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IMPLEMENTATION OF AI-BASED DETECTION INTO THE CLIMATE POLICY WITHIN THE EUROPEAN GREEN DEAL

Abstract

The European Green Deal outlines the European Union's roadmap for the green transition required by the Paris Climate Agreement. As part of its sustainable environmental policies, the European Green Deal aims to integrate digital transformation with the preservation of ecosystem services, the enhancement of green infrastructure, and the long-term sustainability of green networks. Green infrastructure contributes directly to the environmental objectives of the Green Deal by reducing carbon emissions, improving air quality, and conserving biodiversity. Therefore, accurately identifying, monitoring, and mapping green infrastructure is essential to achieving these goals.

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In this context, artificial intelligence (AI)-based automated tree detection systems, a rapidly advancing technology, play a critical role in fields such as forest management, biodiversity monitoring, and carbon footprint assessment. This study aims to support green policy objectives by automatically detecting tree communities in a specified region using AI algorithms applied to open-access satellite imagery. The research was conducted across three sample areas with varying environmental characteristics. The methodology integrates image-processing techniques with object detection algorithms, enabling high-accuracy classification of trees. The results contribute significantly to climate change mitigation efforts, carbon stock monitoring, smart urban planning, and the formulation of agricultural policies. Moreover, the proposed system can function as a decision support mechanism for public institutions, local governments, environmental scientists, and policymakers. In alignment with the European Green Deal's vision of digital green transformation, such AI-based applications hold substantial potential for enhancing environmental sustainability.

Keywords: artificial intelligence, green infrastructure, European Green Deal, digital green transformation, automated tree detection

INTRODUCTION

Climate change, one of the most pressing global challenges of the 21st century, is not limited to rising temperatures alone; it also encompasses a wide range of environmental consequences such as biodiversity loss, diminishing water resources, degradation of forest ecosystems, and the shrinking of natural habitats due to urbanization pressures (Gilman *et al.* 2010; Malanson and Alftine 2023). Scientific evidence clearly identifies anthropogenic greenhouse gas emissions as the primary driver of this transformation (Chen *et al.* 2023; Han *et al.* 2024), thereby reinforcing the urgency for environmentally sensitive, sustainable, and digitally supported new policy frameworks. In this context, the European Green Deal, announced by the European Union in 2019, provides a transformative framework for combating climate change and achieving environmental sustainability goals (Paleasri 2022; Boix-Fayos and de Vente 2023).

The European Green Deal outlines strategic objectives such as achieving a carbon-neutral continent, promoting the efficient use of natural resources, implementing circular economy practices, and preserving biodiversity (Samper *et al.* 2021; Skjærseth 2021; Knez *et al.* 2022). In the realization of these targets, digital transformation plays a key role not only in the domains of production and energy but also in environmental monitoring, planning, and management processes. This integrated approach, referred to as the digital green transition, aims to enable more accurate, timely, and data-driven environmental decision-making (Bertoncelj 2022). Within this framework, digital technologies such as artificial intelligence (AI), Remote Sensing (RS), Geographic Information Systems (GIS), and big data analytics are contributing significantly to the monitoring of environmental assets and changes, representing a paradigm shift in how environmental information is gathered, interpreted, and utilized (Himeur *et al.* 2022; Çağlar *et al.* 2025).

