D4 REPORT: REVIEW OF METHODS AND APPROACHES TO REPORT EMISSIONS FACTORS IN LIVING BIOMASS, SOIL AND HWP IN TREE PLANTATIONS

ACTION A.3

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1 Introduction

Forests and agricultural lands currently cover more than three-quarters of the European territory and naturally hold large stocks of carbon, both in the soil and the living biomass. In December 2021 the European Commission adopted the Communication on Sustainable Carbon Cycles, as announced in the Farm to Fork Strategy, to set out short-to medium-term actions aiming to address current challenges to carbon farming. The aim is to upscale this green business model, rewarding land managers for taking up practices leading to carbon sequestration, combined with strong benefits on biodiversity. Apart from the various practices promoted for the agricultural sector, for the forestry sector particular attention is devoted to afforestation practices, which respect ecological principles favoring biodiversity and enhancing sustainable forest management, including biodiversity-friendly practices and adaptation of forests to climate change.

The establishment of tree plantations on croplands and grasslands represent a valid mitigation option, as they store carbon in the woody biomass (above and below-ground living biomass) and improve carbon content in soil and litter. Wood products from plantations also play an important substitution role replacing high carbon emission materials or energy (e.g., steel, concrete or fossil fuels). Carbon stock changes in the harvested Wood Products (HWP) depend on several factors such as the amount of harvest, the final products and their end use, the service life of products, and the disposal/recycling or use as fuel at the end of service life. The recognition of the role of the use of local wood for manufacturers can also represent a driver for the increase in wood plantations, thus stimulating the demand of local wood as an additional driver of increase of wood plantation in an area. The purpose of this report is to provide the most updated information on the C present in the different types of afforestation of the Lombardy Region, focusing on the carbon stored in living biomass and soil. To increase the number of available data, studies outside the Region but with similar climatic and soil conditions were included.

2 Review of the existing Biomass data at Regional and National level

The review of the existing Biomass data included research on the most important scientific databases, like Scopus and Google Scholar using keywords like “poplar”, “arboriculture”, filtering data first by nation and secondly by region. The parameters investigated were: scientific name; annual average growth (m^3/ha/y); age; plant density per hectare; planting layout; DBH (cm); height (m); volume (m^3); volume per hectare (m^3/ha); dry biomass (t/ha); city; province; region; altitude; latitude; longitude; soil; fertilization; irrigation; pesticides.

In total, only 18 works were found, totally collecting 311 data points. Scientific databases were scarcely available, which resulted in a heavier representation of data sets from gray literature and other, non-peer reviewed sources. Overall, results were fragmented and hardly representative of our specific study area; moreover, studies often reported different metrics, making comparisons and aggregation work complex and prone to inaccuracies.

Finally, Poplar spp were the most represented tree species across studies, covering almost 60% of data points collected. The remaining 40% of data included a large number of species, with very few data points for each species. Walnut (*Juglans* regia, L. 1753) was the second represented species, although data points were not enough to allow for the creation of a robust database.

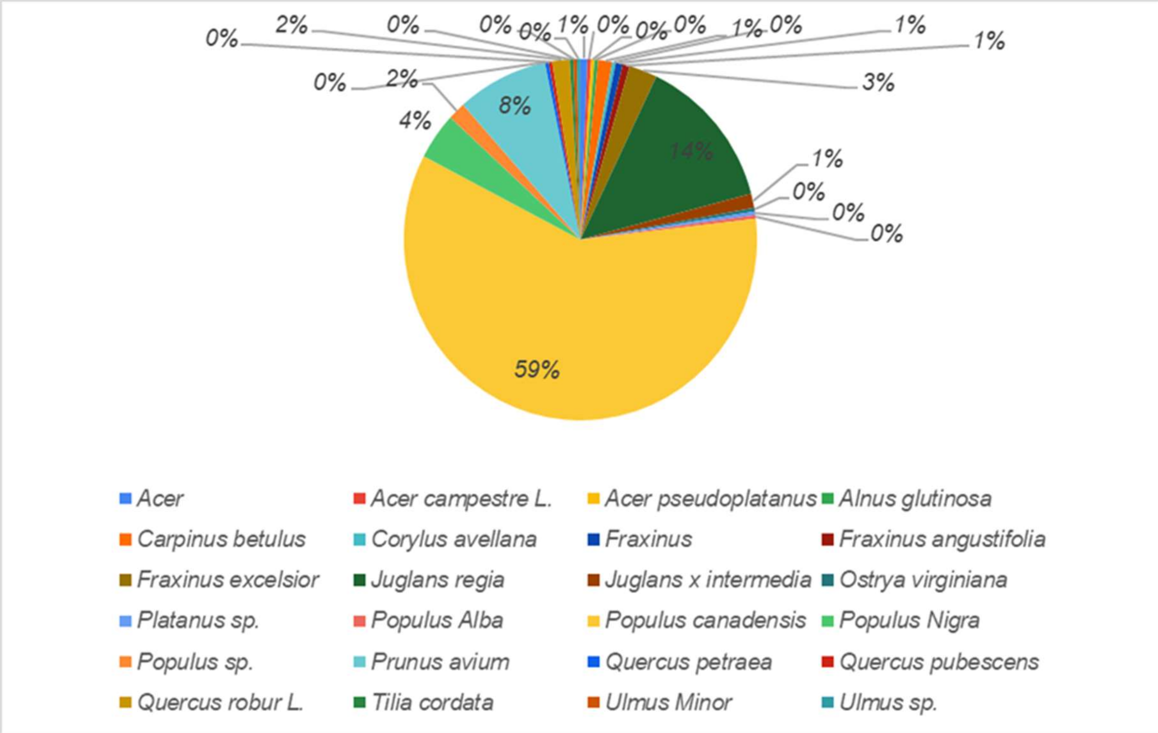

Figure 1. Species found within the review of the existing data

Figure 1 reports the distribution of the species according to the performed literature review. 59% of the data belongs to *Populus xcanadensis*, due to its important commercial value: in fact, the clone 'I-214' is the clone most widespread in the Italian territory.

This fact is confirmed by the INARBO.IT project (https://www.smartforest.it/inarbo.it/), carried on by FederLegnoArredo and CREA. The aim of this project was to estimate the consistency of arboriculture plantations in Italy using satellite images. In Lombardy, in 2017, the poplar plantations occupied 19.580 ha, whereas the totality of the other arboriculture plantations occupied 7.050 ha. In the Padano-Veneta plain (e.g., Piedmont, Lombardy, Veneto, Friuli-Venezia Giulia, Emilia-Romagna regions), poplar were 64.500 ha; arboriculture plantations 21.100 ha (INARBO.IT, 2017).

A full list of the studies included in the database is provided into the reference section.

3 Characterization of tree plantations in the area - Focus on Poplar plantations

Poplar plantations for the production of commercial grade timber is a key value both nationally and internationally. In the Northern part of Italy, poplar cultivation has been a key contributor to the development of sectors such furniture, caravan and automotive, packaging and pulp for paper, by supplying excellent raw material in terms of the required characteristics as well as growth rates and costs associated with cultivation. Additionally, due to the continuous innovation in cultivation techniques and clonal selection, poplar production has remained a competitive productive activity. Nevertheless, poplar cultivation has recently suffered a big decline in the last decade due to various reasons, among which:

- low pricing of the raw material;
- non-recognition of the environmental benefits of the poplar cultivation;
- legislation.

In the last decade, we have seen poplar cultivation farms having decreased in number, from approximately 62.000 in 1970 to only 17.687 in 2010 (FederlegnoArredo, 2012).
Nevertheless, according to the 2005 National Forest Inventory, in Italy there are about 66.270 ha of poplar and 55.983 ha under cultivation of other tree species for commercial purposes.

In Lombardy region poplar cultivation accounts for 23.699 ha (35% of the entire regional area); poplar clones are the main object of commercial wood plantations, accounting for about 88% of the total area under tree cultivation, although there are gaps in the data, especially at the regional level. In Lombardy the most updated data are provided with the contribution of FederlegnoArredo. In terms of carbon sequestration, according to the 2005 National Forest Inventory, Poplar cultivation in

Lombardy stocks about 1.625.190 tons of CO_2 (including the belowground biomass, e.g. rootstock), making the activity relevant for C sequestration purposes.

Poplar timber constitutes the major source of raw material supply for the first transformation industry. About half of the timber consumed Nationally is from some Poplar *spp*, despite the relatively small surface dedicated to it, about 1% of the national forests (Levarato et al., 2018). Other species are also cultivated, although not extensively, probably due to their longer rotation cycle for reaching harvestable dimensions, poor market accessibility, low price points making the venture uncompetitive and low-priced imports from foreign countries (tropics, Eastern Europe).

Currently, efforts are devoted to experiment innovative ways to mix fast growing Poplar spp. with slower growing species such as *Prunus avium* and *Juglans regia*; these are commonly referred to as "policyclic" cultivations. While attractive, such efforts have not yielded sufficient results to grant inclusion in this study (see paragraph 2 "Review of the existing Biomass data at Regional and National level"); also market accessibility is still dubious, resulting in large amounts of biomass ending up in low grade products, such as biomass for energy and fuelwood. Therefore, these systems remain largely experimental and not adopted by the wider sector. For these reasons, only Poplar plantations were included in the study.

In 2018, Chianucci et al. mapped the poplar cultivation in Lombardy. The area detected by the Sentinel satellite amounts to 13.393 ha. (Chianucci et al., 2019). The same survey was performed for the year 2019 and the relative data are showed in the following chapters.

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4 Mapping of poplar plantations

Poplar (*Populus* spp.) plantations for timber production are globally widespread in the Northern Hemisphere (Ball et al., 2005), mainly in China, France, India, Italy and Turkey (FAO/IPC, 2018). The genus Populus is well suited for biomass production due to its fast-growing performance and wood quality, with an estimated production of about 5 million cubic meters per year in European Union countries (Spinelli et al., 2011; Chianucci et al., 2020). Poplar cultivation provides other ecosystem services, such as the prevention of erosion and protection of soil, water quality, habitat for many species (Corona et al., 2020), and it is also directly used for phytoremediation and climate change mitigation. Because of their specific features (fast growth rate and wood quality), the information needed for poplar plantations are increasingly complex and wide ranging, as they must be accurate, frequently updated, and wood supply attributes. However, since National Forest Inventories are typically updated every 10 years, they are not able to produce suitable information to support the management of poplar plantations that are cultivated with 10-12 years rotation for timber employed for plywood production. Traditional specific inventories of poplar plantations both based on photo interpretation or on field surveys are expensive and time-consuming (Chiarabaglio et al., 2018; Mattioli et al., 2019; Corona et al. 2020; Marcelli et al. 2020). When, to reduce their cost, data are acquired on the basis of a sampling design they fail in producing spatially explicit maps (White et al., 2016) that, on the contrary, are even more required for reliable forest plantation management (Di Biase et al., 2018). Such limitations may be potentially overcome by adopting robust automatic classification methods of remotely sensed data, which at the same time are objective and cheaper than traditional approaches and can be repeated to produce near-real-time information due to the vast availability of imagery (Francini et al., 2020, Vaglio et al., 2021).

In the last few years, the increasing availability of open-access optical satellite data and the increased big data analysis capabilities led to a significant advancement in mapping performance of such methods (Li et al., 2015). The advent of more frequent and more detailed images (such as those from Sentinel-

2 -S2- satellite) has led to the beneficial use of deep learning (DL) approaches (Zhu et al., 2017; Ma et al., 2019).

Many studies explored DL for Remote Sensing (RS) tasks, using several Neural Network architectures. Relevant studies were conducted for land cover classification using high-resolution and Landsat imagery (Tong et al., 2020; Alhassan et al., 2020). However, despite good results, both data have limitations. The use of high-resolution images involves long revisit times. While the lower spatial resolution of Landsat imagery is a limiting factor for detailed mapping of highly heterogeneous areas where poplar plantations are located.

Differently, the short revisit time and high spatial resolution of S2, allowed the analysis of vegetative cycles, obtaining good performance using machine learning approaches for crop classification in test sites spread all over the globe (Inglada et al., 2015; Belgiu and Csillik, 2018; Vuolo et al., 2018). Although RS imagery has been widely used for land use and crop classification, only a few studies focused in detail on mapping poplar plantations. The firsts agroforestry area mapping and estimation study was carried out in India (Ahmad et al., 2016; Rizvi et al., 2020). In Turkey, Tonbul et al. (2020) performed the poplar classification using a single S2 image. Hamrouni et al. (2020) combined S2 and SAR imagery (i.e., S1), respectively to map and differentiate into two main stand ages poplar plantations in three French sites. These studies, although S2-based, focused on single tiles, with limited datasets, without exploring the potential of highly frequent satellite imagery in a big data approach to mapping poplar plantations.
The use of multitemporal images is related to the idea that spectral signature of poplar plantations changes in time in a way that is different from that of other crops in the same agricultural areas. Such temporal dynamics are related to phenological changes of poplar trees during the growing season. To perform the Italian poplar plantation mapping update, we developed a DL classification algorithm using multitemporal S2 imagery. The study carried out to map poplar plantations in the large and dynamic Padan Plain, where Italian poplar plantations are concentrated, is presented in D'Amico et al. (2021).

The following paragraphs report the semi-automatic method applied for mapping the Po Valley poplar plantations. This method has been progressively improved, allowing the mapping of the dynamics of poplar plantation in the Po Plain for the years 2017, 2018, 2019, 2020 and 2021.

