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in

Marchetti M. (ed.), Parma C. (ed.), Hamouche Z. (ed.)
OliveCulture Pakistan: Building a Sustainable, Climate-Smart and Competitive Value Chain

Bari : CIHEAM
Options Méditerranéennes : Série B. Etudes et Recherches ;n. 78

2026
pages 149-169

Article available on line / Article disponible en ligne à l'adresse :

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http://om.ciheam.org/article.php?IDPDF=00008204

To cite this article / Pour citer cet article

AUTHA. **Policy framework for promoting olive production as a climate change mitigation strategy in Pakistan.** In : Marchetti M. (ed.), Parma C. (ed.), Hamouche Z. (ed.). *OliveCulture Pakistan: Building a Sustainable, Climate-Smart and Competitive Value Chain.* Bari : CIHEAM, 2026. p.149-169 (Options Méditerranéennes : Série B. Etudes et Recherches; n. 78)

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OPTIONS méditerranéennes

SERIES B: Studies and Research
2026 - Number 78

CIHEAM

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Head of publication: Teodoro Miano

2026	Series B: Studies and Research	Number 78

Centre International de Hautes Etudes Agronomiques Méditerranéennes
International Centre for Advanced Mediterranean Agronomic Studies

Policy framework for promoting olive production as a climate change mitigation strategy in Pakistan*

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Abstract. Olive cultivation is increasingly recognized as a sustainable agricultural system capable of contributing to climate change mitigation through carbon sequestration, reduction of greenhouse gas emissions, and restoration of marginal lands. In Pakistan, the rapid expansion of olive plantations under favorable agro-climatic conditions offers not only economic opportunities but also important environmental benefits. This study evaluates the role of olive groves as carbon sinks by assessing biomass accumulation, carbon stocks, carbon sequestration rates, and greenhouse gas emissions associated with olive cultivation and oil production systems in selected areas of Khyber Pakhtunkhwa and Punjab. The findings indicate that olive orchards exhibit a positive net carbon balance, demonstrating their capacity to offset emissions generated during agricultural and processing activities. In addition, the potential integration of olive cultivation into voluntary and compliance carbon markets is explored within the framework of international climate policies and Pakistan's Nationally Determined Contributions. The development of appropriate policy instruments, carbon accounting systems, farmer cooperatives, and institutional support mechanisms is identified as essential for promoting olive-based carbon projects and strengthening the contribution of the olive sector to climate change mitigation and sustainable rural development in Pakistan.

Keywords. Carbon sequestration – Carbon footprint – Carbon markets – Climate change mitigation.

Cadre politique pour la promotion de l'oléiculture comme stratégie d'atténuation du changement climatique au Pakistan

Résumé. *L'oléiculture s'impose comme un système agricole durable contribuant à l'atténuation du changement climatique grâce à la séquestration du carbone, à la réduction des émissions de gaz à effet de serre et à la valorisation des terres marginales. Au Pakistan, l'expansion rapide des plantations d'oliviers dans des conditions agroclimatiques favorables représente une opportunité économique et un levier important pour la durabilité environnementale. Cette étude évalue le rôle des oliveraies comme puits de carbone à travers l'analyse de l'accumulation de biomasse, des stocks de carbone, des taux de séquestration et des émissions de gaz à effet de serre liées aux systèmes de production oléicole et de transformation oléicoles. Les résultats montrent que les vergers oléicoles présentent un bilan carbone net positif, démontrant leur capacité à compenser les émissions générées par les activités agricoles et industrielles. Enfin, le potentiel d'intégration de l'oléiculture dans les marchés volontaires et réglementés du carbone est analysé dans le cadre des politiques climatiques internationales et des Contributions Déterminées au niveau National du Pakistan. Le développement d'outils politiques adaptés, de systèmes de comptabilisation du carbone et de mécanismes institutionnels apparaît essentiel pour promouvoir les projets carbone liés à l'oléiculture et renforcer la contribution du secteur à l'atténuation du changement climatique et au développement rural au Pakistan.*

Mots-clés. *Séquestration du carbone – Empreinte carbone – Marché de droits d'émission de carbone – Atténuation des effets du changement climatique.*

* This chapter represents an updated version of a document previously published within the framework of the project. https://doi.org/10.48259/bc1962r

I – Introduction

Forest ecosystems and soils represent major terrestrial carbon reservoirs, with a strong capacity to absorb and store atmospheric carbon dioxide (CO_2). Through photosynthesis, trees capture CO_2 and convert it into biomass, storing carbon in trunks, branches, leaves, roots, and fruits, as well as in soil organic matter. This process, known as carbon sequestration, is a key mechanism for mitigating climate change (Lopez-Bellido *et al.,* 2016). Compared with annual crops, tree-based systems exhibit greater potential for long-term carbon storage due to their perennial nature, larger biomass, and reduced soil disturbance. As a result, tree plantations play a central role in nature-based solutions to climate change (Proietti *et al.,* 2016).

