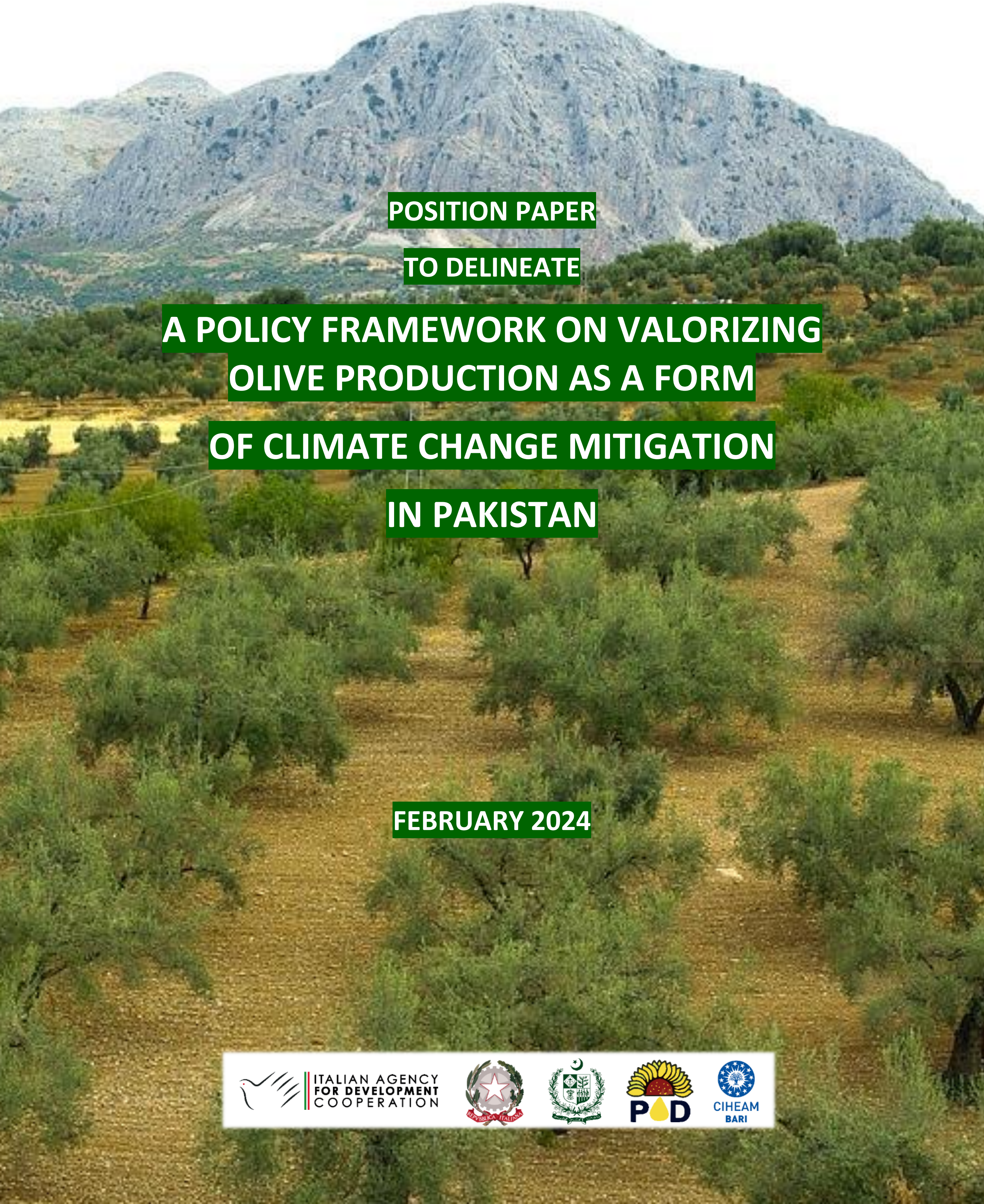
OliveCulture

Holistic and Multi-professional Mechanism for a Pakistani Olive Oil Value Chain



POSITION PAPER

TO DELINEATE

A POLICY FRAMEWORK ON VALORIZING OLIVE PRODUCTION AS A FORM OF CLIMATE CHANGE MITIGATION IN PAKISTAN

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ITALIAN AGENCY FOR DEVELOPMENT COOPERATION

CIHEAM BARI

AUTHORS

Dr. Anwar Ali

Director, Forestry Research Division- Pakistan Forest Institute Peshawar

Mr. Muhammad Arif

Forestry graduate, Master in Rural Sociology

Dr. Marco Marchetti

Agronomist, International Coordinator- OliveCulture Project CIHEAM Bari

Dr. Costantino Parma

Agronomist, Expert senior, OliveCulture Project – CIHEAM Bari (Italy)

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CONTACT DETAILS:

CENTRE FOR ADVANCED MEDITERRANEAN AGRONOMIC STUDIES MEDITERRANEAN AGRONOMIC INSTITUTE BARI (CIHEAM BARI)
Via Ceglie, 9 – 70010 Valenzano (BA), ITALY
Phone: +39 080 4606111 – Fax: +39 080 4606206
Email: iamdir@iamb.it – Website: www.iamb.it

MINISTRY OF NATIONAL FOOD SECURITY AND RESEARCH (MNFS&R),
Islamabad, Pakistan
Phone: – Fax: +92-51-9210616
Website: http://www.mnfsr.gov.pk/frmDetails.aspx

PAKISTAN OILSEED DEPARTMENT (POD)

10-D West, Taimoor Chamber, 2nd Floor, Fazal-ul-Haq Road, Blue Area Islamabad
Phone: 051-9216871 Fax: 051-9216870
Website: www.parc.gov.pk

ITALIAN AGENCY FOR DEVELOPMENT COOPERATION (AICS) in Islamabad
Islamabad, PAKISTAN
Phone: + 92 (0) 51.846.05.76
Email: segreteria.islamabad@aics.gov.it
Website 1: https://islamabad.aics.gov.it/

OLIVECULTURE PROJECT
Islamabad, PAKISTAN - House no. 12, Street no 56, Sector F-8/4
Email: oliveculture.ciheam@gmail.com
Website: http://oliveculture.org/

DISCLAIMER:

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ACRONYMS

AICS	Italian Agency for Development Cooperation
ARR	Afforestation, Reforestation and Revegetation
AFOLU	Agriculture, Forestry and Other Land Use
AGM	Aboveground Biomass
AKIS	Agricultural Knowledge and Innovation System
ARR	Afforestation, Reforestation and Revegetation
BGM	Belowground Biomass
C	Carbon
CE	Carbon Equivalent
CCM	Compliance Carbon Market
CIHEAM	International Centre for Advanced Mediterranean Agronomic Studies
CO2	Carbon Dioxide
COP	Conference of the Parties
cm	Centimeter
DBH	Diameter at Breast Height
EPD	Environmental Product Declaration
Ft	Feet
GHG	Greenhouse Gas
H	Height
Ha/ha	Hectare/hectare
IOC	International Olive Council
IPCC	Inter-Governmental Panel on Climate Change
LCA	Life Cycle Assessment
Kg	Kilogram
MoCC	Ministry of Climate Change and Environmental Coordination
MNFS&R	Ministry of National Food Security and Research
MRV	Measurement, Reporting and Verification
m	Meter
MoU	Memorandum of Understanding
NDC	Nationally Determined Contribution
NGO	Non-Governmental Organization
POD	Pakistan Oilseed Department
t	Tonne
USD	United States Dollar
VCM	Voluntary Carbon Market
VCUs	Verified Carbon Units
VCS	Verified Carbon Standard

EXECUTIVE SUMMARY

The world is exploring ways and means to mitigate climate change by promoting the growth of trees and other vegetation. Enhancing carbon stocks in the terrestrial ecosystem through plantations has gained immense importance in recent years. Olive farming is an important source of carbon sequestration and climate change mitigation. Olive trees seize carbon dioxide from the atmosphere and store this carbon in the form of biomass and soil organic carbon. Carbon credits generated from plantations are traded in the world under the voluntary carbon market or compliance market. Substantial revenues can be earned from the sale of carbon credits. Olive plantation can be used for carbon credits generation which may become an additional source of revenue for the olive growers.