4.1 Materials and methods

4.1.1 Methods overview

The mappings already carried out represented the starting point for the updates. Thus, for the latest 2021 update, information from the 2017, 2018 (Assopannelli, 2019), 2019 and 2020 poplar plantation mappings were used. Specifically, on the basis of poplar plantation locations, the suitable environmental conditions, excluding a priori those with incompatible land uses, were identified and selected. In the remaining areas, based on the Sentinel-2 images, a summer image was generated and used for subsequent segmentation. Through this procedure land parcels with homogeneous spectral behaviour have been aggregated. For each detected polygon, annual patterns of photosynthetic activity were calculated using Sentinel-2 vegetation indices. Analysing the spectral pattern of polygons, potential poplar plantations were identified.

The poplar plantations, indeed, show a peculiar phenological behaviour, different from the most common agricultural crops present in the study area. Possible inaccuracies were corrected through a photointerpretation step. In this study high-resolution PlanetScope imagery (3 m spatial resolution) was used to generate mapping of 2020 specialized poplar plantation (Figure 2).

The reference standard dimensions for poplar plantations are consistent with the FAO/FRA (2000) forest definition and the INFC (2004) classification system (minimum area of 5000 m2, the minimum width of 20 m and the minimum coverage of 10%). Individual land-use classes smaller than the standard dimensions have been considered as areas included within the plantations.

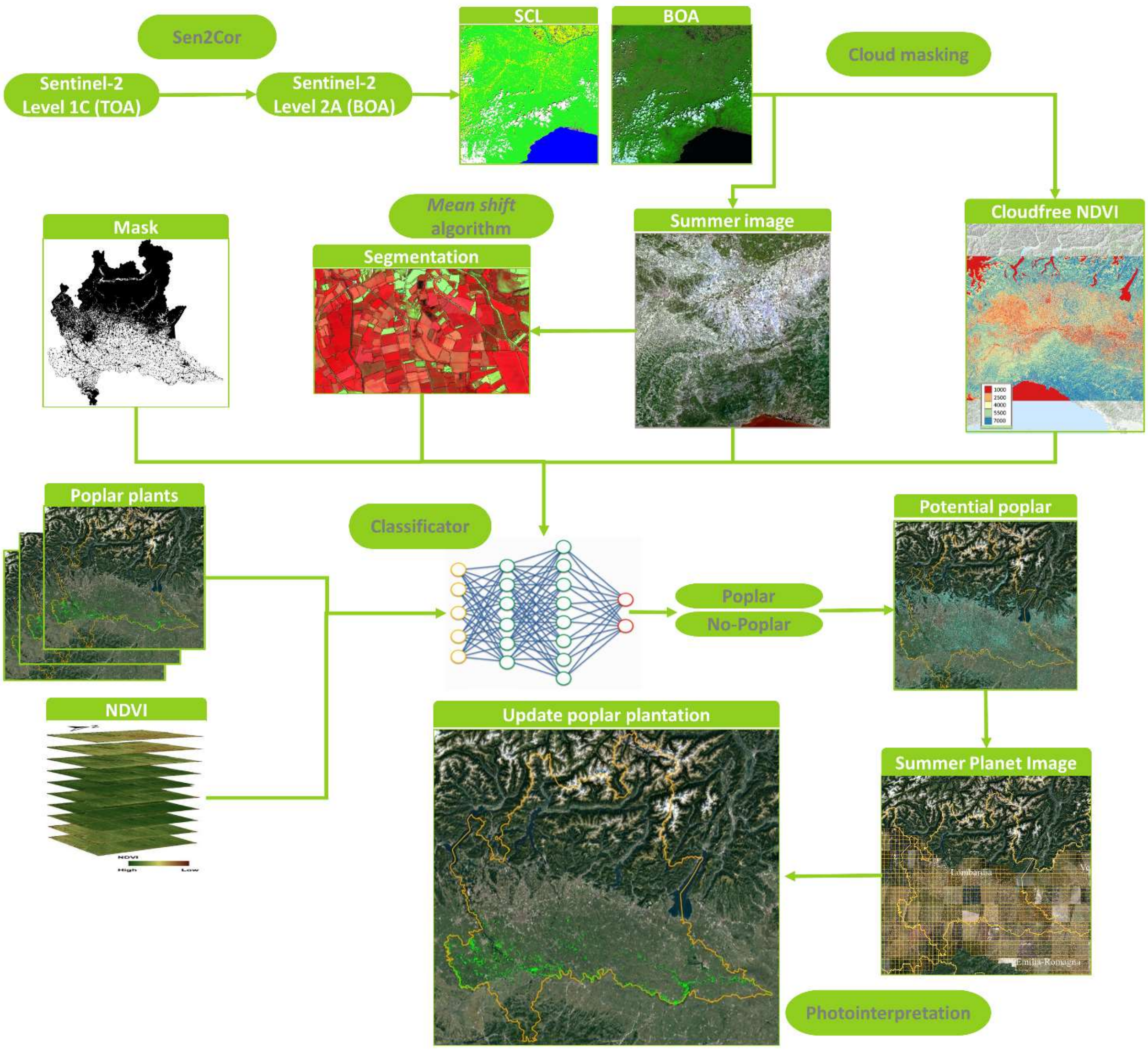

Figure 2. Workflow

4.1.2 Poplar mask

Areas potentially suitable for poplar cultivation were identified by excluding areas with incompatible land uses. These land uses: urban areas, water, and forests, were identified using locally available forest and land use mapping. High Resolution Layers, developed within the Copernicus project, were also used. In particular, Imperviousness and Water & weatness.

Results of poplar plantation mapping from the years 2017, 2018, 2019, and 2020, show the absence of plantation above 600 m above sea level. For this reason, through the information of altitude, obtained from the DTM (Digital Terrain Model) "TINITALY/01 INGV" with a spatial resolution of 10 m, the areas at altitudes higher than 600 m were excluded. Areas not suitable for poplar cultivation were eliminated by overlaying the masks. The elaborations were then concentrated on the remaining areas (Figure 3).

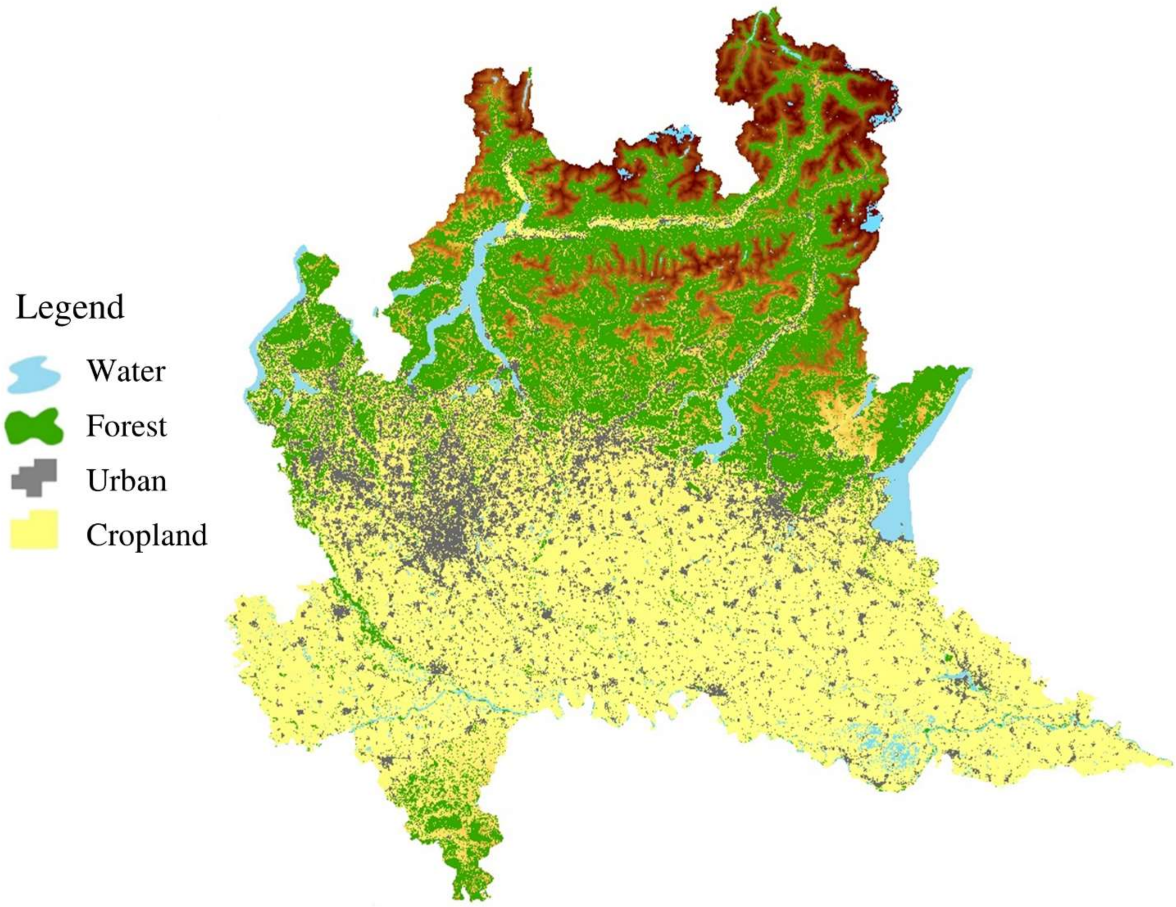

Figure 3. Lombardy Land Use map

4.1.3 Sentinel-2 imagery

The remote sensing data used to map poplar plantations are Sentinel-2 images. Sentinel-2, specifically developed for the observation of environmental resources, is an integral part of the Copernicus European Earth observation program.

The two twin S2 satellites feature an innovative wide-swath width (290 km), high-resolution, MSI sensor with 13 spectral bands, and a spatial resolution ranging between 10 and 60 m depending on the bands (Drusch et al. 2012).

The 10 m resolution bands (three in the visible wavelengths, and one in the Near Infrared, NIR) are highly suitable for application in vegetation mapping with object-based image analysis (OBIA) approaches (Chirici et al. 2016; Garcia et al. 2018; Mura et al. 2018; Francini et al., in review). S2 satellite images, with a revisit time of 5 days, are available in tiles with a fixed size of 100 × 100 km. Through an automated process, all Sentinel-2 images, with less than 80% cloud cover, acquired in the study area between October 2020 and March 2022 were downloaded.

The images are distributed with two levels of pretreatment: 1C, i.e., with the Top Of Atmosphere (TOA) reflectance values, and 2A, i.e., with the reflectance values below the atmosphere (Bottom-Of-Atmosphere), obtained through the application of the Sen2Cor software. The Sen2Cor algorithms detect and classify (Scene Classification map SCL) any anomalies in the images (clouds, snow and shadows) that may affect their use in subsequent processing.

For each month, a cloud-free image was created via the Best Available Pixel (BAP) approach over a four-month time window (using images acquired in the two months following and the two months preceding the month of interest). Specifically, the reflectance values of each pixel per band was calculated by averaging the values that the pixel has assumed over a temporal window of four months, weighted over time distance between image acquisition date and the 15th of each target month.

For each monthly cloudfree mosaic, the most common index of photosynthetic activity, the NDVI (Normalized Difference Vegetation Index), was calculated from the Sentinel-2 bands. NDVI provides information on the health, productivity, development, etc. of the vegetation (Figure 4). For more information refer to D'Amico et al. (2021).

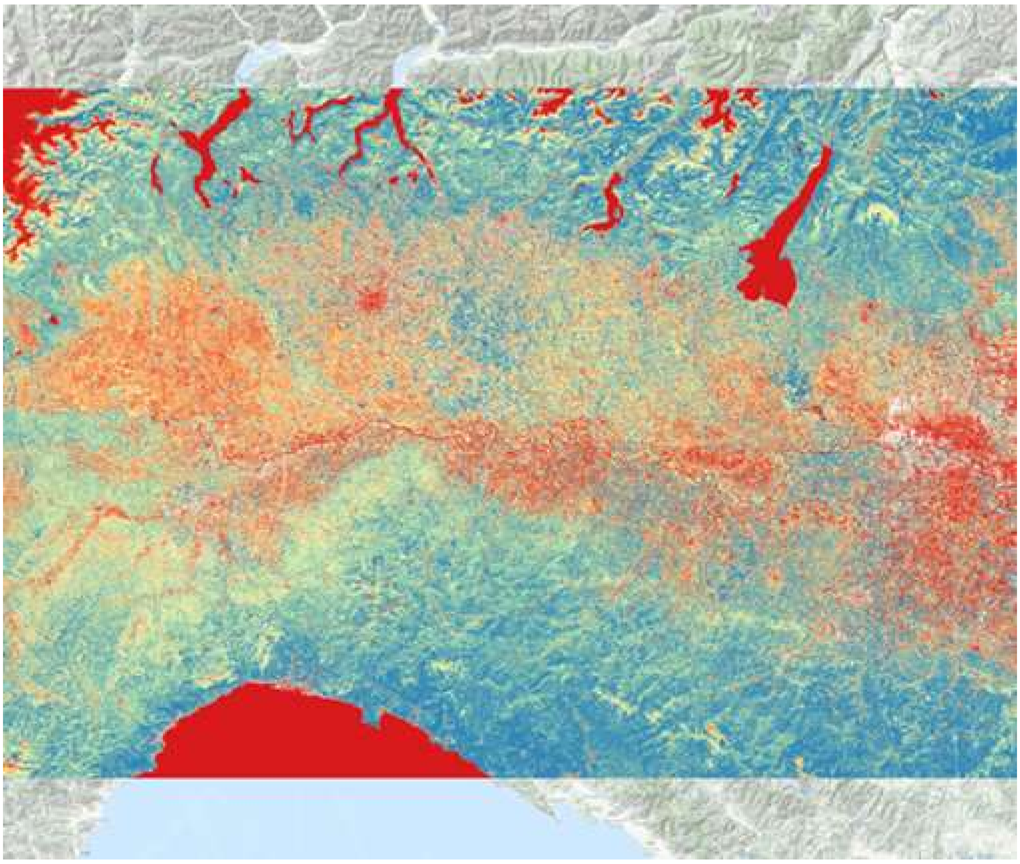

Figure 4. Image recorded in March with NDVI index

4.1.4 Segmentation

It has been chosen to use the Mean Shift (MS) segmentation algorithm that produces a labeled image based on the spectral distance of neighboring pixels. Specifically, if this range distance is below the range radius, the pixels are grouped into the same cluster. The MS algorithm does not require prior knowledge of the number and shape of the clusters (Boukir, Jones, and Reinke 2012), so the best segmentation parameters (i.e. Spatial Radius (hs) equal to 4 pixels, Range Radius (hr) of 500 and 15 pixels as Minimum size (ms)) were selected by visual evaluation using a trial-and-error approach of the alignment between the shape of the polygons generated by segmentation and the boundaries identified in the image (Mathieu, Aryal, and Chong 2007). Segmentation was performed in the summer image with the lowest cloud cover (less than 1%) (Figure 5).