While forests and grasslands are typically considered carbon sinks, conventional agricultural systems often act as sources of greenhouse gases (GHGs), mainly due to soil tillage, the use of synthetic fertilizers and pesticides, and fossil fuel consumption in farm operations (Ceschia *et al.,* 2010). In this context, there is an increasing interest in developing sustainable agricultural systems that enhance carbon sequestration while reducing emissions. Agroforestry systems and orchards, including olive groves, are particularly promising due to their long-life cycle, lower tillage intensity, and capacity to increase soil organic matter (Nair *et al.,* 2010). The overall climate benefit of such systems depends on achieving a balance between carbon sequestration and the minimization of their carbon footprint.

The term carbon footprint refers to the total climatic impact of a system, expressed as the sum of all greenhouse gas emissions and removals across its life cycle (Peters, 2010). It encompasses emissions generated during all stages of production, from raw material acquisition to processing and waste management. In olive production systems, the carbon footprint includes emissions associated with nursery operations, land preparation, irrigation, fertilization, pesticide application, transportation, and oil extraction processes. Carbon footprint assessments help identify key emission sources and guide strategies for reducing environmental impacts.

Olive (*Olea europaea* L.) is one of the most important tree crops globally, both economically and ecologically. Beyond its role in edible oil production, olive cultivation contributes to soil conservation and climate change mitigation. The relationship between olive farming and climate change is bidirectional: olive trees are sensitive to climatic variations, yet they also act as effective carbon sinks by storing CO_2 in perennial biomass and soil, thereby enhancing soil organic matter and long-term carbon storage.

According to the assessment done in 2017 by the International Olive Council, the global olive-growing area, estimated at approximately 10.5 million hectares, has the capacity to capture around 47 million tons of CO_2 annually. On average, one hectare of olive grove can sequester approximately 4.5 tons of CO_2 per year. Furthermore, considering the full life cycle of olive oil production, it is estimated that the production of one kilogram of olive oil can result in a net removal of up to 10 kg of CO_2 from the atmosphere.

Carbon sequestration rates in olive groves vary widely depending on factors such as tree density, age, management practices, and environmental conditions. For instance, Sofo *et al.* (2005) reported sequestration rates of 9.54 and 2.74 t CO_2/ha/year in mature and young olive groves in southern Italy, respectively. Other studies have shown values ranging from 1.51 t CO_2/ha/year in 11-year-old groves (Proietti *et al.,* 2014) to between 2.05 and 4.10 t CO_2/ha/year under different management systems in southern Spain (Lopez-Bellido *et al.,* 2016). Nevertheless, practices such as the use of cover crops can further enhance soil carbon storage (Nieto *et al.,* 2010).

The environmental performance of olive production systems can be effectively evaluated using Life Cycle Assessment (LCA), a standardized methodology that quantifies inputs, outputs, and environmental impacts across the entire life cycle of a product, from "cradle to grave" (De Luca *et al.,* 2018). LCA has been widely applied in Europe to assess the carbon footprint of olive cultivation and olive oil production, providing a comprehensive understanding of both emissions and carbon sequestration (Espadas-Aldana *et al.,* 2019; Fernández-Lobato *et al.,* 2021).

In recent years, increasing attention has been given to enhancing terrestrial carbon stocks through afforestation and sustainable land management practices. This has led to the emergence of carbon credits as a tradable commodity in both voluntary and compliance carbon markets. A carbon credit represents one ton of CO_2 equivalent (CO_2eq) either reduced or sequestered. Olive plantations, due to their carbon sequestration capacity, offer significant potential for generating carbon credits, thereby providing an additional income stream for growers.

In Pakistan, olive cultivation is expanding rapidly due to favorable agro-climatic conditions, including suitable soils, a conducive climate, and the presence of extensive wild olive resources, alongside the increasing adoption of Good Agricultural Practices (GAP) aligned with international standards. However, experiences from other countries indicate that excessive intensification of olive production can lead to negative environmental consequences, including increased GHG emissions, soil degradation, biodiversity loss, and pressure on water resources. Therefore, it is essential to assess and manage these impacts to ensure the long-term sustainability of the sector.