According to the 2017 study of the CO_2 balance of olive oil carried out by the International Olive Council (IOC), the world olive-growing area, which spans 10.5 million hectares according to IOC data, can capture 47 million tons of CO_2 per year. On average, one hectare of olive grove can capture 4.5 tons of CO_2 per year. Considering the total life cycle of olive oil, it can be maintained that the production of one kilogram of olive oil removes 10 kg of CO_2 from the atmosphere. It is worth mentioning that the IOC organized in October 2023 an international workshop "Carbon balance of the olive sector: part of the solution against climate change" and has created a working group on the subject.

Pakistan is a favorable country for olive cultivation due to its soil, environment. and climatic conditions. Currently, *Olea europaea* is being cultivated on about 40,450 acres (16,370 ha) (data 2021-2022) in the country, with an estimated population of 5 million planted saplings[1]. Parts of Balochistan, Peshawar districts, Dir, Kohat, Karak, Malakand, and Merged Areas of Khyber Pakhtunkhwa, Potohar region of Punjab, and Azad Kashmir are ecologically suitable areas for olive farming. No study has been made in the past to assess the potential of carbon sequestration by olive groves in Pakistan. The current study was conducted to assess the

[1] Action Plan and Policy Recommendations for a holistic development of the Pakistani Olive Value Chain. Italian Agency for Development Cooperation, CIHEAM Bari and Government of Pakistan.

carbon sequestration potential of olive groves in Pakistan and suggest policy measures for promoting the trading of carbon credits as an additional source of revenue for olive growers.

The study covers the above-ground and below-ground biomass of olive trees. Data was collected from selected sites in Khyber Pakhtunkhwa and Punjab, where *Olea europaea* groves have been raised, from 10 representative trees of the same age group which were randomly selected, as part of the methodology for measurement of the above-ground biomass and carbon sequestration potential. Data on the carbon footprint of olive farming was collected through a structured questionnaire from the olive growers in the selected farms.

The findings of the field survey indicate that the **average carbon sequestration rate** is 4.69 tonnes of CO_2 per hectare per year for 4-24 years old olive groves planted in 15x15 feet (4.57 m x 4.57 m) spacing, resulting in 478 plants per ha with an average survival of 85%, therefore 406 actual plants per ha. Whereas the **total carbon footprint** (the total amount of greenhouse gases generated) of olive farming and oil production was estimated as 0.989 tCO2eq per ha per year. This includes emissions from land preparation (0.162 tCO2eq per ha), use of fertilizers (0.461 tCO2eq per ha), pesticides (0.126 tCO2eq per ha) and oil extraction (0.240 tCO2eq per ha). As irrigation is mostly based on solar pumps therefore it was not included in the carbon footprint. The **net carbon balance** in olive farming on the conditions sampled is worked out to be 3.70 tCO2eq per ha. The net carbon balance can be further enhanced by reducing the use of chemical fertilizers, pesticides, and tillage, promoting organic farming, using cover cropping, and incorporating residues of olive pruning into the soil.

The study concludes that promoting olive cultivation for climate change mitigation and carbon trading in Pakistan requires the adoption of a comprehensive policy framework that includes promoting sustainable farming practices, amendment in the carbon trading policy, awareness, and capacity building campaigns, involvement of the private sector, establishing linkages with national and international organizations and development of an effective measurement, reporting and verification (MRV) system.

1. INTRODUCTION

1.1. Background

"OliveCulture-Holistic and Multi-Professional Mechanism for a Pakistani Olive Oil Value Chain/OliveCulture" is implemented in Pakistan by CIHEAM Bari. The project is financed by the Italian Government, supervised by the Italian Agency for Development Cooperation (AICS), and executed in close coordination with the Pakistan Oilseed Department (POD) of the Ministry of National Food Security and Research (MNFS&R) through the MoU signed on 22nd July 2022. The OliveCulture Project (the Project, from now onward)) is designed to strengthen the Pakistan olive oil value chain on several levels in a holistic, participatory, and multifunctional way, involving institutions, businesses, farmers, youth and women, and consumers to improve economic, productive, and qualitative performances. The initiative is carried out with the support of Italian experts and trainers from research and education bodies in the technical-agronomic fields and rural development of the olive oil chains, reputed to be an internationally recognized Italian- excellence. The Project, initiated in January 2022, is nearly completed and has pursued the following results:

- Assessed the agronomic, cultural, and social heritage of the olive tree and its properties,
- Formulated an adequate policy supporting the sector and rural development,
- Improved and characterized the Pakistani olive value chain at different levels,
- Engaged Women and Youth in income-generating activities along the olive value chain,
- Promoted the olive culture in Pakistani society.

1.2. Carbon Sequestration and Carbon Footprint of Olive Groves

Forest vegetation and soils constitute a major terrestrial carbon pool with the potential to absorb and store carbon dioxide (CO_2) from the atmosphere. When trees grow, they remove carbon dioxide from the atmosphere through the process of photosynthesis and store this carbon in the form of biomass. This absorption is called carbon sequestration, which is an important strategy in climate change mitigation (Lopez-Bellido et al., 2016). Tree plantations can remove CO_2 from the atmosphere and store it in the form of biomass such as trunks, branches, leaves, fruits and roots, and soil organic carbon. As compared to annual crops, trees have a higher potential for carbon sequestration in their parts (trunks, roots, branches, and leaves), have a longer life than annual crops, and can store carbon in biomass and soil over a longer period (Proietti et al., 2016). Consequently, tree plantations have gained a prime position in nature-based solutions to climate change.

Forests and grasslands are generally considered carbon sinks, whereas agricultural systems mostly serve as sources of greenhouse gases (GHGs) due to soil tillage, the use of chemical fertilizers and pesticides, and the use of fossil fuels in farm operations (Ceschia et al., 2010). Efforts are, therefore, made to develop novel sustainable agricultural systems that can reduce GHG emissions and increase carbon sequestration through storage in plant tissues and soil. Agroforestry and orchards have structural characteristics that allow them to sequester significant quantities of atmospheric carbon, due to their long-life cycle, low intensity of soil tillage, and enrichment of soil organic matter (Nair et al., 2010). The net climate benefits of agricultural systems depend on the potential of the system to sequester atmospheric carbon on one hand, and the ability to have a minimum carbon footprint on the other hand.

The term "carbon footprint" refers to the climatic impact expressed as a specific measurement when all relevant emission sources, sinks, and storage within a system are considered (Peters, 2010). The carbon footprint is one of the most widely used indicators for analyzing the potential environmental impact of an activity or process. It quantifies the GHG emissions that occur during the manufacture and sale of a product from the acquisition of raw material to the generation of the final product and residues management. In the olive agricultural system, carbon footprint includes the GHG emissions associated with different farm operations such as tillage, nursery raising, transportation of plants and products, irrigation, use of chemical fertilizers and pesticides, and extraction of oil from the mills. Through carbon footprint analyses, important sources of emissions can be identified, and areas of emission reduction can be prioritized. Promoting olive plantations on agricultural and wastelands has the potential to remove carbon dioxide from the atmosphere and contribute to climate change mitigation and adaptation.

Olive (*Olea europaea* L.) is the most economically and ecologically important tree crop in many parts of the world. It has many positive economic and environmental impacts which make it an important tree species for edible oil production, soil conservation, and climate change mitigation. The relationship between agriculture, in particular olive cultivation, and climate change is bidirectional. On one hand, the dependence of olive trees on climatic conditions makes them vulnerable to climate change; but on the other hand, olive groves can capture carbon dioxide (CO_2) from the atmosphere and store it in the permanent vegetative structures of the olive trees and soil, thus increasing their organic matter content and transforming them into permanent reservoirs of CO_2.

According to the 2017 study of the CO_2 balance of olive oil carried out by the International Olive Council (IOC), the world olive-growing area, which spans 10.5 million hectares according to IOC data, can capture 47 million tons of CO_2 per year. On average, one hectare of olive grove can capture 4.5 tons of CO_2 per year. Considering the total life cycle of olive oil, it can be maintained that the production of one kilogram of olive oil removes 10 kg of CO_2 from the atmosphere. It is worth mentioning that the IOC organized in October 2023 an international workshop "Carbon balance of the olive sector: part of the solution against climate change" and that a working group has been formally established.