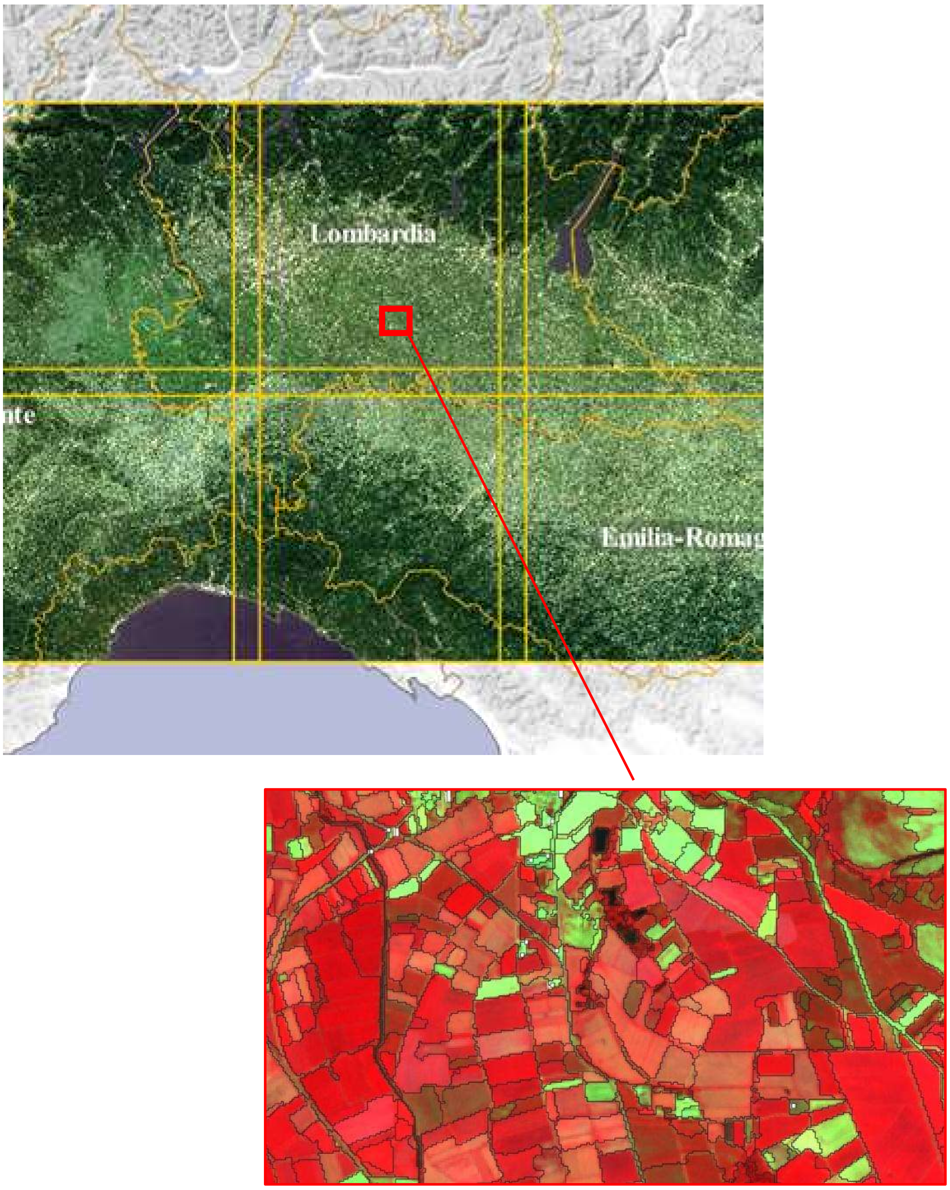

Figure 5. Cloudfree summer Sentinel-2 images, red box below a detail of a segmented area.

4.1.5 Classification

The classification step was developed based on the available information. Within that the location of poplar plantations was identified. Data processed for 2021 (NDVI, Segmentation and Mask of poplar suitable land uses) and the location of 2020 poplar plantations were used. This information layer, along with the 2020 multi-temporal NDVI images, allowed to identify the most representative features of the spectral signature of poplar.

Furthermore, new spectral indices were generated to increase the input variables reducing the noise generated by various sources (lighting conditions, clouds, shadows, and fog).

A set of 55 normalized differential indices based on the 55 pairs of bands available combining the 11 Sentinel-2 bands has been calculated (D'Amico et al., 2021).

For each polygon were calculated the mean and variance of

- NDVI for each month from December 2020 to January 2022 (14 variables);
- Average minimum and maximum NDVI (3 variables);
- ΔNDVI between each month and the next (13 variables);
- Spectral indices (55 variables).

The spectral behavior of the poplar plantations mapped in 2020 was used as input for classifier calibration applied to 2021. The automatic classifier thus allowed to determine for each geometry generated through segmentation (Section 3), the probability that it was effectively a poplar plantation. The classifier identified losses (harvested poplar plantations) and gains (poplar plantations with four years of age and canopy cover greater than 25%) (Lapietra et al., 1994). Polygons with zero probability of being poplar were eliminated (Figure 6). However, given the presence of possible omission errors (i.e., missing poplar plants) and mixing errors (i.e., inclusion of polygons of different classes in the poplar category), these geometries were corrected through photointerpretation.

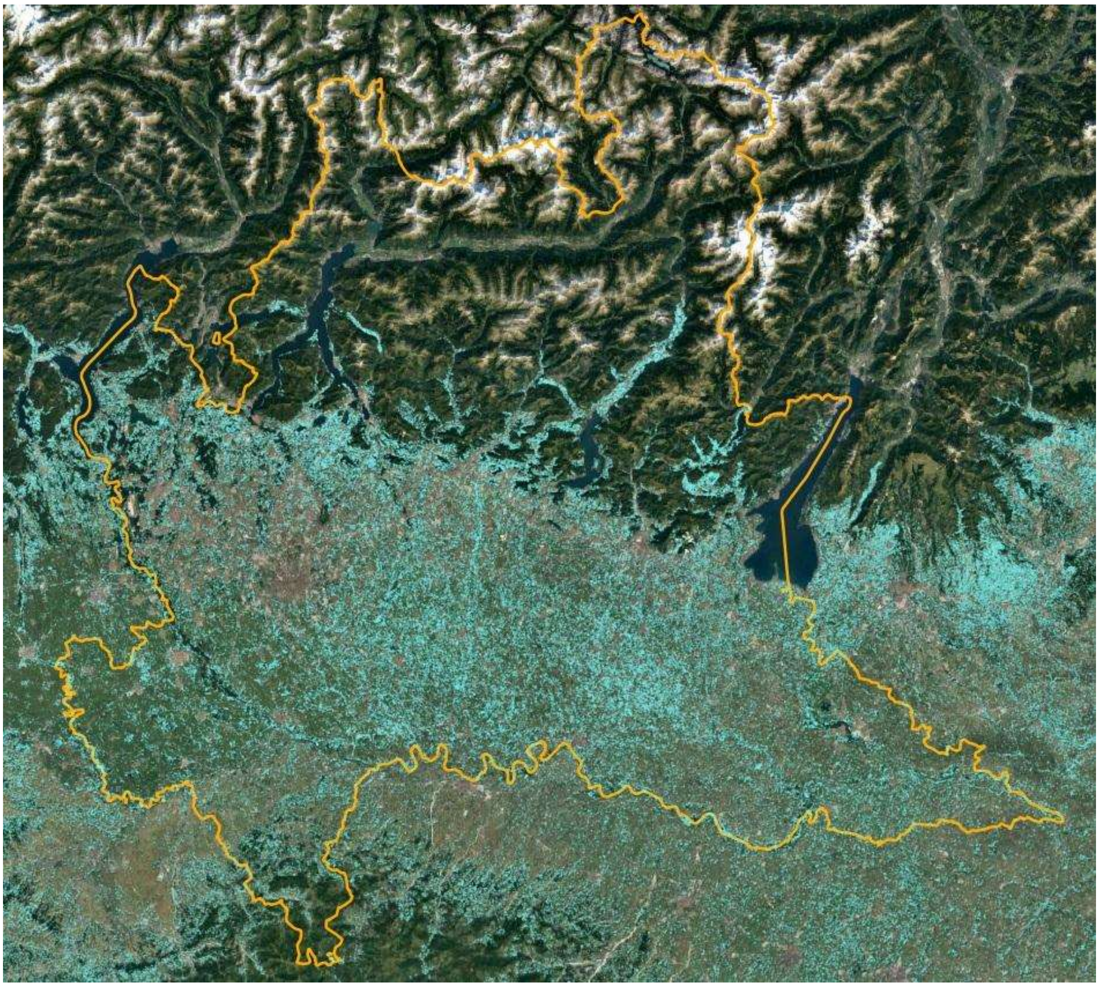

Figure 6. Classification results.

4.1.6 Photointerpretation

For the photointerpretation phase, which allowed the correction of any inaccuracies, high-resolution PlanetScope images (https://www.planet.com/) were used. PlanetScope is a mission consisting of a constellation of nano satellites in constant increase (to date there are more than 150), which provide images with a spatial resolution of 3 meters and a revisit time of one day. For the photointerpretation phase freely accessible PlanetScope RGB images were used (Francini et al., 2020).

In this study, a Planet image for summer 2021 and summer 2020 was produced.

Each image is constituted by a mosaic of 89,151 Tile with 1 km side. Each Tile was obtained by selecting the image with the lowest cloud cover among those acquired during the period June 15-August 30. For the percentage of cloud cover, the information associated with each image was used (Figure 7).

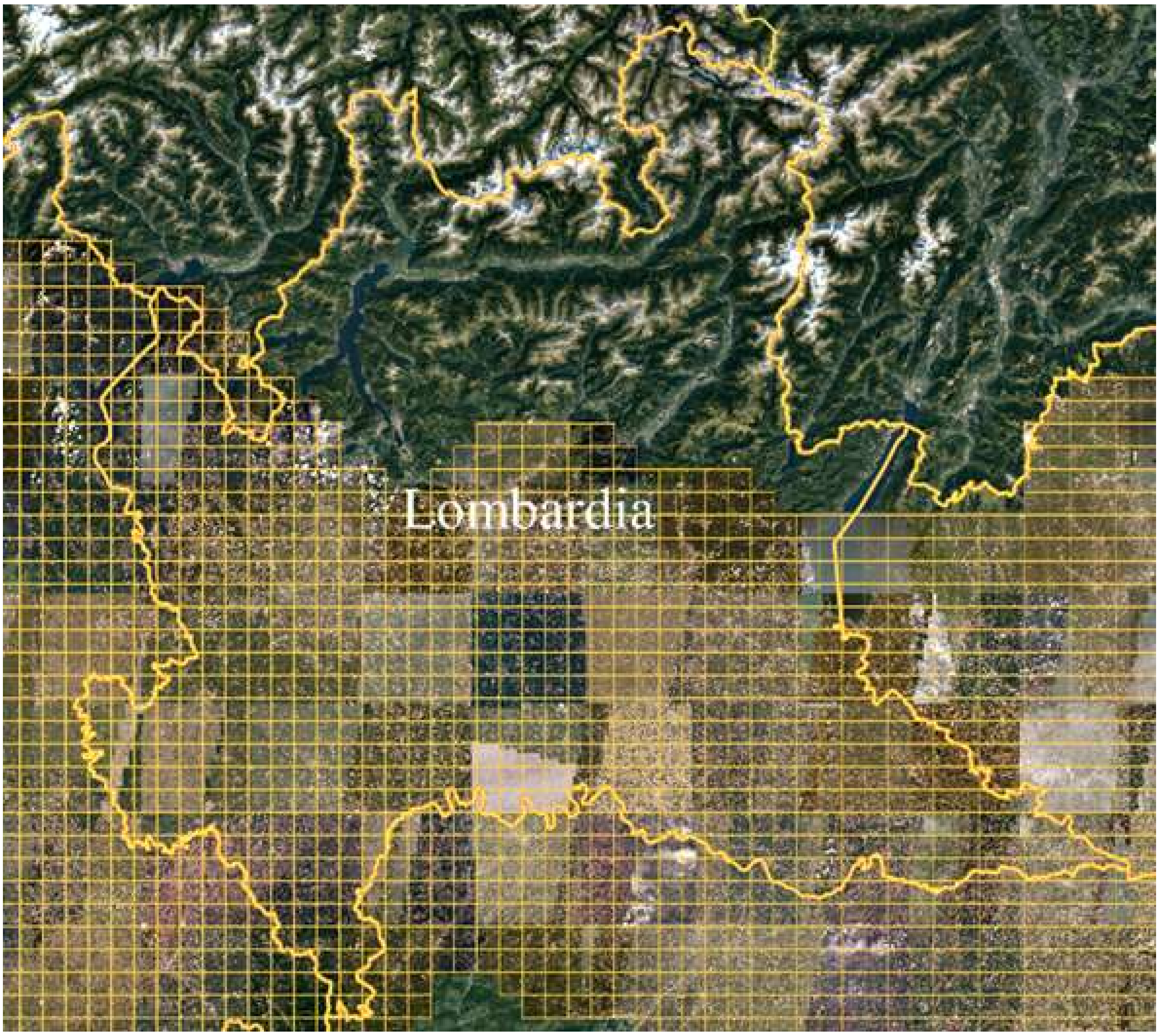

Figure 7. Summer Planet 2020 images.