The present study aimed at evaluating the carbon sequestration potential of olive groves in Pakistan and exploring policy mechanisms to promote carbon credit trading as an additional revenue source for olive growers. Specifically, the main objectives of the study were: i) quantifying carbon sequestration rates of olive trees under different management regimes in selected areas of Khyber Pakhtunkhwa and Punjab, ii) assessing the carbon footprint of olive cultivation by estimating GHG associated with production and oil extraction processes, iii) determining the net carbon balance and the potential generation of carbon credits from olive plantations, and iv) identifying policy measures and strategic options for promoting carbon credit trading within the olive sector in Pakistan.

II – Methodology

1. Assessment of carbon sequestration

The evaluation of carbon sequestration in olive groves included both above-ground and below-ground biomass. Field data were collected from selected sites in Khyber Pakhtunkhwa (KP) and Punjab where *Olea europaea* plantations have been established. The data collection protocol is summarized below, while the detailed questionnaire is provided in Annex I.

At each site, ten representative trees of the same age group were randomly selected. Care was taken to ensure spatial coverage across the entire grove (Torrús-Castillo *et al.,* 2023). The following parameters were recorded for each sampled tree:

a. Variety name
b. Planting year (tree age)
c. Spacing
d. Number of plants per hectare
e. Number of stems per plant (for multi-stem systems)
f. Diameter at Breast Height (DBH, cm), measured at 1.37 m above ground using a caliper (Figure 1a)
g. Tree height (m), measured using a Vertex hypsometer (Figure 1b)

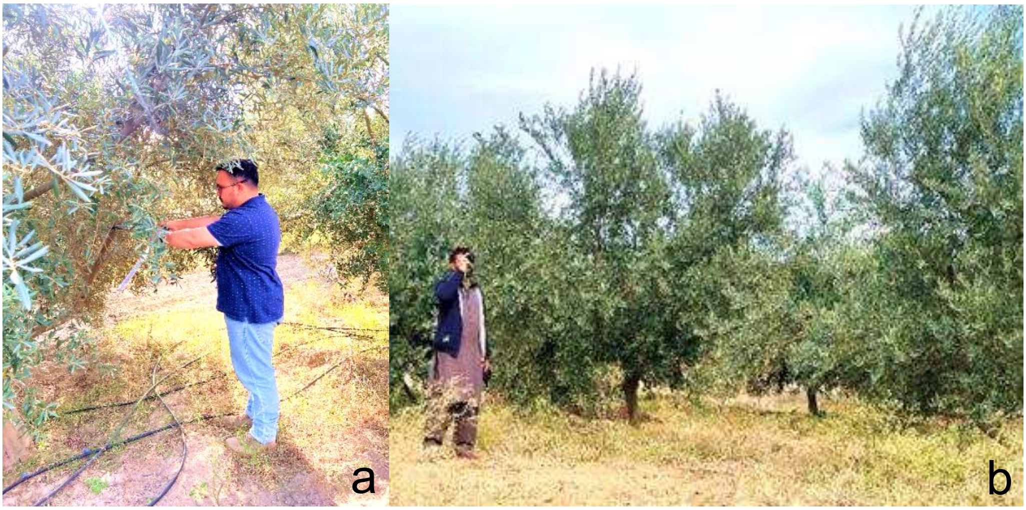

Figure 1. Measuring tree diameter with Caliper (a) and height of stems with Vertex Hypsometer (b).

A. Determination of above-ground biomass

Above-ground biomass (AGB) per tree was estimated using field measurements of DBH and tree height through established allometric equations:

$AGB = 0.623 \times (DBH)^{1.352} \times (H)^{0.703}$

$AGB = 7.8863 + 0.0556 \times (DBH^2 \times H)$

Where AGB is expressed in kilograms (kg), DBH in centimeters (cm), and H in meters (m).

B. Determination of below-ground biomass

Below-ground biomass (BGB) was estimated from AGB using root-to-shoot ratios recommended by the IPCC (2006):

- 0.56 for AGB < 20 t/ha
- 0.28 for AGB > 20 t/ha

C. Conversion to carbon stock and CO_2 equivalent

Biomass values were converted to carbon stock using a conversion factor of 0.47 (IPCC, 2006). Carbon stock was subsequently converted into CO_2 equivalent (CO_2eq) by multiplying by 3.67 (EPA, 2023).

D. Carbon sequestration rate

The annual carbon sequestration rate (t CO_2/ha/year) was calculated by dividing total carbon stock by tree age (Torrús-Castillo *et al.,* 2023). Sequestration rates were analyzed across different age classes and planting densities.

