



Status and Influential Factors of Machinery Used in Forest Operations in Slovenia from 2012 to 2021

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Abstract – Nacrtak

The volume of wood harvested (felling) and forest policy measures (subsidies) are among the factors considered to be important in influencing the equipment used in forestry operations and indicating the level of development of forestry technologies at the regional, national and international levels. An analysis of the dynamics of the equipment (state of equipment) used for forestry operations in Slovenia was carried out. The data were obtained from the publicly available database of the Statistical Office of the Republic of Slovenia, which collects data on the equipment of forestry companies in Slovenia on an annual basis. The analysis showed that for most machinery, there is a weak negative correlation between the volume of felling and the number of units of forestry machinery and equipment (except for timber transport machinery). Further clarification of the impact on the dynamics of the number of forestry machines was carried out by analysing the subsidies distributed under the EU call for proposals for the Rural Development Programme (RDP) (2014 – 2020). The structure of the subsidies distributed in terms of application number and amount of funds is weakly to moderately positively correlated with the variation in the number of each type of machinery, indicating a steady increase in mechanisation, accelerated by the system of subsidies to co-finance the equipment of forestry operators. The main difference observed over the analysed period is the increasing use of exports in timber harvesting and the use of Cut-to-Length (CTL) technology, which is mainly attributable to the high proportion of salvage and sanitation logging following weather disasters.

Keywords: forestry mechanisation, technological modernisation, subsidies, forest management, Slovenia

1. Introduction – Uvod

Technological modernisation is a consequence of societal development across many domains. Currently, we are witnessing the most rapid advancements in the field of information and communication technology, eclipsing the pace of mechanisation that was once the main driver of technological development during the era of industrialisation. Forestry is no exception to this trend. The speed at which modern technological development is adopted is closely tied to societal progress. The ability to keep up with the latest technological trends and innovativeness depends on a society's level of economic development and the availability of resources that are integrated

into technological processes within individual social communities (Weiss et al. 2020).

By recording the technological modernisation of forestry, an objective basis is provided for monitoring the development of the profession. The monitoring of the development of mechanisation in Slovenian forestry began as early as 1966. Data were collected by means of biennial surveys carried out by the Institute of Forest and Wood Economy. Significant shifts were recorded in the period leading up to 1990, when there was a transition from predominantly manual labour and the use of animals for skidding and transport to full mechanisation and the beginnings of automated work (Košir et al. 1993).

Since Slovenia became independent, data on the state of forestry machinery have been collected by the Statistical Office of the Republic of Slovenia (Košir 1996). During this period, the Slovenian forestry profession underwent major organisational changes, the main thread being denationalisation or restitution and privatisation (Premrl et al. 2015). However, technological development did not stagnate. On the contrary, strong positive trends in the development of forestry technologies were recorded, linked to the continuation of automation (machine logging), introduction of cybernetic work systems and drive to reduce the environmental impact of work processes, increase efficiency and, above all, improve work safety. In the case of Slovenia, the dynamics of technological modernisation in forestry are also strongly influenced by the increasingly frequent occurrence of weather disasters as a consequence of climate change (de Groot et al. 2018). Salvage and sanitation work in forests affected by storms have accelerated the introduction of highly mechanised and automated work processes, which are more efficient and safer than the so-called standard technologies (which mainly include motor manual felling and tractor skidding).

In Slovenia, the analysis of mechanisation cannot ignore the ownership and property structure and its consequences for the state and modernisation of technological processes in forestry. Furthermore, Slovenia is influenced by the efforts of the timber processing industry to establish new timber processing chains or to assist existing processes in order to ensure the necessary competitiveness of the sector at a highly developed international level in the immediate neighbourhood. An important contribution to the understanding of the current state and future challenges in Slovenian forest management has been made by the Slovenian Forestry Institute through the presentation »Forest Management Indicators in Slovenia«, which also includes an indicator of forestry machinery (Krajnc and Stare 2022).