With this information layer and the Google Satellite images available in the Google Earth software, it was possible to verify the correctness of the automatically produced map. Specifically, in the final map, the geometries of the harvested plantations and any omission and commission errors in the algorithm were corrected and refined.

4.2 Results

Table 1 shows the areas of poplar plantations with area > 0.5 ha and age > 4 years mapped as of August 31 of the years 2019, 2020 and 2021, as of November 30 of the years 2018 and 2017, in different regions of the Po Valley. Figure 8 shows the mapping result as of 2021.

Table 1. Poplar plantation mapping results

Region	Mapped poplars 31/08/2021 [ha]	Mapped poplars 31/08/2020 [ha]	Mapped poplars 31/08/2019 [ha]	Mapped poplars 30/11/2018 [ha]	Mapped poplars 30/11/2017 [ha]
EMILIA-ROMAGNA	**3207.55**	**3187,96**	**3028,8**	**3280,1**	**3244,6**
Bologna	222.5	174,4	152,7	162,4	166,2
Ferrara	681.3	722,8	686,3	715,7	636,1
Forlì-Cesena	0,0	1,7	1,7	1,7	1,7
Modena	351.5	350,2	311,8	366,3	365,6
Parma	835.49	722,8	748,9	875,3	963,0
Piacenza	455.39	490,0	485,0	488,9	479,5
Ravenna	17.5	11,7	13,3	18,2	18,2
Reggio Emilia	643.87	713,6	628,3	650,9	613,5
Rimini	0,0	0,7	0,7	0,7	0,7
FRIULI-VENEZIA GIULIA	**2733.78**	**2682,9**	**2456,3**	**2804,4**	**3002,7**
Gorizia	117.77	79,6	41,2	57,7	31,3
Pordenone	990.01	775,4	663,5	785,7	857,6
Trieste	0,0	0,0	0,0	0,0	0,0
Udine	1626	1828,0	1751,6	1961,1	2113,8
LOMBARDIA	**15379.29**	**14884,5**	**12699,4**	**13393,1**	**13712,3**
Bergamo	11.3	11,3	17,6	22,5	22,5
Brescia	30.44	28,8	24,2	26,9	27,0
Como	0,0	0,0	0,0	0,0	0,0
Cremona	1967.49	1911,0	1724,7	1789,2	1922,4
Lecco	0,0	0,0	0,0	0,0	0,0
Lodi	1042.62	1068,8	958,3	1023,5	1061,7
Mantova	5139.18	5183,4	3337,8	3235,5	3376,3
Milano	647.27	639,0	633,6	613,9	668,1
Monza e Brianza	0,0	0,0	0,0	0,0	0,0
Pavia	6515.08	6023,3	5977,7	6656,2	6609,7

Region	Mapped poplars 31/08/2021 [ha]	Mapped poplars 31/08/2020 [ha]	Mapped poplars 31/08/2019 [ha]	Mapped poplars 30/11/2018 [ha]	Mapped poplars 30/11/2017 [ha]
Sondrio	0,0	0,0	0,0	0,0	0,0
Varese	25.91	19,1	25,5	25,5	24,7
PIEMONTE	**9615.21**	**9359,8**	**9008,4**	**8943,8**	**9026,1**
Alessandria	3389.95	3283,1	2887,6	2883,2	2825,9
Asti	971.3	926,3	929,9	962,7	983,7
Biella	68.15	54,7	60,0	68,1	85,1
Cuneo	1116.57	1045,8	1034,1	1046,5	1091,9
Novara	548.23	569,6	480,3	528,6	500,9
Torino	2995.03	2939,8	3054,9	2816,3	2887,5
Verbano-Cusio-Ossola	8.1	8,1	8,1	14,6	14,6
Vercelli	517.88	532,4	553,6	623,8	636,5
VENETO	**2689.55**	**2648,6**	**2106,8**	**2240,2**	**2362,9**
Belluno	0,0	0,0	0,0	0,0	0,0
Padova	486.4	578,7	453,1	478,7	494,6
Rovigo	794.02	672,8	531,4	590,1	684,0
Treviso	510.8	509,4	402,3	412,7	401,5
Venezia	355.13	363,2	346,5	335,4	359,9
Verona	537.1	518,7	369,4	418,3	417,8
Vicenza	6.1	5,8	4,1	5,0	5,0
TOTAL	**33625.38**	**32763,8**	**29299,7**	**30661,7**	**31348,7**

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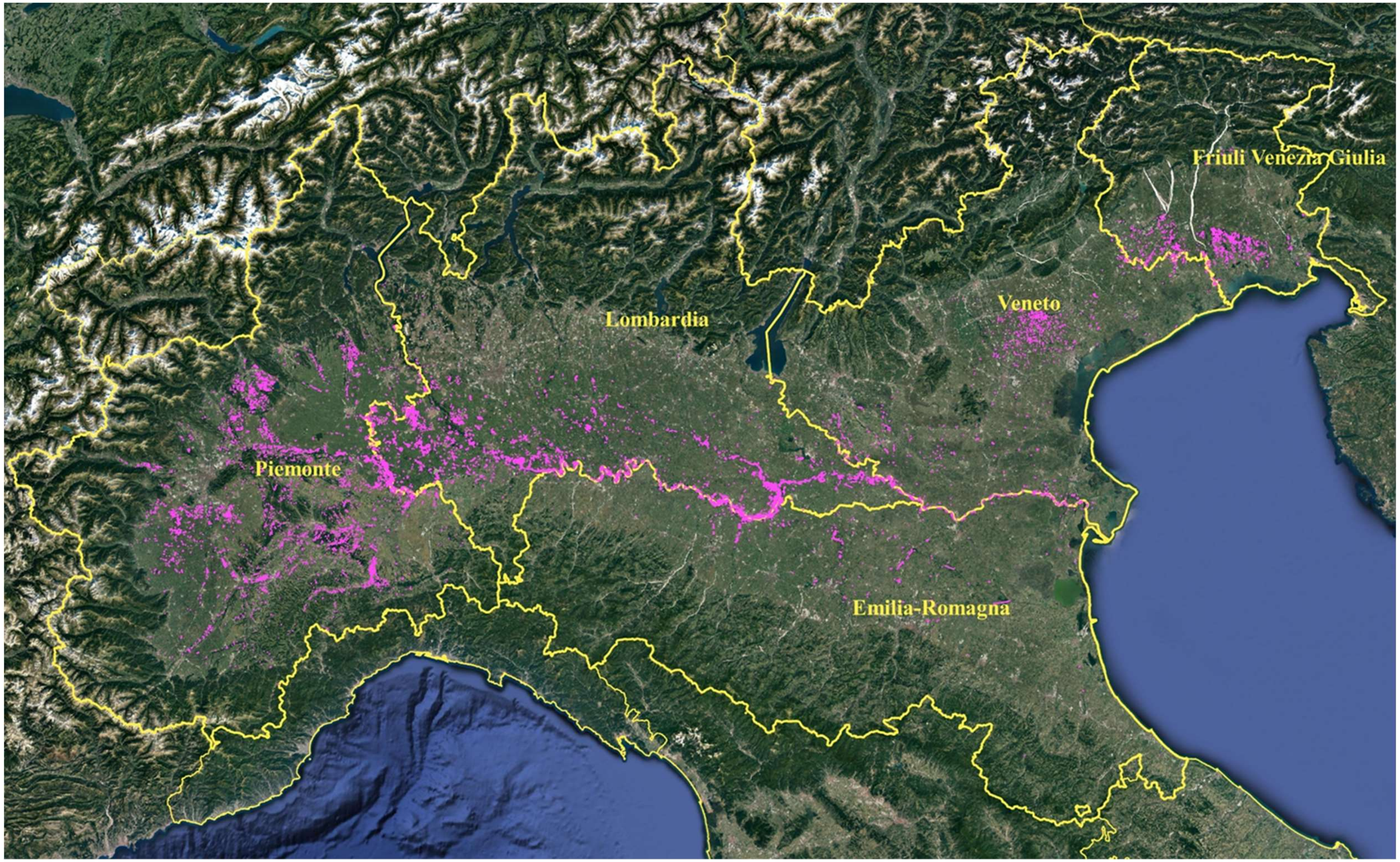

Figura 8. Poplar plantation map update to 2021

Figures 9 and 10 show some of the changes occurred in the poplar plantations identified through a semi-automatic procedure. On the left, with the yellow polygons, are represented the poplar plantations mapped to 2020 with the corresponding Planet image, on the right are shown in green the poplar plantations mapped for 2021 with the Planet 2020 summer image.

Figures 9 and 10. Detail of poplar plantations maps in 2020 and 2021 with respective Planet images.

Table 2 compares the mapping data as of 31/08/2021 of specialized poplar plantation with area > 0.5 ha and age > 4 years with the mapping data of the same as of 31/08/2020.

Table 2. Overall results 2020-2021 with variances

Region	Mapped poplars 31/08/2021 [ha]	Mapped poplars 31/08/2020 [ha]	Total change [ha]	Cut plants [ha]	New plants [ha]
EMILIA-ROMAGNA	**3207.6**	**3188,0**	**19.6**	**434.5**	**454.1**
Bologna	222.5	174,4	48.1	16.2	64.3
Ferrara	681.3	722,8	-41.5	123.3	81.8
Forlì-Cesena	0	1,7	-1.7	1.7	0.0
Modena	351.5	350,2	1.3	41.4	42.7
Parma	835.49	722,8	112.7	61.3	174.0
Piacenza	455.39	490,0	-34.6	109.8	75.2
Ravenna	17.5	11,7	5.8	0.6	6.4
Reggio Emilia	643.87	713,6	-69.7	79.5	9.7
Rimini	0	0,7	-0.7	0.7	0.0
FRIULI-VENEZIA GIULIA	**2733.8**	**2682,9**	**50.8**	**418.7**	**469.5**
Gorizia	117.77	79,6	38.1	3.4	41.5
Pordenone	990.01	775,4	214.7	50.3	265.0
Trieste	0	0,0	0.0	0.0	0.0
Udine	1626	1827,9	-202.0	365.0	163.0
LOMBARDIA	**15379.3**	**14884,5**	**494.9**	**1105.1**	**1600.0**
Bergamo	11.3	11,3	0.0	0.0	0.0
Brescia	30.44	28,8	1.7	4.8	6.5
Como	0	0,0	0.0	0.0	0.0
Cremona	1967.49	1911,0	56.5	197.5	254.0
Lecco	0	0,0	0.0	0.0	0.0
Lodi	1042.62	1068,7	-26.1	135.3	109.2
Mantova	5139.18	5183,4	-44.3	245.2	200.9
Milano	647.27	639,0	8.4	69.5	77.9
Monza e Brianza	0	0,0	0.0	0.0	0.0
Pavia	6515.08	6023,3	491.9	451.3	943.2
Sondrio	0	0,0	0.0	0.0	0.0
Varese	25.91	19,1	6.8	1.5	8.3
PIEMONTE	**9615.2**	**9359,8**	**255.4**	**1192.2**	**1447.6**
Alessandria	3389.95	3283,1	106.8	435.2	542.0
Asti	971.3	926,3	44.9	117.8	162.7
Biella	68.15	54,7	13.4	11.9	25.3

Region	Mapped poplars 31/08/2021 [ha]	Mapped poplars 31/08/2020 [ha]	Total change [ha]	Cut plants [ha]	New plants [ha]
Cuneo	1116.57	1045,8	70.9	148.5	219.4
Novara	548.23	569,6	-21.3	125.8	104.5
Torino	2995.03	2939,8	55.1	261.8	316.9
Verbano-Cusio-Ossola	8.1	8,1	0.0	0.0	0.0
Vercelli	517.88	532,4	-14.4	91.2	76.8
VENETO	**2689.6**	**2648,6**	**40.9**	**407.7**	**448.6**
Belluno	0	0,0	0.0	0.0	0.0
Padova	486.4	578,7	-92.4	131.5	39.1
Rovigo	794.02	672,8	121.3	93.5	214.7
Treviso	510.8	509,4	1.4	42.7	44.1
Venezia	355.13	363,2	-8.1	65.3	57.2
Verona	537.1	518,7	18.4	73.2	91.5
Vicenza	6.1	5,8	0.3	1.5	1.9
TOTAL	**33625.4**	**32763,8**	**861.6**	**3558.1**	**4419.8**

Table 3 compares the mapping data as of 31/08/2020 of specialized poplar plantation with area > 0.5 ha and age > 4 years with the mapping data of the same as of 31/08/2019.

