AI and Sustainability: Territorial Monitoring and Waste Valorization

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Abstract
Artificial Intelligence (AI) plays an increasingly significant role in promoting environmental sustainability by processing large volumes of satellite images for real-time monitoring of the territory and utilizing Machine Learning (ML) to model non-linear relationships between data. This article presents four innovative projects demonstrating AI's importance in achieving environmental sustainability goals. In collaboration with the startup Latitudo 40, two tools have been developed. The first tool supports sustainable land planning by monitoring land use and built-up areas. The second tool provides accurate monitoring of carbon sequestration by green infrastructure, which is essential for balancing industrial emissions. A third project, in collaboration with Eni S.p.A, involves the development of an ML-based platform for the valorization of waste biomass in the production of biofuels. The platform suggests optimal pathways for converting biomass into biofuels, promoting more sustainable energy sources and optimizing environmental resources. The fourth project concerns building an AI system using intelligent cameras to detect fires even at great distances and recognize acts of waste spilling. This project aims to prevent and mitigate the environmental impacts of these events. These four projects showcase AI's potential to promote environmental sustainability and address global challenges.

Keywords
Artificial Intelligence, Environmental sustainability

1. Introduction

Artificial Intelligence (AI) can be crucial in promoting environmental sustainability by proposing innovative solutions to address global challenges and supporting responsible management of natural resources. This article aims to present the work in AI applied to environmental sustainability, highlighting four innovative projects developed in collaboration with prominent partners.

The article is structured into four sections. The first section discusses the work carried out in the field of AI for sustainable land planning through the generation of impervious maps. The second section analyzes the AI project aimed at supporting the monitoring of carbon storage by plants. The third section explores the ongoing development work for an AI-based decision support system for selecting the process of valorization of waste biomass for the production of biofuels. Eni S.p.A. partially supports the latter project, while Latitudo-40 supports the former two.

The fourth project concerns building an AI system using intelligent cameras to detect fires even at great distances and recognize acts of waste spilling. This project aims to prevent and mitigate the environmental impacts of these events.

2. Land use planning

The mapping and continuous monitoring of impervious surfaces are crucial to support sustainable urban management strategies and planning practical actions for environmental changes. The increase of impervious surfaces has a significant environmental impact, including the urban heat island effect, increased urban temperature, and reduced air quality, in addition to being typically linked to the reduction of green areas and open spaces, with negative consequences for people's quality of life.

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Monitoring the evolution of impervious surfaces can help plan urban development more sustainably and resiliently, such as promoting the use of permeable materials for pavements or planning green areas and public parks in dense urban areas.

In [1], a Deep-Learning (DL) model was introduced to extract impervious soil maps at a spatial resolution of 10 m using the multispectral content of Sentinel-2 satellite images. In addition, a Web-GIS application was developed to facilitate access to maps even for non-technical personnel, implementing an inference pipeline leveraging modern distributed parallel computing and MLOPs best practices. This enables fast deployment of the solution on HPC or cloud computing systems, ensuring high scalability. Figure 1 depicts the whole process. A Docker image contains the code of the inference pipeline with all the software dependencies correctly in place. The model and weights are stored in object-based storage for fast and easy replacement. The user request triggers a Kubernetes Job for the flow execution, which pulls the Docker image, deploys an ephemeral Dask cluster, and executes tasks on the cluster. A Dask cluster is composed of one scheduler node and N worker nodes. By increasing the number of workers, we can scale up the number of maximum tasks executable in parallel, giving our solution great flexibility and scalability. Although not mandatory, such a solution fits well with the serverless infrastructure made available by most cloud providers today. Serverless computing is an execution model in which the cloud provider allocates machine resources on-demand, allowing customers to pay only when computational power is needed. Creating a Dask cluster when required and deploying it on a serverless infrastructure dramatically reduced operational costs while maintaining a virtually infinite ability to scale.

3. Carbon monitoring and sequestration

By applying artificial intelligence and computer vision techniques, we can assess the amounts of CO2 absorbed by forest areas globally. These goals are achieved by utilizing multispectral images from the Sentinel-2 mission of the Copernicus program and surface biomass data from ESA's Climate Change Initiative Biomass project. This approach is vital for the United Nations REDD+ program, which requires estimating carbon sinks for each country. It also aligns with the United Nations Sustainable Development Goal 15, which promotes the protection of terrestrial ecosystems and sustainable forest management.

