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METHODOLOGY AND ANALYSIS OF THE COSTS AND BENEFITS IN COMPARING SUSTAINABLE LAND MANAGEMENT PRACTICES IN THE WOCAT DATABASE

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1. Abstract

Through a collaborative effort and partnership between WOCAT, UNCCD Secretariat/Global Mechanism, the Economics of Land Degradation (ELD) hosted by GIZ in collaboration with Altus Impact and the Centre for Development Research (ZEF), that started in 2021. The World Overview of Conservation Approaches and Technologies (WOCAT) database has been exported and systematically harmonised to produce a comparable dataset and dashboard of the costs of adopting and implementing sustainable land management (SLM) interventions. The ECON-WOCAT dataset contains over 500 entries and provides users with quick access to obtaining average establishment and maintenance costs, as well as SLM technologies across all major regions of the world. It is being launched at a time of heightened interest in landscape restoration, regenerative farming, for example, as part of the UN Decade for Ecosystem Restoration and Bonn Challenge.

The dataset contributes to filling a critical gap in terms of scarce and often scattered information on the costs of implementing sustainable land management across ecosystems and regions. The new dataset provides numerous possibilities for its use in planning and implementation of SLM and land restoration projects from global to national levels. For example, the information can be used to identify the funding needs for the implementation of the current land restoration commitments by countries as part of their land degradation neutrality (LDN) action plans.

This new ECON-WOCAT dataset and the accompanying dashboard provide a globally unique source of mutually consistent and comparable information on the costs of SLM technologies

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recommended by the United Nations Convention to Combat Desertification (UNCCD), covering practically every region and most types of terrestrial ecosystems in the world.

2. Introduction

Human life on earth relies upon the health of the land we inhabit, however, the pace of the loss of biodiversity, and the geographic spread of land use and appropriation of ecosystems services is unprecedented in human history[1]. The annual global cost of land degradation is estimated to be in the order of US$490 billion per year, much higher than the cost of action to prevent it[2] (UNCCD 2013) and directly impacting the livelihoods of 1.5 billion people (FAO 2011)[3].

In 2015 the Country Parties of the United Nations Convention to Combat Land Degradation and Desertification (UNCCD) decided to pursue Land Degradation Neutrality (LDN), SDG target 15.3. Today, over 120 countries worldwide are working on setting national voluntary LDN targets and associated measures to achieve a land degradation neutral world. Other important land-related commitments are contained in the UNFCCC Nationally Determined Contributions; post-2020 biodiversity commitments, Bonn Challenge, New York Declaration on Forest. Achieving these commitments, including holding global warming well below 2°C, requires a transformation of the agriculture and forestry sectors from greenhouse gas sources to sinks; and a transformation of our relationship with nature to one that conserves, restores, and enhances its benefits for people and the planet (Rockström et al., 2021[4]). These efforts must begin immediately. Recognizing the state of urgency, in March 2019 the United Nations General Assembly proclaimed the period 2021-2030 the UN Decade on Ecosystem Restoration, with the aim of supporting and scaling up efforts to prevent, halt and reverse the degradation of ecosystems worldwide and raise awareness of the importance of successful ecosystem restoration (A/RES/73/284[5]).

Such efforts need to be underpinned by appropriate governance, fiscal and regulatory frameworks. However, without effective knowledge management and decision tools, to inform the

[1] IPCC, 2019: Summary for Policymakers. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press.

[2] United Nations Convention to Combat Desertification (UNCCD). 2013. The Economics of Desertification, Land Degradation and Drought: Methodologies and Analysis for Decision-Making. Background document. UNCCD 2nd Scientific Conference. http://2sc.unccd.int/fileadmin/unccd/upload/documents/Background_documents/Background_Document_web3.pdf

[3] Food and Agricultural Organization (FAO). 2011. The state of the world's land and water resources for food and agriculture (SOLAW): Managing systems at risk. FAO, Rome and Earthscan, London. http://www.fao.org/docrep/015/i1688e/i1688e00.pdf

[4] Rockström, J., Beringer, T., Hole D. G., Griscom, B. W., Mascia, M. B. Mascia, lFolke, C, Creutzig, F. (2021).We Need Biosphere Stewardship That Protects Carbon Sinks and Builds Resilience. PNAS. September 15, 2021 | 118 (38) e2115218118. https://www.pnas.org/content/118/38/e2115218118

[5] United Nations Decade on Ecosystem Restoration (2021-2030) : resolution / adopted by the General Assembly, https://digitallibrary.un.org/record/3794317?ln=en

design of policy instruments and investment decisions, too many resources will continue to flow to land degrading practices and insufficient resources will be dedicated to sustainable land management (SLM). Sustainable land management (SLM) is the use of land resources to produce goods and provide services to meet changing human needs, while simultaneously ensuring the long-term productive potential of these land resources and their environmental functions (WOCAT Glossary[6]).

Whilst the transition to SLM practices usually involve immediate costs, benefits are often enjoyed over the medium to long term (ELD 2013[7]). Without relieving the capital constraint on farmers and an enabling policy environment, spontaneous adoption of SLM by farmers is often hindered (Westerberg et al., 2021[8]). However, there is a pressing need to scale-up financial flows towards SLM measures and ecosystem restoration, to achieve land degradation neutrality, avoid climate catastrophe and reach net-zero by 2050 (Akhtar-Schuster et al., 2017[9]). SLM projects need to be developed and financed based on accurate estimates of the actual costs – both upfront and recurrent costs - of reaching their desired outcomes. An understanding of how the interventions impact ecosystems (including soils, water, flora, and fauna) and people's livelihoods, in a given regional context, are also important factors when deciding over land uses.

Recognizing this, the World Overview of Conservation Approaches and Technologies (WOCAT) Network was established in 1992 to compile, document, evaluate, share, disseminate, and apply sustainable land management (SLM) knowledge. The centrepiece of this effort is a comprehensive questionnaire and database on best practice SLM technologies (WOCAT Library 2019[10]). Today, twenty years later - the WOCAT database contains more than two thousand SLM technologies and approaches[12] that have been successfully implemented across more than 130 countries within diverse ecosystems, including croplands, rangelands and forested areas, with a particularly dense coverage of the African and Asian continent. The database is acknowledged by the UN Convention to Combat Desertification (UNCCD) as being the main source for obtaining experience on SLM worldwide and is providing a strong basis for the sharing of experiences amongst land users, specialists, researchers, and advisers, who are at the heart of successful SLM.[11]

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[6] https://www.wocat.net/en/glossary#heading-s

[7] ELD Initiative (2013). The rewards of investing in sustainable land management. Interim Report for the Economics of Land Degradation Initiative: A global strategy for sustainable land management. Available from: www.eld-initiative.org

[8] Vanja Westerberg, Angela Doku, Lawrence Damnyag, Gordana Kranjac-Berisavljevic, Stephen Owusu, Godfred Jasaw, Edward Yaboah, Salvatore Di Falco (2019). Reversing Land Degradation in Drylands: The Case for Farmer Managed Natural Regeneration (FMNR) in the Upper West Region of Ghana. Report for the Economics of Land Degradation Initiative in the framework of the "Reversing Land Degradation in Africa by Scaling-up Evergreen Agriculture" project.

[9] Mariam Akhtar-Schuster, Lindsay C. Stringer, Alexander Erlewein et al. Unpacking the concept of land degradation neutrality and addressing its operation through the Rio Conventions, Journal of Environmental Management, Volume 195, Part 1, 2017, Pages 4-15, (https://www.sciencedirect.com/science/article/pii/S030147971630706X)

[10] https://www.wocat.net/library/media/15/

[11] Critchley, W., Harari, N. and Mekdaschi-Studer, R. 2021. Restoring Life to the Land: The Role of Sustainable Land Management in Ecosystem Restoration. UNCCD and WOCAT.

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The WOCAT questionnaire underlying the database has been populated by academics, project developers and land use practitioners (Harari 2022, personal communication). Up until present however, it has not been possible to capitalise fully on the monetary figures found within the database, as they have been recorded in different currencies[12], at different moments in time and for different sized intervention areas. This means that data extraction possibilities were limited to case-study level through the WOCAT portal.

Through a collaborative effort and partnership between WOCAT, UNCCD Secretariat/Global Mechanism, the Economics of Land Degradation (ELD) hosted by GIZ in collaboration with Altus Impact and the Center for Development Research (ZEF), that started in 2021, the WOCAT database has now been systematically harmonised to provide consistent and comparable information on more than 500 SLM practices and technologies. To assure the quality and usefulness of the information that can be extracted from the database, continuous discussions and an interactive review process were undertaken amongst the project partners.

Multiple stakeholders, from private investors, to governments agencies, communities, NGO-supported practitioners, researchers and farmers themselves, stand to benefit from comparable and reliable cost and benefit data on sustainable land management techniques. The data will help relevant stakeholders assess the financial and economic viability of SLM investment and prioritise between intervention types.