Studies focusing on the capacity to use different wood extraction technologies have been carried out in both transition countries (Moskalik et al. 2017) and Fennoscandian countries (Nordfjell et al. 2010). An analysis of the state of the art and modern machinery equipment in different European regions was conducted by Malinen et al. (2016). The study

provides findings regarding the willingness to invest in technological modernisation and the resulting differences in equipment between European regions. Most recent studies have focused on the characteristics of modern machinery and analysed their efficiency, environmental impacts, management practices and the potential for further development of the forestry machinery market (Spinelli et al. 2023, Stankic et al. 2012, Labelle et al. 2019, Aruga et al. 2013).

The aim of this paper was to identify the current status and trends of technology development in terms of the equipment of forestry business entities in Slovenia and to analyse some of the factors influencing the state and dynamics of technology development in the production process of roundwood extraction.

2. Materials and methods – *Materijal i metode*

To analyse the state of the art and trends in the development of forest operation technologies and the relationship between the state of mechanisation and volume of fellings, we used publicly available data from the Statistical Office of the Republic of Slovenia.

Data on the number of forestry machinery units (for groups of forestry machines, Table 1) are collected annually using the full-coverage method by business units (economic operators) classified according to the Standard Industrial Classification of Activities in the activity sector Forestry (A), namely in the subactivities A02.1 Silviculture and other forestry activities, A02.2 Logging and A02.4 Forestry services. Auxiliary farm activities are not included. Around 750 business units are included in the survey (Lešić 2024).

Simple excel operations on worksheets were used to process the data, which were obtained through the web application of the Statistical Office of Slovenia (SURS 2025). Available data for the last decade were analysed (2012 to 2021). Pearson's correlation coefficient was used to analyse the relationship between production (volume of fellings), the number of applications and the amount RDP funds distributed by the number of forestry machinery units.

Table 1 Groups of machinery and equipment for which data is collected annually from companies by the Statistical Office of the Republic of Slovenia

Tablica 1. Skupine strojeva i opreme za koje Statistički ured Republike Slovenije godišnje prikuplja podatke od tvrtki

Group Skupina	Machinery and equipment Strojovi i oprema
Chainsaws Motorne pile	chainsaws and clearing saws/motorised cutters <i>motorne pile i čistači/motorni rezači</i>
Trucks Kamioni	trucks with a forestry body and loading device, semi-trailer trucks (tractors) and construction trucks (tippers) <i>kamioni sa šumarskom nadogradnjom i utovarim uređajem, kamioni s poluprikolicom (tegljači) i građevinski kamioni (kiperi)</i>
Tractors Traktori	adapted wheelbarrows, forestry articulated haulers, adapted caterpillar tractors and tractors for trailers <i>adaptirana kolica, šumski zglobni tegljači, adaptirani traktori gusjeničari i traktori za prikolice</i>
Other machinery and apparatus Ostali strojevi i uređaji	forestry truck trailers and semi-trailers, loaders and other loading equipment, cable cranes, forest road construction machinery, chippers, tractor attachments, other tractor attachments, cars, vans, harvesting and assortment machines, processor units on other machines, articulated semi-trailers, combined machines for felling and harvesting <i>šumarske kamionske prikolice i poluprikolice, utovarivači i ostala utovarna oprema, žičare, strojevi za izgradnju šumskih cesta, iverači, traktorski priključci, ostali traktorski priključci, automobili, kombi vozila, strojevi za pridobivanje sortimenata, procesorske jedinice na ostalim strojevima, zglobne poluprikolice, kombinirani strojevi za sječu i izvoz drva</i>