For green transition policies to be effectively implemented, the preservation and enhancement of green infrastructure – comprising trees, green spaces, forests, and other forms of natural vegetation – are of critical importance (Besley and Persson 2023). Green infrastructure is not merely an aesthetic component; it functions as a carbon sink, improves air quality, mitigates the urban heat island effect, and supports biodiversity, making it a vital environmental asset (Semeraro *et al.* 2021; Belčáková *et al.* 2022). In areas experiencing rapid urbanization, the strategic conservation of green infrastructure is a prerequisite for the development of climate-resilient cities (Kumar *et al.* 2023). However, traditional methods for monitoring these natural assets – such as field surveys and manual tree counting – are impractical, time-consuming, and costly, particularly when applied to large forested areas or in the context of limited resources (Himeur *et al.* 2022). In this regard, automated tree detection presents significant potential for the effective management of green infrastructure in both rural and urban landscapes. Accurate identification of tree count, distribution, and health status plays a crucial role in a variety of applications, including forest fire risk management, urban planning, carbon stock assessment, and biodiversity monitoring (Poláček *et al.* 2023; Capecchi *et al.* 2023). Due to the limitations of conventional techniques, AI-based image processing and object detection algorithms have become increasingly prevalent in recent years (Choi *et al.* 2022; Miranda *et al.* 2023; Heng *et al.* 2024). Artificial intelligence technology, which is fundamentally based on machine learning and enables a machine to acquire knowledge through data processing, focuses on the development of algorithms and models that improve the performance and knowledge bases of computer systems (Luknar 2025). Among these models, the deep learning models have shown strong performance when applied to high-resolution imagery derived from satellite data, unmanned aerial vehicle (UAV) footage, and sensor-based systems (Jintasuttisak *et al.* 2022; Li *et al.* 2023). These models offer automated, high-accuracy detection capabilities, enabling both cost and time efficiencies while ensuring continuous, up-to-date environmental monitoring (Wu *et al.* 2021; Onishi and Ise 2021). These technological advancements are grounded in the integration of RS and GIS (Velasquez-Camacho *et al.* 2023). RS techniques enable large-scale, real-time monitoring and provide valuable insights into vegetation health, moisture levels, and stress indicators through infrared, multispectral, and hyperspectral imagery (Raihan *et al.* 2023). GIS, in turn, facilitates spatial analysis and multilayer visualization of this data, grounding environmental decision-making in a scientifically robust framework (Li *et al.* 2023). The integration of AI algorithms with these systems automates the entire workflow – from data analysis to geospatial mapping – thereby significantly enhancing the efficiency and accuracy of decision support mechanisms (Mohan and Giridhar 2022; Choi *et al.* 2023).

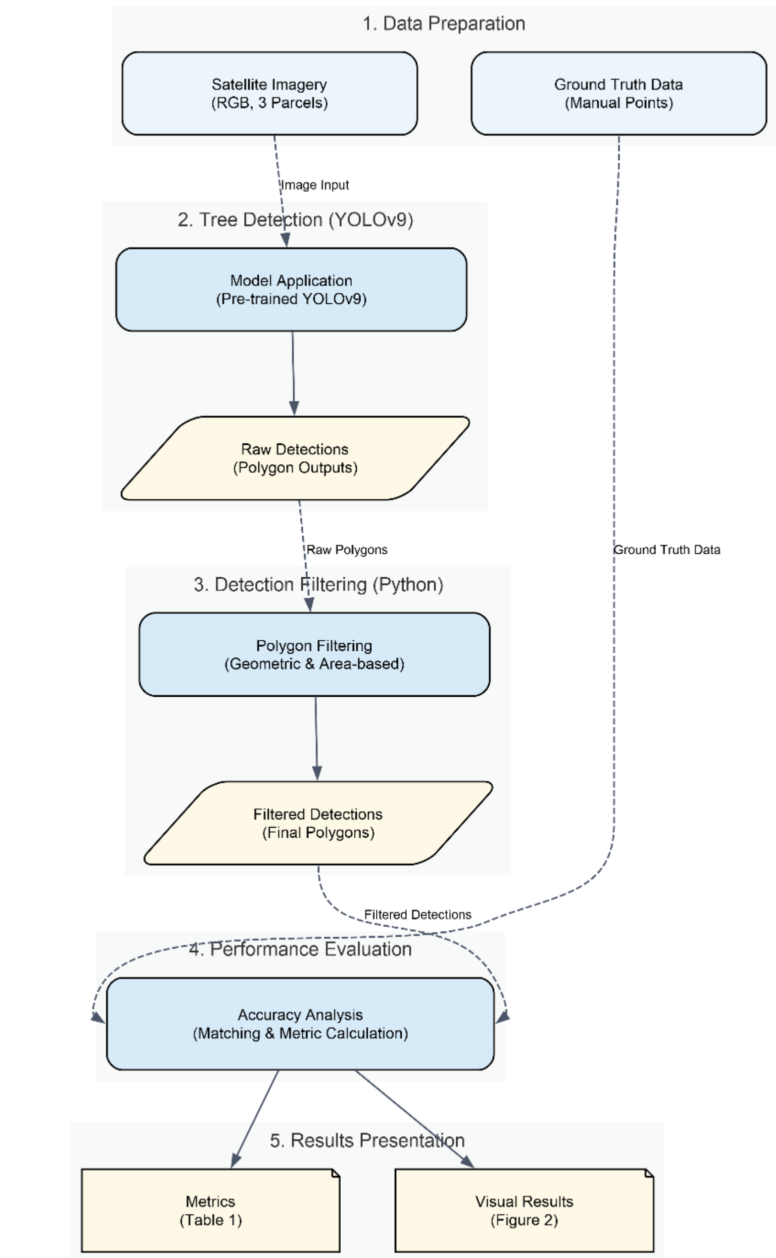
In line with the digital transformation vision of the European Green Deal, this study aims to support the conservation of green infrastructure and enhance environmental management through the automated detection of trees using artificial intelligence. In doing so, the study exemplifies the potential of technology-based solutions to contribute to the Green Deal's overarching goals of building a climate-neutral and environmentally friendly society. Although the Green Deal formally encompasses the 27-member states of the European Union (EU), its objectives are also expected to be supported by countries in cooperation with the EU (EU 2019; Kattelmann *et al.* 2021). Turkey, due to its geographical position and strong economic, political, and environmental ties with the EU, holds significant potential in contributing to the goals of the European Green Deal. While not an EU member, Turkey's participation in the Customs Union and its candidate country status position it in close alignment with EU environmental and climate policies. Consequently, the priorities set forth by the