Alternatively, the dataset user may also be concerned with 'impact first', looking for the SLM practice that has the largest possible benefit with respect to disaster risk resilience, socio-economic provisioning services, water quality and quantity, or income for farmers, as an example. The dataset has therefore been conceived to allow the user to review a basket of alternative SLM methods for achieving desired outcomes, e.g. with respect to disaster risks and water security for any specific region or ecosystem of the world.

In this methodological paper, we explain how the data harmonisation has been conducted and provide snippets of the rich range of results that can be extracted from the database. To make the data even more accessible and allow dataset users to filter on key variables of interest, an online open-access dashboard - the Econ-WOCAT dashboard - has also been developed.

Up until present, there has been no simple method to export the main WOCAT database to excel. Users who have access to the application programming interface (API) have had to harmonise the costs and benefits before any analysis could be done. Together, the new harmonised open-access Econ-WOCAT dataset and dashboard, will be strong levers to democratise access to scarce and scattered data on the costs and benefits of investment in SLM. By helping overcome one of the main information constraints so-far – to scaling sustainable investments – these resources provide a robust basis for immediate global action to use SLM, as a solution to

[12] Some questionnaires contain exchange rates and convert the costs to USD at the time of submission.

achieving land degradation neutrality and tackling important interrelated challenges, including food security, climate change and biodiversity loss.

3. Methodology and Materials

3.1. Data extraction

The data was extracted from the WOCAT database via the private API. The analysis started with the full set of 1236 SLM technologies that is part of more than 2000 approaches and technologies documented in WOCAT (for selection criteria see Chapter 3.5 and Figure 3). The existing QCAT API Scripts[13] were subsequently enhanced to allow for extracting the maximum amount of data of interest. For example, by allowing for the creation of sub-categories of land uses (annual cropping, perennial, woody). This resulted in a set of new variables that were added to the excel dataset. The corresponding scripts handled the conversion of the data from the JSON API response into a tabular csv format. The harmonisation was subsequently completed in Python in a Jupyter notebook, using the pandas and numpy libraries before exporting the dataset back into Excel. The final script can be found on Github[14]. Figure 1 shows the sequence of elements that were involved in producing the final excel-based dataset.

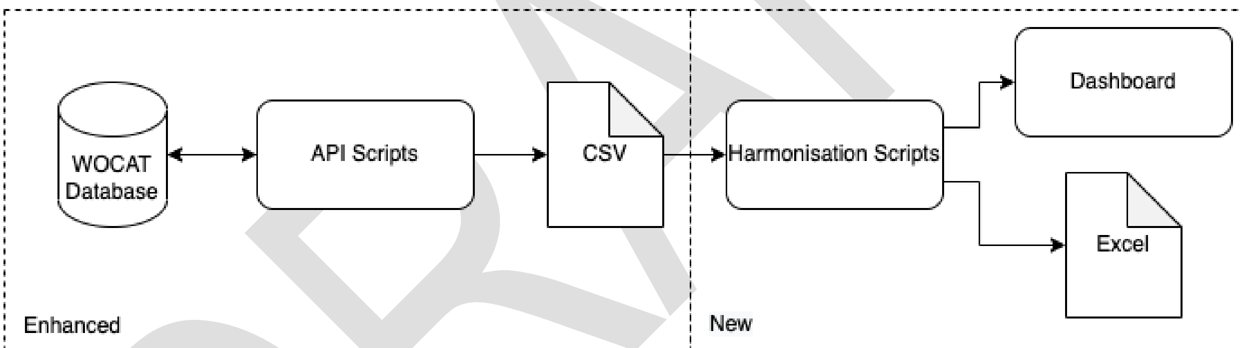

Figure 1: Harmonisation Process

3.2. Costs harmonisation methodology

3.2.1. Inferral of the year that cost data was documented

Many of the SLM technologies recorded within the database were implemented decades ago (43% of questionnaires have a different implementation year to their documentation year). However when documenting the costs, it can be inferred that survey users reported estimates pertaining to the year that the data was entered. This was justified, amongst other reasons, by the fact that many of the practices were ongoing at the time of data-entry. In the absence of a single field containing the year in which the costs were recorded and a limitation on the API that

[13] https://github.com/CDE-UNIBE/qcat-api-scripts
[14] https://github.com/Simon-ent/econ-wocat-dataset

does not allow access to the creation date, the implementation year was calculated on the basis of the following fields:

- Q1.3 Date Documentation
- Q7.1 Date Documentation
- Q2.6 Implementation Year
- Q2.6 Implementation Decades

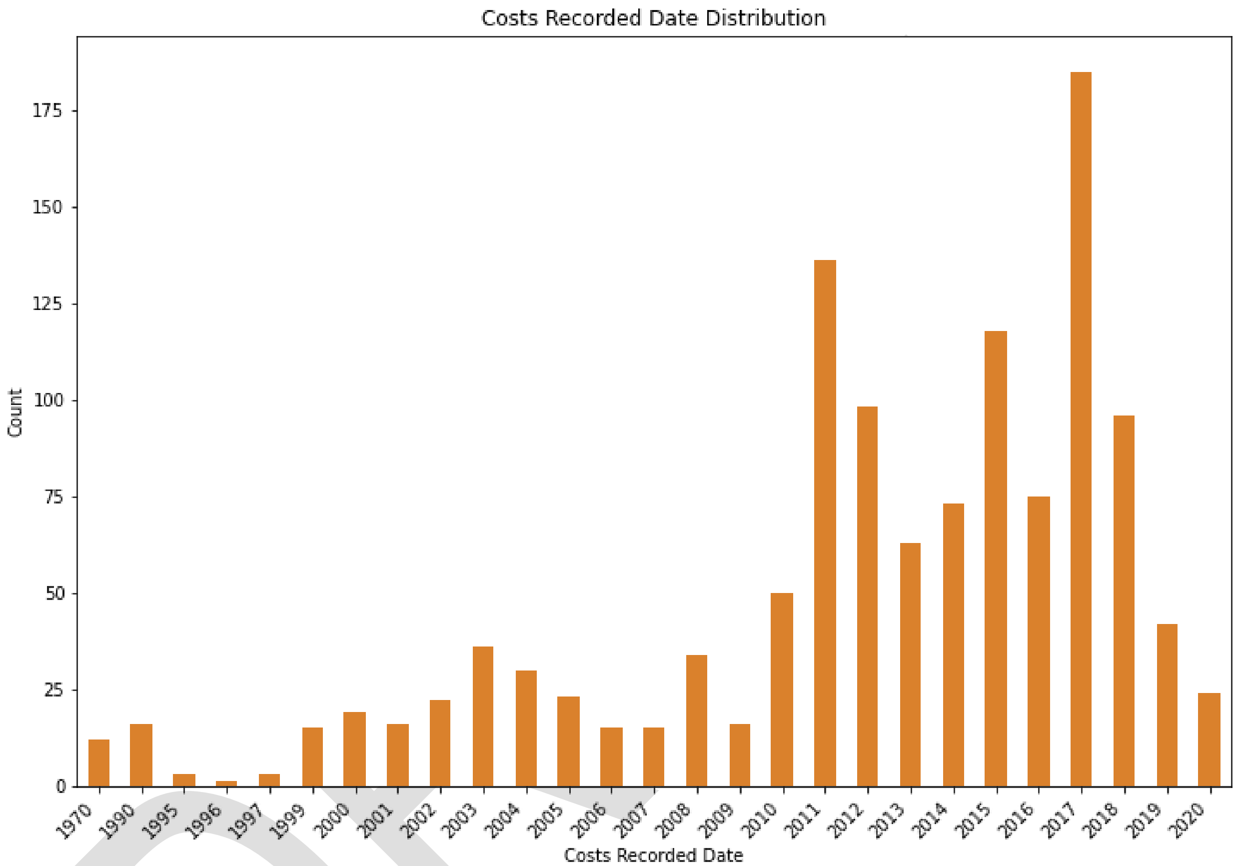

Figure 2: The distribution of cost documentation dates

The date range has been limited to be between 1970-2020 as this corresponds to the available exchange rate and price deflation data from UNSTATS[15].

3.2.2. Currency cleaning

Within the questionnaires users can record the currency used for the costs data within a set of free text fields. This leads to a multitude of formats and languages, including comments and explanations on the exchange rates that were used. After analysing the patterns found within the data entries, the most consistent method for determining the currency was developed by comparing the *Establishment Total Costs* with the data on the *Establishment Total Costs in USD*

[15] https://unstats.un.org/unsd/snaama/Downloads

and likewise for maintenance costs. If both values were the same then the costs were assumed to be in USD, otherwise we assume that the local currency was used.