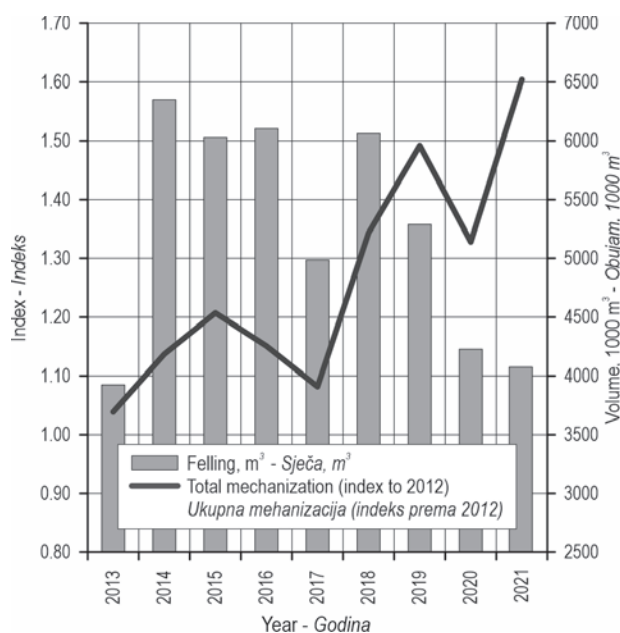


Fig. 1 Index of the number of all recorded forestry machinery units and total roundwood production (felling) for the period 2013 to 2021 in Slovenia

Slika 1. Indeks broja svih zabilježenih jedinica šumarske mehanizacije i ukupne proizvodnje oblovine (sječe) u Sloveniji za razdoblje od 2013. do 2021.

3. Results – Rezultati

The SURS application (SURS 2025) allows for the selection and creation of various queries summarizing data on the number of machinery units (devices and equipment) by year and type of machinery or data on the volume of felling.

Fig. 1 shows two trends that are relatively consistent over most of the analysed period, providing the expected results at first glance. It indicates the number of mechanisation units following the volume of forestry production (felling) in a highly proportional manner. However, the strong increase in the number of mechanisation units in the most recent period and the simultaneous negative trend in felling disagree with the initial assessment. It is therefore reasonable to search for additional influencing factors to explain this discrepancy.

Further analysis was conducted to evaluate the individual groups of machinery for which more detailed data are available. The dynamics of the volume of felling (variable 1) were compared with the dynamics of the number of machinery units (variable 2) using Pearson's correlation coefficient, which measures the consistency of the changes in the values (increase, decrease, stagnation) of both variables.

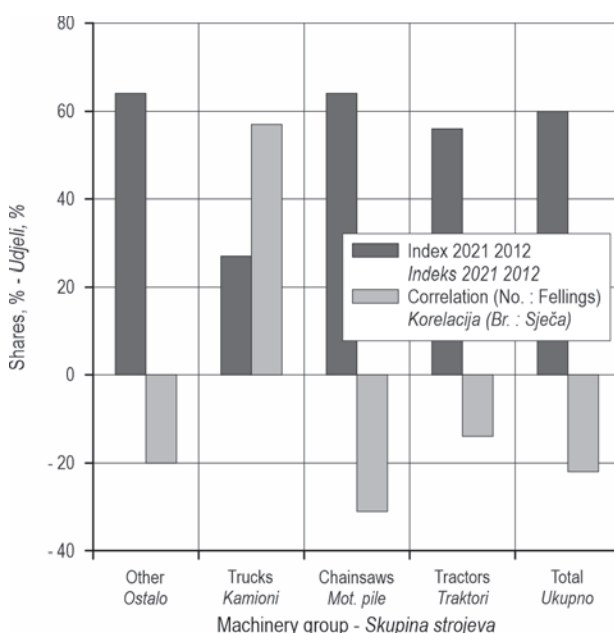


Fig. 2 Growth index of the number of machinery units by machinery group and correlation of the index with felling for the period 2013 to 2021

Slika 2. Indeks rasta broja strojnih jedinica po skupinama strojeva i korelacija indeksa sa sječom za razdoblje od 2013. do 2021.