Table 3. Overall results 2019-2020 with variances

Region	Mapped poplars 31/08/2020 [ha]	Mapped poplars 31/08/2019 [ha]	Total change [ha]	Cut plants [ha]	New plants [ha]
EMILIA-ROMAGNA	**3188,0**	**3028,8**	**159,2**	**613,5**	**772,6**
Bologna	174,4	152,7	21,7	38,2	59,9
Ferrara	722,8	686,3	36,5	101,1	137,6
Forlì-Cesena	1,7	1,7	0,0	0,0	0,0
Modena	350,2	311,8	38,4	84,2	122,6
Parma	722,8	748,9	-26,1	219,8	193,7
Piacenza	490,0	485,0	5,0	47,7	52,7
Ravenna	11,7	13,3	-1,6	1,6	0,0
Reggio Emilia	713,6	628,3	85,3	120,9	206,2
Rimini	0,7	0,7	0,0	0,0	0,0
FRIULI-VENEZIA GIULIA	**2682,9**	**2456,3**	**226,6**	**296,8**	**523,4**
Gorizia	79,6	41,2	38,4	0,0	38,4
Pordenone	775,4	663,5	111,9	46,3	158,2

Region	Mapped poplars 31/08/2020 [ha]	Mapped poplars 31/08/2019 [ha]	Total change [ha]	Cut plants [ha]	New plants [ha]
Trieste	0,0	0,0	0,0	0,0	0,0
Udine	1827,9	1751,6	76,3	250,4	326,7
LOMBARDIA	**14884,5**	**12699,4**	**2185,1**	**2351,3**	**4536,4**
Bergamo	11,3	17,6	-6,3	6,3	0,0
Brescia	28,8	24,2	4,5	4,6	9,1
Como	0,0	0,0	0,0	0,0	0,0
Cremona	1911,0	1724,7	186,3	333,8	520,1
Lecco	0,0	0,0	0,0	0,0	0,0
Lodi	1068,7	958,3	110,5	155,2	265,6
Mantova	5183,4	3337,8	1845,7	482,2	2327,9
Milano	639,0	633,6	5,4	132,2	137,6
Monza e Brianza	0,0	0,0	0,0	0,0	0,0
Pavia	6023,3	5977,7	45,5	1230,6	1276,1
Sondrio	0,0	0,0	0,0	0,0	0,0
Varese	19,1	25,5	-6,4	6,4	0,0
PIEMONTE	**9359,8**	**9008,4**	**351,4**	**1510,1**	**1861,4**
Alessandria	3283,1	2887,6	395,5	332,8	728,2
Asti	926,3	929,9	-3,6	129,1	125,6
Biella	54,7	60,0	-5,2	12,7	7,5
Cuneo	1045,8	1034,1	11,7	186,0	197,7
Novara	569,6	480,3	89,3	87,4	176,7
Torino	2939,8	3054,9	-115,1	596,4	481,3
Verbano-Cusio-Ossola	8,1	8,1	0,0	0,0	0,0
Vercelli	532,4	553,6	-21,2	165,6	144,4
VENETO	**2648,6**	**2106,8**	**541,8**	**340,6**	**882,4**
Belluno	0,0	0,0	0,0	0,0	0,0
Padova	578,7	453,1	125,6	51,0	176,6
Rovigo	672,8	531,4	141,4	86,2	227,7
Treviso	509,4	402,3	107,1	41,0	148,1
Venezia	363,2	346,5	16,7	83,0	99,7
Verona	518,7	369,4	149,3	79,4	228,7
Vicenza	5,8	4,1	1,6	0,0	1,6
TOTAL	**32763,8**	**29299,7**	**3464,1**	**5112,2**	**8576,3**

Table 4 compares the mapping data as of 31/08/2019 of specialized poplar plantation with area > 0.5 ha and age > 4 years with the mapping data of the same as of 30/11/2018.

Table 4. Overall results 2018-2019 with variances

Region	Mapped poplars 31/08/2019 [ha]	Mapped poplars 30/11/2018 [ha]	Total change [ha]	Cut plants [ha]	New plants [ha]
EMILIA-ROMAGNA	**3028,8**	**3224,2**	**-195,4**	**539,1**	**318,9**
Bologna	152,7	162,6	-9,9	22,9	13,0
Ferrara	686,3	715,1	-28,8	101,4	72,6
Forlì-Cesena	1,7	1,7	0,0	0,0	0,0
Modena	311,8	366,4	-54,6	80,1	25,5
Parma	748,9	854,7	-105,7	156,8	51,0
Piacenza	485,0	452,6	32,4	79,2	92,7
Ravenna	13,3	18,2	-4,9	6,8	1,9
Reggio Emilia	628,3	652,2	-23,9	91,9	62,2
Rimini	0,7	0,7	0,0	0,0	0,0
FRIULI-VENEZIA GIULIA	**2456,3**	**2801,1**	**-344,8**	**1042,1**	**697,2**
Gorizia	41,2	57,6	-16,3	20,4	4,0
Pordenone	663,5	786,1	-122,7	336,3	213,7
Trieste	0,0	0,0	0,0	0,0	0,0
Udine	1751,6	1957,4	-205,8	685,5	479,6
LOMBARDIA	**12699,4**	**13426,4**	**-727,0**	**2275,6**	**1567,3**
Bergamo	17,6	22,5	-4,9	4,9	
Brescia	24,2	25,5	-1,3	2,2	1,0
Como	0,0	0,0	0,0	0,0	0,0
Cremona	1724,7	1844,3	-119,6	287,8	161,6
Lecco	0,0	0,0	0,0	0,0	0,0
Lodi	958,3	1034,3	-76,1	184,9	128,9
Mantova	3337,8	3230,3	107,4	339,0	458,8
Milano	633,6	624,1	9,5	76,1	85,6
Monza e Brianza	0,0	0,0	0,0	0,0	0,0
Pavia	5977,7	6619,9	-642,2	1380,7	731,4
Sondrio	0,0	0,0	0,0	0,0	0,0
Varese	25,5	25,5	0,0	0,0	0,0
PIEMONTE	**9008,4**	**8985,8**	**22,6**	**1583,5**	**1612,0**
Alessandria	2887,6	2902,9	-15,3	551,3	542,4

Region	Mapped poplars 31/08/2019 [ha]	Mapped poplars 30/11/2018 [ha]	Total change [ha]	Cut plants [ha]	New plants [ha]
Asti	929,9	963,8	-33,9	170,8	136,9
Biella	60,0	68,0	-8,1	11,7	3,6
Cuneo	1034,1	1048,5	-14,4	172,0	157,5
Novara	480,3	542,1	-61,8	115,2	59,1
Torino	3054,9	2819,1	235,7	405,9	633,4
Verbano-Cusio-Ossola	8,1	14,6	-6,5	6,5	0,0
Vercelli	553,6	626,7	-73,2	150,1	79,1
VENETO	**2106,8**	**2232,7**	**-125,9**	**619,0**	**493,3**
Belluno	0,0	0,0	0,0	0,0	0,0
Padova	453,1	483,6	-30,5	145,3	118,8
Rovigo	531,4	585,2	-53,8	166,3	112,5
Treviso	402,3	406,1	-3,8	111,9	104,5
Venezia	346,5	340,2	6,3	85,2	90,8
Verona	369,4	412,6	-43,1	109,2	66,4
Vicenza	4,1	5,0	-0,9	1,1	0,2
TOTAL	**29299,7**	**30670,1**	**-1370,4**	**6059,1**	**4688,7**

Table 5 compares the mapping data as of 30/11/2018 of specialized poplar plantation with area > 0.5 ha and age > 4 years with the mapping data of the same as of 30/11/2017.

Table 5. Overall results 2017-2018 with variances

Region	Mapped poplars 30/11/2017 [ha]	Mapped poplars 30/11/2018 [ha]	Total change [ha]	Cut plants [ha]	New plants [ha]
EMILIA-ROMAGNA	**3244,6**	**3280,1**	**35,5**	**319,6**	**355,1**
Bologna	166,2	162,4	-3,9	15,7	11,8
Ferrara	636,1	715,7	79,6	89,2	168,8
Forlì-Cesena	1,7	1,7	0,0	0,0	0,0
Modena	365,6	366,3	0,7	27,4	28,1
Parma	963,0	875,3	-87,8	117,9	30,2
Piacenza	479,5	488,9	9,4	40,6	50,0
Ravenna	18,2	18,2	0,0	0,0	0,0
Reggio Emilia	613,5	650,9	37,4	28,8	66,3
Rimini	0,7	0,7	0,0	0,0	0,0
FRIULI-VENEZIA GIULIA	**3002,7**	**2804,4**	**-198,3**	**421,6**	**223,3**

Region	Mapped poplars 30/11/2017 [ha]	Mapped poplars 30/11/2018 [ha]	Total change [ha]	Cut plants [ha]	New plants [ha]
Gorizia	31,3	57,7	26,4	0,0	26,4
Pordenone	857,6	785,7	-71,9	144,0	72,1
Trieste	0,0	0,0	0,0	0,0	0,0
Udine	2113,8	1961,1	-152,7	277,6	124,9
LOMBARDIA	**13712,3**	**13393,1**	**-319,2**	**1027,8**	**708,6**
Bergamo	22,5	22,5	0,0	0,0	0,0
Brescia	27,0	26,9	-0,1	0,1	0,0
Como	0,0	0,0	0,0	0,0	0,0
Cremona	1922,4	1789,2	-133,2	148,3	15,1
Lecco	0,0	0,0	0,0	0,0	0,0
Lodi	1061,7	1023,5	-38,2	84,5	46,2
Mantova	3376,3	3235,5	-140,8	356,2	215,3
Milano	668,1	613,9	-54,2	73,7	19,5
Monza e Brianza	0,0	0,0	0,0	0,0	0,0
Pavia	6609,7	6656,2	46,5	363,4	409,9
Sondrio	0,0	0,0	0,0	0,0	0,0
Varese	24,7	25,5	0,8	1,7	2,5
PIEMONTE	**9026,1**	**8943,8**	**-82,3**	**659,9**	**577,6**
Alessandria	2825,9	2883,2	57,4	220,2	277,6
Asti	983,7	962,7	-21,0	68,1	47,1
Biella	85,1	68,1	-16,9	18,7	1,8
Cuneo	1091,9	1046,5	-45,4	82,9	37,5
Novara	500,9	528,6	27,6	22,6	50,3
Torino	2887,5	2816,3	-71,3	206,8	135,5
Verbano-Cusio-Ossola	14,6	14,6	0,0	0,0	0,0
Vercelli	636,5	623,8	-12,7	40,5	27,8
VENETO	**2362,9**	**2240,2**	**-122,7**	**281,8**	**159,1**
Belluno	0,0	0,0	0,0	0,0	0,0
Padova	494,6	478,7	-15,9	41,9	26,0
Rovigo	684,0	590,1	-93,9	148,8	54,9
Treviso	401,5	412,7	11,2	22,0	33,2
Venezia	359,9	335,4	-24,6	41,9	17,3
Verona	417,8	418,3	0,4	27,3	27,7
Vicenza	5,0	5,0	0,0	0,0	0,0
TOTAL	**31348,7**	**30661,7**	**-686,9**	**2710,7**	**2023,7**

Tables 1 and 2 show an increase in poplar area for the year 2021, as already observed in 2020. These increases in area were expected due to greater interest in poplar wood. The increasing trend is new compared to the data identified for the years 2017-2018 (Table 5) and 2018-2019 (Table 4) (Assopannelli, 2019) and 2019-2020 (Table 3). Results show that the increase in areas with poplar plantations started in 2019 is continuing. (Table 6).

Table 6. Regional area changes in poplar plantations aged ≥ 4 years as of August 31, 2019, 2020, and 2021.

Region	New plants 2021 [ha]	New plants 2020 [ha]	New plants 2019 [ha]	Cut plants 2021 [ha]	Cut plants 2020 [ha]	Cut plants 2019 [ha]
Emilia-Romagna	454.1	772,6	318,9	434.5	613,5	539,1
Friuli Venezia-Giulia	469.5	523,4	697,2	418.7	296,8	1042,1
Lombardia	1600.0	4536,4	1567,3	1105.1	2351,3	2275,6
Piemonte	1447.6	1861,4	1612,0	1192.2	1510,1	1583,5
Veneto	448.6	882,4	493,3	407.7	340,6	619,0
TOTAL	**4419.8**	**8576,3**	**4688,7**	**3558.1**	**5110,2**	**6059,1**

Here the interactive web map of poplar plantations in Lombardy and the Po Valley updated to 2021:

https://drive.google.com/file/d/1tulLA3NIRXI75udc7xfcQCi56Cps8x0r/view?usp=sharing

The instructions to open the map properly:

- download the entire folder
- unzip the folder
- open the HTML file.

