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DYNAMIC ANALYSIS OF FORESTRY SECTOR IN ITALY: A LONG-TERM STATISTICAL ASSESSMENT WITH FAO DATA AND R LIBRARIES

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Abstract: Forestry plays the key role in environmental sustainability and economic wealth of Italy. Forest massifs maintain the ecological balance and climate setting of the country. At the same time, forests are essential sources of products for industry. The research objective is to evaluate the balance between the environmental protection and economic development of forestry. The research questions are: 1) how does forestry sector developing and what are the long-term trends showing its economic profitability? 2) How does the forest area change over decades? To answer these questions, the objective is to evaluate the data on environmental and economic parameters. The methodology included the FAOSTAT dataset on 2001-2023, processed by statistical analysis in R. The increase in forest area is detected from 12,748 to 13,937 T ha. Decline in pulp-and-paper sector is due to growing digitalization and e-commerce: newsprint production decreased from 293 T to 52 T tons, which proves transfer of printing industry towards e-format. Shifting market is in wrapping and packaging paper (360 T to 3.702 T tons). The results show positive trends in reforestation, high revenues from timber production which need further development and investments in forestry.

Keywords: economics; forestry; timber; pulp and paper; sustainable development; statistical analysis; R

1. Introduction

Forests have significant economic and ecological value for the country through providing marketable products (Farnworth et al., 1983; Adger et al., 1995; Bockstael et al. 2000) and delivering essential ecosystem services (Boyd & Banzhaf 2007; Zhang & Stenger, 2014; Shojaie shami et al., 2021). Forest massifs maintain the ecological balance of the country and serve as sources of products for forestry industry with major categories including timber, paper and pulp products. Essential environmental value of forest stands and vegetation consists in climate regulation (Winkel et al., 2011; Lemenkova, 2021; Yu et al., 2025), maintaining biodiversity (Raivio et al., 2001) and providing habitat spaces for rare and valuable species (Ruhl et al., 2020). Forest support healthy ecosystems through improved soil fertility and quality (Woo et al., 2025; Gaston et al., 2019), water purification and creating ecological habitats for rare and valuable species. Moreover, vegetation has important climateregulating function through mitigating temperature extremes carbon

sequestration and hydrological control on humidity (Keleş, 2018; Lemenkova 2025a; Li et al., 2010), hydrological regulating watershed level (Luo et al., 2025; Junttila et al., 2016; Lemenkova, 2022a; Fan et al., 2025).

Besides precious environmental functions, forests play important economic role in the society by providing goods of timber and non-timber origin to support livelihoods (Arts & Buizer, 2009). Economically, this includes direct and indirect use of products (e.g., fuel, wood, food, plants) originating from forest (Agrawal et al., 2008). Finally, forest provide intangible benefits for society through recreation and cultural services. Hence, high revenue from forests makes national forest policy decisions to balance between the environmental protection, which is crucial for nature conservation, and timber industries (Burnett & Davis 2002; Squire et al., 1991).

Such values of forest make them valuable resource for environmental protection agencies and economic purposes. Italy has a variety of tree species in forests that cover ca. 39% of the country. Major species include beech (*Fagus sylvatica*), oak (*Quercus*), and poplar (*Populus alba*). Poplar plantations, especially along the Po Valley, are a major source of feedstock for wood manufacturing sector. However, only a small percentage of forests of Italy is under detailed management for commercial timber, while the majority of the wood produced domestically is used as firewood, with industrial timber production declining. The decline is due to high costs, fragmented and poorly mechanized forestry sector, and strong dependence on imported raw materials.

As a result, forestry sector in Italy is under development and ongoing reconstruction. Currently it includes ca. 72,000 companies which employ 320,000 people. The forestry is characterized by a constantly growing forest area and a mix of modern and traditional equipment. Its major benefit of in Italy consists in the diversification, improving management plans and utilizing wood for structural and non-structural purposes. In 2022, the timber product consumption in Italy experienced a decline by 7.5% due to the pandemic, but then recovered and increased in demand for home improvement products of forestry sector. Nevertheless, the domestic roundwood production is insufficient for domestic needs, leading to significant dependance on import. Therefore, Italy imports a large part of the forestry sector for its needs, and remains a significant importer of timber products among the EU countries.

Commercial forest management in Italy faces challenges with major issues including small private property sizes, raw material shortage, limited transport and shipment capacities. Besides, despite a growing forest area, there is a low rate of timber harvesting compared to the amount grown. On the international level, there is a lack of forestry-related market balance in Italy, compared to other EU countries, e.g. Germany, Spain or France (Knauf, 2015). As a response to such problems, management of forestry industry in Italy is undergoing development. Regional policy in forestry and environmental sector now enhances environmental, social, and economic functions. These primarily include practices of sustainable management, supported by policies and funding, to ensure forest protection and production (Joyo et al., 2025). For instance, the EU Emissions Trading Scheme (EU ETS) brings positive effect by stimulating the pulp-and-paper making enterprises toward technological innovation (Lin et al. 2019). Recent studies using the Italian Community Innovation Survey (CIS) shown that the EU ETS exerted effects on environmental innovations (EI) in CO_2 abatement and energy efficiency controlling for other variables, grouped as internal and external to the firm, and additional

environmental regulation factors (Borghesi et al., 2015).

The fundamental concepts of the economic and environmental aspects of the forestry sector, timber and wood production are reflected in the economic aspects of Italy. An economic and environmental analysis of several case studies on forest products located in Italy was undertaken to analyze multiple products that can be obtained from forestry.

In the geographic sense, forest cultivation for industrial needs in Italy is well-adapted to the Mediterranean climate and has considerable ecological and economic potential. The main type of domestic wood used in the lumber industry of Italy is poplar, grown extensively in the Po Valley. Natural landscapes of forests represent the land surface where diverse environmental processes interplay to provide habitat and resources for life (Goldstein et al., 2002; Klaučo et al., 2013, 2017). Soil quality creates excellent conditions for plantation of forest massifs and wood production (Adams & Attiwill, 1984; Turvey & Smethurst, 1994; Imaya et al., 2005), which includes a variety of items: lumber, plywood, pulp-and-paper, engineered wood for construction and furniture (Lombardo, 2022). Understanding the benefits and demands in forestry sector remain a challenge since it involves the complexity of factors that affect forestry.

Although relevant literature on Italy exists, an integrated, systems-level appraisal of how these measures on environmental protection interact with economic benefits from forestry remains scarce. The studies on aspects of nature conservation seldom integrate industrial feedback loops from financial benefits of forestry, while papers on economical revenues from timber harvesting and wood processing frequently focus on technological aspects of market cycle in forestry, without reference to the environmental sustainability. Consequently, decisions in forest industry lack a holistic lens for prioritizing measures that would balance between forestry industry and environmental protection. Such measures would stimulate production of pulp-and-paper and timber for economic well-being, while taking measures on nature protection and conservation, such as development of network of the protected parks and natural reserves.