The rate of carbon sequestration depends on the olive tree's density, spacing, age, and environmental conditions. Sofo et al. (2005) estimated carbon sequestration in olive groves in southern Italy as 9.54 and 2.74 tCO_2/ha/year in mature and young groves, respectively. Lopez-Bellido et al. (2016) reported that carbon sequestration is significantly high in intensive plantations with proper soil management. Proietti et al, (2014) found that the average annual CO_2 sequestration was 1.51 tCO_2 per ha in 11-year-old olive groves in central Italy. Nieto et al. (2010) have reported that the use of cover crops in olive groves increases carbon storage in soil. Lopez-Bellido et al, (2016) estimated the net carbon balance in the olive plantations in Southern Spain in the range of 2.05 to 4.10 tCO_2/ha.

Olive cultivation in Pakistan is progressively improving the techniques and is pursuing the Good Agricultural Practices (GAP) that are widely adopted in the advanced olive sectors in the world. However, the expansion of olive groves in a very intensified manner in several countries has generated serious problems in the landscapes, whereas olive cultivation in Pakistan has gained momentum for the opposite reasons. The intensification may lead to negative environmental impacts such as a rise in GHG emissions, loss of soil fertility, degradation of habitats, and over-exploitation of scarce water resources. There is a need to quantify these environmental impacts and devise ways and means to reduce them and ensure environmental sustainability.

The environmental sustainability of olive culture can be assessed through the Life Cycle Assessment (LCA) methodology (De Luca et al., 2018; Stillitano et al., 2019). Based on mass and energy balances developed in a steady state, LCA aims at computing all flows in the life cycle of a product through its "cradle" to its "grave" and translating them into impacts. The LCA is an effective tool to assess the environmental impacts during olive farming and oil processing operations, enabling consumers and society to choose products that have low negative environmental impacts. Several studies have used the LCA method to assess the carbon footprint of olive culture in Europe (Espadas-Aldana et al., 2019; Fernández-Lobato et al, 2021). These studies have accounted for all the sources of GHG emissions as well as sequestration in the life cycle of olive oil.

The world is exploring ways and means to mitigate climate change by promoting the growth of trees and other vegetation. Enhancing carbon stocks in the terrestrial ecosystem through plantations has gained immense importance in recent years. As a result, carbon credits have become a new commodity of trade in the world. One carbon credit is the result of a carbon net balance of one tonne of CO_2eq (sequestration minus emission).

Carbon credits generated from plantations are traded in the world under voluntary carbon or compliance carbon market. Substantial revenues can be earned from the sale of carbon credits. Olive plantation can be used for carbon credits generation which will become an additional source of revenue for the olive growers.

Pakistan is a favorable country for olive cultivation due to its soil, environment, and climatic conditions. Wild olives are growing on large tracts in the country with an estimated 80 million wild olive plants belonging to *Olea cuspidata*, *Olea ferruginea,* and *Olea grandiflora*. The history of olive farming in Pakistan dates to the 1950s when grafted olive plants were imported for plantation in different parts of the country. Systematic efforts for olive cultivation were started in the 1980s with the technical assistance of Italy which helped in assessing the possibility of modern olive cultivation in Pakistan. Then, in 2012 through the Pakistan-Italian Debt Swap Agreement (PIDSA) the first significant olive investment was made in the country with a plantation of about 2,300 hectares of olive trees which has been followed by other national initiatives resulting today in 40,450 acres. The current target of the PSDP project[2] is to reach 70,000 acres in a couple of years (Awan et al., 2023). Parts of Balochistan, Peshawar districts, Dir, Kohat, Karak, Malakand, and Merged Areas of Khyber Pakhtunkhwa, Potohar region of Punjab, and Azad Kashmir are ascertained to be ecologically suitable areas for olive farming.

1.3. Objectives of the Study

The current study was conducted within the framework of the Project to assess the carbon sequestration potential of Olive groves in Pakistan and suggest policy measures for promoting the trading of carbon credits as an additional source of revenue for olive growers. The main objectives of the study include the following:

- To assess the carbon sequestration rates by olive trees under various management regimes in selected areas of Khyber Pakhtunkhwa and Punjab.
- To determine the carbon footprint of olive culture in Pakistan by quantifying carbon emissions associated with olive cultivation and oil extraction.
- To determine the net balance of potential carbon credits that can be achieved from olive plantation.
- To identify policy options and measures for promoting carbon credits trading in olive farming in Pakistan.

This Position Paper will examine the existing policy framework for carbon sequestration and carbon trading and will link the outcomes to the “Action Plan and Policy Recommendations for a Holistic Development of the Pakistani Olive Value Chain” developed by the Project for its updating regarding carbon sequestration.

2. METHODOLOGY

The methodology applied for assessing the carbon sequestration potential and carbon footprint of olive farming comprised the following steps:

[2] Promotion of Olive Cultivation on Commercial Scale in Pakistan, initiated in 2014, and financed by the Government of Pakistan.

2.1 Assessment of Carbon Sequestration

Figure 1: Measuring Diameter with Caliper

The assessment of the carbon sequestration potential of olive groves covers the above-ground and below-ground biomass of olive trees. For this purpose, data was collected from selected sites in Khyber Pakhtunkhwa and Punjab where *Olea europaea* groves have been raised. The methodology used for data collection in the field is described hereunder and the Questionnaire (Data Collection Form) is attached in **Annex 1**

After reaching the selected site, 10 representative trees of the same age group were randomly selected for measurement. Effort was made to cover the entire piece of grove while selecting trees for measurement (Torrús-Castillo et al., 2023). The following parameters were measured for each sample tree:

i. Species/Variety Name
ii. Date of planting (Age)
iii. Spacing
iv. No. of plants per ha
v. No. of stems per plant (in case of multi-stem plants)
vi. Diameter at Breast Height (DBH) in centimeters for each stem at 1.37 m above ground level with the help of a caliper (see Figure 1)
vii. Height of stems in meters from ground level to the top with the help of Vertex Hypsometer (a laser-based instrument for measurement of height) (See Figure 2)

Figure 2: Measuring height of stems with Vertex Hypsometer

Figure 3: Measuring above-ground mass.

Determination of Aboveground Biomass:

Above-ground biomass (AGM) for each tree was derived from the field measurements of DBH and Heights of trees using an allometric equation (see Figure 3). The following allometric equations was applied:

AGM = 0.623*(DBH)^1.352*(H)^0.703………………… (Kebede and Soromessa, 2018)

AGM = 7.8863+0.0556*(DBH^2*H) ……………….…. (Ali, 2020)

Where AGM is in Kilogram (Kg), DBH in centimeters (cm), and H in meters (m).

Determination of Belowground Biomass:

Below-ground biomass was derived from the above-ground biomass using root: shoot ratios provided by IPCC Guidelines 2006, which are 0.56 for subtropical dry forests with above-ground biomass less than 20 tons/ha and 0.28 where above-ground biomass is more than 20 tons/ha.

Conversion of Biomass into Carbon Stock

Biomass was converted to carbon stock using a fraction of 0.47 as suggested by IPCC Guidelines 2006.

Conversion of Carbon Stock into CO_2eq.

Carbon stock was converted to CO_2eq. by multiplying it by 3.67 (EPA, 2023).

Carbon Sequestration Rate

The carbon sequestration rate in tonnes of CO_2 per Ha per year was determined by dividing the carbon stock accumulated by the age of trees (Torrús-Castillo et al., 2023). Carbon sequestration potential was determined for different age classes and different spacing.

2.2 Assessment of Carbon Footprint

The carbon footprint of olive production was determined using the Life Cycle Assessment (LCA) analysis of olive plants from field planting to oil extraction. However, nursery operations were not covered. For this purpose, the following methodology was used:

Determination of GHG Emissions in Olive Plants Raising

Calculations of GHG Emissions from land preparation for olive cultivation

Data on the pre-olive land use and management practices was collected to determine the emissions generated due to land use change to olive plantation. Besides GHG, emissions associated with land preparation were also quantified on tractors' hours spent per hectare collecting the data from the farmers/growers. The fuel consumption per hour was determined, which was converted to GHG Emissions using the emissions factor of the fuel used.

Calculations of GHG Emissions from Fertilizer and Pesticides Application

Data was collected through interviews with olive growers about the quantity of manure, chemical fertilizers, and pesticides applied in olive groves. This data was converted to GHG emissions per hectare using emission factors for the manure/fertilizer and pesticides.

Calculations of GHG Emissions from Irrigation

When rainfall is less, then tube-wells are used for irrigation; the source of power employed for tube-well running on diesel or electricity was determined during the field survey. Whereas, where solar panels are installed and tube-well is run through solar energy, then there are no emissions.