The results of the comparison of the dynamics of the number of machinery groups and equipment show that the number increased over the analysed period in all groups. However, in most cases, the increase is not in line with the dynamics of felling. The predominant negative correlation between the two variables is the result of the greater dynamics (both growth and decline) in felling, mainly due to salvage and sanitation forest harvesting operations following weather disasters. As illustrated in Fig. 2, the dynamics and volume of felling were most closely aligned with the equipment of forestry companies for timber transport (trucks).

Further analysis was conducted based on forest operation phases (felling, skidding and transportation). The variation in the number of individual machines used in felling, processing and transportation is presented using an index that compares the number of machines in the current year with the number of machines in the base year 2012.

All phases of forest operations (felling and processing, skidding, transportation) indicate a trend of continuous modernisation of machinery. In both the felling and processing phases, there is a departure from the prevailing trend of increasing machinery in the case of the number of harvesters. In the skidding phase, there is a record increase in the number

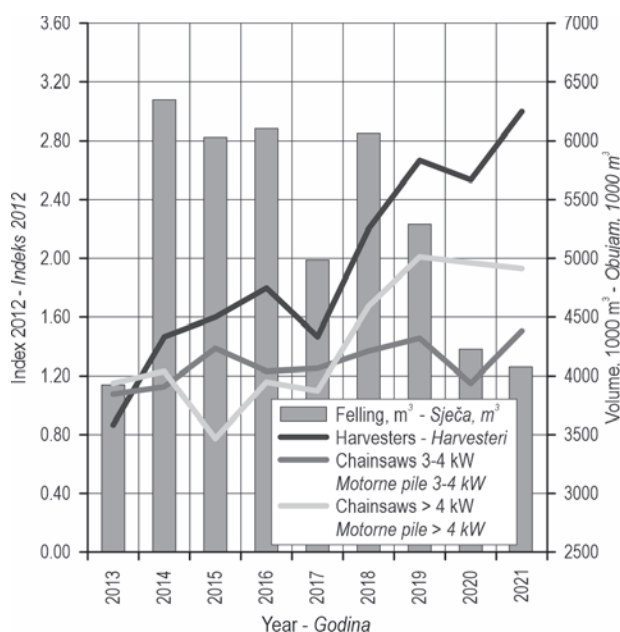


Fig. 3 Annual felling and dynamics of the number of felling and processing machinery units from 2013 to 2021

Slika 3. Godišnji obujam sječe i dinamika broja strojnih jedinica za sječu i izradu od 2013. do 2021.

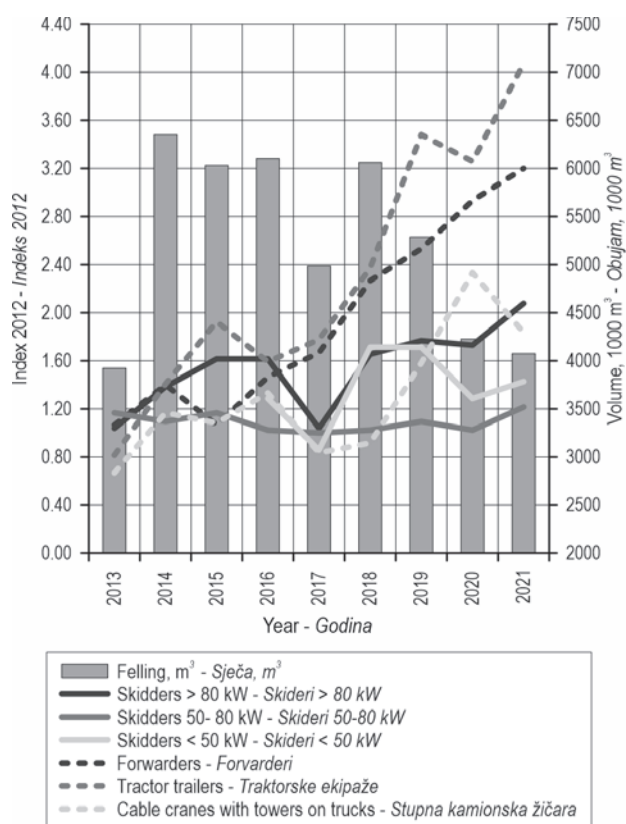


Fig. 4 Annual felling and dynamics of the number of skidding machinery units from 2013 to 2021