3.2.3. Price inflation and conversion to USD

There are a number of different methods by which past nominal costs can be converted to real, inflation adjusted costs in a common currency. Two approaches were considered: (1.) accounting for inflation of the local currency and then converting to USD, or (2.) converting to USD and then inflating with US inflation rates. As labour accounts for the largest share of costs (see section 4.4) associated with establishing and maintaining a SLM technology, we chose the former approach, following (Turner et al. 2019)[16] who recommends inflating local currency for non-tradable goods and services.

To harmonise the economic costs recorded in different years, they were converted into real, inflation adjusted data. To do this we used the *Implicit Price Deflator in national currency* from UNSTATS price deflation data[17] and chose 2020 as the base year, reflecting the most recent available price deflator (or price index, that was available).

To convert the measurements so that they are measured in 2020 figures, the 2020 price index is divided by the index value for the implementation year (Equation 1). Once all the costs are derived in 2020 local currency values they are converted to USD, using the 2020 exchange rate from UNSTATS.

$$Cost\ Inflation = \frac{2020\ Index\ Value}{Implementation\ Year\ Index\ Value} \quad (1)$$

3.2.4. Calculating the costs breakdown

When compiling the cost of a technology, all needed inputs are taken into consideration. Input sub-categories within the WOCAT questionnaire include labour, equipment, plant material, fertilisers and biocides, and construction materials. Labour, refers to paid and unpaid labour (i.e. unpaid labour provided by family members) and is accounted for in both cases, as the sum total of the number of days worked times the value of a day's worth of work.

Establishment costs are those expenses which are incurred to set up the technology. Establishment costs can last over a very brief period of time (e.g. for the construction of a pond sand filter) or over a few years (e.g. for reforestation activities in a watershed). As the timeframe for the establishments are not recorded, we assume they are incurred in the first year when estimating total present value costs (see section X below). The maintenance costs relate to annual recurrent expenses, starting the year after the establishment costs. They can include any of the inputs mentioned above.

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[16] Hugo C. Turner, Jeremy A. Lauer, Bach Xuan Tran, Yot Teerawattananon, Mark Jit, Adjusting for Inflation and Currency Changes Within Health Economic Studies, Value in Health, Volume 22, Issue 9, 2019, Pages 1026-1032, ISSN 1098-3015, https://doi.org/10.1016/j.jval.2019.03.021. (https://www.sciencedirect.com/science/article/pii/S1098301519321497)

[17] https://unstats.un.org/unsd/snaama/Downloads

Within each of the cost categories (labour, equipment, plant material etc.) the data analyst can enter free text to describe the individual breakdown of the costs, for example, rakes, farmer's knife, machete, leather gloves, axe under the “equipment” sub-category. It was beyond the scope of this analysis to categorise the items within the smaller sub-categories. Item totals were therefore combined to produce a total value for each sub-category for the 2020 base year.

Another important metric for the analysis is the number of labour days required to establish the technology and maintain it. A similar process to extracting the costs data has been followed but instead of looking at the *total costs per input* values the *labour quantity* has been used. The *labour quantity* values have been assumed to be entered per day for every questionnaire.

3.2.5. Total Present Value cost of SLM practices and average annual present value costs (annuity values)

The cost of investing in a given SLM technology is a function of the establishment cost and the annual maintenance cost. Whilst establishment costs may run over the first one to three years, in most cases they are incurred in the first year. It has therefore been assumed for all the observations that establishment costs are incurred in the first year and the annual maintenance cost applies as of the second year. Consequently, the total present cost has been estimated as per equation 2 for a time horizon of 10 years[18]. The resulting annuity costs have also been calculated, equivalent to the present value of the average annual costs generated over the 10-year accounting period (equation 3).

$$PV\ Cost = Establishment\ cost_{t0} + \sum_{t=1}^{T} Maintenance\ cost_t/(1+r)^t \qquad (2)$$

$$Annuity = \frac{r*PV\_Cost}{1-(1+r)^{-t}} \qquad (3)$$

where

PV Cost = The total present value cost

r = discount rate, 0%, 2.5% and 5%

T= time horizon (10 years, 0 to 9)

As the majority of costs are borne in the establishment of the technology and the benefits normally follow a few years later for SLM practices, the total present values are particularly sensitive to the

[18] Well-noting that maintenance costs can continue for as long as the technology is being implemented. A 10-year time horizon was selected to allow for harmonising the cost data with elicited estimates on long-term perceived benefits. Theseare elicited for a 10-year period in the WOCAT questionnaire.

discount rate. For that reason, total present value cost and annuities have been calculated for a range of discount rates (0%, 2.5%, 5%) and reported in the dataset and dashboard.

A rate of 0% is justified because of the long tail of benefits from implementing SLM practices[19]. A positive discount rate may also be justified based on the opportunity cost of drawing funds from the private or the public sector. In this case, the cost of investing in SLM is the value of what the investment would have produced in its alternative use. Since most variations in nominal rates are due to changes in inflationary expectations the real interest rate is appropriate for Cost Benefit Analysis (CBA). The real rate of interest is equal to the nominal lending interest rate less the inflation rate. A rate of 2.5% was chosen based on the 5-year average of US real interest rates, which is considered as a good indicator of world real interest rates[20] (Marco et al. 2019)[21]. A rate of 5% was also used as recommended by the European Commission's for CBA analysis[22] and to approximate the return on long-term government bonds (CNN money[23]) that typically serve to finance projects with significant public goods.

In many cases, nominal interest rates and personal discount rates, faced by farmers in developing and emerging economies, are significantly higher than the range that has been used here. Should the dataset user wish to analyse SLM costs using other discount rates, they can simply extract the non-discounted values and apply the desired discount rate.

3.3. Benefits harmonisation

In assessing benefits from SLM technology uptake, WOCAT questionnaire uses a proxy indicator - notably, the perspectives of the land users on how they perceive the benefits of a technology (this is not linked to any time frame). The perceived on-site and off-site benefits for each SLM technology have been aggregated for each sub category based on the median value. The resulting list of aggregated impact score categories are:

- Socio-economic impacts
  - Production benefits, including items such as crop and quality, fodder production, and quality, wood and non-wood production, livestock production… see question 6 of the WOCAT questionnaire.

[19] https://blogs.worldbank.org/governance/using-zero-discount-rate-could-help-choose-better-projects-and-help-get-net-zero-carbon
[20] https://data.worldbank.org/indicator/FR.INR.RINR?locations=US
[21] Marco Del Negro, Domenico Giannone, Marc P. Giannoni, Andrea Tambalotti, Global trends in interest rates, Journal of International Economics, Volume 118, 2019, Pages 248-262, ISSN 0022-1996, https://doi.org/10.1016/j.jinteco.2019.01.010.
(https://www.sciencedirect.com/science/article/pii/S0022199618302927)
[22] https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf
[23] https://money.cnn.com/retirement/guide/investing_bonds.moneymag/index3.htm#:~:text=Since%201926%2C%20large%20stocks%20have,according%20to%20investment%20researcher%20Morningstar.

  - Water availability and quality benefits, including items such as drinking water availability and quality, water availability and quality for livestock, irrigation water availability, quality and demand… etc.
  - Income and costs benefits, with items such as, farm income, diversity of farm income sources, workload, economic disparities
- Socio-cultural impacts, with respect to food security, recreational opportunities..
- Ecological water cycle / runoff benefits
- Ecological soil benefits
- Ecological biodiversity benefits
- Ecological climate and disaster risk benefits
- Off-site benefits

The WOCAT questionnaire also records the perceived cost benefits over the short (1-3yrs) and long (10yrs) term in relation to the establishment and maintenance costs. These responses have also been included in the dataset and analysis.

3.4. SLM Group classification

The WOCAT questionnaire has a total of 27 SLM groups of which the researcher or project manager can select up to 3 when classifying the technologies that were implemented. This results in 241 possible combinations of SLM groups[24]. To facilitate data analysis, these were subsequently condensed into 13 SLM Groups for the ECON-WOCAT dataset. Table 1, shows how the connection between the ECON-WOCAT database grouping, that of WOCAT's original grouping following Critchley, Harari and Mekdaschi-Studer (2021) and UNCCD-SPI SLM grouping following Sanz et al. (2019).