2. Assessment of carbon footprint

The carbon footprint of olive production was assessed using a LCA approach, covering stages from field establishment to oil extraction. Nursery operations were excluded. The following emission sources were considered:

A. Land preparation

Data on previous land use and management practices were collected to estimate emissions associated with land-use change. Fuel consumption for land preparation was calculated based on tractor operating hours per hectare and converted into GHG emissions using standard emission factors.

B. Fertilizers and pesticides application

Information on the application rates of manure, chemical fertilizers, and pesticides was obtained through farmer interviews. These inputs were converted into GHG emissions per hectare using established emission factors.

C. Irrigation

Irrigation-related emissions were estimated based on the energy source used for groundwater extraction (diesel, electricity, or solar). Systems powered by solar energy were considered emission-free for this component.

D. Oil extraction

Emissions from oil extraction were calculated based on energy consumption at processing facilities. Both electricity use and fuel consumption (diesel or petrol generators) were considered, particularly in areas affected by power outages.

All collected data were compiled and analyzed using Microsoft Excel to quantify total greenhouse gas emissions and carbon sequestration.

3. Policy context and government priorities

The Government of Pakistan has prioritized carbon sequestration and climate change mitigation through various policies, strategies, and action plans at both federal and provincial levels. These initiatives emphasize nature-based solutions, including afforestation and sustainable agricultural practices.

The present study reviews the existing policy framework related to carbon sequestration and carbon trading within the olive sector. The findings are aligned with the “Action plan and policy recommendations for a holistic development of the Pakistani olive value chain” (Chapter III), with the objective of integrating carbon-related considerations into future policy development.

III – Field survey findings

1. Olive farming practices

Olive cultivation in the surveyed areas is practiced under diverse systems and spatial arrangements. The majority of plantations are established as structured orchards, either as monocultures or with intercropping of annual crops. In some cases, mixed orchards combining olive with citrus species (*e.g.,* lemon) were observed, while other systems include linear plantations along field boundaries or scattered individual trees.

In regularly established groves, planting density varied considerably, with spacing ranging from 10x12 ft to 20x30 ft. Common configurations included 10x15, 12x12, 15x15, 15x20, 20×20, and 25x25 ft. The recommended standard spacing is 20x20 ft (approximately 6x6 m), corresponding to about 109 trees per acre. According to surveyed growers, tree survival rates after 13 years ranged between 80% and 85%, while fruit production typically begins approximately four years after planting. The main olive varieties cultivated in the study area include Arbequina, Coratina, Manzanilla, BARI-1, BARI-2, and Frantoio.

Irrigation practices vary across farms: approximately 80% of farms are irrigated, while 20% rely solely on rainfall. Among irrigated farms, 72% use solar-powered systems, whereas the remaining 28% depend on diesel or electricity-driven tube wells. Intercropping practices were observed in 36% of farms, involving annual crops such as wheat and mustard, as well as perennial crops like citrus.

The surveyed farms are located at altitudes ranging from 300 to 922 meters above sea level. Notably, 68% of olive plantations have been established on previously uncultivated or marginal lands, while 32% were developed on agricultural land formerly used for cereal and pulse production.

2. Attributes of sampled farms

A total of 22 farms were selected for detailed analysis, located in the provinces of KP and Punjab (Figure 2). Farm sizes varied widely, ranging from 0.5 to 120 acres. The age of olive trees ranged from 4 to 22 years. A summary of the key characteristics of the sampled farms is presented in Table 1.

Figure 2. Location of samples farm.

Table 1. Attributes of samples farms.

Farm	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

The Diameter at Breast Height (DBH), measured at approximately 1.37 m above ground level, ranged from 1.53 cm to 25.60 cm, with an average of 10.08 cm. Tree height varied from 2.05 m to 6.82 m, with an average of 3.95 m. Figure 3 shows the relationship between tree age and DBH in olive trees. A quadratic trendline indicated a positive relationship, with DBH increasing as tree age increases (R^2 = 0.7635).