Slika 4. Godišnji obujam sječe i dinamika broja strojnih jedinica za privlačenje drva od 2013. do 2021.

of »self-loading trailers«, closely followed by articulated semi-trailers.

An analysis of the equipment for the so-called standard technology (which mainly includes chainsaw felling and tractor skidding) shows an increase in the number of more powerful chainsaws and also more powerful specialised forestry tractors, along with a relative stagnation of weaker forestry tractors. In the skidding phase, the equipment of forestry companies with cable cranes (Pearson's correlation coefficient = -0.71) corresponds well to the dynamics of felling. The value of the coefficient shows a strong negative correlation, which is due to factors other than the weather and, consequently, the volume of felling, particularly in the second half of the analysed period, influencing the dynamics of equipment in forestry companies.

In order to clarify additional influential factors associated with the dynamics equipment in forestry companies in Slovenia, we summarised the data

from an analysis of state subsidies that were provided under the RDP to stimulate investment in forestry technologies, mobilise and pre-industrialise timber processing, strengthen the forest-wood chain, increase the added value of timber, and promote professionalisation and greater safety in forest work (Stare and Krajnc 2021).

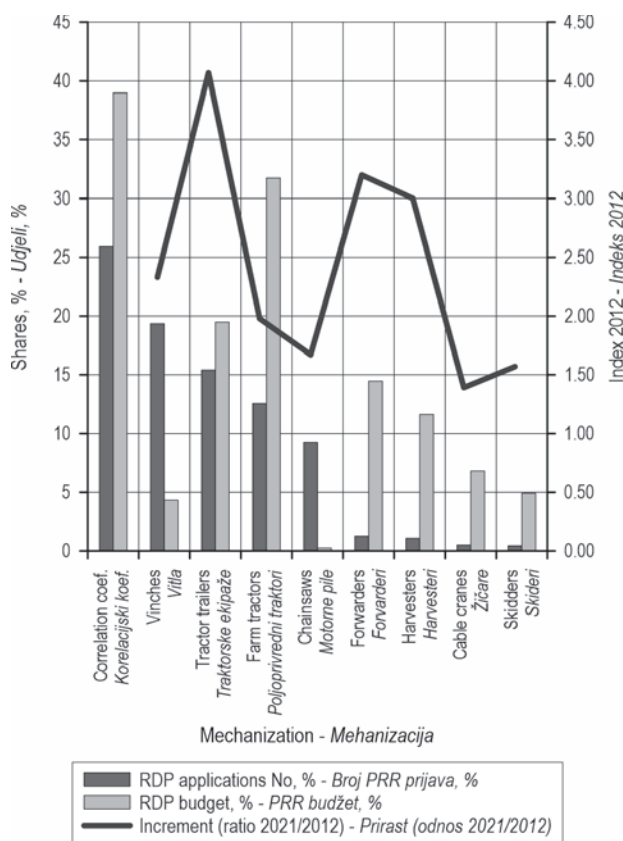


Fig. 5 Share of the number of RDP applications and RDP funds distributed by type of machinery, index of the increase in the number of machinery units compared to the year 2012 and correlation coefficient between the number of RDP applications or funds and the index of the number of machinery units

Slika 5. Udjeli broja PRR (Program ruralnog razvoja) zahtjeva i PRR sredstava raspoređenih prema vrsti strojeva, indeks povećanja broja strojnih jedinica u usporedbi s 2012. godinom i koeficijent korelacije između broja PRR zahtjeva ili sredstava i indeksa broja strojnih jedinica