This research project uses statistical data available from the Food and Agriculture Organization (FAO) of the United Nations (UN). Existing applications of FAO in forestry and environmental research prove its robustness and applicability (Skulska et al., 2019). Spatial and descriptive data are employed from national services for regional approach focused on the analysis of forestry in Italy. It compares five sectors of forestry at regional level with varied situation on economic development in forest sector. We applied diverse workflows of R libraries for updating data and harmonization using combination of old data for retrospective analysis and novel data from the FAO-based survey to evaluate the period of 1961-2023. The qualitative-quantitative modelling of forestry development employed statistical methods of data processing by R programming and computing software to model economic trends, and spatial analysis by GIS. Important feature of R is provided by scripting techniques, which enable automating repetitive tasks and creating dynamic content in statistical computing of large datasets (Bilina & Lawford, 2012; Lemenkova, 2022b; Bröker et al., 2005). Available archived FAO datasets were processed by R statistical methods for accurate and effective visualization, to reveal trends in ecological and economic processes.

The importance of statistical data as a source of environmental and economic information can be illustrated by their practical application, including biodiversity monitoring (Sona et al., 2025), risk assessment (Jindal et

al., 2020; Lemenkova, 2024a), analysis of deforestation and aridification (Lemenkova, 2024b), environmental mapping, monitoring landscape dynamics, to mention a few.

Rapid development of the advanced statistical methods of data analysis presented effective modelling tools for dynamic updates for retrospective and perspective data analysis: R packages and libraries of Python (Chen, 2021; Hu et al., 2022; Lemenkova 2025b; Adun et al., 2021). Currently, there are no integrated studies that present an in-depth overview of both ecological and economic datasets that comparatively analyze the diversified landscapes and economic forestry sector of Italy. Using the advanced statistical methods for economic data processing, we performed the trend analysis of forestry products to demonstrate current situation and dynamics. Using advanced tools in R for studying environmental and economic variables is a powerful approach. Here, we use the RStudio for modelling FAO-based data.

This study contributes to this gap by quantifying a revenue from forestry and analyzing trends in production in 2 recent decades, and analyzing how forest stands increase in the pattern on land cover types in Italy. To achieve this goal, this study answers the following research questions: 1) how does forestry sector developing and what are the long-term trends showing its economic profitability? 2) How does the forest area change over decades? Answering these questions by R-based data analysis of FAO archives, this study provides insights into the variation between diverse environmental and economic parameters of forestry sector across the country, and their response to the environmental factors and trade affecting their dynamics – technologically, economically, and in ecological terms. This cumulative analysis of supported by statistical modelling in R aims to highlight the differences and variations in wood production and revenues and their changes over time for country level.

Research hypothesis of this study consists in the following statement: Forest industry in Italy will have higher impact factor on the economics due to the high revenues obtained from the furniture manufacturing and pulp-and-paper industry, provided the sustainable development of environmentally protected areas is supported through optimized land management.

This study develops a systematic approach to monitoring and comparative analysis of the forestry sector in Italy using advanced scripting tools of R libraries (Cribari-Neto & Zarkos, 1999). The specific aim is to model, analyze, and compare Italian landscape on forest industry using FAO data in 5 distinct categories: production quantity, import quantity and value, export quantity and value. The situation of forest trade was selected because forestry sector is rapidly growing in Italy, with forest area increasing by ca. 100,000 ha per year due to the abandonment of marginal agricultural land. The country has approximately 11.4 M ha of forest, covering about 39% of its territory. The significant portions of forestry are managed for timber production and conservation. The development of forestry in Italy is guided by a governmental support and includes initiatives for biodiversity protection and sustainable forest management.

Current state-of-the-art in research on Italian forestry has gap between the existing environmental applications and the advanced statistical methodologies. Based on literature analysis, the existing approaches of modelling dynamics in forestry sector in Italy are mostly relied on traditional methods with limited regional extent. This project aims to minimize this gap by developing appropriate methodologies by R for integrated extensive modelling using advanced tools and RStudio software. R is selected because it is a powerful

open-source programming language specifically designed for statistical analysis. Many case studies report the use of R in research on data modelling, visualization and analysis (Kleiber & Zeileis, 2008; Lemenkova, 2019a, 2019b; Anderson et al., 2018; Shahare et al., 2024). R provides a flexible and robust environment for data handling and statistical modeling, supported by a vast collection of libraries (Peabody, 2023; Choi & Asilkalkan, 2019). Its scripting nature allows for reproducible analysis, making it a crucial tool in environmental data science.

2. Materials and Methods

The Food and Agriculture Organization (FAO) data form a valuable information on environmental and economic variables that can be used for practical scientific purposes. The importance of such data is widely discussed in relevant works and can be summarized as follows:

1. First, statistical data present a key source of information on environmental, economic, climate and social-economic categories. It is a ground basis for modelling aimed at practical decision making on the environment protection, analysis of climate change and balance with economic development in forestry, including production of wooded materials.
2. Comparative analysis of economic and environmental categories enables to evaluate vulnerable sectors with rapidly changing trade rates to detect continuous process of economic development of country and to get insight into landscape dynamics.
3. Processing, interpreting, and visualising multi-format datasets using advanced statistical tools and software, such as R, improves interpretation of the datasets for statistical purposes.
4. Data interpretation provides information for the long-term economic prognosis. This is especially actual for forestry and wood production, since this sector should maintain the balance between forest protection and nature conservation on the one hand, and economic development on the other (production of wood and paper for export and regional needs).

The geospatial analysis of forest landscapes has been based on the QGIS to analyze the location of the protected forest stands in Italy and their proximity to the industrial centers (**Fig. 1.**).

With the advances of FAO mission and statistical data acquisition on forestry and environment, the amount of economic-geographic data that can be used for modelling is increasing progressively. This includes both open-source datasets and repositories, as well as data obtained from census, archives and official agencies for updates of economic and environmental analysis. Automated handling of these data for statistical analysis in environmental and economic monitoring remains a challenge. The solution to these tasks can be found using integration of data and computer-based processing through application of R statistical libraries. Technical algorithms of R use advance syntax which provides excellent instruments for in-depth environmental and economic analysis. Such integrative approach stands apart from the traditional descriptive analysis through methods of statistical visualization and analysis of diverse categories of data. Techniques included computed regression of the data, box plots, multi-facetted graphs, correlation plots and pie charts.