Green Deal have a direct influence on Turkey's environmental policy landscape. In this context, the present study, conducted in Turkey, aligns with the country's commitment to contributing to these goals through its ratification of the Paris Agreement and its formulation of the Green Deal Action Plan. This national plan aims to enhance environmental sustainability, reduce carbon emissions, and promote the transition to a green economy (Ministry of Trade 2021). Therefore, the current study holds particular relevance in supporting Turkey's alignment with Green Deal objectives. The methodology presented in this article offers not only academic contributions but also practical implications. It aims to provide local governments, environmental planners, and conservation specialists with a scalable, verifiable, and sustainable tool for environmental monitoring.

MATERIAL AND METHOD

In this study, the detection and counting of trees in agricultural lands with varying soil characteristics were carried out using up-to-date and open-access Google satellite imagery, combined with an artificial intelligence-supported deep learning approach. The proposed methodology consists of four main steps: data preparation, model implementation, postprocessing of model outputs, and accuracy assessment (Figure 1).

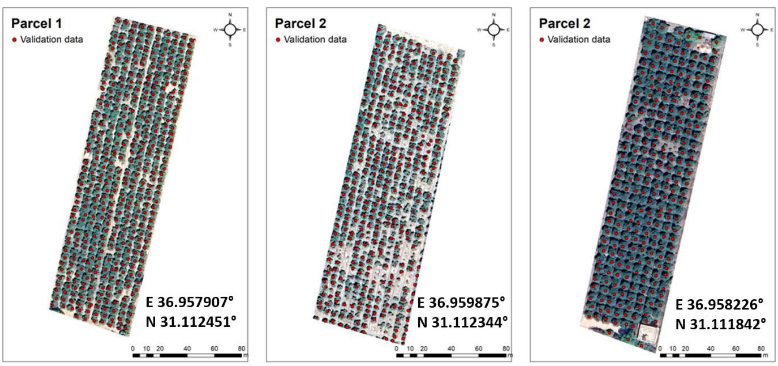
Figure 1. Method flowchart



Source: Authors

The study was conducted on three distinct agricultural parcels (Parcel 1, Parcel 2, and Parcel 3), each characterized by different ground conditions, geometrical configurations, and tree density patterns. Perennial agricultural lands were selected due to their dual significance in both economic productivity and ecological value. The trees within these parcels provide a wide range of ecosystem services, including carbon sequestration, oxygen production, urban heat island mitigation, and support for biodiversity, while also contributing to the economy through fruit yield. For tree detection, high-resolution RGB satellite imagery obtained from the Google Earth platform was utilized. To evaluate the performance of the model, the tree locations within each parcel were manually digitized and converted into point geometries to create ground truth datasets (Figure 2).