SLM Groups used in ECON-WOCAT Dataset	**WOCAT Database SLM Groups**	**UNCCD-SPI SLM groups**
Agroforestry	Agroforestry, windbreaks and shelterbelts	Agroforestry, Afforestation/Reforestation
Protected area	Area Closures	Reducing deforestation, Grazing pressure management
Terraces and bunds	Cross-slope barriers	Soil erosion control
Forest management	Natural and semi-natural forest management; forest plantation and management	Sustainable forest management, Forest restoration, Afforestation/Reforestation, Reducing deforestation
Improving ground cover	Improved ground and vegetation cover	Vegetation management

[24] The original data is available in the ECON-WOCAT dataset, in the SLM Groups (WOCAT) column

Integrated crop-livestock management	Integrated crop-livestock management	Agro-pastoralism, Animal waste management
Integrated soil fertility management	Integrated soil fertility management	Integrated soil fertility management, Animal waste management
Irrigation and water management	Irrigation management; surface water management; ground water management; water diversion and drainage	Water management
Minimum tillage	Minimal soil disturbance	Minimum soil disturbance
Grazing land management	Pastoralism and grazing land management	Grazing pressure management, Vegetation management
Crop rotations	Rotational systems	Vegetation management, Fire, pest, and diseases control
Water harvesting	Water harvesting	Water management
Miscellaneous	Energy efficiency, Home gardens, Improved plant varieties/ animal breeds, Post harvest measures, Waste management	

Table 1: SLM Group mapping between ECON-WOCAT, WOCAT and UNCCD-SPI

3.5. Technology area harmonisation

To estimate establishment and maintenance costs in per hectare terms, the total area considered in providing the SLM costs was extracted from each of the following 4 free-text fields in order of preference:

1. Q4.3 Tech per area size
2. Q4.3 Tech per unit
3. Q4.3 Tech per volume unit
4. Q4.5 Labour costs unit

It required significant data scraping to obtain the total area, as data-entries were made in different units and languages[25]. The majority of area estimates were provided in hectares. Those that were provided in other units were converted to hectares. The resulting distribution of the technology area under consideration (in hectares) used for estimating cost in $/ha terms, are shown in Figure 3. It should be noted that the total area over which an SLM technology is implemented may be larger than the area that was used for reporting SLM costs.

[25] For each of the fields the extraction looks for both a value and unit, then a value only and finally a unit only. These are then combined where only the blanks are filled in, so if a questionnaire has a result for all 3 only the value and unit from the first extraction is kept. As many questionnaires did not contain area data in any of the Q4.3 fields the labour units were also considered from the cost breakdown to identify if the costs are per hectare. It is assumed that if only a unit has been provided then the costs are provided for that unit only.

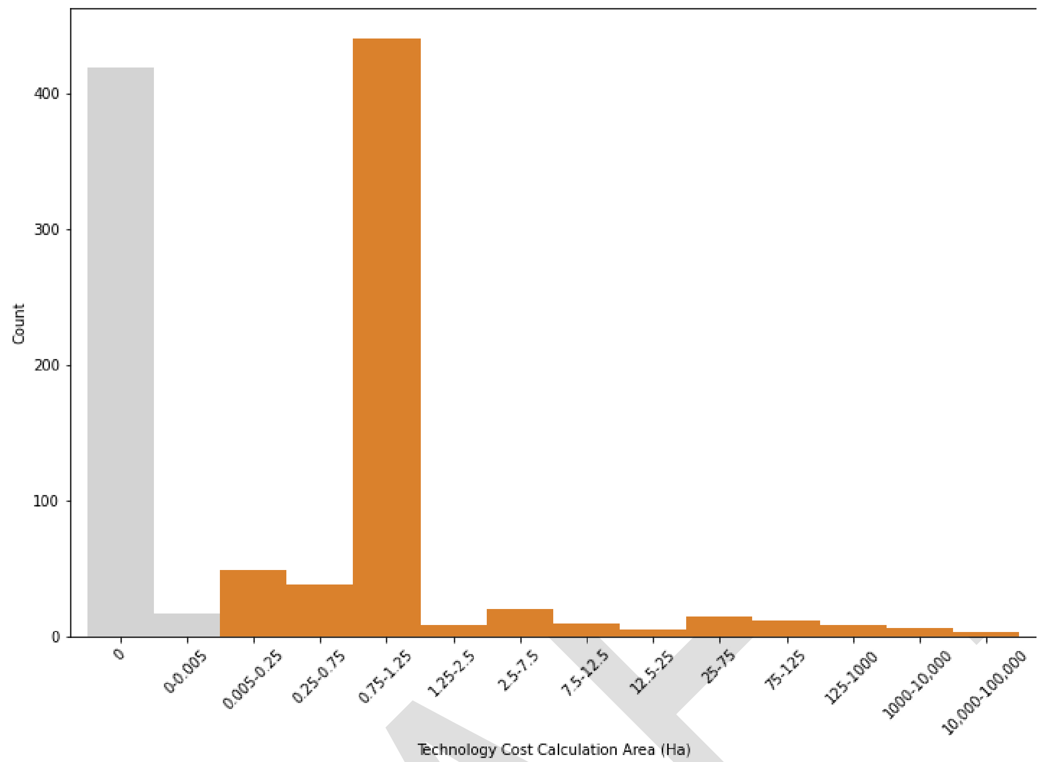

Figure 3: Non-uniform histogram of technology area used for costs. Technologies using less than 0.005ha or with no area have been excluded from the analysis (grey), technologies included (orange).

3.6. Separation of the dataset

The WOCAT database comprises 2185 entries on SLM approaches and technologies. An SLM Approach (Approaches) defines the ways and means used to implement one or several SLM Technologies and UNCCD PRAIS Practices are SLM best practices that countries had previously reported through the UNCCD reporting platform (PRAIS) both of which are not included in this economic analysis. The total number of entries available to be analysed was 1236 which can be broken down into the three main categories: no costs data, no area data and those with area and costs data. Technologies for which there was no cost data (14.8%) have been removed from the dataset. The remaining dataset can then be split again into those that have no extractable area (419 technologies) or a very small area (18 technologies) and those that can be analysed with costs per hectare (616 technologies). As the technology area trends to zero the costs per hectare trend to infinity resulting in anomalies when comparing costs. The split in the datasets has been selected as 0.005 hectares (538 sq feet or 50 sq metres), this leaves smallholder farming practices in the main dataset but removes technologies that aren't designed to scale to the per hectare level. As seen in Figure 4, the majority of technologies within the smaller dataset have no area data (96% of the Smaller Dataset) and only 18 technologies (4%) have an area between 0-0.005 hectares. Most of the technologies analysed have been costed per hectare (436 of 616) although often they are implemented on larger scales.

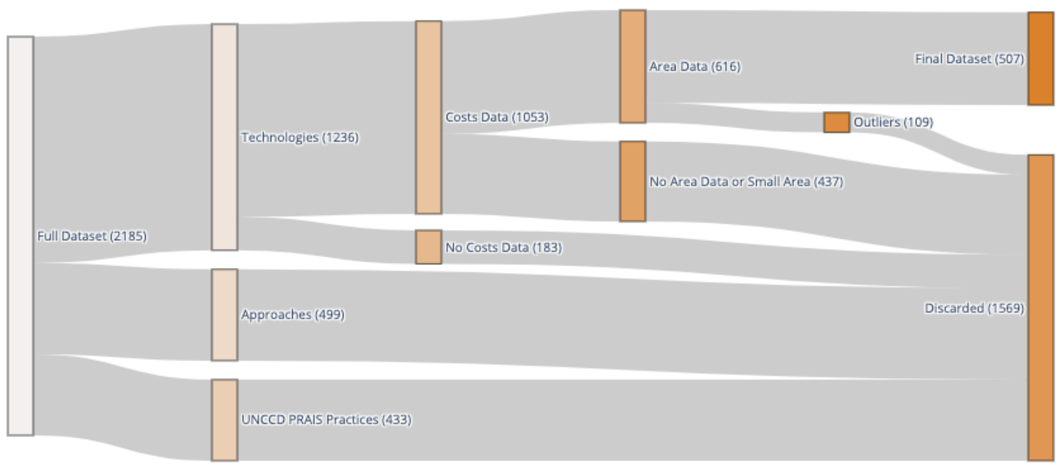

Figure 4: The split of entries with no costs data, no area or small area and the main dataset

Finally, outliers and technologies priced per unit (instead of per area) were removed from the 616 technologies to leave a final 507 technologies. The outliers were calculated by SLM Group using Equations 4 and 5.

$$Upper\ Outliers > Q3 + 1.5\ IQR \quad (4)$$
$$Lower\ Outliers < Q1 - 1.5\ IQR \quad (5)$$

Where:
Q1 = Lower Quartile (25%)
Q3 = Upper Quartile (75%)
IQR = Inter Quartile Range (Q3-Q1)

4. Results

In the following section, we provide snippets of the kind of results that can be produced by the new harmonised ECON-WOCAT dataset. The purpose is therefore not to provide a comprehensive account of all the potential socio-economic data that can be extracted and combined, but rather to give a first insight into the actual costs and benefits of adopting SLM technologies and the questions that the database allows to answer. For example, w*hich regions have the highest per hectare costs of SLM implementation? What share of these costs are used for establishment, versus maintenance? How do costs vary according to the land use type where SLM practices were implemented, or across technologies? …. etc.*

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4.1. SLM costs by region

The majority of SLM technologies entered into the database are located in Sub-Saharan Africa and Asia with very few recorded for Australisia and North America. This has more to do with the countries in which the organisations that are contributing to WOCAT operate than the true global spread of SLM technologies. In regions with lower average labour wages we see overall lower costs (as judged by the median).