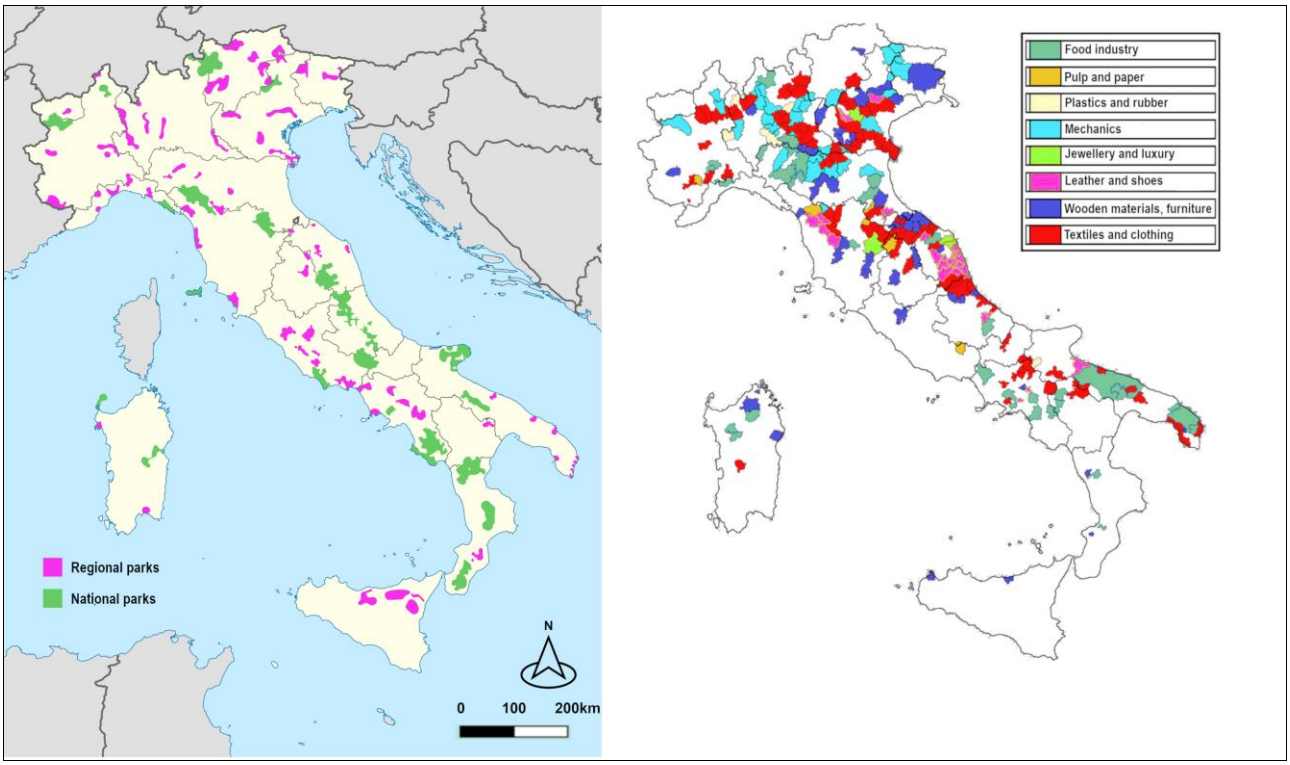

Fig. 1. Location of the protected forest stands in Italy (left). Source: Wikipedia, modified by the author; Industrial districts per sector in Italy (right) Source: ISTAT (2001), modified by the author.

The collected data were converted to tables with comma separated values (.csv format) and exported in into R. The important issue in forestry and environmental analysis is quantitative measure of trends in economic values of forestry products. This becomes the issue in regions with restricted wood and timber, such as Italy. To this end, we evaluated the dynamics over an extended period (1960 to 2023) covering a long-term period of six decades. Changes were interpreted using libraries of R (ggplot2 and others) to compare actual and retrospective data. This enabled to explain the distribution and structure of forestry sector, their dominant types and revenue for the country, changes and relation to forest protection, based on the statistical analysis. The methodology included statistical techniques of data analysis to evaluate perspective for forestry sector. In FAO repository, we selected the domain on "Forestry Production and Trade" in Italy (area code M49 380) with code "FO". The selected element with code 5516 covered data on forestry production.

The following categories of forestry sector were evaluated and assessed for economic analysis of trade and production: wood fuel (coniferous and non-coniferous); sawlogs and veneer logs, coniferous; pulpwood, (production 1961-2023, from coniferous and non-coniferous, diverse categories); other industrial roundwood, coniferous and non-coniferous (production); wood charcoal, chips, pellets and particles; recovered paper and paper production (diverse categories). Afterwards, the same categories were evaluated for export quantity (in m^3) and export value (in thousands $ USD), to analyze the revenue of forestry in the economic sector of the country and to evaluate trends and dynamics in monetary benefits from forestry industry in Italy.

The next step included the same categories of forestry production and trade with focus on import. This enabled to analyze the dependance of the country on imported products, their

values and price, and to compare the missing products in the economic system of the country. Although forestry sector in Italy includes a variety of companies, its domestic roundwood production is insufficient for domestic needs, which creates dependance on import of raw materials and finished products. This step highlighted the quantity and price of the imported goods in forestry.

The dynamics of land cover types was evaluated using remote sensing (RS) data of Moderate Resolution Imaging Spectroradiometer (MODIS) sensor (Barnes et al., 1998; Kahn & Sayer 2023). Evaluating the intensity of landscape dynamics using remote sensing (RS) data enables to reveal current state of the land cover types and analyze trends (Kocaman & Ağaçcıoğlu, 2025; Kesgin Atak & Tonyaloğlu, 2025; Lemenkova, 2025c; Chaves et al., 2025). RS data support comparison of ecosystem structure in its different areas, associated with climate factors. A sensor on NASA's Terra and Aqua satellites, MODIS collects RS data in 36 spectral bands, providing global coverage every one to two days which makes it reliable source of geo-information (Justice et al., 1998; Salomonson et al., 2006). On these data, changes of forest coverage were evaluated to highlight the environmental dynamics.

3. Results

The results demonstrated two issues: 1) environmental positive dynamics through reforestation trends in Italy with continuously increasing areas covered by forests; 2) the economic dynamics in forestry industry with a distinction on raw products: pulp and paper (newsprint, packaging paper, tissue and household paper, and paper for printing and writing), timber products (chips), wood and sawn wood. The rapidly developing forestry sector supplies products for economic industry and contributes to the country's well-being and sustainable development.

The evaluation of land cover types in Italy aimed at assessment of current trends in landscape dynamics according to distribution of land categories (in 1000 ha). The class “Artificial surfaces” (including urban and associated areas) demonstrated the rise in coverage from 1567,77 T ha in 2001 until 1587,51 T ha in 2023, which indicates a stable increase of the impervious surfaces due to urbanization. Variations in land cover types are shown in **figure 2**. The area occupied by herbaceous crops in Italy decreased from 11859,17 in 2001 until 10897,35 in 2023. Grasslands covered 3220,95 T ha in 2001, while 2023 their coverage slightly decreased to 3124,04 T ha, which proved the decline in ecosystems dominated by grasses. Forests and tree-covered areas, in contrast, increased from 12748,35 in 2001 to 13937,72 T ha in 2023, which proved their restoration at the country levels.

The Maquis shrubland, which is a shrub-covered area in Italy are presented by a dense vegetation of evergreen shrubs and small trees in coastal and Mediterranean regions. Their coverage declined significantly from 23,5 to 4,92 T ha. Such negative dynamics proves vulnerable state of landscapes, due to the climate warming, typical for southern regions. This type of ecosystem requires temperate or humid winters and hot, dry summers. Recent effects from climate change affected their distribution in the Mediterranean coasts. Shrubs or herbaceous vegetation, aquatic or regularly flooded are found in freshwater marshes, lagoons, and wetlands of Italy, such as the Padule di Fucecchio. These habitats feature communities like the *Phragmitetum communis* (common reed) and other aquatic and marsh plants, though the diversity can be impacted by factors like invasive species. This land cover type contrasts with other natural

vegetation types in Italy, such as coastal and inland shrubland (macchia), pastures, and grasslands. Their distribution declined from 284,73 T ha in 2001 to 201,67 in 2023, which proves the effects from climate and human activities (**Fig. 3.**).

Terrestrial barren land declined in Italy from 178,7 to 148,03 T ha, which correlates with the increase of areas in construction or natural regeneration of forests (e.g., the increase of forests and shrubland). Permanent snow and glaciers declined from 28,04 T ha in 2001 to 9,64 in 2023, according to MODIS satellite data. This concerns the mountain chains of Italy, such as Alps, Apennines and Dolomites.