In contrast to the volume of felling, Fig. 5 shows a positive correlation between the dynamics of forestry company equipment in Slovenia and the number of applications and the amount of RDP funds distributed through the RDP program. The weak (number of applications) to moderate (amount of funds distributed) correlation between the analysed variables

also explains, in our assessment, the discrepancy between the increase in the number of machinery units and the volume of felling in the second half of the analysed period. This conclusion is based on the fact that applications for the call for proposals were dominated by private owners – individuals (78%) and private owners – sole proprietors (13%), and that the latter (i.e. legal entities) accounted for 38% of the funds disbursed to co-finance the purchase of machinery and equipment (Stare and Krajnc 2021).

4. Conclusions with discussion – Zaključci s raspravom

Like other social spheres, the forestry profession is undergoing intensive technological modernisation, both globally and in the case of Slovenia. Trends in the modernisation of the forestry profession have various influencing factors, including those aimed at optimising the implementation of measures, introducing ergonomic and environmentally-friendly innovations, and the prevailing and continuous pursuit of maximising the productivity of processes (Norfield et al. 2010). Technological innovations, however, can have different impacts on different factors. Thus, the introduction of heavy forestry machinery increases the efficiency of salvage and sanitation measures (positive aspect) but also increases the risk of the negative impact of these measures on forest soils (negative aspect) (Leverkus et al. 2021).

If the production process of silviculture is successful (resulting in increased growing stocks in forest stands), then the capacity to carry out both silvicultural work and final felling (or stand regeneration) must be increased in a timely and appropriate manner. The large growing stock of forest stands is linked to tree age and uniformity of stand structures, which in today's climate of intense change, negatively impacts forest resilience. The dynamics of the intensity of forest management planning should therefore influence the regulation of the capacity to implement the measures required to ensure the conditions for the realisation of the planned (socially desirable) ecosystem services of forests (Košir and Krč 1994). The capacity to implement forest management measures in developed forest countries can be indirectly assessed by the number and structure of forestry machines. In addition to the availability of machinery, the capacity to implement measures is also influenced by the availability of a skilled workforce and the level of work organisation based on professionally designed planning, preparation, implementation and control of work processes.

The volume of forest production (felling) and forest policy measures (e.g. subsidies) are among the important factors that influence the level of equipment used by forestry operators and indirectly reflect the level of development of the forestry profession. Both of these factors were analysed using the dynamics of the level of equipment of forestry companies in Slovenia as an example. The study showed that Slovenia is technologically modernising towards the increasing use of modern CTL technologies. However, due to the ownership and tenure situation, a large proportion of forest work is still carried out using standard technologies. Similar conclusions were drawn from the analysis of the use of RDP 2014–2020 funds (Stare and Krajnc 2021). This study also concludes that the structure of forestry machinery equipment may also be influenced by previous RDP calls. For example, in the previous RDP call (2007–2013), most funds were allocated for the purchase of tractors, for which in the subsequent RDP call (2014–2020) beneficiaries applied for forestry upgrades (e.g. winches and accessories for winches).

Similar to some other countries that have undergone transition through restitution and privatisation in the last 30 years, Slovenia is also increasingly classified as a country with a highly mechanised roundwood extraction process. This classification mainly includes Western and Northern Europe and the Baltic States (Malinen et al. 2016). Due to the increased mechanization of the roundwood extraction process in Slovenia, the Slovenian data collection and classification system from the Statistical Office of the Republic of Slovenia should be reconsidered – particularly the vast group »Other machinery and apparatus« (see Table 1).

The diversity of mechanisation is also influenced by geographical diversity. The correlation between the state of the machinery for wood skidding with cable cranes and the volume of felling and the distribution of subsidy funds is high in the analysed case and negative in relation to the volume of total felling. This can be explained by the fact that Slovenia has forests where it is only economically and rationally feasible to perform certain operations using cable cranes. Hence, we are witnessing the steady modernisation and growth in the number of cable cranes. The same conclusions can be found in foreign literature (Spinelli 2023). A similar conclusion can be drawn for the correlation between the number of low power machines and the prevailing fragmentation of private forest ownership (Marence et al. 2016).