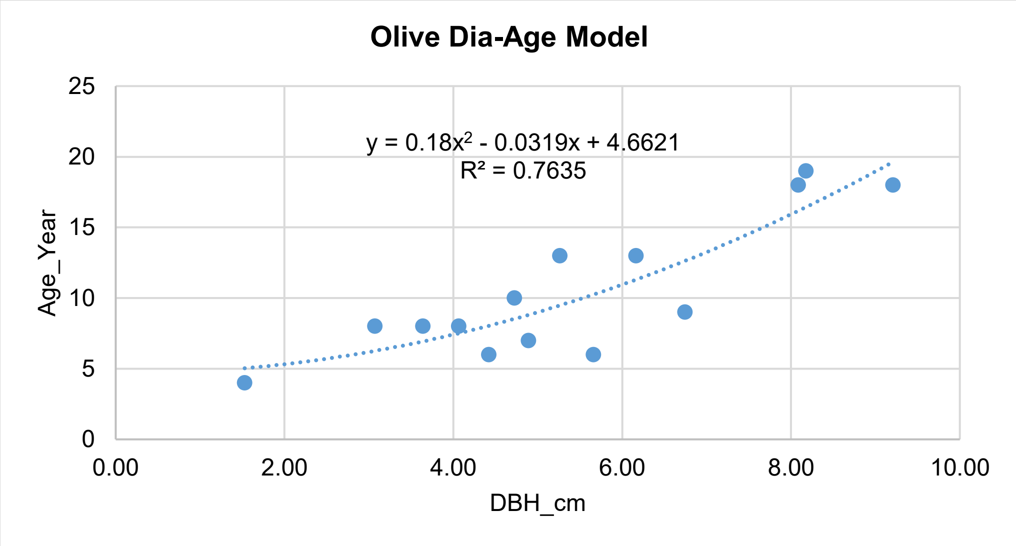

Figure 3. Relationship between DBH and age of olive trees.

3. Biomass and carbon stocks

Plant biomass consists of above-ground biomass (AGB) and below-ground biomass (BGB). Above-ground biomass includes stems, branches, twigs, leaves, and fruits, while below-ground biomass comprises root systems. In the sampled farms, AGB ranged from 0.84 to 196.70 t/ha, with an average of 50.67 t/ha. Below-ground biomass was estimated from AGB using root-to-shoot ratios recommended by the IPCC (2006), resulting in values ranging from 0.47 to 55.07 t/ha, with an average of 14.63 t/ha.

The corresponding above-ground carbon stock varied between 0.39 and 92.45 tC/ha, with a mean of 23.81 t C/ha, while below-ground carbon stock ranged from 0.22 to 25.88 t C/ha, averaging 6.88 t C/ha (Table 2).

Table 2. Mean and range of biomass and carbon stocks in sampled farms.

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 (t C/ha)	23.81	0.39-92.45
Below-ground carbon stock (t C/ha)	6.88	0.22-25.88

4. Carbon sequestration

Carbon sequestration was estimated based on total biomass (AGB + BGB). Biomass was converted to carbon stock using a factor of 0.47, following IPCC (2006) guidelines, which assume that carbon constitutes 47% of dry biomass. Carbon stock was then converted to CO_2 equivalent (CO_2eq) using a factor of 3.67. The annual carbon sequestration rate was calculated by dividing the accumulated CO_2 by the age of the trees. Results indicate an average sequestration rate of 4.69 t CO_2/ha/year for olive groves aged 4-24 years, planted at a spacing of 15x15 ft (approximately 478 trees/ha), with an average survival rate of 85% (Table 3, Figure 4). It should be noted that these estimates are preliminary, as they are based on a limited dataset comprising 22 sample plots, with some age classes represented by a single observation (*e.g.,* 4-year-old groves). More robust estimates will require a larger number of sample plots across a wider range of geographic conditions.