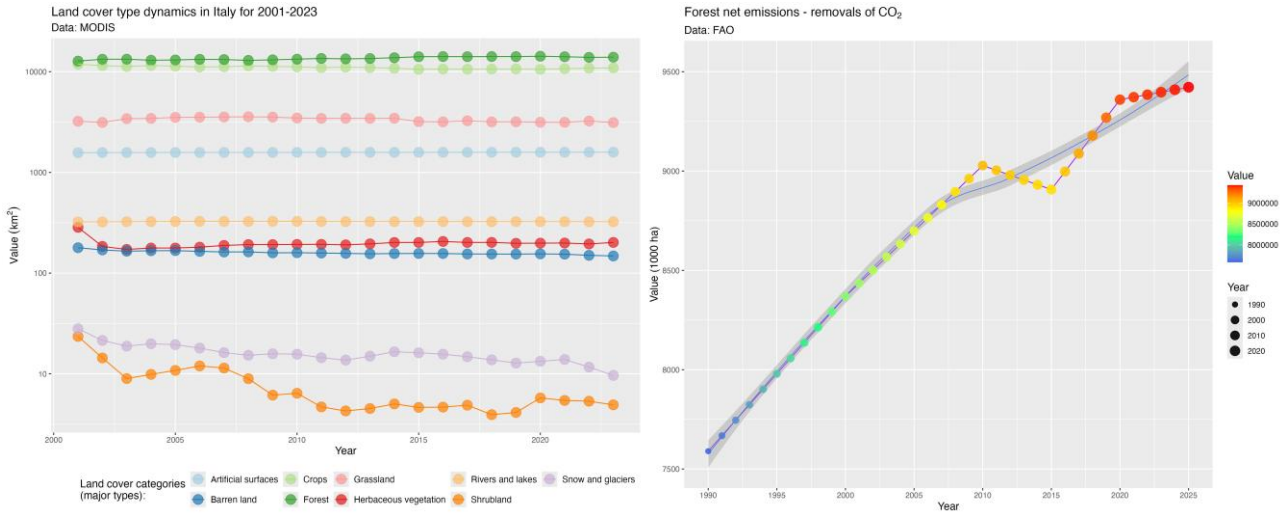

Fig. 2. Dynamics of land cover types in Italy (left) and forest emissions as CO_2 removals in 1000 ha (right). Data: FAO and MODIS. Software: R. Source: author.

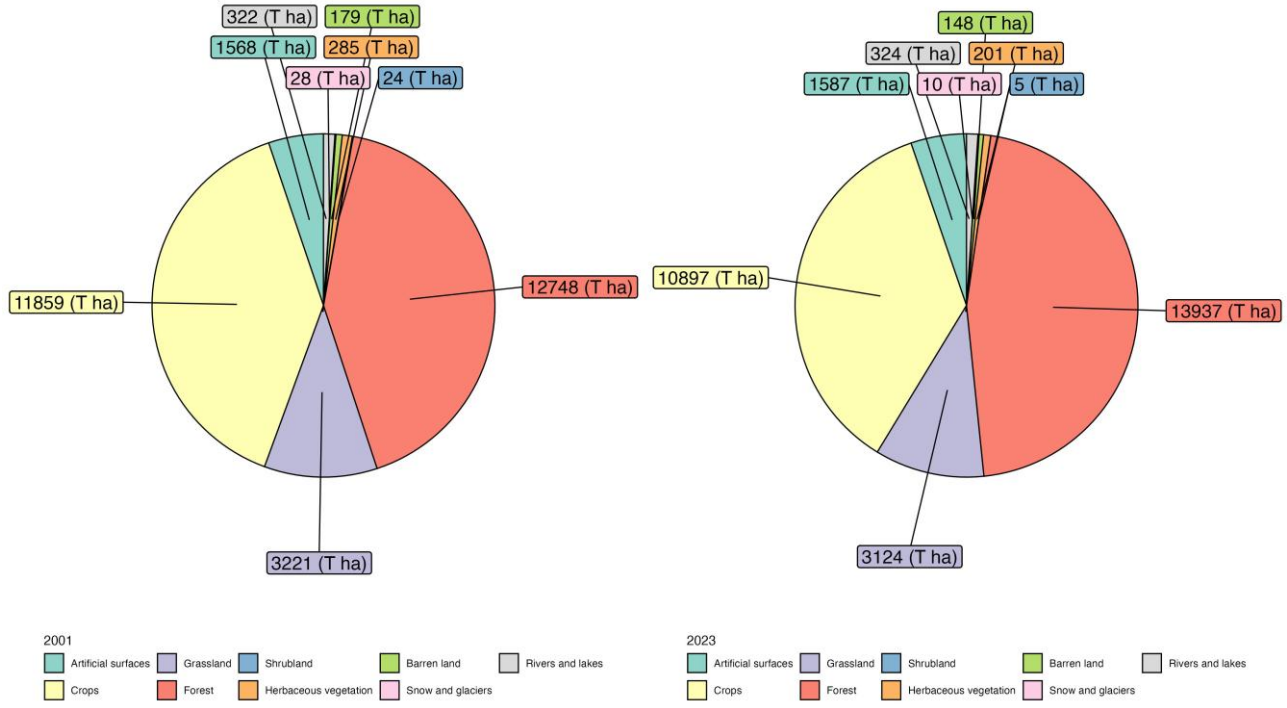

Fig. 3. Dynamics in share of land cover types (major categories) for Italy: 2001 (left) against 2023 (right). Data: MODIS. Software: R. Graph source: made by the author.

This proves gradual increase in temperatures that lead to the glacier and snow melt in the high Alpine areas. The category "Inland water bodies" did not experience significant changes during the evaluated period: in 2001, the inland water bodies occupied the area of 322,11 T ha, while in 2023 their coverage changed only a little, to 323,6 T ha. This indicates relatively stable situation of river network in Italy (**Fig. 3**).

In the forestry sector, numerous wood-based products are produced, such as recovered paper, wrapping of packaging, newsprint, roundwood, case materials, sawnwood, wood-based panels and cellulose and paper products for household papers. At the same time, pulp and paper industry is among the most energy-intensive industries which affect environment through increased industrial CO_2 emissions. Therefore, forestry sector and related pulp-and-paper industry of Italy followed the EU Emission Trading Scheme (ETS) directives which brings positive effects by stimulating the pulp-and-paper making enterprises toward technological innovations and less energy consumption. The pulp and paper industry strongly related to forestry sector and is currently accounts for about 6 % of the regional energy use.

