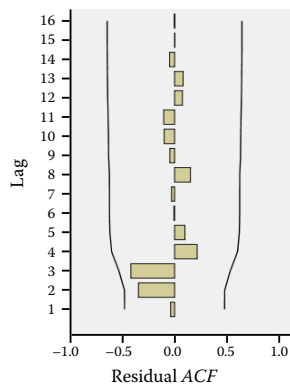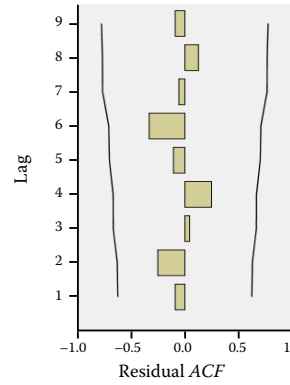
(B) Paper and paperboard

(C) Pulp for paper

(D) Sawn wood

(E) Wood fuel

(F) Wood pellets and other agglomerates

(G) Wood-based panels

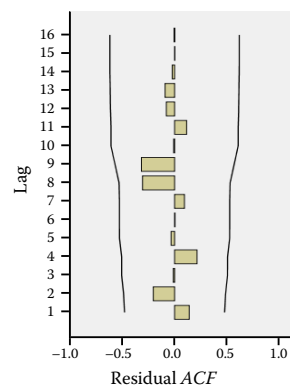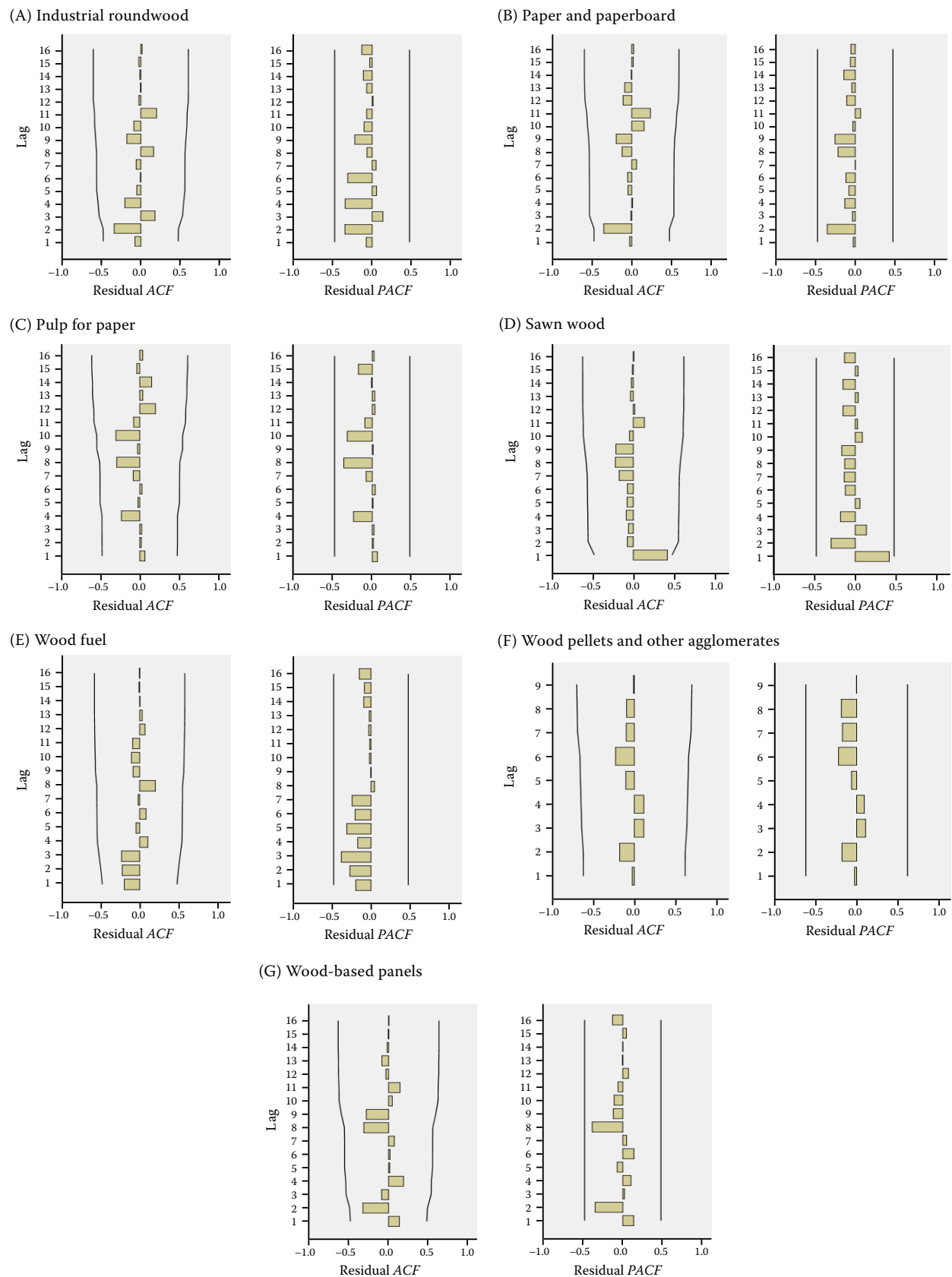Figure 4. (A–G) Residual diagnostics *ACF* and *PACF* for the export of wood and wood products