The project detailed in [2] employs an artificial intelligence (AI) system to estimate the carbon stock of surface biomass. This tool enables continuous monitoring of carbon absorption on a global scale, thereby facilitating the control of losses due to natural disasters or human activities. Fig. 2 illustrates the carbon absorption before and after the wildfire in the WWF nature reserve in Naples in 2017. End-users can access a tool that generates an absorption map for a specified area by inputting the coordinates of their area of interest. This tool has been used to create a carbon credit trading platform in collaboration with an industrial partner. By purchasing carbon credits, individuals and organizations can compensate for their carbon footprint—the amount of greenhouse gas emitted by a person or activity—thus reducing their environmental impact. The purchase of carbon credits supports projects that reduce or absorb emissions, such as reforestation and sustainable agricultural production initiatives. The developed model calculates the total carbon absorbed by a specific project. As a result, it evaluates the number of carbon credits generated, allowing potential buyers to determine the number of credits that can be purchased for a particular project.

4. Waste biomass valorization

In collaboration with Eni S.p.A., a project is underway to develop a platform aimed at valorizing waste biomass in the production of biofuels. The main objective is to create a machine learning-based platform to identify the most suitable process for obtaining high biofuel yields and the desired chemical properties from waste biomass. A decision support system based on machine learning models and data-driven approaches is being developed, rather than physically based models. This choice is motivated by the complexity of biomass conversion processes, which are often difficult to describe in detail using equations. At the same time, artificial intelligence is particularly effective in capturing nonlinear relationships directly from data.

The planned platform will be able to analyze waste biomass from the agro-industrial chain and suggest the most suitable one among the possible transformation processes for producing a biofuel with desired properties in terms of yield and chemical composition. The data used to train the decision support system will be collected from various chemical processes in scientific literature. A Natural Language Processing pipeline has been set up to retrieve relevant articles related to a specific process of interest and automatically extract the necessary data to support the data collection process. The platform will implement the principles of industrial symbiosis, intended as a production system that favours and optimizes the exchange and sharing of material resources or energy flows between different production chains. The results of the machine learning models system will be validated with the support of expert chemical engineers in bio-refining.

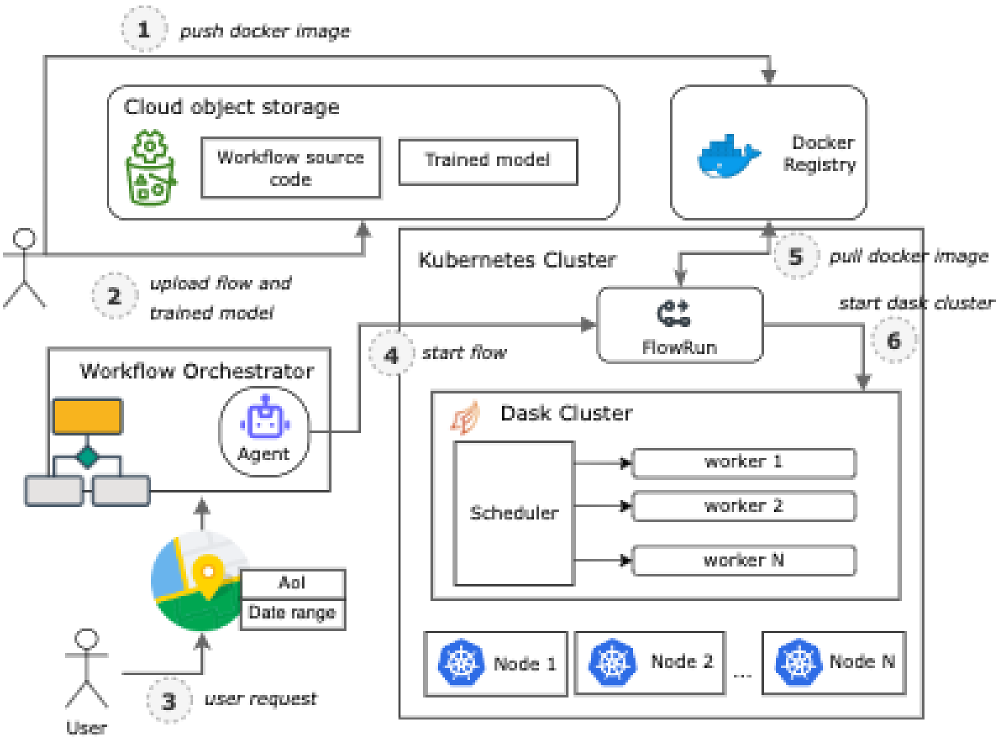

Figure 1: Flow execution process for the imperviousness map generation. A Docker image stores libraries' dependencies. The model, weights and flow code are stored in object-based storage. During flow execution, the orchestrator pulls the image from the Docker registry and starts a Dask cluster using it. Finally, the prediction flow is executed on the Dask cluster.