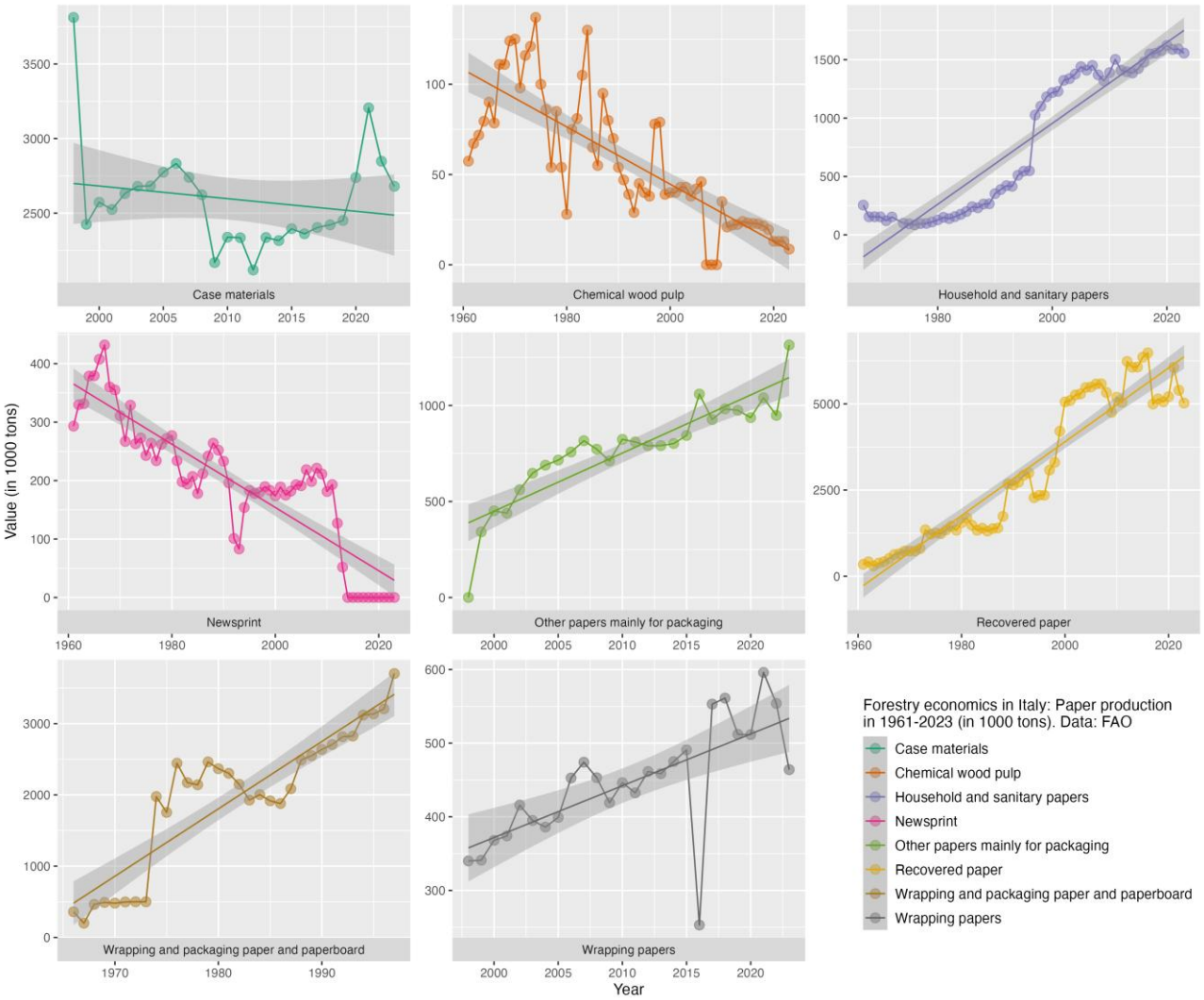

Fig. 4. Forestry economics in Italy: Paper production in 1961-2023 (in 1000 tons). Data: FAO. Software: R. Graph source: made by the author.

Newsprint production experienced decline from 293 T tons to 52 T tones in recent decades, due to the transfer of printing industry towards e-format. Other types of products, in contrary, increased: production of wrapping and packaging increased from 360 T tons to 3.702 T tons, household, case materials generally decreased from 3.811 T tons to 2.680 T tons, despite some fluctuations related to market demand. The recovered paper increased in volume from 344 T tons to 5.022 T tons. Such market dynamics was estimated in metric tons and indicated the development of forestry production and trade section. The data on pulp production were investigated in detail with analyses of the national wood fiber balances for the pulp and paper sector for recent decades (**Fig. 4.**)

The next part of the analysis compares the major export products in wood fiber and pulp-and-paper input (including produced and recovered paper), wrapping paper and paperboard sector with the export output of this sector (**Fig. 5**). The most significant data inputs were identified: 'recovered paper', followed by 'other paper and paperboard' with diversified items, and 'printing and writing papers'. the analysis also determined the minimal input categories, such as 'newsprint' which experienced shift towards the e-based platforms of newspapers both globally and at the regional level.

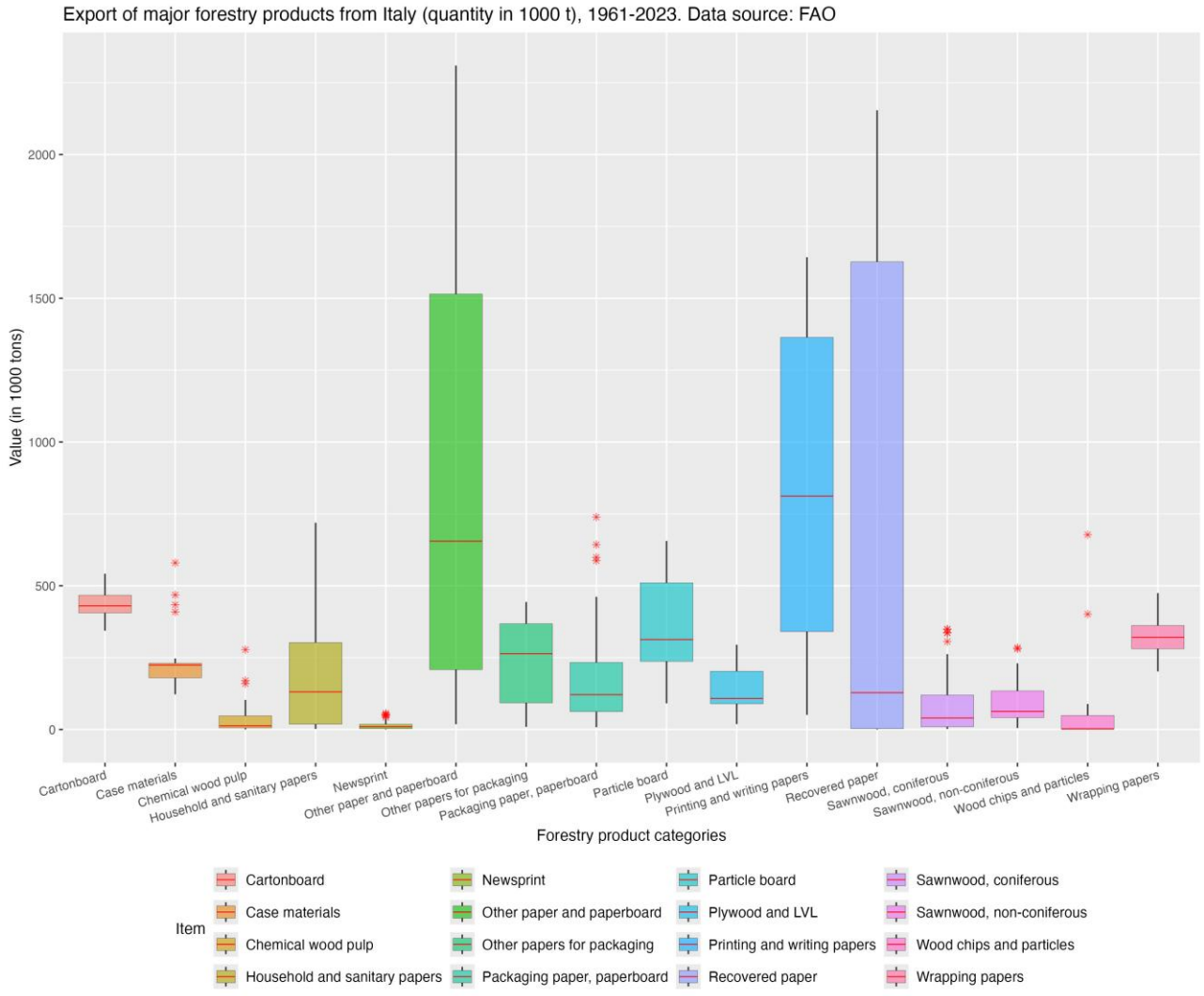

Fig. 5. Forestry products export quantity in Italy (in t), 1961-2023. Data source: FAO (category: "Forestry production and trade"). Software: R. Graph source: made by the author.