ACF – autocorrelation function; *PACF* – partial autocorrelation function

residuals graph confirms that the residuals of the ARIMA models for the production (Figure 2A–H), import (Figure 3A–G) and export (Figure 4A–G) of wood/wood products were free from white noise, reflecting precise estimates by these models.

Forecast of production, import and export of wood/wood products for the period 2022–2030

The forecasted value of production, import, and export of wood/wood products for the period of 2022–2030 is given in Table S5 in the ESM. Forecasted values of quantity indicate that the production of all wood and wood products would rise from 4 291.1 to 4 495.2 million m^3 of industrial wood and wood products and from 619.7 to 653.8 million t of other associated wood products during the years 2022–2030. Imports of industrial wood, wood products, and other associated wood products are expected to reach 357.3 million m^3 and 167.9 million t in 2022 and 389.7 million m^3 and 173.2 million t in 2030, respectively. With respect to the export of industrial wood, wood products, and other associated wood products, they are expected to reach 320.9 million m^3 and 161.8 million t in 2022 and 369.2 million m^3 and 168.7 million t in 2030, respectively.

Evaluation of the top 10 countries from G20 for wood and wood products from 2004 to 2021

Production. The top 10 countries of the G20 produced between 90.6% of WF and 74.8% of the wood pellets and other agglomerates. The result shows that the USA was the primary producer of IRW, PP, sawlogs, SW, and WPO. China was the biggest manufacturer of PB and WBP, while India held the top spot for just one commodity, fuel wood (Table S6 in the ESM). In India, FW still accounts for the majority of wood consumption, accounting for 75% in rural areas and 21.7% in cities (National Portal of India 2023).

Import. The import share of the top ten nations of the G20 ranged from 64.6% to 89% of all products. In terms of the import value, the top 10 countries of the G20 group hold a market share of 75% in all categories, in which PB (26%) was followed by PP (15.4%), IRW (15.0%), SW (15.0%), WBP (13.0%), WPO (1.0%), and WF (0.2%). China was the biggest importer of IRW and PP in the study period, followed by the USA for sawn wood, Germany for PB, Italy for WF, and the UK for WPO (Table S7 in the ESM).

Export. The total export value of the G20 nations for wood/wood products was USD 3 307 081.9, in which IRW (49.9%) was dominant and had the highest market share, followed by PB (15.9%), PP (15.2%), WBP (14.2%), WPO (3.7%), WF (0.9%), and SW (0.2%). Exports of all types of wood/wood products from the top 10 nations ranged from 68.4% to 92.8% (Table S8 in the ESM). Russia was the top exporter of IRW, with the USA ranking second, followed by Germany, which was the top exporter of PP, followed by Canada for SW and PP, Latvia and Croatia for WF, the USA for WPO, and China for WBP.

According to the World Bank estimates, the demand for lumber would increase fourfold by 2050 compared to the current demand. Gresham House predicts that the use of wood will rise by 3.1%, primarily for panel products (Johnston and Buongiorno 2017). Under the current circumstances, this demand has to be met by the major G20 countries like Canada, the US, northern Europe, Australia and Russia, thus providing a good opportunity for these countries. Unites States, Russia, Canada, Germany and China are major players in the wood sector being major wood importer and exporter countries in the G20 group. Sawn wood exports of the USA in 2021 were 2.9 million m^3 whereas in 2022 sawn softwood exports were 2.54 million m^3 (USDA FAS 2023). During that time, sawn hardwood production from US forests was 15.93 million m^3 in 2021 and 17.64 million m^3 in 2022 (HMR 2023). China is the main market for the USA, hardwood accounting for a total of 33% of all hardwood lumber exports from the USA, followed by Canada (19%) and Vietnam (11%). Meanwhile, in terms of imports, Canada holds the top position with a total of 38% of all imports, followed by Brazil (16%) and Germany (8%) (USDA FAS 2023).