Calculations of GHG Emissions from Oil Extraction

Olive fruits are crushed with the help of machines/mills to extract virgin oil. These machines/mills are run through electricity, but very often by generators, due to power outages, which are using diesel/petrol. Emissions associated with oil extraction were quantified using emission factors for the quantity of electricity or fuel used in the mill.

All the field data was entered in the MS Excel spreadsheets and analyzed for quantification of emissions and sequestration.

Figure 4: Assessing GHG Emission from Oil Extraction Mill

2.3 Identification of Priorities of the Government of Pakistan for Carbon Sequestration

The Government of Pakistan is giving high priority to carbon sequestration and climate change mitigation. Several policies, strategies, and action plans have been prepared to promote nature-based solutions to climate change mitigation and adaptation at the federal and provincial levels. This Position Paper will examine the existing policy framework for carbon sequestration and carbon trading in the olive value chain and will link the outcomes to the "Action Plan and Policy Recommendations for a Holistic Development of the Pakistani Olive Value Chain" for its updating regarding the Carbon Sequestration.

3. FINDINGS OF FIELD SURVEY

3.1 Olive Farming Practices

Olive cultivation is practiced in the target area in various forms and patterns. Most of the olive plantations are in the form of systematic orchards with no intercropping or intercropping of annual crops. Some fields are in the form of mixed orchards of olive and lemon while some are in the form of linear plantations along boundaries of fields or the form of scattered trees. In case of regular groves, spacing found varied from 10x12 feet to 10x15, 12x12, 15x15, 15x20, 20x20, 25x25, and 20x30 feet. The basic recommended spacing is 20x20 feet (6 m x 6 m) resulting in 109 plants per acre. The survival rate varies between 80% to 85% after 13 years as reported by the growers in the surveyed area. Fruiting is started after 4 years of plantation.

The varieties planted in the surveyed area include Arbequina, Coratina, Manzanilla, BARI 1, BARI 2, Frantoio, etc.

About 80% of the farms have irrigation systems and 20% are dependent on rainfall; 72% of the irrigated farms have installed solar systems for irrigation. The remaining 28% are mostly dependent on diesel or electricity-based tube-well systems. Intercropping of annual crops (i.e. wheat, and mustard), and permanent crops (i.e. lemon and citrus) was observed in 36% of farms. The altitude of these farms varies from 300 m to 922 m (A.B.S.L.). About 68% of these farms have been established on non-agricultural land or wasteland which was lying barren before olive plantations, whereas 32% were established on agricultural fields which were used before raising cereals and pulses before the establishment of olive orchards.

3.2 Attributes of Sampled Farms

The selected 22 sample farms were located in the provinces of Khyber Pakhtunkhwa (KP) and Punjab, as shown in Figure 1. The farm size varied from 0.5 acres to 120 acres. Trees' age varied from 4 to 22 years. The plant diameter at Breast Height (DBH) measured at approximately 1.37 m (4.5 ft) above the ground level ranged from 1.53 cm to 25.60 cm, with an average of 10.08 cm and the plant height varied from 2.05 m to 6.82 m with average of 3.95 m. The main attributes of the farms are given in the Table 1 below:

Table 1: Attributes of Sampled Farms

S.No	Location	X	Y	Elevation (m)	Area (Acre)	Irrigation System
1	Maraji Bala (Manki Shareef) -Noshera - KP	3109002	1077325	550	44	Solar (Drip)
2	Manki Shareef	3110164	1080381	449	17	Solar
3	Manki Shareef	3111005	1079557	485	--	Rainfed
4	Pir Sabaq Farm - Nowshera	3116511	1089768	283	120	Rainfed
5	Shami Road – Peshawar – KP	3072079	1088489	310	0.8	Electric pump
6	PFI - Peshawar	3065163	1087556	364	0.43	Canal

7	Sangbhatti – Swabi -KP	3139230	1119048	400	22	Solar (Drip)
8	Sangbhatti – Swabi	3139334	1118948	400	4.5	Solar (Drip)
9	Sangbhatti - Swabi	3139430	1118648	400	37	Solar (Drip)
10	Sangbhatti - Swabi	3139400	1118248	400	19	Solar (Drip)
11	Shabaz Ghari- Mardan – KP	3127401	1114410	331	0.8	Solar
12	Shabaz Ghari - Mardan	3127479	1114520	332	50	Solar
13	Haji Lawang – Bajaur – KP	3069030	1171586	836	1.5	Solar
14	Khar - Bjaur	3064546	1166118	878	0.5	Electric pump
15	Khar - Bajaur	3064475	1166261	868	5.5	By tanker
16	Salarzai - Bajaur	3069048	1179106	922	-	Rainfed
17	Mian Shah Kalay - Bajaur	3078154	1176532	762	18.5	Rainfed
18	BARI – Chakwal – Punjab	3184055	971440	525	1.08	Solar
19	BARI - Chakwal	3184123	971418	505	0.72	Solar
20	Arshad Qadri Orchard - Chakwal	3178877	959111	615	50	Solar
21	Arshad Qadri Orchard - Chakwal	3178679	959150	629	40	Solar
22	Master Rafique Orchard - Chakwal	3178578	960861	605	10	Solar