With regards to the costs associated with implementing sustainable land management (all technologies included) Western Europe (4273 USD/ha) Eastern Asia (4035 USD/ha) and Southern Europe (2857 USD/ha) have the highest total PV costs, considering a 10-year time horizon (using a 2.5% discount rate), compared to for example Sub-Saharan Africa (288 USD/ha), Central Asia (644 USD/ha) and North Africa (813 USD/ha). Figure 5 shows a box-plot featuring the median establishment and maintenance costs, and associated lower and upper quartiles for the region of interest. The round dots show the actual observations that underlie the box-plot statistics.

Region	Summary		PV Costs	Establishment Costs			Maintenance Costs		
	Count	(%)	(2.5%)	Median	Q1	Q3	Median	Q1	Q3
Sub-Saharan Africa	197	38.86	288.70	90.81	14.63	435.67	8.98	0.12	105.08
Southern Asia	62	12.23	1,054.40	152.17	16.72	1,070.76	12.40	0.24	211.05
South-eastern Asia	55	10.85	770.92	248.97	21.17	1,589.04	33.76	1.45	273.25
Central Asia	53	10.45	644.49	120.55	16.75	763.51	23.53	0.01	171.93
Southern Europe	31	6.11	2,857.63	1,508.30	198.98	3,321.15	28.69	0.00	251.07
Latin America and the Caribbean	29	5.72	1,892.14	481.82	163.42	1,509.65	80.37	2.72	427.84
Northern Africa	24	4.73	813.18	342.24	98.66	1,516.24	41.06	0.00	302.39
Western Asia	18	3.55	309.98	163.78	15.27	692.51	1.38	0.02	57.87
Western Europe	15	2.96	4,273.16	1,233.14	108.09	3,711.37	30.83	0.00	789.31
Eastern Asia	8	1.58	4,035.32	573.36	170.13	1,874.20	30.04	15.00	579.75
Eastern Europe	7	1.38	352.74	69.56	0.00	458.05	44.25	12.99	47.89
Northern Europe	5	0.99	1,844.69	803.25	423.08	1,844.69	0.00	0.00	0.00
Australia and New Zealand	3	0.59	1,191.84	6.70	3.35	10.47	148.68	75.05	426.96

Table 2: Costs distribution by Region

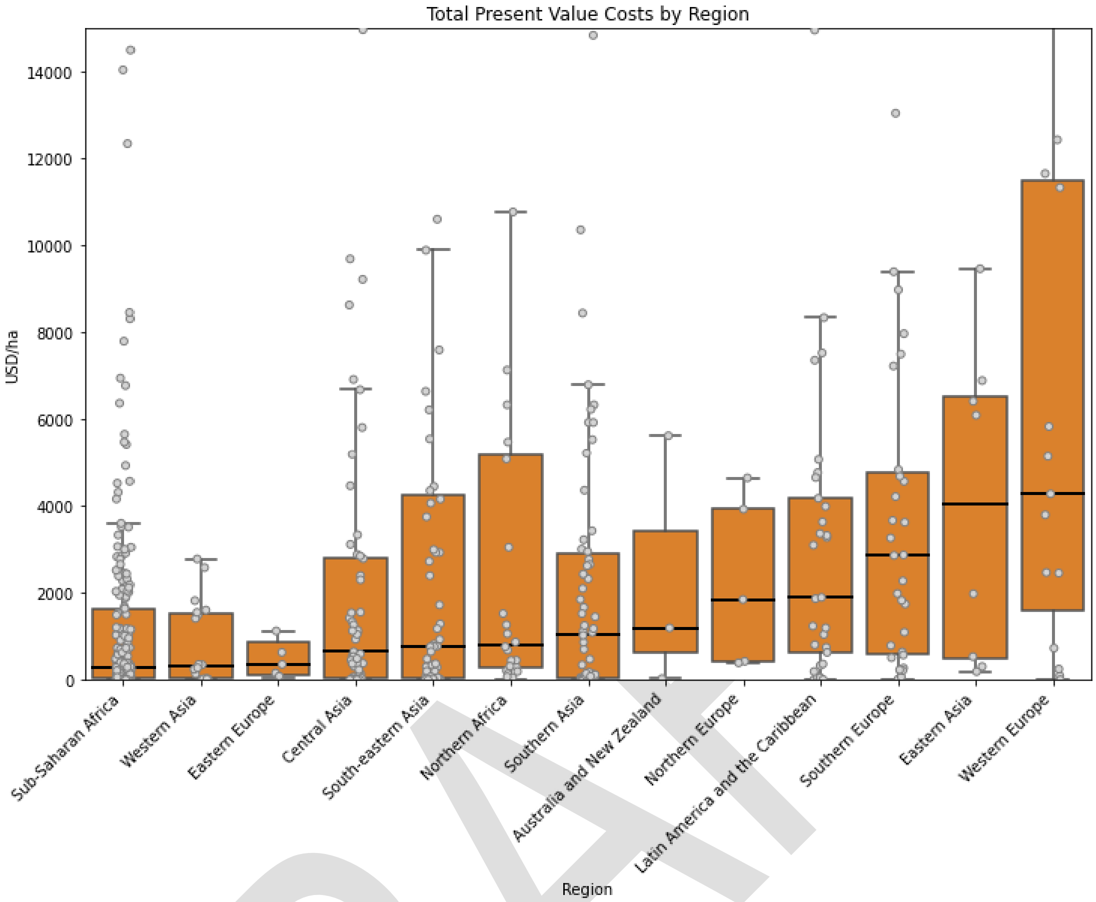

Figure 5: Total present value costs by region. (The orange box is bound by the upper and lower quartiles and the black line marks the median value)

4.2. Costs of implementing sustainable land use management by land use

The SLM technologies from the WOCAT database have been implemented in diverse ecosystems, with with the majority targeting croplands (43%), mixed cropland and grazing land systems (15%), but also grazing land (8%), woodlands (8%), unproductive lands (2%) and and other mixtures, (table 3). Table 3, also shows the first-year establishment costs, annual maintenance costs and total present value costs, for a 10-year time horizon (discounted at 2.5%). Not surprisingly, it is costly to implement SLM practices on unproductive land, with average PV costs in the order of 1645 USD/ha. This resonates with the LDN response hierarchy[26] (Avoid > Reduce > Reverse land degradation) which calls for prioritising the avoidance and reduction of land degradation, over reversing past degradation on degraded land.

The implementation of SLM within forest and woodland is the most costly (total PV cost of 2690 USD/ha), followed by SLM strategies employed with settlements (e.g. roof water harvesting), the

[26] SPI Science-Policy Brief (2016). Land in Balance. Available from URL: https://www.unccd.int/resources/brief/land-balance

restoration of unproductive land, mixed crop, forest and woodland (1552 USD/ha). The implementation of SLM practices on grazing or cropland or mixtures of these are in the order of 316 to 763 USD/ha for a 10-year time-horizon.

Land Use	Summary		PV Costs	Establishment Costs			Maintenance Costs		
	Count	(%)	(2.5%)	Median	Q1	Q3	Median	Q1	Q3
Cropland	220	43.65	763.08	162.29	6.99	961.98	25.64	0.24	156.35
Cropland—Grazing land	78	15.48	501.57	158.05	23.80	1,099.74	19.53	0.16	169.57
Cropland—Grazing land—Forest/ woodlands	55	10.91	328.59	82.69	18.25	356.01	20.80	2.38	165.07
Grazing land	42	8.33	316.85	252.81	17.11	634.29	0.19	0.00	18.14
Cropland—Forest/ woodlands	41	8.13	1,552.65	409.69	51.28	1,687.62	83.57	7.21	259.45
Forest/ woodlands	26	5.16	2,689.07	497.78	140.32	1,634.48	55.29	1.45	346.82
Grazing land—Forest/ woodlands	17	3.37	226.34	191.14	98.84	699.97	1.04	0.00	14.12
Other mixed land uses	11	2.18	288.85	55.31	25.60	361.73	7.11	0.00	53.75
Restoring unproductive lands	10	1.98	1,645.69	1,485.35	117.36	3,619.08	0.66	0.00	344.55
Settlements	2	0.40	2,545.12	2,429.05	1,221.12	3,636.98	14.56	7.97	21.15
Waterways, waterbodies, wetlands	2	0.40	510.86	510.86	255.44	766.27	0.00	0.00	0.00

Table 3: Distribution of costs by Land Use type (PV costs estimated using T=10 years and r=2.5%)