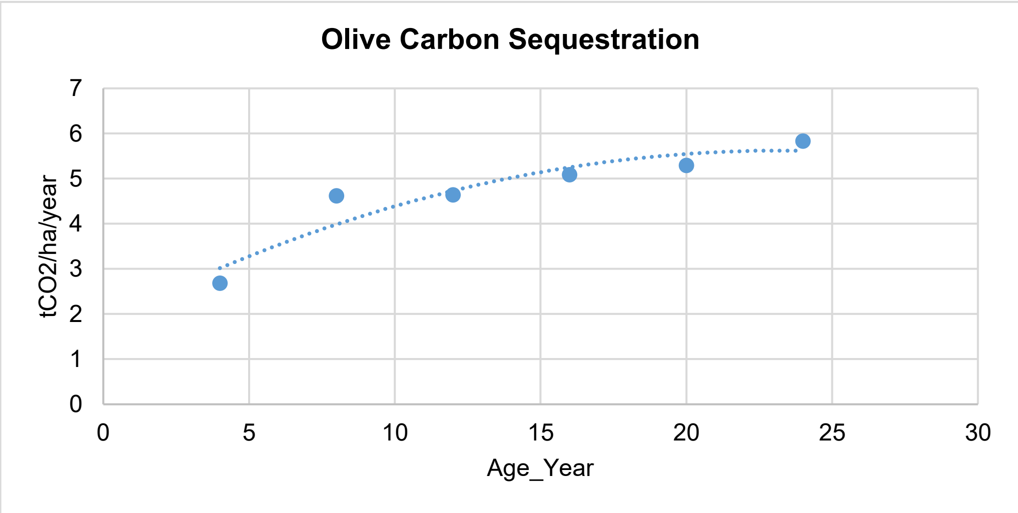

Figure 4. Olive carbon sequestration rate.

Table 3. Carbon sequestration rates and biomass accumulation across different age classes of olive groves.

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

5. Carbon footprint

The total carbon footprint of olive cultivation and processing was estimated at 0.898 t CO_2eq/ha/year. This includes emissions from land preparation (0.162 t CO_2eq/ha), fertilizer application (0.461 t CO_2eq/ha), pesticide use (0.126 t CO_2eq/ha), and oil extraction (0.240 t CO_2eq/ha). Irrigation-related emissions were not included, as most farms rely on solar-powered systems. Detailed estimates of GHG emissions from individual operations are given in the following tables (4-6).

A. GHG emissions from land preparation

GHG emissions from land preparation were estimated at 0.162 t CO_2eq/ha/year. These emissions arise primarily from diesel consumption by machinery such as bulldozers and tractors used for land leveling, plowing, and intercultural operations.

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

B. GHG emissions from fertilizers and pesticides applications

The use of chemical fertilizers and pesticides contributes significantly to the carbon footprint due to emissions associated with their production, packaging, transport, and application. Although farmyard manure is also applied, its contribution to emissions is relatively minor. Total emissions were estimated at 0.461 t CO_2eq/ha/year from fertilizers and 0.126 t CO_2eq/ha/year from pesticides (Table 5).

C. GHG emissions from oil extraction

Olive oil extraction involves mechanical processing, typically powered by electricity. However, due to frequent power outages, diesel generators are often used, resulting in additional emissions. The estimated emissions from oil extraction amount to 0.240 t CO_2eq/ha/year (Table 6).

Table 5. GHG emissions from fertilizers and pesticides.

Activity		Quantity used per year (Kg per acre)	Equivalent carbon emissions (kg CE/kg)*	Annual emissions per acre (tonCO2eq)	Annual emissions per ha (tonCO2eq)
Fertilizers	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

Table 6. GHG 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

6. Net Carbon balance

Based on the findings, the average carbon sequestration rate of olive groves was estimated at 4.69 t CO_2eq/ha/year, while the total carbon footprint was approximately 0.99 t CO_2eq/ha/year. This results in a net carbon balance of 3.70 t CO_2eq/ha/year, indicating that olive cultivation under the studied conditions acts as a net carbon sink.

The net carbon balance can be further improved through the adoption of sustainable management practices, including reduced use of chemical fertilizers and pesticides, minimized soil tillage, promotion of organic inputs, implementation of cover cropping, and incorporation of pruning residues into the soil.

IV – Evaluation of olive cultivation for carbon credit trading in Pakistan

Pakistan is among the countries most vulnerable to climate change and is therefore prioritizing both mitigation and adaptation strategies. Under its Nationally Determined Contributions (NDCs), Pakistan government has committed to GHG emissions by 50% by 2030, of which 15% is unconditional and 35% is conditional upon international financial support.

Pakistan's current GHG emissions are estimated at approximately 500 million tons of CO_2 equivalent (CO_2eq) and are projected to rise to nearly 1,600 million tons by 2030. After the energy sector, agriculture is the second-largest contributor, accounting for about 200 million tons of CO_2eq in 2018 (Government of Pakistan, 2021). This highlights the significant potential for emission reduction and carbon sequestration within the agricultural sector.

In response, the Government of Pakistan has developed the "Draft Policy Guidelines for Trading in Carbon Markets" (October 2023), which provide an operational framework for carbon trading. The policy outlines two primary market mechanisms: compliance markets and voluntary carbon markets (VCM). Compliance markets are driven by regulatory requirements at national, regional, or international levels, whereas voluntary markets facilitate the trading of carbon credits on a non-mandatory basis.

Carbon markets function as trading systems where carbon credits are bought and sold, with each credit representing one ton of CO_2 (or its equivalent in other greenhouse gases) that has been reduced, avoided, or sequestered.