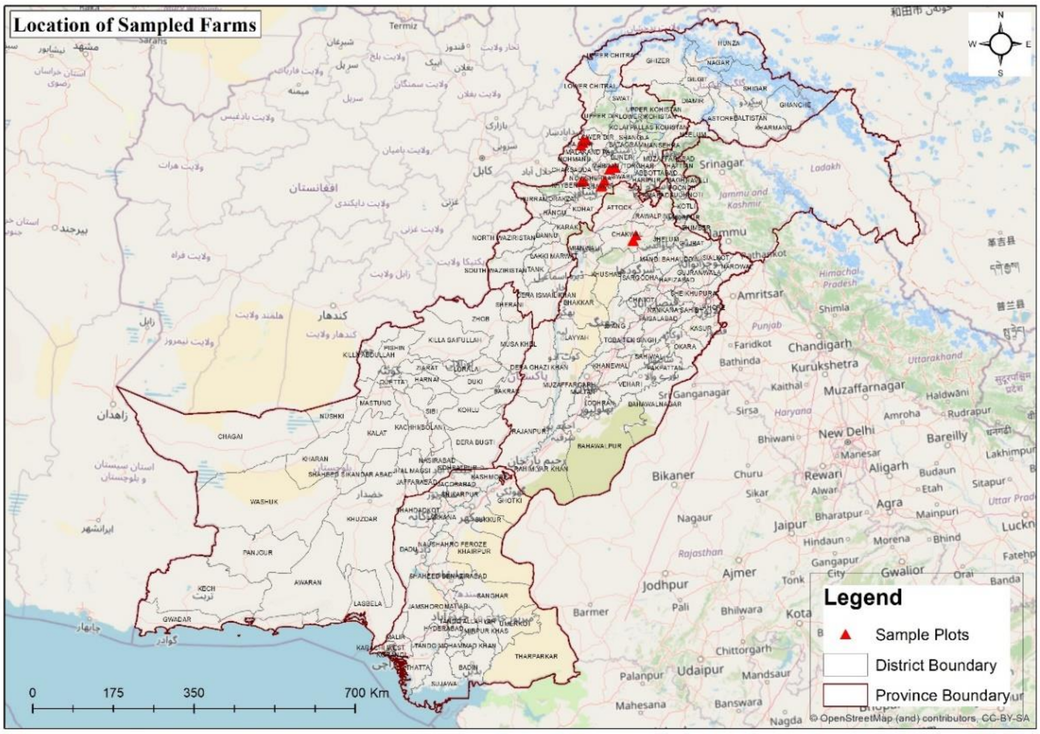

Figure 1: Location of Sampled Farms

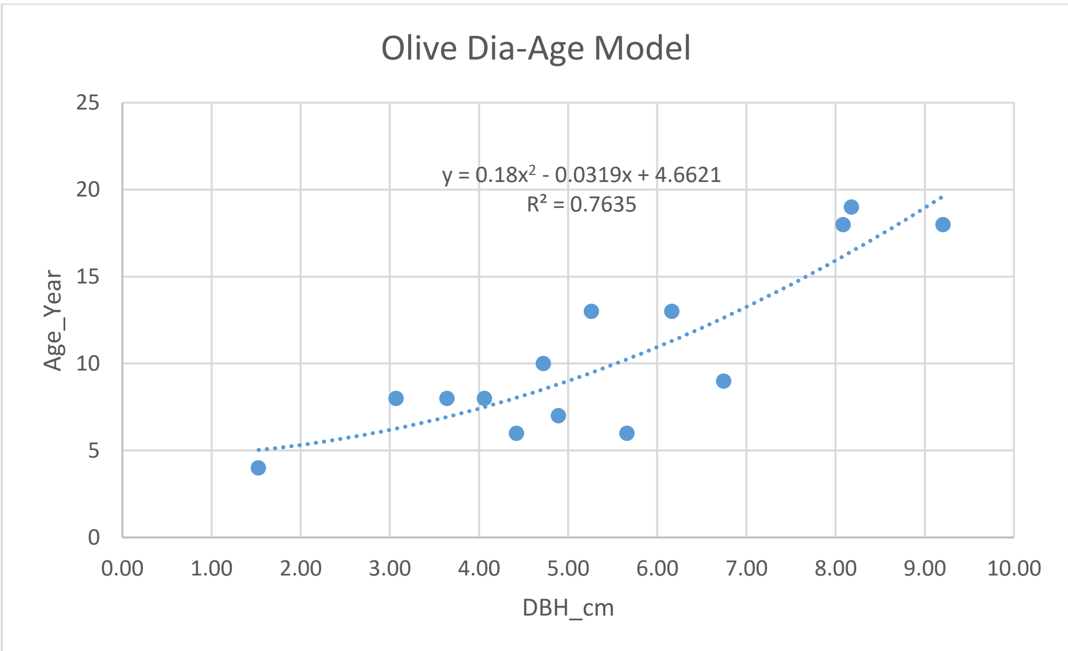

Figure 2: Olive Diameter Age Model

3.3 Biomass and Carbon Stocks

Plant biomass comprises above-ground biomass and below-ground biomass. Above-ground biomass includes stems, branches, twigs, leaves, and fruits whereas below-ground biomass comprises roots biomass. The above-ground biomass in the sampled farms varied from 0.84 to 196.70 tons/ha with an average of 50.67 tons/ha. On the other hand, below-ground biomass was derived from the above-ground biomass using the root: shoot ratios provided in the IPCC Guidelines. The average below-ground biomass resulted in 14.63 tons/ha with a range of 0.47 to 55.07 tons/ha.

The above-ground carbon stock in the sampled farms varied from 0.39 to 92.45 tC/ha with an average of 23.81 tC/ha, and below-ground carbon stock ranged from 0.22 to 25.88 tC/ha with an average of 6.88 tC/ha as shown in Table 2.

Table 2: Biomass and Carbon Stock

Variable	**Mean (ton/ha)**	**Range (ton/ha)**
Above-ground Biomass	50.67	0.84-196.70
Below-ground Biomass	14.63	0.47-55.07
Above-ground Carbon Stock (tC/ha)	23.81	0.39-92.45
Below-ground Carbon Stock (tC/ha)	6.88	0.22-25.88

3.4 Carbon Sequestration

Carbon sequestration in the sampled farms was determined by estimating the above-ground and below-ground biomass. The biomass was converted to carbon stock by multiplying it with 0.47 as suggested by IPCC Guidelines 2006, which mention that 47% of the dry biomass of plants comprises carbon. As carbon sequestration occurs in the form of CO_2, carbon stock was converted to CO_2 by multiplying it with 3.67. The annual carbon sequestration rate was determined by dividing the CO_2 accumulated by the age of the plants.

The findings of the field survey indicate that the average carbon sequestration rate is 4.69 tonnes of CO_2 per hectare per year for 4-24-year-old olive groves planted in 15x15 feet spacing, with 478 plants per ha and an average survival rate of 85%. The detail is given in the following Table 3.

It is worth mentioning here that these are preliminary estimates that are based on the data collected from a limited number of sample plots i.e. only 22, wherein some age groups (e.g. 4 years) have only one sample plot. More precise estimates will be derived from a large number of sample plots covering more geographical areas in the future.

Table 3: Carbon Sequestration Rates

Age (Year)	Survival %age	Plant Density (Number of plants per ha)	Aboveground Biomass (t/ha)	Belowground Biomass (t/ha)	Total Biomass (t/ha)	Carbon Sequestration (tCO_2/ha/year)
4	90	430	4.875	1.365	6.240	2.683
8	90	430	16.767	4.695	21.461	4.615
12	85	406	25.286	7.080	32.366	4.640
16	85	406	37.003	10.361	47.364	5.092
20	80	382	48.068	13.459	61.527	5.292
24	80	382	63.590	17.805	81.395	5.834
Average		**406**	**32.598**	**9.127**	**41.726**	**4.693**

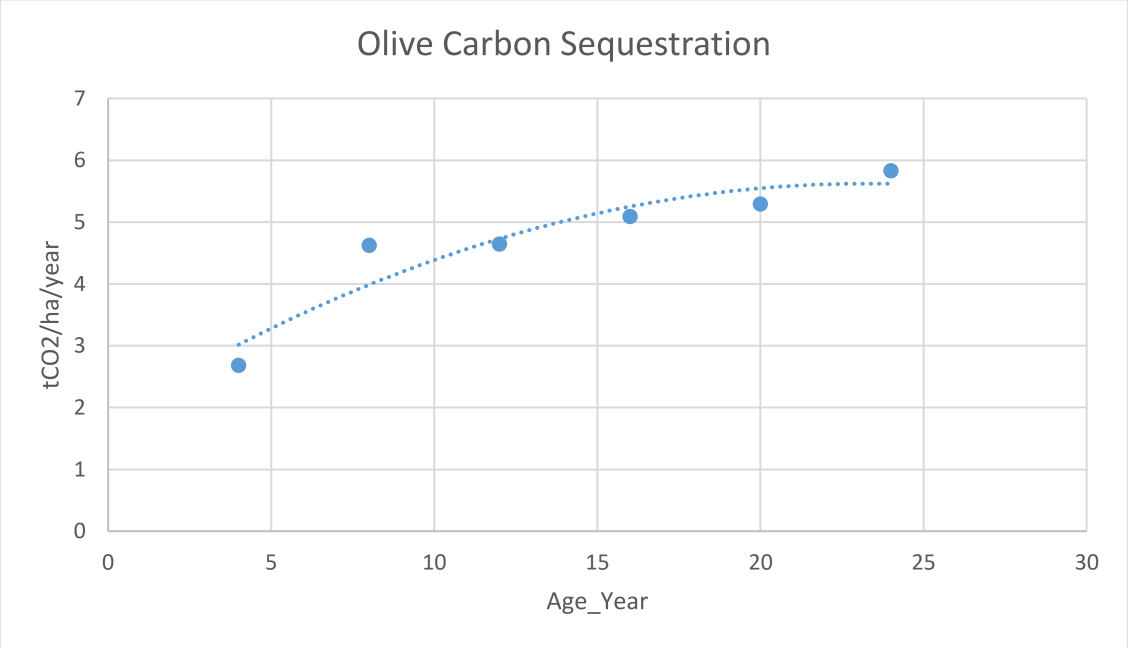

Figure 3: Olive Carbon Sequestration Rate

3.5 Carbon Footprint

The total carbon footprint of olive farming and processing was estimated as 0.898 tCO2eq per ha per year. This includes emissions from land preparation (0.162 tCO2eq per ha), use of fertilizers (0.461 tCO2eq per ha), pesticides (0.126 tCO2eq per ha) and oil extraction (0.240 tCO2eq per ha). As irrigation is mostly based on solar pumps, irrigation was not included in the carbon footprint. The details of GHG emissions from different operations are given in the following tables.

GHG Emissions from land preparation

The total GHG emissions from land preparation were estimated at 0.162 tCO2eq per ha per year. These include emissions from energy consumption by machinery used for leveling and plowing of land for raising plantations and intercropping of annual crops.

Table 4: GHG Emissions from land preparation

Activity	Source of Emissions	Energy Consumption per acre per year (Liter)	Emission per Liter (KgCO2/L	Annual Emissions per Acre (tonCO2)	Annual Emissions per ha (tonCO2)

Land Preparation	Energy (Diesel) Consumption by Bulldozer and Tractor	92.40	2.7	0.066	0.162

GHG Emissions from application of fertilizers and pesticides

Chemical fertilizers and pesticides are important inputs used in olive cultivation which produce GHG emissions from production, packaging, storage, and distribution. Farmyard manure is also used but its emissions are negligible as compared to fertilizers. The total annual emissions from the use of fertilizers and pesticides in the sampled farms were estimated as 0.461 and 0.126 tCO2eq per ha respectively, as shown in Table 5.