In 2021, the European Union (EU) showed a 4.3% (89.4 million m^3) increase in sawn softwood production; in contrast to the production its consumption of sawn softwood increased by 6.1%, which is slightly over 100 million m^3 in volume. Export of sawn softwood from the EU mainly came from Germany (8.8%) and Finland (6.4%), while the largest EU exporter, Sweden, had a 9.8% decline in exports. China is the main market for sawn softwood wood from the EU. In terms of sawn hardwood, the EU faced a depletion of resources as the consumption of sawn hardwood exceeded production. Even

then exports of sawn hardwood from Europe increased by 20% to over 3.2 million m^3 in 2021. China imported 29% or 950 000 m^3 of those volumes. This has led to the price hike of hardwood timber in domestic markets (UNECE, FAO 2022).

Presently, Russia is one of the world's largest timber exporters, as it owns more than a fifth of the world's forested areas. Traditionally, Russia was the biggest exporter of roundwood to Asia as well as to the EU. In 2021, the growing global demand for packaging and wooden constructions placed Russia in the limelight with a new export record of USD 12.5 million (Gordeev and Pyzhev 2022) despite the Ukraine war-related sanctions. Russia, being the world's fourth largest softwood producer, produces ~40 million m^3 of softwood (ITTO 2022b), of which domestic consumption is only 10 million m^3. Presently, Russia exports 28.5 million m^3 of timber globally.

Out of the G20 countries, China is the biggest importer of Russian roundwood (Zhang, Gan 2007; Gordeev 2020), followed by Japan and South Korea. In 2020, Russia had a whopping 58% market share in China's market, followed by New Zealand (29%), Canada (9.4%), Vietnam (8.2%), USA (7.8%), EU/EFTA (7.4%), Australia (7.3%), and Thailand (5.7%) (ITTO 2022a). China's log imports from Russia in 2022 were about 2.21 million m^3, which was a 7% (13.09 million m^3) reduction compared to the preceding year (ITTO 2023).

The restriction of China's logging from natural forests provided the Russian wood sector with a huge opportunity. Russia not only provided the timber market but also provided logging rights at a low cost. China gets the very much-needed raw material for its wood-based panel production from these forests and supplies plywood and furniture to other countries (Barbu and Tudor 2022), making China the world's biggest exporter of wood products. The USA is the largest importer of manufactured products from China. China imports sawn timber and paper pulp from Canada and the USA (Liu and Ning 2023). 61% of China's hardwood comes from Papua New Guinea, Russia, the Solomon Islands, Brazil, and the United States. In 2022, China's hardwood log imports were 12.4 million m^3, which is actually a 10% decrease from 2021 (USDA FAS 2023).

In terms of wood and wood product marketing, the African Union will likely have a far-reaching impact. While analysing wood imports between the G20 countries, it is important to understand the India-Africa ties, as both these subjects can gain much from cooperative initiatives. India has a long trade history with African countries, which is likely to get prioritised in trade and correcting supply chains. In 2017, wood exports from Africa accounted for around 63% of exports to India, which is about 9.2% of India's total wood imports (Afreximbank and Exim India 2018). When India's traditional wood-supplying countries, such as Malaysia and Myanmar, started reducing wood imports, it was the African timber market that supplied India with major hardwood species and face veneer species for the Indian wood-based panel sector. Still, the wood coming from Ghana, Gibbon, Cameroon, Ecuador, Ethiopia, Democratic Republic of the Congo, Senegal, Togo, Tanzania, and Ivory Coast constitutes a major amount in India's wood imports, especially teak, okoume and pine wood. Pinewood is India's major wood import and Russia produces a good amount of pinewood. Still, wood trade between Russia and India does not take place due to the high logistic cause involved. However, Ukraine war-related sanctions from the USA and EU, as well as China's reduction in wood import from Russia, can push forward the Indo-Russian wood ties.

Paper and paperboard production from the G20 countries accounted for 94.3%, whereas PP is 92.9%. In 2022, the USA produced nearly 183 million m^3 of pulpwood PB products, which is 1.6% less than in the previous year, i.e. 185.7 million m^3. In relation to this, the domestic PB production also declined by 3.3%, from 68.2 t in 2021 to 66 million t in 2022 (UNECE, FAO 2022). In the European Union, total PB declined by 4.9% in 2022 to 95.5 million t (Valois 2023). Meanwhile, China's production of wood pulp grew by 16.9% to 21.2 million t; it also produced over 124.25 million t of paper and paper products in 2022, an increase of 2.64%. India produced 17.284 million t of PB in 2020 (FAO 2022). In 2022, India's imports of PB products were 1751.5 thousand t.