Hence, the exported of newsprint paper increased from 9000 in 1961 to 354.396 in 2023. Besides, the recovered pulp production as a residual volume increased significantly from 3754 until 2154.058.

The dynamics of the recovered pulp production was calculated and compared for recent decades for cartonboard (dropped from 401,471 to 343,670 tons), case materials (148,000 increased to 468,151 tons) and wood pulp (800 increased to 159284 tons). The production of cartonboard is obviously decreased comparing to the production of packaging paper and paperboard which demonstrated more than 739000 thousand tons recently. Such dynamics in pulp and paper export production is shaped by a strategic focus on decarbonization and a strong EU market position. Key dynamics include a push for greater energy efficiency, electrification, and low-carbon fuels to meet climate goals. The market also faces challenges from high energy costs and digital substitution, while opportunities exist in high-quality, sustainable packaging demand driven by luxury and food sectors.

Table 1 shows the calculated and summarized trends between diverse land cover types of Italy during recent decades, based on MODIS data and FAO repository.

Table. 1. Forestry export value in Italy: dynamics for 2003-2023 (in millions USD). Data source: FAO (category: “Forestry production and trade”).

Year	Case materials	Household and sanitary papers	Newsprint	Paper and paperboard	Recovered paper	Wrapping and packaging paper
2003	73,8	185,71	2,8	1152,5	65,2	371,1
2004	99,9	201,75	6,9	1297,6	71,7	39,1
2005	44,91	238,93	9,16	1242,3	82,54	491,08
2006	108,95	1062,7	9,04	2327,03	102,6	506,1
2007	121,52	1219,81	5,74	2607,97	178,5	498,35
2008	101,09	1253,86	8,51	2696,69	259,61	535,43
2009	46,5	1133,53	8,36	2277,48	207,51	434,74
2010	140,91	374,68	3,89	1619,83	319,18	478,25
2011	175,68	415,83	2,23	1698,99	396,31	404,12
2012	164,45	379,02	2,1	1716,77	336,52	524,63
2013	183,72	431,31	1,47	1943,56	297,96	568,04
2014	164,41	458,51	0,82	2029,3	279,14	598,33
2015	164,9	389,86	0,79	1798,48	264,8	515,74
2016	165,03	350,65	1,51	1751,2	302,33	517,57
2017	177,4	361,75	1,11	2011,86	349,86	570,77
2018	185,32	473,24	1,3	2109,32	309,69	581,22
2019	159,59	413,88	0,78	1843,38	205,44	464,02
2020	224,01	469,96	1,2	1875,84	201,34	402,66
2021	413,81	482,39	3,12	2375,17	321,83	481,99
2022	366,51	602,04	3,38	2603,35	298,21	567,57
2023	274,25	516,56	1,42	2115,07	271,09	482,04

The largest values for the imported products in Italy were found for the following seven categories (**Fig. 6.**): 1) Sawnwood, coniferous; 2) Chemical wood pulp; 3) Other paper and paperboard; 4) Chemical wood pulp, sulphate, bleached; 5) Industrial roundwood, coniferous (export/import); 6) Sawlogs and veneer logs, non-coniferous; 7) Printing and writing papers.

Italy relies heavily on imports for its coniferous sawn wood production, with a significant portion of its demand met by foreign sources. While domestic production has seen increases, it is insufficient to meet consumption, which is estimated to be around 6-7 M m^3 annually, with import accounting for ca. 90%. Major suppliers are primarily within the EU and other regions. The graph in **figure 6** shows that the peak in the import of the coniferous sawnwood was on 2007 when it reached 6438000 m^3 imported to the country. Sawlogs and veneer logs are essential raw materials imported to Italy, as essential items for production of sawn timber for construction, furniture, and pallet. Since Italy is a major player in the EU furniture production, recognized globally for high-end and design-focused pieces and a top exporter, it has a high dependance on the sawlogs and veneer logs. Fig. 6 shows the peaks in the volume of sawlogs and veneer logs imported to Italy, reached 1491600 m3 in 1980.