Table 5: Emissions from fertilizers and pesticides

Activity	**Quantity used per year (Kg per acre)**	**Equivalent carbon emission (kg CE/kg)***	**Annual Emissions per Acre (tonCO2eq)**	**Annual Emissions per ha (tonCO2eq)**
Fertilizer use:				
Urea (N:46%)	50	1.35	0.135	0.378
DAP (P:46%, N:18%)	50	0.2	0.017	0.042
Potash (K:60%)	50	0.15	0.016	0.041
Total	150	1.7	0.186	0.461
Pesticides:				
Insecticides	1.5	4.65	0.007	0.016
Fungicides	1.5	4.65	0.044	0.110
Total	3	4.65	0.051	0.126

*Values taken from Lal, 2004

GHG Emissions from oil extraction

Olive fruits are crushed in the mills for oil extraction. These mills are normally run by electricity but due to frequent load shedding, these are run by diesel generators or engines. The emissions generated from the fuel consumption by the mills are given in Table 6.

Table 6: Emissions from oil extraction

Activity	Diesel consumption per 500 kg fruit (Liter)	Fruit Production Per Acre (Kg)	Emission per Liter (KgCO2/L)	Annual Emissions per Acre (tonCO2eq)	Annual Emissions per ha (tonCO2eq)
Oil extraction	6	3000	2.7	0.097	0.24

3.6 Net Carbon Balance

As the carbon sequestration is 4.69 tCO2eq per ha and the carbon footprint is 0.99 tCO2eq per ha, the net carbon balance in olive farming is worked out to be 3.70 tCO2eq per ha under the conditions that were sampled. The net carbon balance can be further enhanced by reducing the use of chemical fertilizers and pesticides, tillage, promoting organic farming, cover cropping, and incorporating residues of olive pruning into the soil.

4. EVALUATION OF OLIVE CULTURE FOR CARBON CREDITS TRADING IN PAKISTAN

Pakistan is among the top ten most vulnerable and affected countries by climate change and shall, therefore, give high priority to climate change mitigation and adaptation. According to Pakistan's Nationally Determined Contributions (NDCs), the Government of Pakistan has committed to reduce its GHG emissions by 50% by 2030, 15% of which will be unconditional and 35% conditional with the provision of international grant finance.

The current emissions of Pakistan are about 500 million tonnes of CO_2eq which are expected to reach 1600 million tonnes by 2030. After energy, agriculture is the second highest emitting sector with GHG emissions of about 200 million tonnes of CO_2eq in 2018 (Govt of Pakistan, 2021). Thus, there is a high potential for emissions reduction in the agriculture sector.

The Government of Pakistan has recently developed "Draft Policy Guidelines for Trading in Carbon Market" (October 2023) to provide an operational strategy for carbon trading. The policy envisions the establishment of two distinct market mechanisms: Compliance and Voluntary Markets. Compliance Markets emerge as a result of national, regional, and/or international policy or regulatory mandates, whereas the Voluntary Carbon Market (VCM), both at national and international levels, pertains to the voluntary issuance, trading, and purchase of carbon credits. These markets are designed to cater to different needs and objectives, each operating within its guidelines.

Carbon markets represent trading systems for the purchase and sale of carbon credits, with each carbon credit equivalent to one ton of carbon dioxide or the corresponding quantity of other greenhouse gases mitigated, sequestered, or avoided.

The development of the international Compliance Market is gaining momentum under Article 6 of the Paris Agreement. Article 6 permits nations to collaborate voluntarily, utilizing carbon markets to fulfill their NDCs while allowing for climate action ambition raising, ensuring environmental integrity, and promoting sustainable development. During COP-26, global leaders established international standards for carbon markets governed by Article 6 of the Paris Agreement.

Article 6 provides guidelines for the creation and verification of carbon credits and safeguards against double counting through corresponding adjustments. Several countries have shown interest in entering into bilateral agreements with Pakistan to purchase carbon credits from Pakistan under Article 6 Framework of the Paris Agreement.

VCM functions independently of compliance markets, serving as platforms where carbon credits are procured voluntarily, typically by organizations. The primary purpose of these credits is not to meet legally mandated emissions reduction targets but to align with voluntary environmental commitments. The VCM enables private investors, governments, NGOs, and businesses to voluntarily purchase carbon credits to offset their emissions. The value of global VCM has reached 2 billion USD in 2021-22, and it is expected to reach 40 billion USD by 2030 due to the enormous interest of buyers in the market.

The Policy Guidelines for Carbon Trading have set some requirements for eligibility for carbon trading under the compliance market, which are analyzed for olive projects in the following Table 7.

Table 7: Olive cultivation eligibility assessment for carbon credits

S.No.	Eligibility Criteria	Applicability in Olive Culture
1	The potential projects must be aligned with Pakistan's NDC priorities.	Olive cultivation falls under the Agriculture Sector which is included in Pakistan's NDC.

2	Compliance with Cooperative Approaches of the Paris Agreement: these include the specifications for the carbon credits to be real, verified, and additional; authorized for purposes other than NDC; and ensuring safeguards. This alignment is essential to ensure environmental integrity, safeguards, and restrictions on the transfer of carbon credits or mitigation outcomes.	The potential credits from olive plantations are real and can be easily verified through analysis of before and after plantations through pictures and satellite imagery. Olive credits are additional as it is not a business-as-usual case in Pakistan. Olive cultivation has positive environmental impacts and thus fulfills environmental integrity criteria.
3	Adherence to Article 6, Paragraph 4: these include the activity designed to ensure mitigation and adaptation co-benefits/ economic diversification that does not lead to an increase in global emissions; deliver real, measurable, and long-term benefits; minimize the risk of non-performance over multiple NDC periods; minimize the risk of leakage; ensure environment and social safeguards.	Olive culture ensures mitigation and adaptation co-benefits, leads to economic diversification in the real term, and does not increase emissions. Olive trees having a long life (more than 100 years) have a high likelihood of permanence of carbon credits. There is no risk of leakage as olive cultivation does not affect deforestation or shifting of emissions to other places.
4	Preferential Authorization for Shorter Crediting Periods	Olive plantations can start generating carbon credits in 3-4 years.
5	Promotion of Nature-Based Carbon Projects	Olive cultivation is the best case for nature projects of carbon credits

Eligibility Criteria under VCM

Olive plantations fulfill all the eligibility criteria under the Voluntary Carbon Market. There are several standards of VCM: Verified Carbon Standard (VCS), Gold Standard (GS), Climate, Community and Biodiversity (CCB), Plan Vivo Standard, etc.

The Verified Carbon Standard (VCS), formerly the Voluntary Carbon Standard, is a standard for certifying carbon emissions reductions administered by Verra. VCS is the world's most widely used crediting program. It ensures the quality and integrity of the projects it certifies. Once certified, the project becomes eligible to be issued Verified Carbon Units (VCUs).

The olive plantation projects are eligible under the Afforestation, Reforestation, and Revegetation (ARR) category of the Agriculture, Forestry, and Other Land Use (AFOLU) Sector of VCS. VCS Project Requirements and the assessment of olive plantation are given in the following Table 8:

Table 8: VCS Project Requirements and olive position

S.No.	Requirement	Applicability to Olive Plantations
3.2.1	There are currently six AFOLU project categories eligible under the VCS Program: Afforestation, Reforestation and Revegetation (ARR), Agricultural Land Management (ALM), Improved Forest Management (IFM), Reduced Emissions from Deforestation and Degradation (REDD), Avoided Conversion of Grasslands and Shrublands (ACoGS), and Wetland Restoration and Conservation (WRC).	The olive plantations fulfill the ARR Category requirement.
3.2.3	Where an implementation partner is acting in partnership with the project proponent, the implementation partner shall be identified in the project description. The implementation partner shall identify its roles and responsibilities concerning the project, including but not limited to, implementation, management, and monitoring of the project, over the project crediting period.	The olive cultivation involves implementation partners i.e. local landholders who will act in partnership with the project proponent. The roles and responsibilities of these partners will be properly identified.
3.2.4	Activities that convert native ecosystems to generate GHG credits are not eligible under the VCS Program. Evidence shall be provided in the project description that any project areas were not cleared of native ecosystems to create GHG credits (e.g., evidence indicating that clearing occurred due to natural disasters such as hurricanes or floods). Such proof is not required where such clearing or conversion took place at least 10 years before the proposed project start date. The onus is upon the project proponent to demonstrate this, failing which the project shall not be eligible.	The olive cultivation does not include activity that converts native ecosystems. The olive plantation areas have not been cleared of native ecosystems in the past 10 years. The GIS/RS-based assessment of historical land use/land cover change will be required to assess land use change.
A1.1	Eligible ARR activities are those that increase carbon sequestration, and/or reduce GHG emissions by establishing, increasing, or restoring vegetative cover (forest or non-forest) through the planting, sowing, or human-assisted natural regeneration of woody vegetation. Eligible ARR projects may include timber harvesting in their management plan. The project area shall not be cleared of native ecosystems within the 10 years prior to the project's start.	As olive plantation increase carbon sequestration, hence fulfill the ARR requirements. Timber harvesting will also be included in the olive project plan. The project areas will not include areas that have been cleared of native ecosystems in the past 10 years.