Shapefiles and all the results of the mapping can be found in the Project folder here: https://drive.google.com/drive/folders/1ad-tJTocFSw-E5jfpSkXsHA3eOc49otY

5 Environmental sustainability in poplar plantations

The national and international scientific community is making efforts to improve the sustainable management of poplar cultivation. At the national level, poplar cultivation is spread in the northern areas, where it requests opportune environmental conditions available within the floodplains of rivers. In the latter areas, the cultivation is considered to have an impact on soil caused by the tillage, and the use of chemical products required for the phytosanitary treatments (Chiarabaglio P.M et al., 2014). Although poplar plantations are grown using intensive methods, their impact is less than that of the agricultural crops with which they are in rotation.

The research for improving the environmental sustainability of poplar plantations takes into account various levels of the poplar production chain and different methods applicable at the same time. Some of the studies are focused to assess new or a mix of poplar clones to challenge and adapt the cultivation to the new environmental needs due to the ongoing climate change so increase the chain sustainability (e.g requiring minor chemicals for phytosanitary treatment and fertilization inputs).

In a recent investigation, (see Cantamessa et al., 2022) poplar clones called MSA, that in the Italian language means for "maggior sostenibilità ambientale" meaning greater environmental sustainability, have been used to provide a reduction of carbon emissions quantified through the life cycle assessment (LCA) calculation. The same study highlights how organic fertilization can decrease emissions until negative values.
Allegro et al in 2014 studied in the Lombardy region the behavior and adaptability of new poplar clones, more tolerant to the main pests and diseases and less demanding in terms of cultivation. Furthermore, based on the scientific knowledge and results, standards for the certification of sustainable poplar plantations management have been developed according to Programme for the Endorsement of Forest Certification

(PEFC) and Forest Stewardship Certification (FSC). Among the various measures adopted by these certification systems, some of the most important is the construction of polyclonal plantations able to reduce the phytosanitary risk, the containment of the tillage within the first years of cultivations or through grassing, the rational use of chemical interventions against the principal pathogen, and the efficiency in the use of water resources.
Similar cultivation procedures were mentioned years before by Gianni Allegro et al in the manual for "Poplar Quality productions in respect of the environment" as part of the 2000-2006 Rural Development Plan. Environmental sustainability in poplar plantations is also enhanced by the adoption of agroforestry practices. The latter method is considered a multifunctional system capable of providing a wide range of economic and environmental benefits (Corona et al., 2018). In this system agricultural surfaces of trees are mixed with shrub forests that can be associated with cropland and or with livestock activities improving at the same time the quality and the resilience of the ecosystem. In addition, Corona et al 2018 highlighted that, beyond the positive externalities at the environmental level of the agroforestry method, the planting layout adopted in that cultivation may negatively influence the commercial values of the harvested wood product suggesting an eventual decrease in the technological features. Conversely, a case study in the Po Valley located in north Italy showed how the agroforestry system with cereal and crops and the poplar clone 'I-214' can be economically advantageous and positively linked to the wood price (Rosso. L et al., 2021.).

5.1 Carbon farming in poplar plantations

The integrated management of the poplar plantations towards agroforestry is a central theme also at Italian and International level (see Singh et al., 2021; Sun et al., 2018) and will become more and more important during the next few years.

Despite agroforestry management together with other carbon farming practices such as minimum tillage or grassing are applied within poplar plantations, few data are available on the Soil organic carbon (SOC) or on the effect on carbon sequestration obtained through the harvested wood product (HWP). Currently, it is the plantation itself that is being studied as a possible carbon farming technique and provides a minimum amount of data needed for investigations at the European and regional scale. Indeed, it is the passage between arable crops to plantations that is investigated as a possible benefit for carbon accumulation within the soil and litter, and within above and below ground woody biomass.

6 Analysis of carbon mitigation potential of poplar plantations

6.1 Soil carbon stock in poplar plantations

Soil organic carbon (SOC) is considered one of the best indicators for soil quality (Reeves, 1997) and can be used as an indicator to investigate the sustainability of the agricultural supply chain. Indeed, SOC is strictly correlated to the biological, physical and chemical soil parameters and is considered strategic in order to reduce carbon dioxide emissions as defined by the article 3.4 of the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC).
The sustainable management practices applied in agriculture to reduce greenhouse gasses (GHGs) are various and show a growing scientific interest, indeed beyond fixing CO2 into the soil they activate a series of indirect advantages to the soil and the relative culture (e.g. increase of soil organic matter, water retention, erosion stabilization etc).

This section of the study focuses on the specific effects of land-use change associated with the conversion of agriculture fields to poplar plantations. Indeed, producing wood biomass through plantations has become popular in the last decades and poplar is one of the most important species used worldwide. The commercial requests behind the plantations are various, passing from bioenergy production to construction plywood, packaging, wood wool, chipboard and the paper industry. The 43% of the Italian poplar production for wood-furniture automotive, packaging, and paper sector, are located in the Lombardy region on 19.850 hectares within the north plain of Italy (Corona et al., 2018). Poplar cultivation of the Lombardy region represents for Italy the most internal source of timber for industry.
Despite the good productivity of the poplar production chain the cultivation is to be considered made with energy inputs that can have negative environmental impacts although these impacts are far less than those of agricultural crops (Allegro et al., 2006). For this reason, European rural development plans (RDP) financing for crops that provide for simplified cultivation techniques and at the same time researchers are moving

towards improving the sustainability of the production with the introduction of agroforestry systems (Yasin et al., 2018) and sustainable cultivation techniques and certification schemes for sustainability (Corona et al., 2018).

This research will focus on the need to better quantify the effects of land-use change associated with the poplar production on SOC measured at 30 cm depth.

6.1.1 Objective

The aim of this analysis was to investigate and quantify the potential of poplar plantations to mitigate climate change, in the Lombardy region in Italy, by reducing GHG emissions by capturing CO_2 from the atmosphere and storing it within the soil system. Consequently, the SOC stock of poplar plantations of the region or in similar pedoclimatic conditions to those of the Lombardy region was derived from the scientific literature using the most common sources of research (e.g., Scopus; web of science etc).

6.1.2 Materials and method

The bibliographic research was used to build a database collecting all the European studies focused on SOC annual sequestration rate and stock within the soil of poplar plantations. The SOC stock measured in Mg of Carbon per hectare (Mg C ha^{-1}) was directly taken from each study whether available or calculated using Equation 1 when it was not reported but present the data for its calculation. The annual rate of organic carbon measured in Mg C ha^{-1} $year^{-1}$ was calculated using Equation 2. In cases, data were presented only in figures, WebPlotDigitizer Version 4.5 was used for the extraction of data (https://apps.automeris.io/wpd/).

$$\text{SOC stock (Mg C ha}^{-1}\text{)} = SOC_{conc} \times BD \times Depth \times (1\text{-}Rockmass) \quad [1]$$

where:

SOC_{conc} is the organic C concentration of the fine earth (g C kg^{-1} soil), BD is the apparent soil bulk density (g soil cm^{-3}), depth is the depth of investigated soil layer (cm), and the Rockmass is the rock fragments fraction in mass percentage (mass%/100)

$$SOC\ sequestration\ rate(Mg\ C\ ha-1\ yr-1) = \frac{SOC\ final\ -SOC\ initial}{Years} \quad [2]$$

where:

SOC final represents the carbon stock at a certain period after the plantation establishment (Mg C ha^{-1}) while the SOC initial is the carbon stock of the previous land management before the plantation (Mg C ha^{-1}), while years is the number of years after the poplar plantation establishment.

Additional variables which can affect the SOC stock were also recorded (i.e., the land use before the plantation establishment and its relative management).

Particular attention was used to define the woody assortment derived from the plantations, which affects the rotation cycle. When this information was not directly available, other elements were used for the classification according to Table 7.

Table 7. Pillars followed to divide the poplar plantations' woody array

Poplar for Bioenergy	Poplar for wood productions
Density > 500 plant/hectare	Density < 500 plant/hectare
Cutting cycle <= 5 years	Cutting cycle > 5 years

Finally, a standardized climatic classification was carried out for each study involved in the analysis using the spatial data gained from "The Environment Stratification of Europe" (EnS) proposed by Metzger and Marc (2018). The EnS is a statistically derived land classification, providing a novel global spatial framework for the integration and analysis of ecological and environmental data. The EnS has a 1 km spatial resolution and is projected in the INSPIRE ETRS89-LAEA projection. The dataset distinguishes 84 strata that are relatively homogeneous in environmental conditions and can be aggregated into 13 environmental zones (EnZ). The principle used to study the SOC of poplar plantations within the Lombardy region was guided by climate variability. The latter was used as a driving factor for the data investigation: the SOC stocks found in climates equal to those present in the Lombardy region were grouped and statistically analyzed through a boxplot.

The data harmonization, in terms of soil classification and depth of soil sampling investigated in the study, has followed procedure according to the A2 Action of this project, called "Carbon farming practices - cropland and livestock management". Indeed, considering the heterogeneity in the soil classification system found between the reviewed studies, the USDA soil texture online application (https://www.nrcs.usda.gov/wps/portal/nrcs/site/soils/home/) was used to proceed with a standard and comparable method. Concerning the depth of soil sampling investigated, we used all the data within the 0-30 cm soil layer. In the case of data taken from samplings at depths below than 30 cm proportional rescaling was applied, assuming the SOC to be a constant function of soil depth. In contrast, the samples from depths lower than 30 cm rescaling were not considered. For detail see the paragraph 1.6 of the A2 action.

6.1.3 Results

We collected and analysed SOC data measured by a total of 17 studies located within European territory. The created datasets span several years, from 2005 to 2021 raising the total of 55 data used in this analysis (according to the data harmonization operations presented in the materials and method). The selected database variables are shown in Table 8.

Table 8. Selected variables used to build the poplar plantation database

Variables Group	Selected variables
SOIL CARBON CONTENT AND SOIL TYPE	Soil type (Clay, Clay-Loam, etc)
	Soil texture (% Clay, % Sand, % Silt)
	Soil macro-classes (USDA Classification)
	Soil pH
	Bulk density (Mg/m^3)
	Carbon concentration (g/kg)

Variables Group	Selected variables
	Carbon stock (Mg ha^{-1})
	The annual rate of carbon stock (Mg ha^{-1} $year^{-1}$)
	The carbon stock reported at 30 cm (Mg ha^{-1})
	The annual rate of carbon stock reported at 30 cm (Mg ha^{-1} $year^{-1}$)
	Soil sampling depth (cm)
	Soil sampling depth reported at 30 cm
CLIMATIC ZONE	Altitude (m a.s.l)
	Climate type
	Mean annual temperature (°C)
	Rainfall (mm)
PLANTATION MANAGEMENT	Year/s since transition
	Plantations management (Irrigation – fertilization – organic or conventional)
	Plantation Cycle (year)
	Species
	Plant per hectare
	Harvested wood production (Biomass – panels, etc)
	Previous Land use (agricultural with grain, fallow, etc)
GEOGRAPHIC INFO	Location info (Coordinate, Nation, City)

The criteria used to analyse the data consider, besides the climatic zone, the variables of the land use change from pasture to plantation (PA-PLA) or from cropland to plantation (AGR-PLA), and the type of assortment as defined in Table 7. The soil type was not taken into consideration within the following analysis since there was not enough data to aggregate the results according to this variable.

Figure 11 shows the location of all the considered studies within the European territory accounting for selected variables (e.g., woody array, land-use change, climate zone) while Figure 12 shows the climatic zones of the Lombardy region. The data within each climatic zone were used to quantify the SOC rate at Regional level for Lombardy.