The state of equipment of forestry companies is influenced by a number of factors. This study fo-

cuses on just a few of them that were considered to have a significant impact on the dynamics and type of equipment. The modern business environment is therefore no longer limited to the national level, as work is also carried out abroad. To better assess the relationship between trends in machinery equipment in Slovenia, it would be necessary to include felling in neighbouring countries or outside of Slovenia, where Slovenian forestry companies also carry out forest work. This is particularly important in the case of the increased occurrence of large-scale natural disasters that cause comprehensive damage. These disasters result in a higher volume of salvage and sanitation forest operations, which cannot be carried out solely by mobilising capacity at the national level.

The question remains: who is shaping the trends in forestry mechanization, and how successful they are in doing so? One of the study's conclusions could be that policy drivers – rather than purely production demands – are increasingly influencing mechanization trends. While production demands are variable drivers, the ongoing modernization of forest operations leads to increased available capacity. This, in turn, promotes further improvements in organization work processes to ensure better utilisation of capacities and resources in order to optimise production costs per unit of product.

Acknowledgment – *Zahvala*

This research was funded by the CRP research project Planning technologies and quality assessment of forest works in support of the bioeconomy (CRP V4-2209), funded by the Ministry of Agriculture, Forestry and Food and the Slovenian Research and Innovation Agency.

Additional support was provided by the Slovenian Research Agency, the research program »Forest wood value chain and climate change: transition to circular bioeconomy« (P4-0430).

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Sažetak

Stanje i utjecajni čimbenici strojeva korištenih u šumskim operacijama u Sloveniji od 2012. do 2021. godine

Obujam pridobivena drva (sječa) i mjere šumarske politike (subvencije) ubrajaju se među čimbenike koji se smatraju važnim utjecajima na opremu koja se koristi u šumarskim operacijama te pokazuju stupanj razvoja šumarskih tehnologija na regionalnoj, nacionalnoj i međunarodnoj razini. Provedena je analiza dinamike opreme (stanja opreme) koja služi za šumarske operacije u Sloveniji. Podaci su dobiveni iz javno dostupne baze podataka Statističkoga ureda Republike Slovenije, koji na godišnjoj razini prikuplja podatke o opremljenosti šumarskih tvrtki u Sloveniji. Analiza je pokazala da za većinu strojeva postoji slaba negativna korelacija između obujma sječe i broja jedinica šumarskih strojeva i opreme (osim strojeva za prijevoz drva). Daljnje pojašnjenje utjecaja na dinamiku broja šumarskih strojeva provedeno je analizom subvencija raspodijeljenih u okviru poziva EU-a za podnošenje prijedloga za Program ruralnoga razvoja (PRR) (2014–2020). Struktura raspodijeljenih subvencija s obzirom na broj zahtjeva i iznos sredstava slabo je do umjereno pozitivno korelirana s varijacijama u broju svake vrste strojeva, što pokazuje stalan porast mehanizacije, koji je ubrzan sustavom subvencija za sufinanciranje opreme šumarskih izvođača. Glavna razlika uočena tijekom analiziranoga razdoblja sve je veća primjena izvoza u pridobivanju drva i upotreba »Cut-to-Length« (CTL) tehnologije, što se uglavnom pripisuje visokomu udjelu sanacijske sječe nakon vremenskih katastrofa.

Ključne riječi: šumarska mehanizacija, tehnološka modernizacija, subvencije, gospodarenje šumama, Slovenija

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Received (Priljeno): June 6, 2025
Accepted (Prihvaćeno): July 17, 2025
Original scientific paper – Izvorni znanstveni rad