The international compliance carbon market is evolving under Article 6 of the Paris Agreement, which enables countries to cooperate in achieving their NDC targets through carbon trading mechanisms. Article 6 establishes rules for the generation, verification, and transfer of carbon credits, while ensuring environmental integrity and preventing double counting through corresponding adjustments. Following agreements reached at COP26, international standards for these markets have been further strengthened. Several countries have expressed interest in entering bilateral agreements with Pakistan to purchase carbon credits under this framework.

In parallel, VCM operates independently of regulatory obligations and allows entities, including private companies, governments, and non-governmental organizations, to purchase carbon credits to offset their emissions. The global value of the voluntary carbon market reached approximately USD 2 billion in 2021-2022 and is projected to grow significantly, potentially reaching USD 40 billion by 2030, driven by increasing demand for corporate climate commitments. The recently developed policy guidelines also define eligibility criteria for participation in compliance carbon markets. These criteria are evaluated in relation to olive-based carbon projects in the following section (Table 7).

Table 7. Olive cultivation eligibility assessment for carbon credits.

Eligibility criteria	Applicability in olive culture
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.
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.
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 terms, 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.
Preferential authorization for shorter crediting periods	Olive plantations can start generating carbon credits in 3-4 years.
Promotion of nature-based Carbon projects	Olive cultivation is the best case for nature projects of carbon credits

1. Eligibility criteria under the VCM

Olive plantations meet the key eligibility criteria for participation in VCM. Several internationally recognized standards operate within the VCM, including the Verified Carbon Standard (VCS), Gold Standard (GS), Climate, Community and Biodiversity Standards (CCB), and Plan Vivo Standard. Among these, the VCS, administered by Verra, is the most widely used global carbon crediting program. It provides a robust framework to ensure the quality, transparency, and integrity of carbon reduction and sequestration projects. Projects certified under this standard are issued Verified Carbon Units (VCUs), each representing one ton of CO_2 equivalent reduced or sequestered.

Olive plantation projects are eligible under the Afforestation, Reforestation, and Revegetation (ARR) category within the Agriculture, Forestry, and Other Land Use (AFOLU) sector of the VCS. These project types focus on increasing carbon stocks through the establishment and management of tree-based systems, making olive groves particularly suitable candidates. The specific VCS project requirements and their applicability to olive plantation systems are summarized in Table 8.

Table 8. Verified Carbon Standard project requirements and applicability to olive plantations.

Requirement	Applicability to olive plantations
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.
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.	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.
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.	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.
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 increases 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.

V – Recommendations for developing a policy framework to valorize olive production as a climate change mitigation strategy

Promoting olive cultivation as a climate change mitigation strategy and integrating it into carbon markets in Pakistan requires a comprehensive and coordinated policy framework. This framework should encompass sustainable agricultural practices, integration into carbon trading mechanisms, awareness and capacity building, private sector engagement, institutional linkages, and the establishment of a robust Measurement, Reporting, and Verification (MRV) system.

1. Promoting sustainable farming practices for carbon sequestration in olive groves

- Encourage agroforestry systems by integrating olive trees with compatible crops and species to enhance carbon sequestration and biodiversity.
- Promote climate-resilient olive varieties adapted to local conditions, particularly under increasing drought stress. The “crop per drop” approach should be emphasized to maximize water-use efficiency and productivity.
- Adopt optimal planting density. A standard spacing of 20x20 ft (6x6 m), equivalent to 109 plants per acre or 269 plants per hectare, is recommended, with flexibility based on site-specific conditions.
- Implement efficient irrigation systems such as drip irrigation and rainwater harvesting to optimize water use and enhance biomass production.
- Maintain proper canopy structure through regular pruning to improve growth and productivity.
- Improve soil management through the use of cover crops (especially legumes) and incorporation of residues as green manure to enhance soil organic carbon and reduce erosion.
- Incorporate pruning residues into the soil to improve fertility and carbon storage.
- Reduce reliance on chemical fertilizers by promoting organic inputs such as compost and manure.
- Encourage integrated pest management and the use of plant-based pesticides to minimize chemical inputs.
- Promote organic farming practices in olive cultivation.
- Expand the use of solar-powered irrigation systems to eliminate emissions from diesel and electricity use.
- Promote renewable energy solutions, including solar-powered oil extraction units.

2. Integration of olive-based carbon projects into carbon trading policy

- Recognize olive cultivation as a priority sector for carbon sequestration within national carbon trading policies and NDC targets.
- Prioritize olive-based carbon projects due to their long lifespan and high carbon sequestration potential.