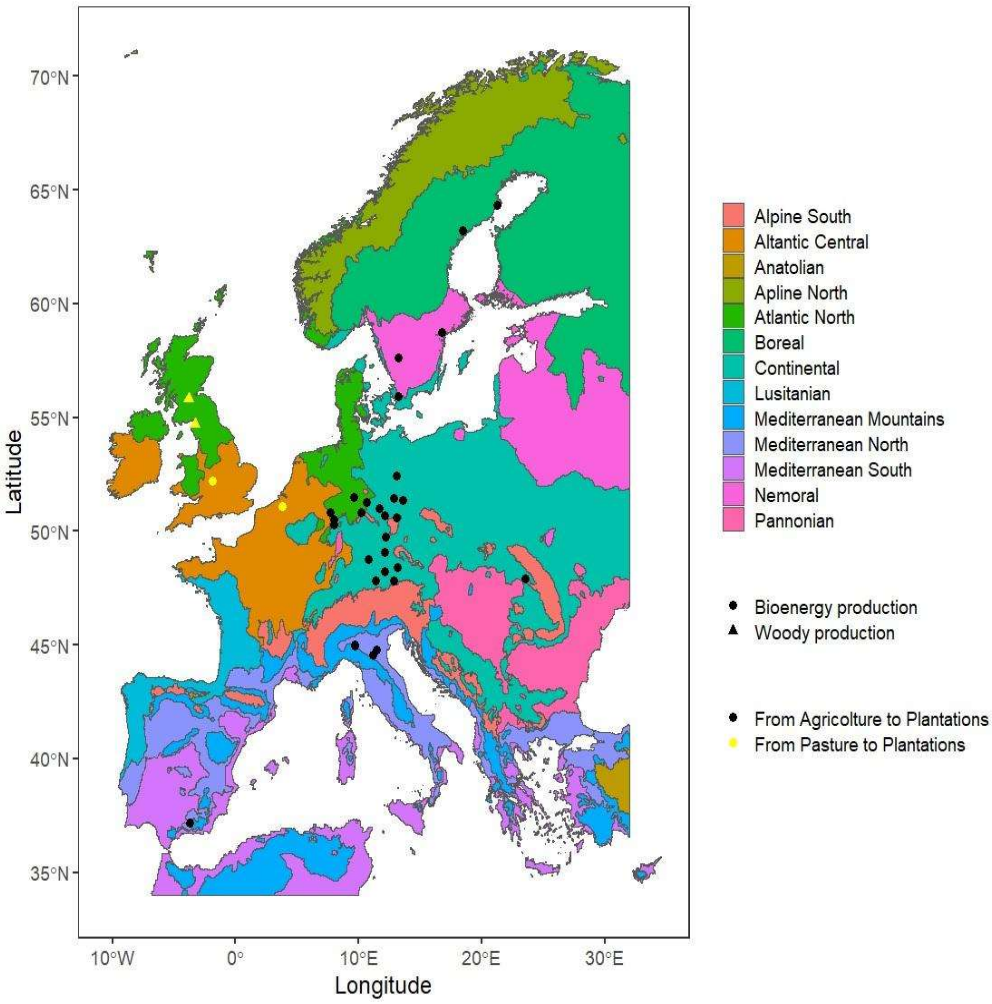

Figure 11. Location of studies within the European territory overlapped on the climatic zones. Each location may contain more than one SOC data. Triangle identifies the plantations used for wood production while the circle for bioenergy production. The yellow color corresponds to the land-use change from pasture to plantations while the black color shows the passage from agriculture to plantations.

The poplar sites, which are located mainly in the central part of Europe, are spread over 10 different climatic zones. The land-use change that is more represented is the AGR-PLA with 93% of the cases while the PA-PLA represents only the 7% of the data available with 8 observations. Concerning the wood array the bioenergy class comprises 98.3% of the data so there are not enough observations to characterize the array of wood products that shows only 1.7% of cases with 2 data.

The climatic areas of the Lombardy region according to the EnS data classification are:

a) Alpine South;
b) Mediterranean mountains;
c) Mediterranean north (Figure 12).

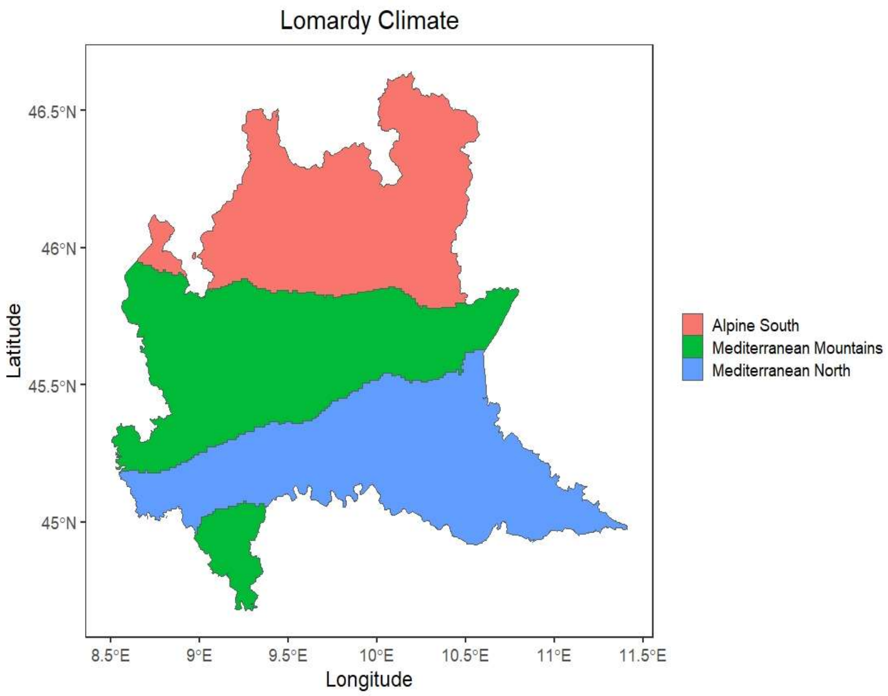

Figure 12. Climate map of the Lombardy region according to the Environment Stratification of Europe (Metzger and Marc 2018).

For each climate zone, the statistics were performed through the boxplot as shown in Figure 13.

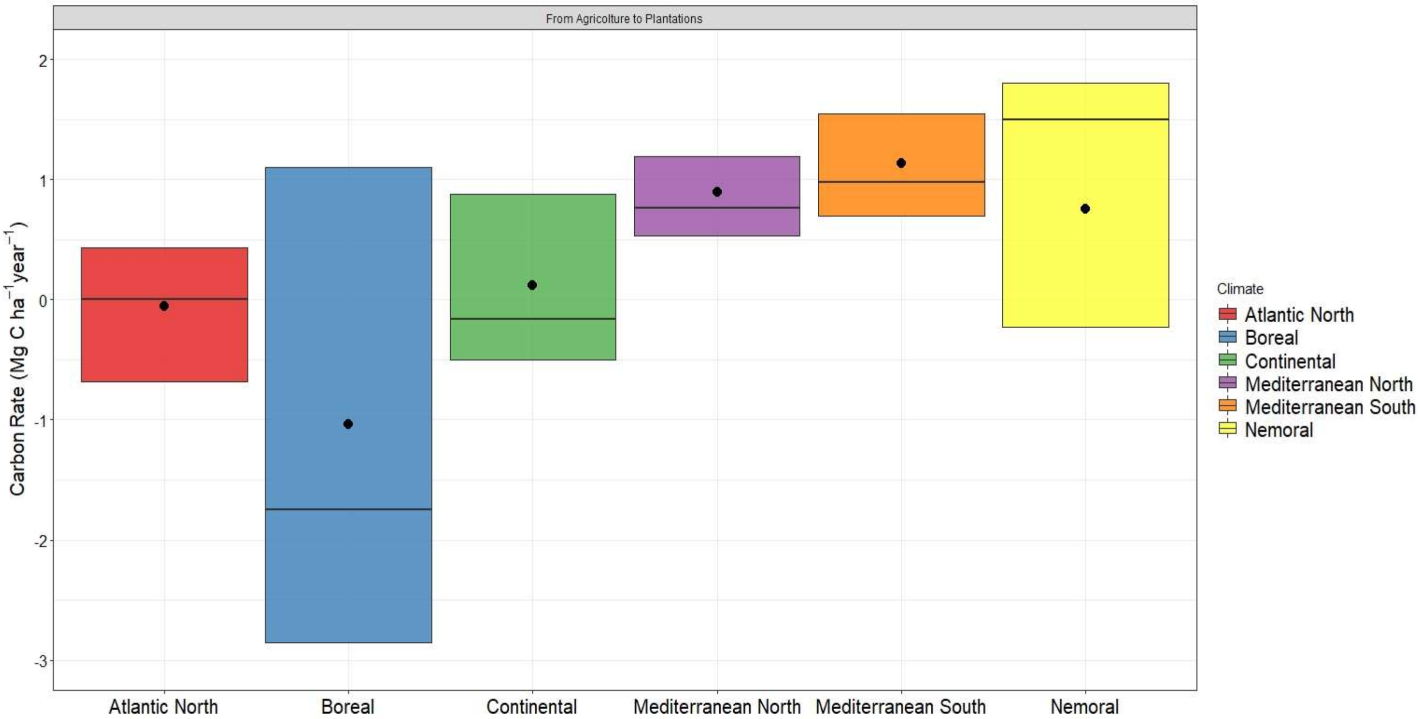

Figure 13. SOC annual rate expressed in Mg of Carbon per hectare per year is shown through boxplots considering the poplar plantations within different climate conditions of Europe. The x-axis shows the climate type while the boxplot located in the y-axis shows with the black horizontal bar the median annual rate of SOC change, the upper limit shows the 75th percentile, the lower limit shows the 25th percentile. The black circle inserted in each boxplot shows the mean annual carbon rate of poplar plantation within each climate.

A threshold value of three observations was established such a minimum to compose each boxplot meaning that each climatic zone is represented whether the threshold value is reached. The land use change from PA-PLA did not reach the minimum number of significant values to compose the boxplot therefore was not taken into consideration.

The Mediterranean North climate highlighted from the violet boxplot, groups all the data available within the climate zones comparable with those present in the Lombardy region. The median yearly carbon accumulation is equal to 0.76 Mg C ha^{-1} yr^{-1} and equal to a mean of 0.89 Mg C ha^{-1} yr^{-1} and is the third largest value found after the Nemoral and Mediterranean South climate. Table 9 reports all the median and values shown within the boxplot above.

Table 9. Median and mean values relative to SOC sequestration rate for the AGR-PLA land-use change are shown. Bold characters refer to the Mediterranean North climatic zone comparable to the ones of the Lombardy region.

Mean Carbon sequestration rate (Mg C ha-1 year-1)	Median carbon sequestration rate (Mg C ha-1 year-1)	Climate zone
0.75	1.5	Nemoral
1.13	0.97	Mediterranean South
0.89	**0.76**	**Mediterranean North**
-0.05	0	Atlantic North
0.11	-0.16	Continental
-1.03	-1.75	Boreal

The poplar plantations located in the Mediterranean north and south climate showed the highest potential in terms of SOC rate and are the unique boxplots with the interquartile range that shows only positive values. Grouping all the variables under investigation in the different climates in all Europe, land use-change, and wood array production, we observe that in 50% of the cases there is a negative impact of poplar plantations on median SOC sequestration rate with a range that goes from -1.75 Mg C ha^{-1}yr^{-1} to 0 Mg C ha^{-1} yr^{-1}. The remaining 50% of the observations show a positive SOC sequestration rate with a range from 0.76 to 1.5 Mg C ha^{-1} yr^{-1}.

6.1.4 Discussion

The results of this preliminary investigation are in agreement with the available scientific literature. Indeed, to have strong and reliable data about SOC stock and dynamics within poplar plantations, beyond a more consistent number of studies, several additional factors should be considered and studied in different soil and climate conditions:

i) detail on the soil characteristics, type of land use and relative management before conversion; (Georgiadis et al., 2017; Rowe et al., 2016; Tolbert et al., 2002).

ii) Analyse plantations management: if and how irrigation, fertilization or organic inputs to the soil may affect the SOC stock and sequestration rates (Berhongaray, G and Ceulemans 2015; Neff et al. 2002).

iii) Investigate whether the soil depth at which the soil samples are taken may influence the SOC measurement (Sierra et al., 2013).

iv) The timing of the soil sampling: immediately after drilling the stumps or at another time when soils of the plantations are less disturbed (Cerli et al., 2009). Furthermore, a correlation between SOC content and time since transition of the plantations from agricultural fields showed contrasting results in previous studies hence would be important to evaluate the possible impact of the rotation cycle on SOC stock strictly related also to the density per hectare of the plants.

v) The effect of re-conversion of poplar plantations to arable use and or perennial grassland at the end of the rotation cycle (Toenshoff et al., 2012).

6.2 Carbon stock of Harvested Wood Products (HWP)

For the analysis of the carbon stock in wood products harvested from the Lombardy region, a production accounting approach was adopted using various available databases as well as field data collected within the study region by CREA. The analysis was done breaking down the value chain into two fundamental portions:

1. From standing trees to raw material delivered to the processing facilities.

2. From raw material to raw finished product, to be employed for the various applications.

6.2.1 Carbon Content of Standing Trees

The biomass present in poplar plantations was analysed and the carbon content on a hectare basis was derived, taking into account the average basal density of poplar timber and the average yield per hectare based on a 10-year rotation. Then standard IPCC values were utilized for the calculation of the standing stock of C in the average Poplar plantation at the end of its 10-year rotation. Table 10 shows the values adopted in this analysis.

Table 10. Values adopted in the analysis**.** For the basal density of Poplar timber, values suggested by Corona et al., 2018 were adopted.

Poplar Cultivation	Unit	Value	Source
Average Yield (10 year rotation)	$m^3\ ha^{-1}$	**220.0**	Crea, 2020
Basal Density, Poplar ('I-214' clone)	$Mg\ m^{-3}$	**0.29**	Crea, 2020
Timber Yield per Ha	Mg	**63.8**	*calculation*
Carbon factor	-	**0.5**	IPCC
Carbon Content	Mg	**31.9**	*calculation*

C to CO2eq	-	**3.67**	IPCC
Mg CO2eq Content per ha	**Mg CO2eq ha^{-1}**	**117.1**	*calculation*

6.2.2 Carbon Content after extraction and haulage

After having calculated the gross amount of Carbon stored in Poplar trees having reached the end of their rotation cycle, it has been calculated the value net of harvest activities and haulage to the wood processing facilities, where the transformation into final products is carried out.

In this step, two approaches were adopted: the first, using field-collected data from studies carried out by CREA in the study region; the second, using the Life CO2 PES&PEF web tool. The latter is a web tool developed through another LIFE project, and it allows for the estimation of C stored in raw logs felled within tree plantations, net of emissions linked to the felling and sizing operations themselves.