	Scale: projects should have reasonable scales to be financially viable	There is a need to establish cooperatives/associations of olive growers and prepare carbon projects nesting several farmers together to fulfill the scale criterion.

5. RECOMMENDATIONS FOR DELINEATING A POLICY FRAMEWORK ON VALORIZING OLIVE PRODUCTION AS A FORM OF MITIGATION TO CLIMATE CHANGE

Promoting olive cultivation for climate change mitigation and carbon trading in Pakistan requires the adoption of a comprehensive policy framework that includes promoting sustainable farming practices, amendment in the carbon trading policy, awareness, and capacity building campaigns, involvement of the private sector, establishing linkages with national and international organizations, and development of an effective measurement, reporting, and verification (MRV) system.

5.1 Promoting Sustainable Farming Practices for Carbon Sequestration in Olive Groves

- Encourage the adoption of agroforestry practices that integrate olive cultivation with other crops and trees when there are gaps in the olive orchards. This helps sequester more carbon in the soil and promotes biodiversity.
- Promote the cultivation of climate-resilient olive varieties that are well-suited to the local climate conditions, particularly in the current prolonged dry weather. Crop per drop is the best strategy aimed to ensure that every drop of water applied to crops contributes to a higher yield. This ensures better yields, carbon sequestration, and adaptation to changing weather patterns.
- Maintain an appropriate spacing at the time of plantation to get the maximum benefit of yields and carbon sequestration. For this purpose, spacing of 20x20 feet (6 m x 6 m) resulting in 109 plants per acre or 269 plants per hectare is recommended as standard, adaptable to variety, soil, and climatic conditions.
- Implement water-saving technologies and irrigation practices to ensure efficient water use and promote plant growth for maximum yield and carbon sequestration. Drip irrigation and rainwater harvesting are suited for olive cultivation in Pakistan.

- Maintaining the proper canopy of plants through adequate pruning.
- Apply proper soil management practices e.g. cultivating cover crops particularly legumes in the orchards and incorporating cover crop residues as green manure. This will increase soil organic carbon and protect the soil against erosion.
- Incorporating tree pruning residues into the soil of olive groves to enhance fertility and soil organic carbon.
- Reduce the application of chemical fertilizers and use organic manures, compost, and cover crops to maintain and improve soil fertility.
- Use plant-based pesticides and apply integrated pest management measures to reduce the chemicals e.g. pesticides, fungicides, herbicides.
- Promote organic farming in olive groves.
- Promote solar irrigation system in olive farms to avoid the consumption of diesel or electricity-based machines/tube wells.
- Promote the use of solar mills for oil extraction.

5.2 Incorporating Olive Carbon Projects in the Proposed Carbon Trading Policy

- The proposed carbon trading policy of Pakistan needs to recognize the importance of olive culture for carbon sequestration and meeting NDC targets of emissions reduction in the agriculture sector.
- There is a need to give top priority to olive-based carbon credits in the agriculture sector as olive has a long life of more than 100 years and have a high potential for carbon sequestration.
- There is a need to conduct a detailed feasibility of olive carbon projects to determine the suitability for both the Voluntary Carbon Market as well as Compliance Market under Article 6 Framework of the Paris Agreement.
- The private sector should be given incentives to invest in olive carbon projects.
- Farmers should be given incentives in the form of credit facilities, soft loans, and subsidized inputs to grow olive also for carbon sequestration.
- The process for projects registration and issuance of NOCs should be made easy for olive growers.

5.3 Awareness Raising

- Launch comprehensive awareness campaigns to educate farmers, processors, traders, consumers, policymakers, and the general public about the environmental benefits of olive cultivation, including its potential to sequester carbon and mitigate climate change.
- Print and electronic media including social media platforms should be used for this campaign.
- Encourage farmers to participate in carbon farming initiatives, where they can earn carbon credits by sequestering carbon in the soil through sustainable practices. This involves registering with carbon trading platforms and following approved methodologies.

5.4 Capacity Building

- Develop and conduct a comprehensive training program for olive growers and officers of the Agriculture Department and other stakeholders on carbon trading through olive farming.
- Main topics for training would include measurement of carbon stocks in olive groves, accounting of GHG emissions, development of project design documents, measurement, reporting, and verification (MRV) of olive carbon projects, marketing of carbon credits and sustainable management practices for efficient carbon sequestration.
- There is also a need to develop the capacity of government agencies to enable them to serve as certification, validation, and verification bodies for olive carbon credits and projects, under the Voluntary as well as Compliance carbon market.
- It is recommended to establish a cell in the Agriculture Departments at the provincial level to develop and implement carbon projects in partnership with olive growers and other stakeholders.

5.5 Establish Olive Growers Cooperatives/Associations/Clusters

- As most of the olive growers are small farmers, they will find it difficult and uneconomical to bear the transaction costs of carbon projects.

- It is recommended to organize olive growers in the form of cooperatives, associations, or clusters for carbon credit generation and trading through olive farming. This shall include the nesting of several farms in one carbon project at the district or tehsil level to meet the requirement of scale and reduce the cost of project registration, certification, validation, and verification. In this way, the volume of credits will also become substantial and attractive for investors and buyers.
- The cooperatives shall be registered with the relevant bodies as per law; other forms shall follow norms and procedures in place.

5.6 Involvement of Private Sector

- The private sector is an important player in the Voluntary carbon market. On one hand, the private sector can work as a middleman, intermediary, or retailer in carbon trading, and on the other hand, it can buy carbon credits to offset its emissions. It is therefore recommended to devise a policy to ensure the participation of the private sector in olive carbon projects.
- There is also a need to sensitize and mobilize the private sector and potential investors to invest in olive carbon projects, which can become a source of income for investors and olive growers. This can be done by entering into partnerships with olive growers and the government to undertake olive carbon projects in public-private partnership (PPP) mode.

5.7 Establish Linkages with National and International Organizations

- Strengthen the Agricultural Knowledge and Innovation System (AKIS) which is the combined organization and knowledge flows between individuals, organizations, and institutions that use and produce knowledge for agriculture and interrelated fields. AKIS contributes to the Rural Development Policy's cross-cutting objective of modernization, knowledge sharing, innovation, and digitalization. Though AKIS does not currently exist in Pakistan in a structured form, its development and promotion will help in enhancing olive cultivation for climate change mitigation and oil production.
- Collaborate with non-governmental organizations (NGOs) and international organizations that specialize in sustainable agriculture, climate change mitigation

carbon accounting, and carbon trading. These partnerships can provide additional resources and expertise for promoting carbon trading.

- There is a need to establish close collaboration among the MNFS&R, the OliveCulture Project and the other significant endeavors leading oil cultivation, and the Ministry of Climate Change and Environmental Coordination (MoCC) at the federal level, and between Agriculture and Forest Departments at the provincial level.
- There is a need to establish linkages with different standards of the Voluntary carbon market for olive carbon projects. In addition to the Verified Carbon Standard (VCS), Climate Community and Biodiversity (CCB), and Gold Standard (GS), Plan Vivo and Open Forest Protocol (OFP) should also be considered.