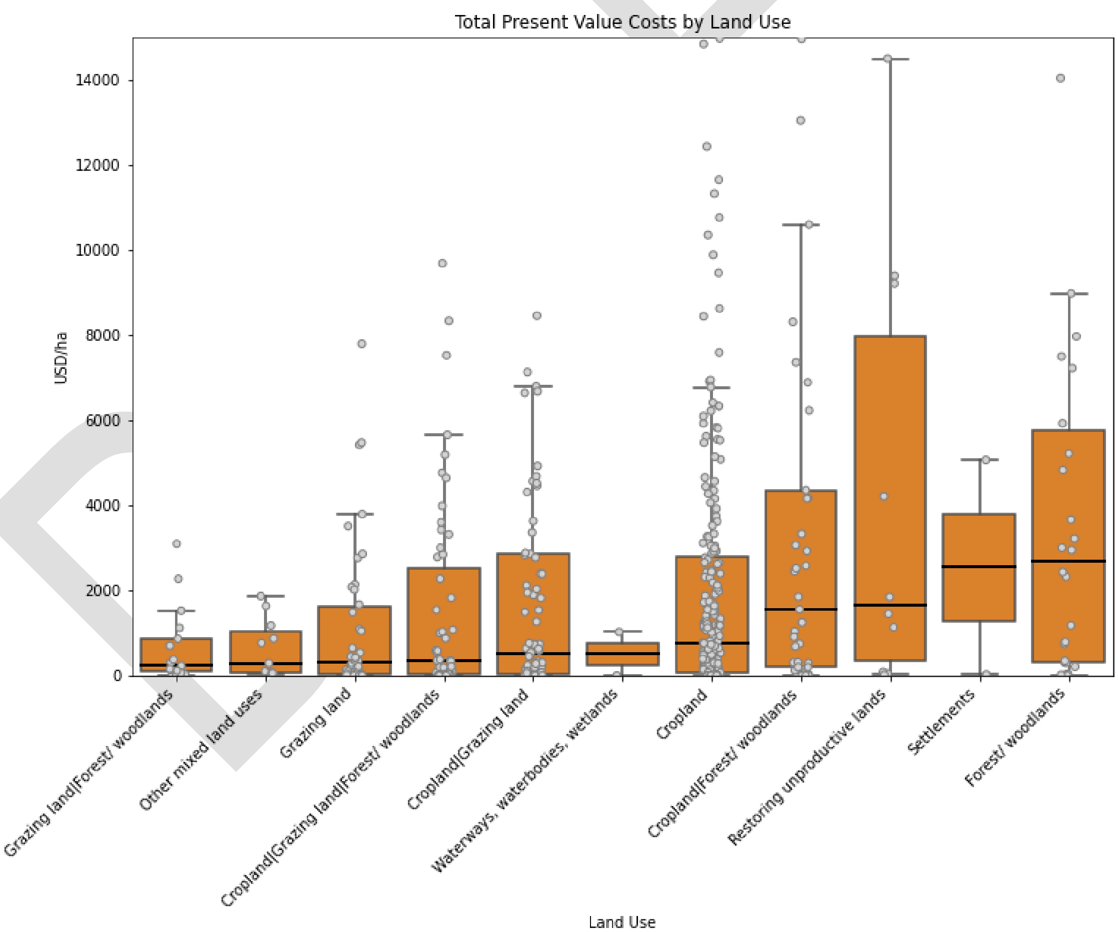

Figure 6: Total present value costs by land use (T=10 years, r=2.5%. The orange box is bound by the upper and lower quartiles and the black line marks the median value)

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4.3. Costs of implementing sustainable land management by SLM Group

According to WOCAT, SLM is defined as the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions[27]. WOCAT focuses mainly on efforts to prevent and reduce land degradation, through agronomic, vegetative, and structural SLM practices. Despite the long-term benefits of implementing SLM there are obstacles to large-scale adoption, due to the associated costs of implementing the SLM practices. The ECON-WOCAT dataset allows for a first-hand insight to those costs.

For this purpose, SLM practices recorded in the WOCAT questionnaire have been categorised using WOCAT's methodology (Critchley, Harari and Mekdaschi-Studer 2021). The connection between the WOCAT SLM group categorisation and mapping to UNCCD-SPI SLM groups can be found in Table 4, following Sanz et al. (2019).

Considering the total costs for a 10-year time period, the most expensive SLM measures are related to integrated-crop livestock management[28] (2510 USD/ha), forest management (1913 USD/ha), crop rotational systems[29] (1683 USD/ha) and agroforestry (1176 USD/ha). All of these exceed 1000 USD/ha in present value terms. The average annual maintenance costs remain less than 100 USD/ha nevertheless.

Situated in the mid-range, minimum tillage and integrated soil fertility management measures[30] have median total present value costs of approximately 600 USD/ha and are generally acknowledged to be a promising measure for wide-scale adoption, because of their relatively low upfront establishment costs (Reichhuber et al., 2019[31]; Liniger and Critchley 2007[32])

Terraces and bunds are amongst the cheapest technologies to implement, requiring less than 100 USD/ha in establishment costs and less than 10 USD/ha in annual maintenance costs. Note however, that there is a wide distribution of costs, pending on the region in which the specific technology is implemented. Table 5 breaks down the cost of the 4 most prevalent SLM technology groups, by region. Whilst the average establishment costs for terraces are below 60 USD/ha in

[27] WOCAT. What is SLM for WOCAT https://www.wocat.net/en/slm/sustainable-land-management
[28] Including: Integrated soil fertility,
[29] Including: Crop rotation, fallows, shifting cultivation, potentially with other measures, such as cross slopes measures or integrated soil fertility management.
[30] Seeking to optimize soil nutrient and water for crop growth, achieved by combining the application of chemical and organic soil additives cuhas livestock manure, compost and green manure.
[31] A. Reichhuber, N. Gerber, A. Mirzabaev, M. Svoboda, A. López Santos, V. Graw, R. Stefanski, J. Davies, A. Vuković, M.A. Fernández García, C. Fiati and X. Jia. 2019. The Land-Drought Nexus: Enhancing the Role of Land-Based Interventions in Drought Mitigation and Risk Management. A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany.
[32] Liniger, H. and Critchley, W. (2007) Where the Land Is Greener: Case Studies and Analysis of Soil and Water Conservation Initiatives Worldwide, CTA, Wageningen.

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Sub-saharan Africa, in Latin America and the Caribbean, establishment costs are in the order of 255 USD/ha. *The example shows how the ECON-WOCAT dataset and dashboard can be used for analysing data by multiple filters of interest (SLM cost by region, by land use type, by category of benefit, etc.)*

Interventions aimed at improving grazing land management have the lowest per hectare costs, of approximately 170 USD/ha over a 10-year horizon. In this regard, it should be recalled that grazing land intervention areas tend to be significantly larger than for many cropping systems (with lower per hectare profitability). It is therefore not unexpected that SLM implementation costs are of smaller magnitudes for grazing management compared to SLM practices focused on cropping systems.

*Should the user wish to understand more about the specific interventions, they can apply relevant filters and access the individual case-studies directly from the ECON-WOCAT database, or the ECON-WOCAT dashboar*d.

Finally, it is important to note, that when the practitioner fills in the WOCAT survey, he can select up to three types of measure (agronomic, vegetagive and structure) and a total of three practices (water harvesting, etc) when describing the technology involved. Therefore, although we provide a cost-estimate for a single SLM measure, it is very likely that it is implemented in parallel to other measures. In using the ECON-WOCAT dataset and database however, the user can also decide to look at the cost of an individual practice only.

SLM Group	Summary		PV Costs	Establishment Costs			Maintenance Costs		
	Count	(%)	(2.5%)	Median	Q1	Q3	Median	Q1	Q3
Improved ground cover	89	18	787	226	32	1,109	20	0	140
Agroforestry	75	15	1,176	285	46	973	84	5	359
Terraces and bunds	70	14	135	60	18	253	7	0	37
Forest management	50	10	1,913	427	47	1,327	62	1	377
Crop rotational systems	39	8	1,683	241	16	1,466	60	4	623
Irrigation and water management	32	6	442	139	14	1,121	1	0	55
Protected areas	29	6	700	274	50	1,447	19	0	77
Grazing land management	28	6	173	69	21	428	0	0	17
Integrated soil fertility management	22	4	633	141	13	547	34	0	154
Water harvesting	22	4	414	199	18	691	12	0	40
Miscellaneous	20	4	1,561	238	11	2,502	7	0	860
Minimum tillage	19	4	644	47	1	758	4	0	52
Integrated crop-livestock management	12	2	2,510	1,638	107	6,991	98	17	524