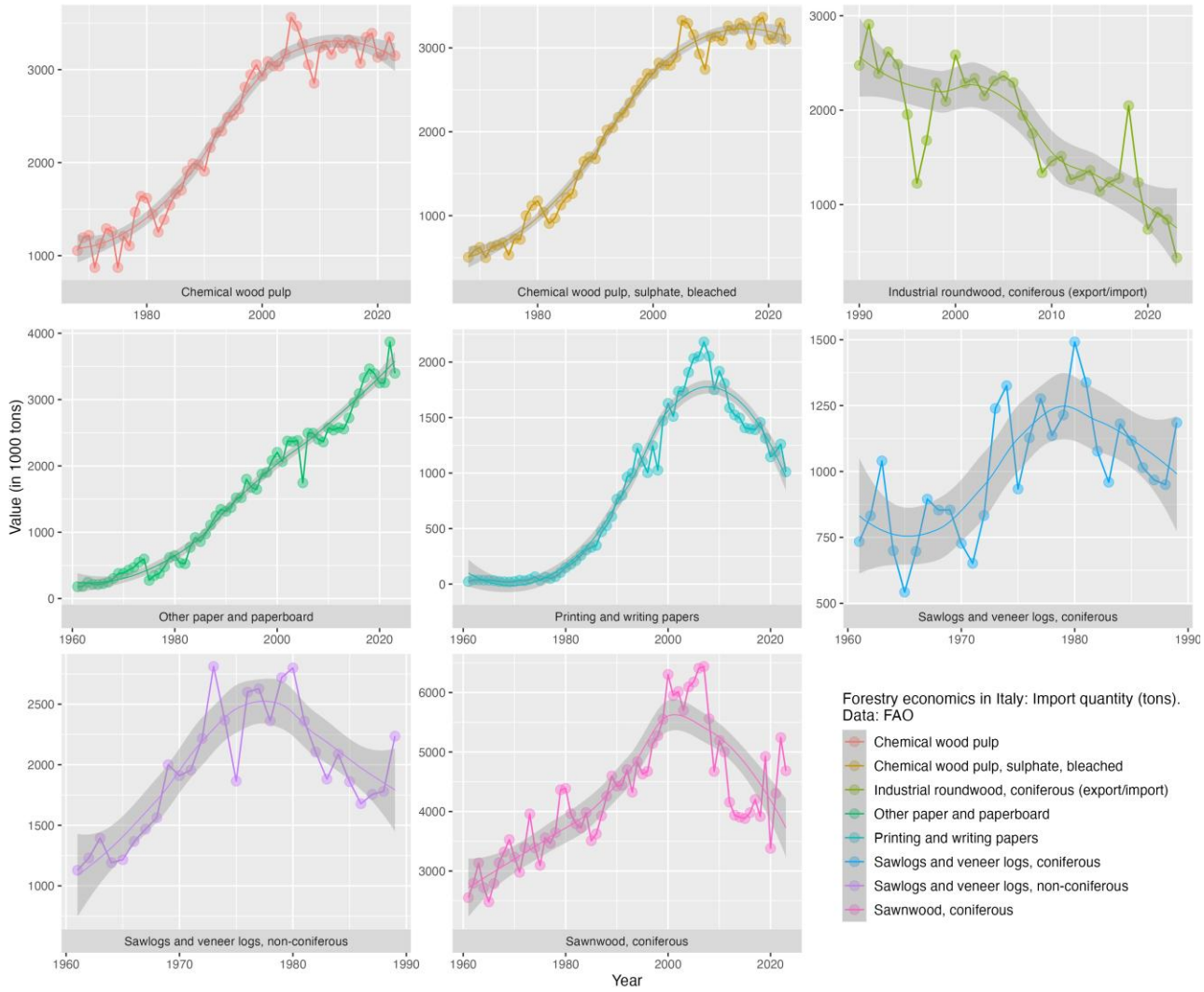

Fig. 6. Forestry import quantity (tons). Data source: FAO (category: "Forestry production and trade"). Software: R. Graph source: made by the author.

Italy imports significant quantities of chemical pulp for paper production, with key supplying countries including France, Germany, and the US. A major supplier of chemical pulp for fibrous cellulosic material, is France. The highest volume of the imported chemical pulp is reached in 2019 with 3392219 m^3. Due to the high demand for the industrial roundwood, Italy remains a significant net importer of this forestry product. While the country has a substantial forest cover, it imports roundwood additionally to meet the high demand of its industries, especially furniture. In 2022, the average import price was ca. $96 per m^3, with a 14% increase from previous years (**Fig. 6.**).

The analysis is focused on forestry sector to compare economic flows in wooden and pulp-and-paper production material in Italy(import/export) with environmental situation on forest stands. The analyses revealed balanced development in forestry industry and forest protection. An increase of forest areas over the Apennines Peninsula was detected, along with the decrease in pulp-and-paper production which demonstrated a clear shift towards the growth of e-commerce and distribution of e-books. Data-driven integration of FAO data, statistical analysis and methods of R statistical software present the reliable source of information for the analysis of the relationship between economic activity and its environmental impact in forest industry. Monitoring of the economic dynamics was performed with regards to the environmental impacts.

The analysis of the dynamics in timber and pulp-and-paper industry of Italy is characterized by a push for efficiency, sustainability, and diversification. The concept of the economic-driven environmental protection consists in the importance of nature conservation for society and climate, maintaining sustainable development. The FAO data on category “Forestry production and trade” was analyzed for important categories of forestry import in Italy for recent two decades (**Table 2**).

The presented data on forestry sector development of Italy and dynamics of land cover types with the role of forest and natural reserves is intended for analysis of sustainable economic growth. Traditionally, the economic growth is linked to environmental pressure through increased resource use. Nevertheless, it also leads to the environmental improvement through innovations in green technology and the development of environmental goods and services. This complex relationship in forestry industry is a focus of environmental economics aimed at sustainable development. The statistical findings support and policy recommendation integrates climate adaptation for sustainable development goals: new directives in Italy (National Climate Change Adaptation Plan (PNACC), 2023), which provides guidance for integrating climate adaptation into planning procedures on environmental protection, and updated the guidelines for adaptation strategies and plans in silviculture and forestry.

The national directives for the wood industry in Italy include compliance with the European Timber Regulation (EUTR) through national legislation like Legislative Decree n. 178/2014. Key directives involve sustainable forest management, supported by initiatives like the revised Italian Forest Stewardship Standard, and policies promoting the management and use of domestic wood resources. These directions are in line with the presented results which demonstrate major trends in forestry sector of the country. To summarize the key results based on the FAO data analysis, the main issues in forestry industry of Italy, include the following items:

- The highest land cover type in Italy is occupied by forests following by crops, according to the MODIS data, which proves favorable situation in environmental sense (**Fig. 2.**, left).
- Increased emissions from forest during 20th century, according to the FAO data, which include relevant ecosystem carbon pools, according to FAO data: aboveground biomass, below ground biomass, dead wood, litter, soil organic carbon, and greenhouse gases (CO_2, CH_4, N_2O). The emissions were increasing during 20th century, but now the situation stabilized due to the undertaken measures of environmental protection (**Fig. 2.**, right).
- Expanding forest area due to rural abandonment (**Fig. 3.**)
- Growing focus on digitalization and paper production (**Fig. 4.**)
- Dynamic in commerce with high values in export of paper products – packaging paper, recovered paper, printing and writing paper (**Fig. 5.**)
- shift in forest management towards biodiversity and resilience with a high dependence on imported wood despite increased domestic production (**Fig. 6.**).

Table 2. Forestry import value in Italy in two decades (in millions USD) by categories. Data source: FAO.

Year	Chemical wood pulp	Chemical wood pulp, sulphate, bleached	Industrial round-wood, coniferous	Other paper and paperboard	Printing and writing papers	Wood charcoal	Wood residues	Sawn-wood, coniferous
2003	1616,93	1483,82	182,31	1757,87	1490,75	12,85	40,52	1074,99
2004	1735,39	1576,61	202,78	1866,08	1695,77	15,7	73,82	1253,25
2005	1813,69	1691,92	185,3	1191,69	1761,88	18,4	72,76	1214,03
2006	1974,44	1870,76	203,08	2030,04	1819,06	19,96	100,89	1462,77
2007	2261,49	2166,84	211,69	2299,88	2143,98	23,5	49,59	1672,18
2008	2310,7	2216,05	205,09	2404,84	2192,37	26,73	95,56	1427,28
2009	1587,88	1526,54	143,91	2005,16	1753,9	28,65	106,48	1075,6
2010	2390,14	2312,72	153,99	2192,03	1815,34	25,58	257,44	1225,54
2011	2388,8	2300,29	172,2	2509,08	1892,64	28,65	336,62	1306,76
2012	1991,42	1944,35	125,53	2255,65	1526,87	26,93	36,28	981,13
2013	2160,23	2138,4	133,14	2531,39	1484,14	27,82	42,31	966,42
2014	2090,01	2072,66	141,93	2624,55	1446,92	28,5	42,75	989,13
2015	2098,21	2080,03	102,96	2314,03	1133,19	25,72	14,16	818,24
2016	1823,9	1804,12	108,02	2311,96	1133,14	26,54	12,62	813,41
2017	1981,1	1960,33	119,69	2814,68	1161,18	24,01	16,31	892,71
2018	2526,46	2500,82	137,35	3119,09	1330,14	27,02	19,22	940,22
2019	2138,5	2116,03	82,79	2677,55	1168,6	27,16	17,1	801,68
2020	1576,71	1553,55	53,39	2419,56	944,1	30,31	15,99	733,4
2021	2115,45	2081,1	85,25	2982,72	1053,43	32,93	25,74	1464,82
2022	2704,36	2656,01	85,63	4071,75	1438,67	33,56	23,87	1553,82
2023	2221,86	2182,56	66,79	3258,93	1226,39	41,04	28,88	1116,79

Hence, this work highlighted the environmental perspectives in Italy and dynamics of forests with favorable situation. The rate of forest expanding is ca. 100,000 ha/year, i.e., 30% of land recently dedicated to biodiversity conservation. At the same time, the economics of the country experience restructuring and shift towards less printing and more e-based productions, which can be seen on the demonstrated graphs with dynamics of import and export products in forestry sector.