Figure 2. Study area data (The red dots represent the validation data)



Source: Authors

For the detection of tree crown centroids, the pre-trained "Tree-Tops Detection" model available within the "Model Zoo" collection of the QGIS Deepness plugin was employed. This model operates with an input resolution of 640x640 pixels and was trained on a custom dataset comprising a combination of various open-source image collections. It is built upon the YOLOv9 architecture as the underlying object detector, with the confidence threshold set at 0.10 and the Intersection over Union (IoU) threshold at 0.50 (Lu and Wang, 2024). YOLOv9, as the latest advancement in the YOLO series, introduces architectural innovations and enhanced training strategies that significantly improve detection accuracy while preserving real-time inference speeds (Wang *et al*. 2024; Chien *et al.* 2024). Evolved from the YOLOv7 framework, YOLOv9 is based on a novel module known as Generalized Efficient Layer Aggregation

Network (GELAN), which allows for optimized parameter utilization by leveraging more efficient convolutional operators. One of the most notable innovations in YOLOv9 is the integration of Programmatic Gradient Information (PGI), a newly proposed training enhancement framework (Zhang 2024). PGI improves gradient flow during training, mitigates information loss in deep neural networks, and enhances parameter learning through more targeted and enriched input data (Kumar *et al*. 2024). These architectural and algorithmic improvements result in measurable gains in both speed and accuracy when compared to previous YOLO versions (Ikmel and El Amrani 2024; Ye *et al.* 2024; Topgül *et al.* 2025). Initially, the model outputs tree crown detections as bounding polygons within the input satellite imagery. These raw polygon outputs (input_raw_polygon_path) were subjected to a sequence of post-processing steps using Python and the GeoPandas library to reduce noise and exclude non-tree objects. The post-processing included reprojection of all spatial data into a locally appropriate projected coordinate reference system (EPSG:32636) for accurate geometric calculations, removal of null or invalid geometries, area-based filtering using absolute or relative thresholds calculated within the projected CRS (a coordinate reference system that transforms geospatial data from the Earth's 3D surface to a 2D map projection), and additional filtering based on polygon aspect ratios. The resulting filtered polygons were exported as a shapefile (output_filtered_polygon_path) and used for further analysis in comparison with ground truth datasets across the sample parcels.

After the automatic detection of trees using artificial intelligence-supported deep learning algorithms, the verification phase was initiated. To quantify the detection performance of the filtered tree polygons, the metrics presented in Table 1 were calculated based on ground truth points. In this phase, matching was performed by checking whether a ground truth point was located within a filtered predicted polygon. The evaluated metrics include the Ground Truth Tree Count (GT), Estimated Number of Polygons (ENP), True Positives (TP), False Positives (FP), and False Negatives (FN), which are frequently used in the literature (Reddy and Karthikeyan 2022), along with derived measures such as Precision, Recall, and F1 Score. The corresponding equations were implemented within an automated workflow (Equations 1, 2, 3, and 4).

$$Accuracy = \frac{TP + TN}{(TP + TN + FP + FN)} \qquad \text{(Equation 1)}$$

$$Precision = \frac{TP}{TP + FP} \qquad \text{(Equation 2)}$$

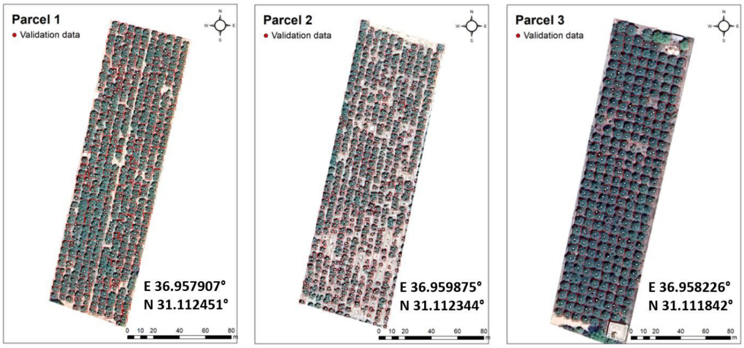
$$Recall = \frac{TP}{TP + FN} \qquad \text{(Equation 3)}$$

$$F1\ Score = \frac{(2 \cdot Precision \cdot Recall)}{(Precision + Recal)} \qquad \text{(Equation 4)}$$