Table 4: Costs distribution by SLM Group

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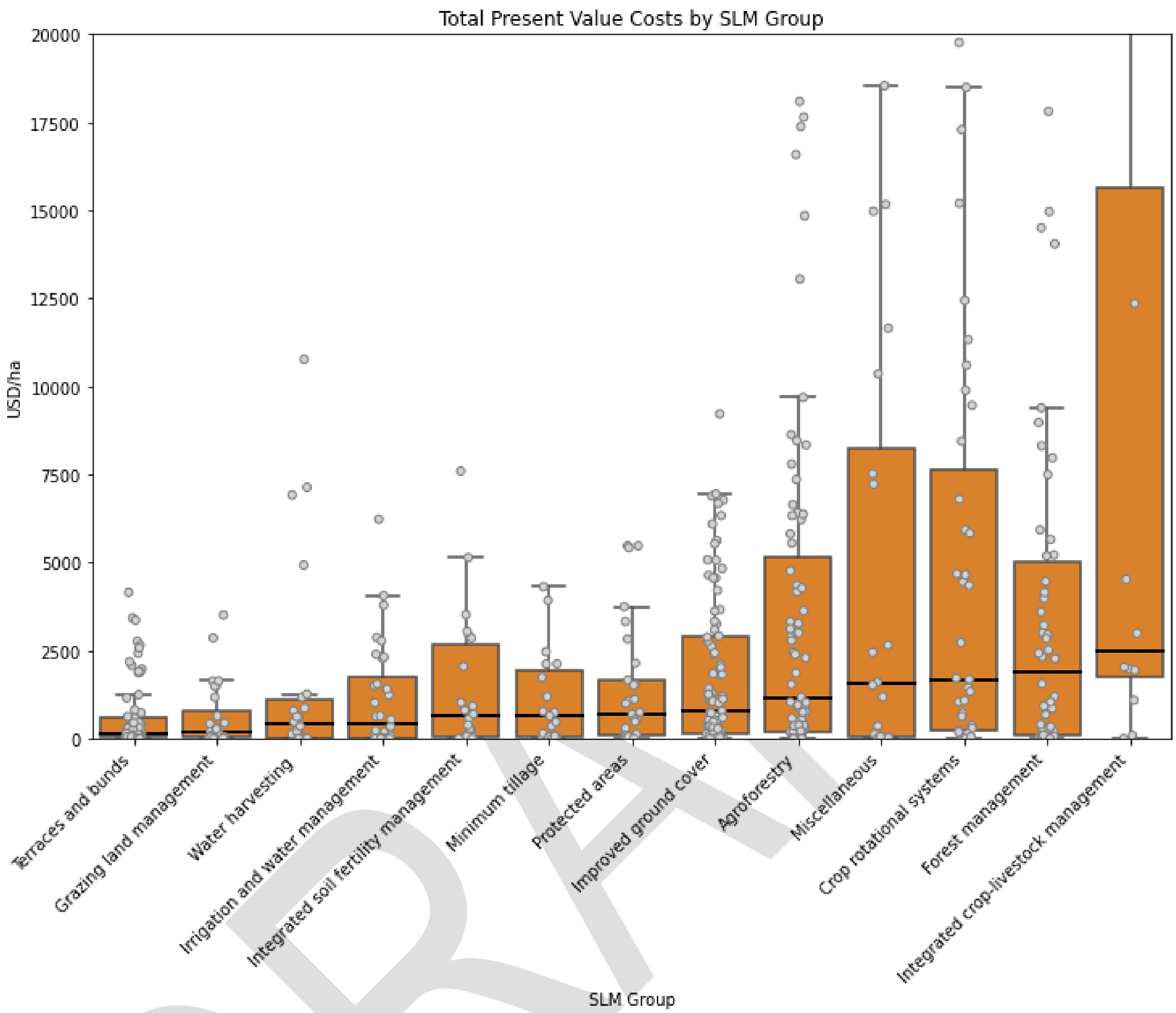

Figure 7: Total present value costs by SLM group (The orange box is bound by the upper and lower quartiles and the black line marks the median value)

SLM Group	Region	Summary		PV Costs	Establishment Costs			Maintenance Costs		
		Count	(%)	(2.5%)	Median	Q1	Q3	Median	Q1	Q3
Agroforestry	Central Asia	14	4.93	994.27	160.30	46.40	533.47	114.43	2.97	280.53
	Eastern Asia	3	1.06	531.09	409.17	292.11	573.36	15.99	15.64	364.10
	Latin America and the Caribbean	8	2.82	3,900.29	752.39	364.98	1,562.55	433.51	293.77	496.11
	Northern Africa	3	1.06	6,331.73	1,867.07	933.54	9,035.77	382.12	264.66	471.12
	South-eastern Asia	13	4.58	2,393.30	762.08	177.30	914.09	70.22	14.06	472.59
	Southern Asia	4	1.41	2,766.67	1,305.32	700.42	2,835.37	183.34	24.46	519.74
	Southern Europe	1	0.35	13,049.56	2,424.76	2,424.76	2,424.76	1,332.95	1,332.95	1,332.95
	Sub-Saharan Africa	28	9.86	371.51	158.32	3.15	366.58	20.21	0.23	101.01
	Western Europe	1	0.35	4,273.16	446.16	446.16	446.16	480.12	480.12	480.12
Forest management	Central Asia	5	1.76	2,844.36	1,072.97	697.20	1,232.34	58.35	40.18	222.23
	Latin America and the Caribbean	5	1.76	1,192.81	412.51	7.64	574.93	97.89	5.39	427.84
	Northern Africa	5	1.76	207.62	105.53	78.05	159.11	3.69	2.64	16.26
	South-eastern Asia	4	1.41	318.37	96.57	21.86	185.39	27.83	16.57	46.56
	Southern Asia	10	3.52	2,689.07	497.78	220.84	726.12	272.37	72.93	346.82
	Southern Europe	7	2.46	7,969.01	6,035.64	2,205.17	7,997.19	119.33	0.00	546.92
	Sub-Saharan Africa	13	4.58	2,517.41	401.30	7.09	1,358.82	185.70	0.16	433.05
	Western Asia	1	0.35	28.19	15.27	15.27	15.27	1.62	1.62	1.62
Improved ground cover	Australia and New Zealand	1	0.35	5,621.31	0.00	0.00	0.00	705.23	705.23	705.23
	Central Asia	14	4.93	1,128.25	213.83	58.05	1,187.36	60.18	8.75	154.91
	Eastern Asia	2	0.70	6,492.04	4,301.21	3,461.11	5,141.31	274.85	144.48	405.23
	Eastern Europe	1	0.35	1,120.47	767.37	767.37	767.37	44.30	44.30	44.30
	Latin America and the Caribbean	4	1.41	1,641.44	1,523.50	124.93	3,371.54	14.80	2.04	27.09
	Northern Africa	4	1.41	908.10	355.34	232.96	490.45	41.06	27.83	193.01
	Northern Europe	2	0.70	3,242.73	1,323.97	1,063.61	1,584.33	240.72	120.36	361.08
	South-eastern Asia	3	1.06	16.54	5.94	3.54	45.12	1.33	1.14	75.94
	Southern Asia	9	3.17	1,847.62	627.71	48.25	1,087.11	12.74	2.43	184.29
	Southern Europe	12	4.23	2,541.79	725.29	437.22	3,360.58	0.00	0.00	43.92
	Sub-Saharan Africa	34	11.97	258.98	85.07	5.70	342.75	7.14	0.03	109.04
	Western Asia	3	1.06	345.00	345.00	179.12	819.00	1.15	0.57	33.57
Terraces and bunds	Central Asia	1	0.35	54.07	54.07	54.07	54.07	0.00	0.00	0.00
	Eastern Asia	1	0.35	1,976.75	1,625.27	1,625.27	1,625.27	44.10	44.10	44.10
	Latin America and the Caribbean	5	1.76	628.20	254.50	151.30	1,892.14	37.24	22.01	46.88
	Northern Africa	1	0.35	447.25	447.25	447.25	447.25	0.00	0.00	0.00
	South-eastern Asia	7	2.46	47.39	13.93	5.31	66.68	3.25	1.45	29.79
	Southern Asia	11	3.87	102.06	25.17	12.47	918.33	7.48	0.00	39.74
	Southern Europe	1	0.35	268.23	139.72	139.72	139.72	16.12	16.12	16.12
	Sub-Saharan Africa	40	14.08	135.46	59.64	20.99	185.22	7.12	0.22	22.55
	Western Asia	3	1.06	18.62	15.27	14.80	789.11	0.42	0.31	63.89

Table 5: Costs distribution by selected SLM Groups and Region.

4.4. Breakdown of the costs of establishing and maintaining SLM practices

In terms of the categories of inputs that are required to implement the SLM practices, figure 8 and 9 below shows that the vast majority of costs are related to labour effort. Specifically, for SLM technology groups such as water harvesting, minimum tillage, integrated soil fertility management, irrigation and water management, and setting up a protected (enclosed) area, labour costs represent more than 90% of all costs (calculated from table 6). For crop rotations and agroforestry, integrated crop-livestock management, equipment and plant material represent a noticeable share of the implementation costs. As for the annual maintenance costs of the SLM technologies, these relate almost exclusively to labour effort (table 7). The labour intensive nature of SLM implies that SLM practices are more likely to be rolled-out and scaled-up where labour resources are more abundant and during the slack season.