Consumption of wood products

The trends of the utilisation of wood products by production and import (total demand) to use in consumption and export (produce output) are presented in Figure 5. In the last 18 years, the G20 nations consumed more than 77% to 95% of wood in different wood product categories, produced
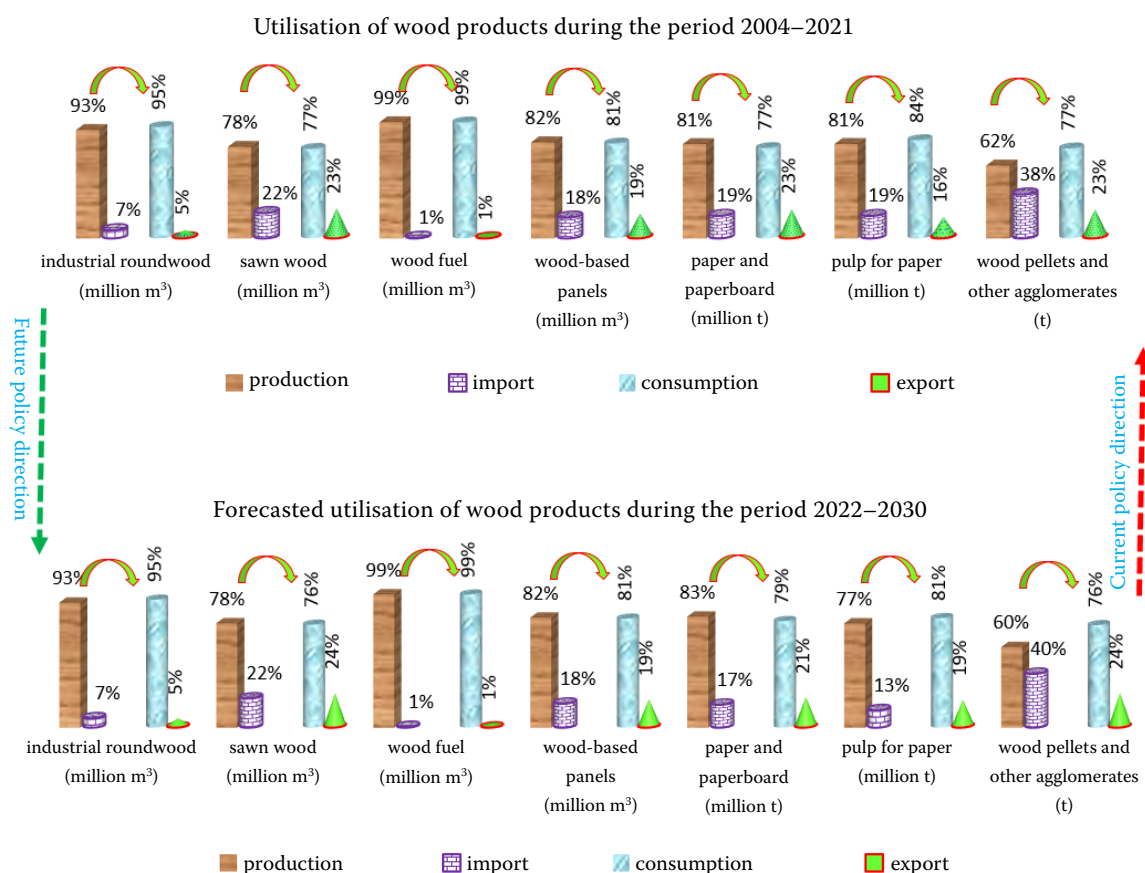
Figure 5. Performance of the G20 countries wood/wood products

and imported it; in this, more than 62% to 99% were produced in different wood product categories. SW (23%), WBP (19%), PB (23%), PP (16%), and WPO (23%) were the main exports.

CONCLUSION

From 2004 to 2021, the G20 nations produced wood/wood products in which IRW was 25 092.9 million m³, which was the dominant and highest production, followed by WF with 16 359.8 million m³, SV with 16 162 million m³, SW with 6 918.8 million m³, WBP with 5 667.1 million m³, PB with 6 705.7 million t, PP with 3 138.1 million t, and WPO with 332.6 t. The G20 nations significantly impacted global output from 2004 to 2021, covering 81% and 82.7% of the import and export values, respectively. The suitable ARIMA models for production were (0, 1, 0) for all items except WF(0, 0, 1). The best-fit ARIMA models for import were all suitable (0, 1, 0), with the exception of WPO(0, 0, 1). The best fits for export were all suitable (0, 1, 0),

with the exception of PB(0, 0, 1). The trend shows that the G20 countries produce a sufficient amount of wood required for their consumption, and they consumed more than 77% to 95% of wood, while they had a much lower export of different wood product categories outside of the G20 group. The predicted trend of production, import, consumption, and export of wood/wood products would not change by 2030; it will follow the same policies and trends. If the population and consumption continue to rise, then good policies will be required to satisfy the future demand and supply of wood/wood products.

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