RESULTS

In this study, a comprehensive analysis was conducted using artificial intelligence and deep learning algorithms to detect trees in three agricultural parcels with distinct morphological characteristics. The applied method was trained on high-resolution satellite imagery and field data, demonstrating applicability under heterogeneous conditions such as varying vegetation densities and terrain structures. The performance exhibited by the deep learning models yielded promising results for automatic tree detection. Model outputs were evaluated through accuracy analyses, with detection success assessed separately for each parcel. The mapping process was considered a critical stage for visually presenting tree detection results and examining model accuracy on an area-based scale. The maps shown in Figure 3 facilitate a comparative interpretation of the performance of the AI-supported deep learning method used for automatic tree detection under different parcel conditions, thereby visually supporting the applicability of the proposed approach.

Figure 3. Trees detected by deep learning algorithms after Python-based filtering (The blue dots represent the detected trees)



Source: Authors

The performance of the "Tree-Tops Detection" model used in this study was demonstrated across three different agricultural parcels using Google satellite imagery. Parcel 1 consists of trees planted on bare soil with partially regular row and spacing patterns, some gaps, and mostly similar crown diameters. The applied model successfully detected the regular groups but showed errors in areas with morphological variations. Parcel 2, also situated on bare soil, contains trees with mixed gaps and diverse shapes. The varying tree morphologies in this parcel notably increased the model's error rate in detection. Parcel 3 is characterized by a green ground cover with trees arranged in regular rows and spacing, exhibiting uniform shapes. In this area, the model achieved higher accuracy compared to the other parcels (Table 1).

Table 1. Automatic Tree Detection Performance Metrics for Different Parcels

Metrics	Parcel 1	Parcel 2	Parcel 3
True Tree Count (Ground Truth)	406,00	362,00	243,00
Estimated Number of Polygons (ENP)	474,00	511,00	263,00
True Positive (TP)	404,00	359,00	247,00
False Positive (FP)	88,00	158,00	21,00
False Negative (FN)	26,00	24,00	11,00
Precision	0,82	0,69	0,92
Recall	1,00	0,99	1,02
F1 Score	0,90	0,82	0,97

Accuracy: 0,78, 0,66, 0,88

Source: Authors

The model demonstrated F1 scores ranging from 0.82 to 0.97 across the three parcels. The highest F1 score (0.97) was observed in Parcel 3, while the lowest F1 score (0.82) was recorded in Parcel 2. Overall accuracy values were calculated as 0.78 for Parcel 1, 0.66 for Parcel 2, and 0.88 for Parcel 3. These performance variations among parcels are closely related to the characteristics of the terrain and tree cover. For example, in Parcel 3, which showed the highest performance, trees are more homogeneous, dense, and regularly spaced with clear contrast against the ground. In contrast, Parcel 2, which exhibited the lowest performance, contains sparser trees, variable ground conditions, and spectral/textural properties similar to tree crowns, resulting in an increased number of False Positives (FP). Parcel 1 demonstrated moderate performance, where the high number of False Positives reduced the precision value. Generally, the relatively low number of False Negatives (FN) across all parcels indicates that the model is capable of detecting existing trees but tends to produce more FPs as ground complexity increases and tree density decreases. The model's performance is influenced by factors such as tree density, homogeneity, contrast with the ground, and the presence of treelike objects on the terrain.