5. Environmental Hazard Detection

AI applied to image interpretation can play a fundamental role in safeguarding and monitoring an environment. Thanks to the development and scientific evolution of deep learning, some problems that have always been considered unsolvable can be tackled with adequate deep architecture. In this case, methods for the real-time detection of events that can cause significant damage to agriculture and the environment, such as forest and crop fires and waste spills in unpredictable areas that create harmful leachates for the surrounding crops. The Italian state forestry corps declares that from 1970 to today, 12% of the forests have been destroyed by about 5,000 fires a year. The Anti-Mafia Investigation Directorate reports that 14,000 tons of waste have been spilt, estimating about 8,000 eco-crimes.

Therefore, a possible solution would be to cover the territory with intelligent cameras (self-sufficient from a computational point of view or at most accompanied by a small-sized embedded system) with video-analysis algorithms on board capable of detecting such events of interest by sending one or more detection notifications to appropriate management centres. The currently available systems described in the literature are based on methodologies that still need to be fully developed, and their performance limits their diffusion on a large scale. They can be improved above all considering their sensitivity, i.e. their ability to detect fires even at great distances and recognize acts of waste spilling without being confused by the behavioural dynamics that can be detected.

Therefore, the project proposal arises from these needs just described and aims to design and implement an innovative deep system capable of bridging the limits described by limiting the occurrences of false positives, which represent a further limit to the large-scale diffusion of these systems. The aim of the research is the design and testing of deep neural networks for the detection of fires and illegal waste spills, also re-identifying the perpetrator of this crime (classifying the colour of the clothes, identifying the gender and verifying the presence of the bag and hat). These networks must overcome the limitations present in the literature, i.e. test on small datasets that are not representative of the real conditions and decrease in "in-the-wild" performance. The research

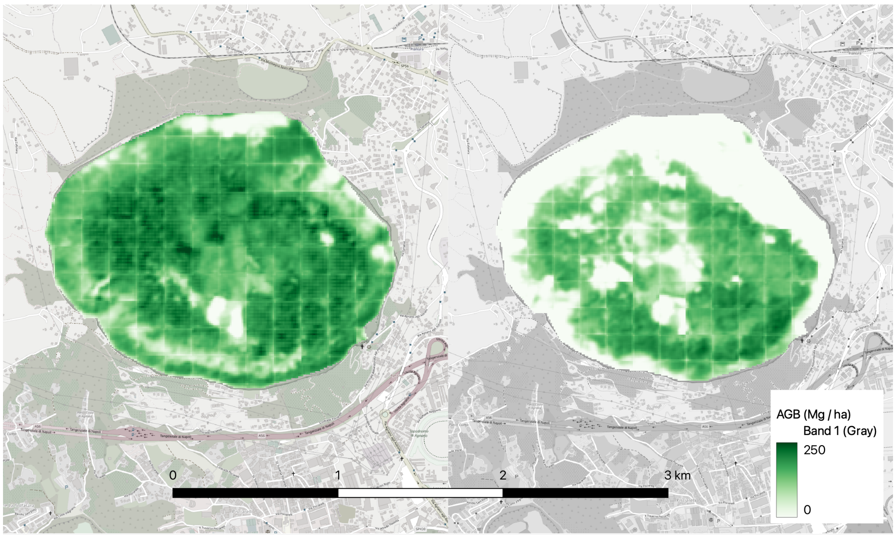

Figure 2: On the left is the predicted above-ground biomass raster of the Astroni nature reserve before the July 2017 fire; on the right is the predicted above-ground biomass raster after a significant fire event in the same area.

includes the definition of innovative architectures of neural networks, the definition of training methodologies and experimental validation procedures in real contexts, and comparing them with existing situations. Optimizing the system for real-time execution of onboard cameras with limited computing resources will also be addressed.

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