The major trend is driven by rising demand for e-commerce, e-publishing and shifts towards packaging and online commercialization of the news (decline of volume of paper-based books and printed newspapers). Hence, the products that naturally used high consumption in forestry industry now decreased the demand for pulp-and-paper products. Such trends also face pressure to reduce its high energy and water consumption. Modelling and visualization of FAO datasets highlighted such dynamics in pulp-and-paper industry through time series analysis of categories analyzed by variables. Besides the environmental applications, updated datasets on forestry industry can be used for monitoring economic growth to reveal the characteristics of market and their correlation with the use of natural resources, e.g., forest cuts and logging. This enables to detect cases of overuse of resources as information for decision taking on land protection.

4. Discussion

Highlighting and interpreting the links between economic trends in forestry and environmental dynamics of land cover types requires integration of diverse large datasets (Pudzis et al., 2025; Vallejos et al., 2025; Lu et al., 2025). Interpreting such data enables to reveal and detect precious information with a particular focus on forest areas. Such evaluation of landscape dynamics is possible using data analysis for environmental monitoring. For instance, climate-related hazards (rise in temperature, decline in precipitation) can be evaluated using time series (Barlık, 2025; Yi et al., 2025; Lemenkova 2021). However, the use of such information relies on the effective methods of data processing. This becomes especially challenging in the era of big data and enables to use additional methods of data analysis (Frantz et al., 2022; Li & Dong, 2022). The solutions to this problem are provided by advanced statistical tools which present accurate and standardized methods to automate the statistical workflow (Malviya et al., 2016; Salloum et al., 2019). Processing multi-format statistical and spatial data for environmental monitoring and economic analysis is possible using R, which enables automated data analysis through the advanced algorithms embedded in its libraries.

In this study, we demonstrated the use of R for highlighting the inks between the environmental and economic sectors of forestry in Italy. The dynamics of the forestry sector of Italy recently undergone a restructuring. The data from FAO reflect a development forestry sector driven by digital transformation of business structure, increasing forest area due to land abandonment, and the need for new management strategies. This includes a shift toward sustainable practices, increase in nature protection actions, importance of non-timber products (firewood), and challenges related to forest fires and adaptive measures to climate change in Italy following the EU regulations.

The development of statistical instruments, such as R, provided environmentalists and economists with a principally new approach to data processing through scripts. This enables to rapidly process large volumes of data, such as FAO repositories, and extract information to find correlations between the variables. Statistical data are also well suitable for

integrated monitoring that includes multi-disciplinary domains, such as environmental economics in forestry.

With rapid development of programming, data analysis and modelling became more accurate and systematic due to the diverse and constantly developing statistical techniques. Nowadays, dynamic monitoring in large repositories containing economic and climate data become possible using such tools as R. Advanced statistical tools makes data analysis systematic and precise. Libraries of R enable to evaluate the distribution of diverse variables across various countries in different time periods which shifts research into the novel perspectives of big data analysis:

1. The economics of forestry in Italy reflects industrial demand for forest products. Therefore, the import and export of forestry products include lumber, paper, and biofuels, as well as non-market ecosystem services. The dynamics of forestry sector is driven by social factors and policy on market profitability and sustainability.
2. Forest areas are influenced by climate change through the effects of temperature on soil, hydrology and vegetation, rainfall patterns, and variations in weather which control the variability of natural habitats and wildlife. Climate change also drives the dynamics of land cover types through reforestation, and cause habitat changes.
3. Forestry industry depends on a renewable forest resource. At the same time, it relies on sustainable management practices that balance harvesting with regeneration of forest stands. Key factors of forestry sector include ecosystem integrity, effective governance, and economic drivers. The latter include market demand for wood and paper products, and technological innovation in processing and practices.

Monitoring forest industry in the context of economics and environmental sustainability is particularly actual for land management. Specifically for Italy, understanding structure of forestry sector and dynamics in this industry is especially difficult as it includes the balance between the economic demands and protection of natural resources.

Conclusions

Forest management in Italy recently undergone significant changes and restructuring. It is aimed at sustainable use and protection create novel opportunities in forestry sector which focus on gradual improving of management scheme, expanding tree plantations and forest stands. Nowadays, the country undertakes measures on optimization of the resource use and strengthening the contribution of the forestry sector to rural development. This is especially valuable for southern regions of the country which have dominantly rural profile. The National Forestry Strategy of the country aims to promote sustainable production and consumption of forest products and woods, and has allocated additional resources for forestry infrastructure. The formation of trademarks and development of different products depend on internal and international market (mostly, EU-based) and processes related to industrial improvements in the forestry sector. The actuality of monitoring statistical data in forestry industry has significantly increased in Italy along with reforestation and increased need for forestry products in the EU market.

This study employed the advanced tools of R for statistical analysis of forest production and trade in Italy and identification of variations in regional scale. Using multi-source FAO-based data, different environmental and economic characteristics of forestry were analyzed for diverse parameters. This enabled to analyze major trends in the economic and

environmental development in contrasting sectors of forestry across Italy (paper and pulp production, import and export, revenues, volume of products). Economic trends in forest industry is driven by a complex combination of financial and environmental factors that include direct revenue from timber and wood products, the value of ecosystem services, and climate finance. Italy is actively restructuring its forestry management to adapt to climate change. This includes strong measures on promoting climate-resilient silviculture: planting mixed stands of conifers and broadleaves to increase resilience to extreme climate events in northern Italy, enriching forest stands with local, native species, adapted to climate setting and practicing forest regeneration for carbon sequestration. Such activities strengthen the environmental function of forest stands on carbon sequestration and climate regulation. Regenerating new forest stands in central Italy has positive impacts on biodiversity, soil stability, and water cycles. Measures on restoring degraded areas enable ecological reforestation of lands degraded by erosion or fire in southern Italy.

Balancing economic value of forests and their role in nature protection can be complex. Finding optimal balance between societal development through monetization of forest products (wood, timber, pulp and paper, etc.) and protecting natural parks and reserves involve both risks and opportunities. For example, natural factors of forest stands can be primarily categorized as climate-related issues (patterns of precipitation and variations in temperature) and managing climate change impacts to capitalizing on carbon credits. Therefore, statistical data analysis to support studies focused on the analysis of forest role in economics and environment are essential for land management and decision making. This paper contributed to such issues through R-based statistical analysis of FAO dataset for analysis of trends in forestry of Italy.

The values of forest in ecological balance can not be overestimated. The processes of climate and environment affect forest landscapes and form ecosystems that reflect a complex interplay of factors: climate, topography, soil, hydrologic processes, and anthropogenic activities. Analysis of forest health enables to accurately evaluate the impacts of the processes and the effects affecting landscape structure, associated with climate change (Slepetiene et al., 2025; Chen et al., 2025; Lemenkova, 2025c; Shi et al., 2025). The long-term perspectives and benefits of forest studies consist in the applications for theoretical statistical approach which can be of interest for environmental analysis and land planners (applied ecology and landscapes in forest areas).

Future studies on forest management can employ the integrated methods of statistical analysis, GIS and RS to monitor forestry in economic context. Using datasets can present new insights into the economic-environmental analysis of the forestry industry to better understand their resilience and economic value. The benefits of the data analysis of forest landscapes and monitoring their economic role for finding balance between the society and environment.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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