Limitations of the study include the use of a pre-trained general model without region-specific tuning, constraints related to the resolution and quality of Google satellite imagery, and the potential human error introduced by manual digitization of validation data. For future work, it is recommended to train the model with region-specific samples for increased accuracy, employ data augmentation techniques, utilize higher-resolution imagery, develop additional machine learning-based filtering layers alongside existing filtering steps, and test different deep learning architectures. For optimal model performance, high-resolution images captured during active growth periods, with minimal shading and a clear distinction between tree crowns and the ground, are ideal. When applying this model in urban green spaces, challenges such as heterogeneity in tree species and sizes, complex backgrounds, and shadows may arise; these challenges can be mitigated by expanding the training dataset and incorporating 3D data sources like LiDAR. In natural forests, dense and interwoven canopies, high species diversity, dense understory vegetation, and topographic shadows present significant challenges; here, higher-resolution drone or LiDAR data may provide viable solutions. In conclusion, the YOLOv9based "Tree-Tops Detection" model offers promising results for tree detection using Google satellite images; however, its performance varies according to site-specific conditions. Therefore, the proposed recommendations for further model development and adaptation to different environments should be considered.

DISCUSSION AND CONCLUSION

Global climate change, as one of the most urgent environmental challenges of our time, necessitates the development of new strategies and technological solutions worldwide. In this context, the European Green Deal, proposed by the European Union with the goal of making the continent carbon-neutral by 2050, centers on policies that promote environmental sustainability (Selim 2021). Among these policies, agricultural and forest management, carbon sequestration, and the traceability of natural resources are of paramount importance (Keith *et al.* 2021). At this juncture, artificial intelligence–supported tree detection technologies, incorporating tools such as deep learning and machine learning, emerge as powerful instruments in achieving these objectives. Leveraging AI algorithms and satellite imagery, fruit trees in agricultural lands can be detected with high accuracy, enabling the creation of digital forest and agricultural maps (Yu *et al.* 2022; Gan *et al.* 2023). This technology holds significant potential not only for production planning but also for monitoring carbon stocks and reducing carbon footprints (Gaur *et al.* 2023; Manikandan *et al.* 2025). Trees, especially long-lived fruit trees, act as natural carbon sinks by absorbing atmospheric carbon dioxide (CO_2) through photosynthesis (Gelaye and Getahun 2023). Therefore, monitoring the number, species, and development status of these trees constitutes critical data for carbon balancing policies (Wambede *et al.* 2022).

Within the nature-based solutions framework advocated by the European Green Deal, detecting and increasing tree presence in agricultural lands is actively encouraged (Davies *et al.* 2021; Tanneberger *et al.* 2021). The sustainability of such solutions depends not only on tree planting but also on the accurate detection, monitoring, and management of these trees (Palomo *et al.* 2021). This study presents a practical method that combines open-source satellite imagery with AI algorithms for the automated, high-accuracy detection of trees. Using the proposed approach, rapid and practical quantification of tree counts in a given region is possible, growth trends can be identified, and yield predictions for agricultural production can be developed, thereby enabling the optimization of environmental and agricultural policies. The application of this technology also holds importance in terms of transparency and accountability. The European Union's carbon markets, sustainable agricultural subsidies, and green financing instruments are shaped based on specific environmental outcomes. Data collected through AI provides verifiable evidence for such mechanisms, enhancing the effectiveness of climate policies.

Results obtained from this study demonstrate that using AI technologies for detecting trees in a region is faster and more cost-effective than traditional detection methods while achieving acceptable accuracy. Moreover, the use of AI specifically for automatic detection of fruit trees carries strategic value not only for agricultural productivity but also for combating climate change, carbon sequestration, and realizing the goals of the European Green Deal. The widespread adoption of this technology will contribute to building sustainable agricultural and forest management policies on digital foundations, thereby strengthening the balance between rural development and environmental conservation.

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ИМПЛЕМЕНТАЦИЈА ДЕТЕКЦИЈЕ ЗАСНОВАНЕ НА ВЕШТАЧКОЈ ИНТЕЛИГЕНЦИЈИ У КЛИМАТСКУ ПОЛИТИКУ У ОКВИРУ ЕВРОПСКОГ ЗЕЛЕНОГ ДОГОВОРА

Резиме

Европски зелени договор представља план Европске уније за зелену транзицију коју захтева Париски споразум о климатским променама. Као део својих одрживих политика заштите животне средине, Европски зелени договор има за циљ да интегрише дигиталну трансформацију са очувањем екосистемских услуга, унапређењем зелене инфраструктуре и дугорочном одрживошћу зелених мрежа. У том контексту, аутоматизовани системи за детекцију дрвећа засновани на вештачкој интелигенцији (ВИ), технологија која се брзо развија, играју кључну улогу у областима као што су управљање шумама, праћење биодиверзитета и процена угљеничног отиска. Ова студија има за циљ да подржи циљеве зелене политике аутоматским откривањем заједница дрвећа у одређеном региону користећи алгоритме ВИ примењене на сателитске снимке отвореног приступа. Методологија интегрише