The tool allows for a wide selection of tree species, so that C stocks are accurate based on timber characteristics. Table 11 shows the calculated values.

Table 11. Shows the calculated values

Poplar Timber Carbon	Unit	Value	Source
CO2e Emissions: harvest, assortment	Mg CO2e m-3	**0.048**	CREA
Net CO2e Content after extraction	Mg CO2e m-3	**0.484**	CREA
Net CO2e Content after extraction	Mg CO2e m-3	**0.743**	Life CO2PES&PEF

We noticed a variance between the values derived from the application of the two different approaches, and opted for the adoption of CREA values, which we considered more accurate, having been collected in appropriate surveys in real cases, and applying specifically to the Poplar cultivation in scope of this project. The value of **0.484 Mg CO2eq m^{-3}** was then adopted, representing the net carbon content in a cubic meter of Poplar timber at the beginning of the transformation process.

6.2.3 Carbon Content after primary processing

In this final step, it has been calculated the Carbon Content in the final products, which are then commercialized in the open market. For these, it has been followed the production accounting approach, in line with the accounting methods defined by Regulation 841/2018/EU. First, the HWP falling within the main categories (panels, sawn wood, paper) were identified, then the first order decay function was adopted, applying the methodologies and the default half-life defined in the annex V of the 841/2018/EU regulation.

6.2.4 Harvested Wood Products (HWP) within the Study Region

The main categories of HWP as reported in the European Regulation are: paper products, sawn wood and panels, with panels including all types of engineered wood panels, such as plywood, oriented Strand Board (OBS), chipboard and medium density fibreboards (MDF). Data collected by CREA were utilized to identify the HWP in scope of the study region, and the split based on the amount of biomass flowing into each category was calculated. The split is generally dependent on tree sized attained, with plywood (panels) being the most profitable and sought-after HWP, which though requires larger diameters, and low incidence of defects in the harvested logs. For this, it is typical that the most important portion of a harvested log is used to produce panels.

In the split adopted, it has been considered an average plantation, with medium sized trees. Larger incidences of panels are possible but limited to very productive areas. Below is the split of assortments adopted (Table 12):

Table 12. The selected assortments are showed

Assortment Split	%
Panels (Plywood)	63%
Sawn Wood	22%
Wood Chips & Fuelwood	15%
Total	**100%**

6.2.5 Production processes for HWPs

The processing of raw material from the plantation into final wood products involves the loss of some of the carbon stored in the timber. This is due to:

1. Emissions involved in the production process, including energy uses and the production of other components involved, e.g. glue production in the case of engineered wood panels.

2. Recovery rates: that is the loss of timber due to transformations, e.g. sawing the round logs into planks, or peeling the logs into the veneers used for plywood production.

In this analysis, both factors have been accounted. For the Production Emissions Factors, values from Eco Invent were analysed as well as an LCA Study carried out by CREA with a local plywood manufacturer. ECOINVENT: a not-for-profit Life Cycle Inventory (LCI) database supporting environmental assessments of products and processes worldwide. The database was utilized to extract emission factors linked with the various types of wood processing active in the study region.

Production Processes: Emission Factors

Table 13 shows the Emission factor values for the production of 1 cubic meter of HWP. As for other instances, whenever possible, it has been preferred utilizing values collected locally, rather than general European values from Ecoinvent. For Panel production (Plywood) it has been therefore adopted the value from CREA (LCA), while for Sawn Wood the value from Ecoinvent.

Table 13. Emission factor values for the production of 1 cubic meter of HWP

Emission Factors, Production Processes	Unit	Value	Source
Emissions for the processing of 1 m3 into Plywood Panels	Mg CO2e m^{-3}	0.311	CREA
Plywood {RER}| plywood production | APOS, U	Mg CO2e m^{-3}	0.467	ECOINVENT
Sawnwood, hardwood, raw {Europe without Switzerland}| sawing, hardwood | APOS, U	Mg CO2e m^{-3}	0.0462	ECOINVENT

Noticeable is the high emission values for Plywood production, mainly due to utilization of Urea Formaldehyde Resins (RER) for gluing the veneers together. See diagram from ECOINVENT in Figure 14:

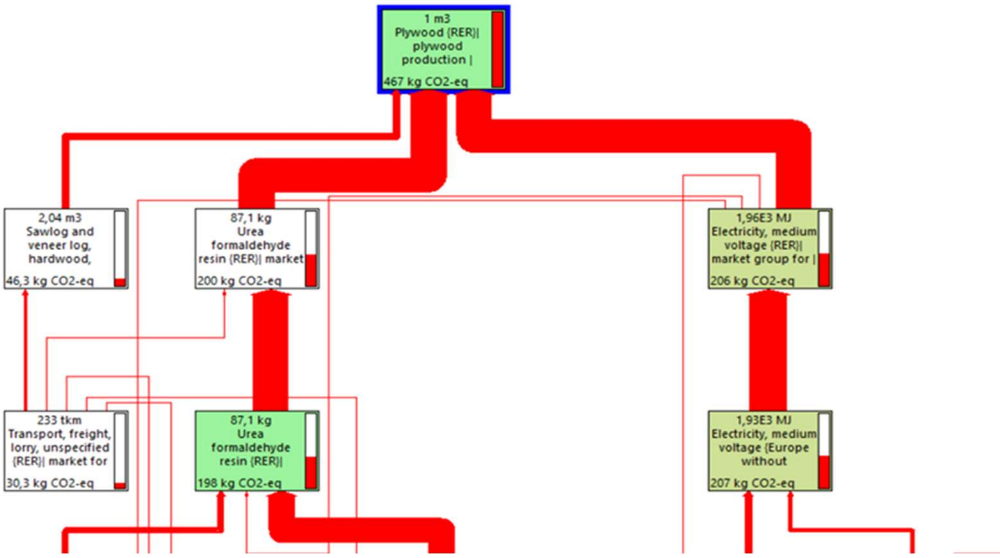

Figure 14. ECOINVENT diagram

Production Processes: Recovery Rates

For recovery rates, we looked up values used for studies in the investigated area, cross-checking with standard values used at European and Global level. The unrecovered wood is assumed to be utilized as fuelwood or shredded and degraded on the soil, therefore releasing its stored carbon.

An exception is the common practice of recovering sawn timber from the core material going to Plywood manufacture, that is the portion of the log that cannot be peeled due to machine limitations. It is estimated by CREA that the core of logs for Plywood accounts for 8% of the volume.

Table 14 shows the recovery of material for each of the two HWP production processes.

Table 14. Recovery of material for each of the two HWP production processes

Recovery Rates	%

Panels (Plywood)	42%
Sawn Wood	45%

6.2.6 Net Carbon Storage in HWP

After including the emissions related to production processes of the various HWP categories, and accounting for timber losses during the production processes we have calculated the net carbon content of HWP categories, also applying the first order decay function, using the half-life (HL) values reported in the regulation [1]. The values are reported in the Table 15 for year of production (*i*) and the following year (*i*+1).

Table 15. Values reported in the regulation [1].

Net Carbon, Final HWPs [gG CO2e m-3]	HL	k	Year i	Year i+1
Panels (Plywood)	25	**0.028**	**0.173**	**0.169**
Sawn Wood	35	**0.020**	**0.438**	**0.430**

6.2.7 Year 2020 Analysis

The calculation reported above was then applied to the actual harvesting and wood processing of Poplar spp in the Study Region in the year 2020. The results of the calculations are shown below (Table 16).

Table 16. Volumes extracted from plantations within the Study Area in 2020, including the calculation Carbon Content of the volumes in Gg of CO2e pre harvest (trees still standing) and post harvest (factoring in emissions due to harvest, extraction, and haulage to transformation sites).

2020 Poplar Production	Unit	Value	Source
Harvests	ha	**2,351.3**	CREA
Harvests	m^3	**517,286**	CREA
Carbon Content Pre Harvest	Mg CO2e	**275,274**	*calculation*
Carbon Content Post Harvest	Mg CO2e	**250,585**	*calculation*

In Table 17, the split between HWPs of the harvested volumes, and the subsequent production of finished goods of each HWP category. It has been then reported the calculated net sequestration for each HWP category in the year of production (*i*=2020) and in the following year based on the first order of decay function applied.

Table 17. Split between HWPs of the harvested volumes

2020 Poplar HWP	Unit	Value	Source
Roundwood to Panels (Plywood)	m^3	**325,890**	CREA

2020 Poplar HWP	Unit	Value	Source
Roundwood to Sawn Wood	m^3	**113,803**	CREA
Finished Panels (Plywood)	m^3	**136,874**	-
Finished Sawn Wood	m^3	**77,283**	-
Panels (Plywood); i=2020	Mg CO2e	**23,737**	-
Sawn Wood; i=2020	Mg CO2e	**33,867**	-
Panels (Plywood); i+1	Mg CO2e	**23,088**	-
Sawn Wood; i+1	Mg CO2e	**33,203**	-
Total; i=2020	**Mg CO2e**	57,604	**-**
Total; i+1	**Mg CO2e**	56,291	**-**

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[1] https://eur-lex.europa.eu/legal-content/IT/TXT/?uri=CELEX%3A32018R0841

7 Conclusions

The literature review has shown that few data are available regarding specific sustainable techniques used for the cultivation of poplar plantations and relative impact on carbon sequestration. Currently it is the plantation itself that is investigated such as carbon farming techniques.

Despite this the International scientific community is making efforts to improve the sustainable management of poplar cultivation, including the use of the agroforestry practices applied to minimize the impact on carbon stock at various level, improve the biodiversity-friendly applications and keep and increase the organic matter of the soils (Corona et al., 2018; Singh et al., 2021; Sun et al., 2018).

7.1 Mapping poplar plantations

Poplar cultivation in Italy, as it plays an important role in mitigating climate change, is an example of Carbon Farming. In addition to that, it represents a strategic sector for the forest-wood supply chain, the most significant internal source for the national timber industry, although it occupies a very small area (less than 1% compared to national forest area). In accordance with the literature, the mapping has shown that, in the Po Valley area, Lombardy is the Italian region where poplar plantations are mainly located, with 15379.3 ha in 2021. Within the Lombardy region, poplar plantations are mainly located in the areas of Pavia, Mantua, Cremona and Lodi, in the southernmost part of the region. Over the years, using advanced methodologies based on remote sensing data, the mapping of poplar plantations has been progressively and effectively updated, and it is expected to continue in the future. Indeed, this is essential to always have a defined and detailed overview of the poplar distribution. In conclusion, to develop support strategies for improving Carbon Farming practices and the contribution of poplar plantations on climate change mitigation, it is necessary to increase the knowledge about the distribution of poplar plantations in Italy, with a particular focus in the Padan Plain Regions (Piedmont, Lombardy, Emilia-Romagna, Veneto and Friuli Venezia-Giulia), where the poplar cultivation is mainly located.

7.2 Analysis of soil carbon mitigation potential of poplar plantations

The scarcity of data highlights the main limitations of this analysis and the difficulty to have reliable data about the SOC rate under poplar plantations within Lombardy region. Despite the analysis being based on a small dataset, the Mediterranean north climate present also in Lombardy region looks one of the most promising in terms of SOC accumulation.

At global scale, studies focusing on SOC of poplar plantations reported contrasting results, from SOC accumulation even up to 1.0 and 1.6 Mg C ha^{-1} year^{-1} (Hansen, 1993; Arevalo et al., 2011) to SOC losses (Walter et al., 2015). According to the results of this investigations the contribution of poplar plantations in terms of SOC rate and stock can be considered site-specific, and the following suggestions should be followed for future research:

i) Continue to evaluate case by case in order to fully investigate the impact of poplar plantations on SOC in site-specific conditions.

ii) Extensive research and database development to aggregate data and relative selected variables cited in the discussion section (e.g. soil type, plant density, history of the agriculture management)

Finally, the action A5 of this project will allow the investigation of the SOC stock in some selected farms having poplar plantations within the Lombardy region. The latter step can be considered crucial to compare and update the results based on site-specific characteristics.

7.3 Carbon stock of Harvested Wood Products (HWP)

The analysis conducted on the carbon stock of HWP demonstrates how wood products can play a significant role in the retention of the carbon sequestered by Poplar plantations. At the same time, the analysis highlights the impact of production processes and recovery rates in the attrition of the CO2e sequestration along the value chains. Increase in efficiencies, improved use of biomass, and adoption of eco-friendly production processes (e.g. avoidance of high emitting glues in Plywood production) are all factors that will play a great role in increasing the potential long term sequestration of CO_2e.

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9 Data availability

- The databases that support the investigation of the Soil organic carbon (SOC) and Carbon stock of Harvested Wood Products (HWP) in poplar plantations are available at: https://docs.google.com/spreadsheets/d/11H-of47-2yDv9vsdO-xseUbMG1my8m1D/edit?usp=sharing&ouid=115685915629707379640&rtpof=true&sd=true
- The environment stratification of Europe available at: https://datashare.ed.ac.uk/handle/10283/3091
- The WebPlotDigitizer site used to extract data from the figures available at: https://apps.automeris.io/wpd/
- The online application used to reclassify soil texture (USDA, online source) available at: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054167
- High-resolution PlanetScope images used for the photointerpretation phase in the poplar plantations mapping are available at: https://www.planet.com/
- Google Satellite images used in the photointerpretation phase available in the Google Earth software: https://earth.google.com/web/