- Conduct detailed feasibility studies to assess the viability of olive carbon projects under both voluntary markets and compliance mechanisms (*e.g.,* Article 6 of the Paris Agreement).
- Provide financial incentives (*e.g.,* soft loans, subsidies, and credit facilities) to encourage farmers to adopt carbon-oriented olive farming practices.
- Facilitate private sector participation through incentives and supportive regulatory frameworks.
- Simplify procedures for project registration, certification, and issuance of No Objection Certificates (NOCs) to reduce barriers for growers.

3. Awareness raising

- Implement nationwide awareness campaigns targeting farmers, processors, policymakers, and the general public on the environmental and economic benefits of olive cultivation.
- Utilize print, electronic, and digital media platforms to disseminate information.
- Promote participation in carbon farming initiatives, enabling farmers to generate income through carbon credit schemes.

4. Capacity building

- Develop and deliver targeted training programs for farmers, extension workers, and government officials on carbon accounting, project development, and carbon market mechanisms.
- Key training areas should include carbon stock measurement, GHG accounting, project documentation, MRV systems, and carbon credit marketing.
- Strengthen institutional capacity to support certification, validation, and verification of carbon projects at both voluntary and compliance levels.
- Establish dedicated units within provincial agriculture departments to support the development and implementation of olive carbon projects.

5. Formation of olive grower cooperatives and clusters

- Organize smallholder farmers into cooperatives, associations, or clusters to overcome financial and technical barriers associated with carbon project development.
- Promote aggregation (“nesting”) of multiple farms into single carbon projects at district or sub-district levels to achieve economies of scale and reduce transaction costs.
- Ensure legal registration and institutional support for such farmer organizations to facilitate participation in carbon markets.

6. Private sector engagement

- Encourage private sector participation as investors, intermediaries, and buyers within carbon markets.

- Promote public-private partnerships for the development and financing of olive carbon projects.
- Raise awareness among investors about the economic potential of olive-based carbon credits as a sustainable investment opportunity.

7. Strengthening institutional linkages

- Develop and strengthen the Agricultural Knowledge and Innovation System (AKIS) to enhance knowledge exchange, innovation, and technology adoption in olive cultivation.
- Foster collaboration with national and international organizations working in climate change mitigation, sustainable agriculture, and carbon markets.
- Enhance coordination among key institutions, including the Ministry of National Food Security and Research (MNFSR), the Ministry of Climate Change (MoCC), provincial agriculture and forestry departments, and ongoing olive development initiatives.
- Establish linkages with international carbon standards and certification bodies to facilitate market access for olive carbon credits.

8. Establishment of a Measurement, Reporting and Verification (MRV) system

- Develop a dedicated MRV framework tailored to olive-based carbon projects.
- Integrate this system within national institutions (*e.g.,* MNFSR) and link it with provincial systems and the National Carbon Registry under MoCC.
- Establish standardized carbon accounting protocols aligned with international methodologies.
- Ensure that carbon credits meet key quality criteria: real, measurable, additional, permanent, and free from double counting.
- Conduct comprehensive national-level studies on GHG accounting and carbon credit potential in olive cultivation.
- Expand future carbon accounting to include all carbon pools: above-ground biomass, below-ground biomass, litter, deadwood, and soil organic carbon.
- Develop locally calibrated allometric equations for more accurate biomass estimation.
- Apply standardized LCA approaches (*e.g.,* using SimaPro software) to evaluate environmental impacts (Annex II).

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Annexes

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 use (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 N˚	Variety	Shoot/Stem N˚	Diameter at base (cm)	DBH (cm)	Height (m)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Annex II

Life cycle assessment 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 software, and it could be a future supplement and implementation of the methodology given under Section II-2 for the measurement of some environmental indicators, not only related to CO_2 emission, to go along with the calculation of carbon storage capacity. Starting from the calculation of CO_2 emission, the amount of CO_2 the tree can store would be subtracted from this, resulting in the actual amount of CO_2 emitted into the atmosphere.

As reported at Section II-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 LCA or life cycle analysis, 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 GHG 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), of chemical inputs, such as agrochemicals and their active 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), 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 is 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), 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 CO_2eq): 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 C_2H_4eq): 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 SO_2eq): 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 PO_4eq): 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 (m^3 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) *m^2*year/m^2 or m^2a. 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, 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*m^2yr). 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 for lower future ore grade). This category includes impacts related to the depletion of minerals and fossil fuels (Cardone *et al.,* 2018).