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технике обраде слика са алгоритмима за детекцију објеката, омогућавајући високопрецизну класификацију дрвећа. Детекција и бројање дрвећа на пољопривредним земљиштима са различитим карактеристикама земљишта спроведени су коришћењем ажурних и отворено доступних сателитских снимака компаније *Google*, у комбинацији са приступом дубоког учења подржаним вештачком интелигенцијом. Предложена методологија се састоји од четири главна корака: припрема података, имплементација модела, постпроцесна обрада излаза модела и процена тачности. За детекцију центроида круна дрвећа коришћен је претходно обучени модел "Tree-Tops Detection" доступан у оквиру колекције "Model Zoo" додатка *QGIS Deepness*. Након аутоматске детекције дрвећа коришћењем алгоритама дубоког учења подржаних вештачком интелигенцијом, започета је фаза верификације. У овој фази, упаривање је извршено провером да ли се тачка истинитости налази унутар филтрираног предвиђеног полигона. Процењивана метрика укључује Истинитост броја стабала на терену (GT), процењени број полигона (ENP), истинито позитивне резултате (TP), лажно позитивне резултате (FP) и лажно негативне резултате (FN), заједно са изведеним мерама као што су прецизност, подсећање и F1 резултат. Резултати су показали да се оцене F1 крећу од 0,82 до 0,97 на све три парцеле. Највећа F1 оцена (0,97) примећена је на парцели 3, док је најнижа оцена F1 (0,82) забележена на парцели 2. Укупне вредности тачности израчунате су као 0,78 за парцелу 1, затим 0,66 за парцелу 2 и 0,88 за парцелу 3. Ове варијације у перформансама међу парцелама су уско повезане са карактеристикама терена и покривача дрвећем. Генерално, релативно мали број лажно негативних (FN) резултата на свим парцелама указује на то да је модел способан да детектује постојеће дрвеће, али има тенденцију да производи више FN резултата како се сложеност тла повећава, а густина дрвећа смањује. На перформансе модела утичу фактори као што су густина дрвећа, хомогеност, контраст са тлом и присуство објеката налик дрвећу на терену. Ограничења студије укључују употребу претходно обученог општег модела без специфичних подешавања за одређени регион, ограничења везана за резолуцију и квалитет сателитских снимака компаније *Google* и потенцијалну људску грешку коју уводи ручна дигитализација података о валидацији. За будући рад, препоручује се обука модела са узорцима специфичним за одређени регион ради повећане тачности, коришћење техника проширења података, коришћење снимака веће резолуције, развој додатних слојева филтрирања заснованих на машинском учењу поред постојећих корака филтрирања и тестирање различитих архитектура дубоког учења. Закључно, модел "Tree-Tops Detection" базиран на *YOLOv9* нуди обећавајуће резултате за детекцију дрвећа коришћењем *Google* сателитских снимака. Међутим, његове перформансе варирају у зависности од услова специфичних за локацију. Стога треба размотрити предложене препоруке за даљи развој модела и прилагођавање различитим окружењима. Резултати добијени овом студијом показују да је коришћење технологија ВИ за откривање дрвећа у региону брже и исплативије од традиционалних метода откривања, уз постизање прихватљиве тачности. Штавише, употреба ВИ посебно за аутоматско откривање воћака носи стратешку вредност не само за пољопривредну продуктивност, већ и за борбу против климатских промена, секвестрације угљеника и остваривања циљева Европског зеленог договора. Широко усвајање ове технологије допринеће изградњи одрживих политика пољопривредног и шумарског управљања на дигиталним темељима, чиме ће се ојачати равнотежа између руралног развоја и очувања животне средине.

Кључне речи: вештачка интелигенција, зелена инфраструктура, Европски зелени договор, дигитална зелена трансформација, аутоматизовано откривање дрвећа

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