5.8 Establish Measurement, Reporting and Verification (MRV) System

- Olive carbon projects are different from other carbon projects of agriculture and forestry sectors. Therefore, there is a need to establish a dedicated system for Measurement, Reporting, and Verification (MRV), and Certification of the olive carbon projects.
- The proposed MRV system can be potentially placed in the MNFS&R and linked to provincial MRV Systems based in the provincial agricultural departments. This system should also be linked with the National Carbon Registry to be based at the MoCC, Islamabad.
- There is a need to establish a uniform carbon accounting protocol for olive culture in line with international standards and best practices.
- The MRV System should be focused on ensuring the high quality and integrity of credits from the olive culture i.e. the credits should be real, verifiable, permanent, additional, and must not be counted or claimed more than once.
- It is recommended to conduct a full pledged study at the country level on GHG Accounting and carbon credit generation in olive cultivation in Pakistan.
- All carbon pools of the ecosystem i.e. above-ground Biomass, below-ground Biomass, litter, dead wood, and soil organic carbon may be included in the future carbon accounting.

- It is also recommended to develop local allometric equations for above-ground and below-ground Biomass estimation.
- It is recommended to apply the international and consolidated Life Cycle Assessment (LCA) method for environmental impacts assessment of olive culture using the SimaPro Software (**Annex II**)

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7. ANNEXURES

ANNEX I: DATA COLLECTION FORM

OLIVE CARBON SEQUESTRATION AND FOOTPRINT

Location: _________________________

Name of Grower_______________________________

X_____________________Y_______________________Elevation________________________

Area under Olive Orchard (in acres) ____________Date of Plantation_____________________

Survival %____

Source of Irrigation_________________________Spacing______________________________

Intercropping____

Landuse before olive_____________Crops Grown before olive__________________________

Ploughing done before planting: Yes____________No________________________________

If yes, then mention tractor hours per acre____

Fertilizer dose (per year): Name of Fertilizer____

Dose per plant per year__________________or Dose per Acre per year___________________

Pesticides use (per year): Name of Pesticide____

Dose per plant per year___________________or Dose per Acre per year__________________

Yield of Fruits per plant___________________Yield of Fruits per acre_____________________

Yield of Oil per plant___________________Yield of oil per acre__________________________

Oil extraction machine is run on: a) electricity______b)Diesel__________c)Petrol___________

Fuel consumption per kg oil: a) electricity units______b)Diesel__________c)Petrol__________

Tree No.	Variety	Shoot/Stem No.	Diameter at base (cm)	DBH (cm)	Height (m)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

ANNEX II: LIFE CYCLE ASSESSMENT (LCA) METHOD FOR ENVIRONMENTAL IMPACTS ASSESSMENT OF OLIVE CULTURE USING THE SIMAPRO SOFTWARE.

The suggested tool for environmental assessment of the oil supply chain is SimaPro software3, and it could be a future supplement and implementation of the methodology given under Section 2.2. For the measurement of some environmental indicators, not only related to CO2 emission, to go along with the calculation of carbon storage capacity. Starting from the calculation of CO2 emission, the amount of CO2 that the tree can store would be subtracted from this, resulting in the actual amount of CO2 emitted into the atmosphere.

As reported at Section 2.2, the main objective is to carry out an initial assessment and quantification of the environmental impact associated with olive cultivation and oil production in Pakistan, to be conducted with the **Life Cycle Assessment (LCA)** or life cycle analysis which is the **EPD method (2018)**, in accordance with the guidelines of **ISO 14040**. The specific objectives are as follows:

- **Quantify environmental impact**: measure and assess the environmental effects of the oil supply chain considering the main impact categories such as greenhouse gas emissions and land use.
- **Identify key factors**: key environmental impact factors include fertilizer and pesticide use, fuel and irrigation water consumption, and yield for each type of legume.
- **Recommendations for improvement**: provide recommendations or information on sustainable practices or interventions that can help reduce the environmental impact associated with oil production in the target context.

The **functional unit (FU)** in LCA is the object of the assessment; therefore, in the **inventory phase of LCA**, all inputs used to produce it are considered; it serves as a reference point against which stock inputs and outputs are measured (ISO, 2006). This includes the quantification, based on field data (primary), about chemical inputs, such as agrochemicals and their active

[3] The use of a tool, as an aid to assessing its own **environmental impact** and thus mitigating such phenomena as soil erosion, water pollution, gas emission and acidification, becomes needed in the process of **sustainable farming**.

ingredients, as well as the fertilizers used, based on the titers and units of fertilizer, the energy consumption associated with the cultivation process, and the amount of water used.

LCA is recognized worldwide as the **main tool for assessing the environmental performance of a product or service and provides an in-depth analysis of the environmental impact** of a product's life cycle. For this purpose, cultivation data collection is carried out, directly from the producer, through a general description of the farm and data collection field (cultivation method, etc.), from which field information on cultivation operations (tillage, planting, fertility management and insect and pathogen control, irrigation, harvesting), as well as an inventory of the capital used in cultivation (machinery, equipment, facilities) are obtained.

The computer program **SimaPro i**s used as a tool for calculating the main environmental impact categories, through which is possible to collect, analyze and monitor data on the environmental performance of products and services. The software enables various applications, such as the calculation of carbon and water footprints, biodiversity, and provides the basis for eco-design of products and environmental product declarations (EPDs).

The impact assessment is done following the **EPD method in accordance with ISO 14040** to assess the environmental impacts of olive throughout their life cycle. In addition to the **EDP method (2018)**, the environmental assessment was also integrated using **Eco-Indicator 99**.

Through the combination of these two methods, the following indicators can be calculated:

- **Global warming (GWP100)** - measured in kilograms of carbon dioxide equivalent (kg CO2 eq): this category assesses the potential of greenhouse gas emissions and their contribution to global warming. The higher the indicator, the greater the impact generated on global warming by the production process analyzed,
- **Ozone depletion (ODP)** - measured in kilograms of tri-chloro fluoro methane equivalent (kg CFC-11 eq): this category assesses the potential of substances to deplete the ozone layer. The higher the indicator, the greater the potential of inputs used in the ozone depletion phenomenon,
- **Photochemical oxidation** - measured in kilograms of ethylene equivalent (kg C2H4 eq): this category assesses the potential of substances to contribute to photochemical smog

formation. The higher the indicator, the greater the potential of substances used in the process of photochemical smog formation,

- **Acidification** - measured in kilograms of sulfur dioxide equivalent (kg eq SO2): this category assesses the potential of substances to cause the formation of acid rain. The higher the indicator, the greater the contribution the substances used have in the process of acid rain formation,
- **Eutrophication** - measured in kilograms of phosphate equivalent (kg PO4 eq): this category assesses the potential of substances to cause nutrient enrichment and eutrophication of water bodies. The higher the indicator, the greater the negative impact the substances used have in the process of eutrophication of water bodies,
- **Abiotic depletion, fossil fuels/components** - measured in megajoule equivalent (MJ eq) for fossil fuels, and in kilograms of antimony (kg Sb eq) for components: this category assesses the consumption of nonrenewable fossil resources as well as non-fossil naturally occurring elements. The higher the indicator, the greater the negative contribution the substances used have in the abiotic depletion process,
- **Water resource scarcity**-measured in cubic meters equivalent (m3 eq): this category, which is based on the AWARE Method, represents the amount of available water that remains per area in a watershed after demand from humans and aquatic ecosystems has been met. The higher the indicator, the more water is removed from the available watershed,
- **Land use**--measured in terms of damage, as a result of land conversion or land occupation and expressed as fraction potentially disappearing (PDF)* m2*year/ m2 or m2a.Land use (in anthropogenic systems) has an impact on species diversity. Based on field observations, a scale expressing species diversity by land use type was created. Species diversity depends on land use type and area size.

The inclusion also of **Eco-Indicator 99**, during the environmental assessment, allowed the grouping of the different indicators, from the impact categories, within 3 damage categories:

1. **Damage to human health** - in which the various disabilities caused by diseases are weighted; these harms are expressed in terms of years of life lost and years of life lived in disability. These data are summarized in Disability Adjusted Life Years (DALY=Disability Adjusted Life Years), an index also used by organizations such as the World Bank and WHO. This category

includes aspects such as carcinogens, respiratory organics, respiratory inorganics, climate change impacts, radiation, and ozone depletion,

2. **Damage to ecosystem quality** - this is the loss of species in each area over a given period (PDF*m2yr=Potentially Disappeared Fraction of plant species). This category includes elements such as ecotoxicity, acidification/eutrophication, and land use impacts,
3. **Damage against resources** - this is the excess energy required to compensate for future extraction of minerals and fossil fuels (MJ surplus energy requirement to compensate lower future ore grade). This category includes impacts related to the depletion of minerals and fossil fuels (Cardone et al., 2018).