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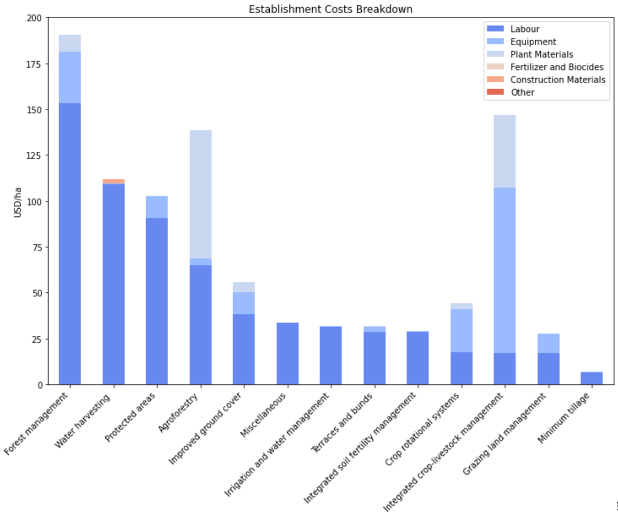

Figure 8: Average establishment costs breakdown by SLM Group

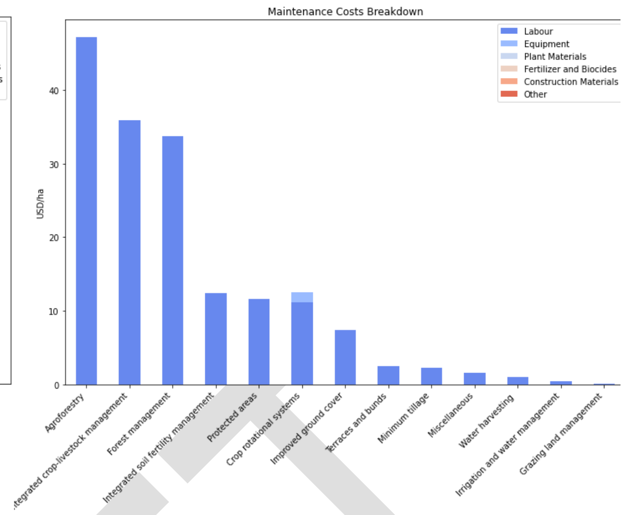

Figure 9: Average maintenance costs breakdown by SLM Group

	Labour	Equipment	Plant Materials	Fertilizer and Biocides	Construction Materials	Other
Forest management	153	28	9	0	0	0
Water harvesting	109	1	0	0	2	0
Protected areas	91	12	0	0	0	0
Agroforestry	65	3	70	0	0	0
Improved ground cover	38	12	6	0	0	0
Miscellaneous	34	0	0	0	0	0
Irrigation and water management	31	0	0	0	0	0
Terraces and bunds	29	3	1	0	0	0
Integrated soil fertility management	28	0	0	0	0	0
Crop rotational systems	18	23	3	0	0	0
Integrated crop-livestock management	17	90	40	0	0	0
Grazing land management	17	10	0	0	0	0
Minimum tillage	7	0	0	0	0	0

Table 6: Establishment costs breakdown by SLM Group

	Labour	Equipment	Plant Materials	Fertilizer and Biocides	Construction Materials	Other
Agroforestry	47	0	0	0	0	0
Integrated crop-livestock management	36	0	0	0	0	0
Forest management	34	0	0	0	0	0
Integrated soil fertility management	12	0	0	0	0	0
Protected areas	12	0	0	0	0	0
Crop rotational systems	11	1	0	0	0	0
Improved ground cover	7	0	0	0	0	0
Terraces and bunds	3	0	0	0	0	0
Minimum tillage	2	0	0	0	0	0
Miscellaneous	2	0	0	0	0	0
Water harvesting	1	0	0	0	0	0
Irrigation and water management	0	0	0	0	0	0
Grazing land management	0	0	0	0	0	0

Table 7: Maintenance costs breakdown by SLM Group

4.5. Perceived benefits by SLM group

Finally, the Econ-WOCAT dataset also provides information on a multitude of perceived benefits that derive from the SLM interventions (ecological, water quality and quantity, production benefits in terms of crops, forage, timber and NTFPs, cultural benefits, household income etc.). For the sake of illustration only, we show the aggregated benefits for production related ecosystem services and income in figure 10 and 11 for the main SLM groups under consideration. As can be seen, in all cases, production benefits are considered positive to very positive by land users in at least 60% of the case-studies. In terms of income, at least 50% of the studies report positive to very positive outcomes. However, for crop rotational systems, or protected areas, there are a noticeable share of studies (15-20%), reporting slightly negative to negative outcomes. For crop rotational systems, this may be due to the fact that they are relatively expensive (as shown above), whilst protected areas designation, may limit what can be harvested and therefore associated income. Individual case-studies (with qualitative free-text) can be consulted to better understand the reasons behind the specific results

4.5.1. Production Benefits by SLM Group

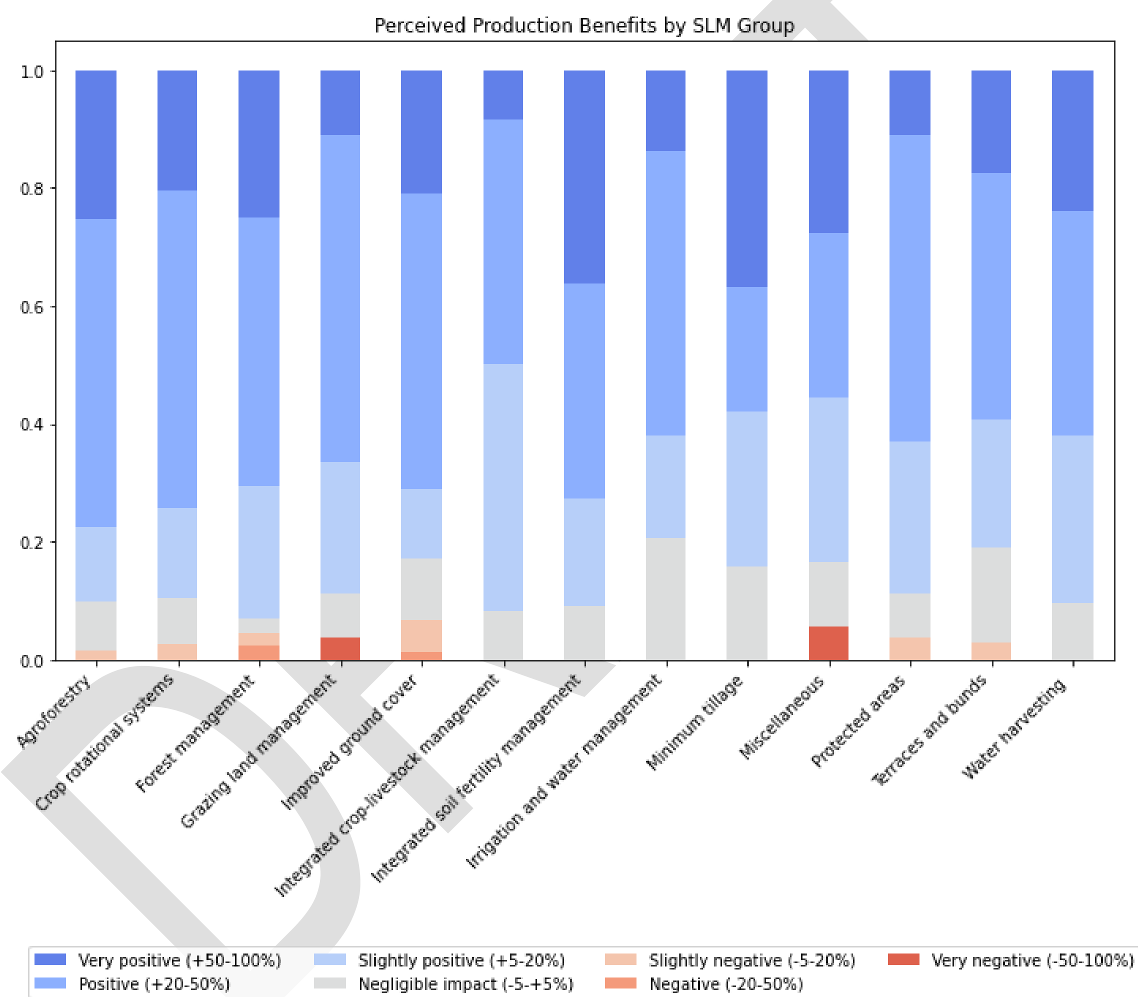

Figure 10: Production Benefits by SLM Group

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4.5.2. Income Benefits by SLM Group

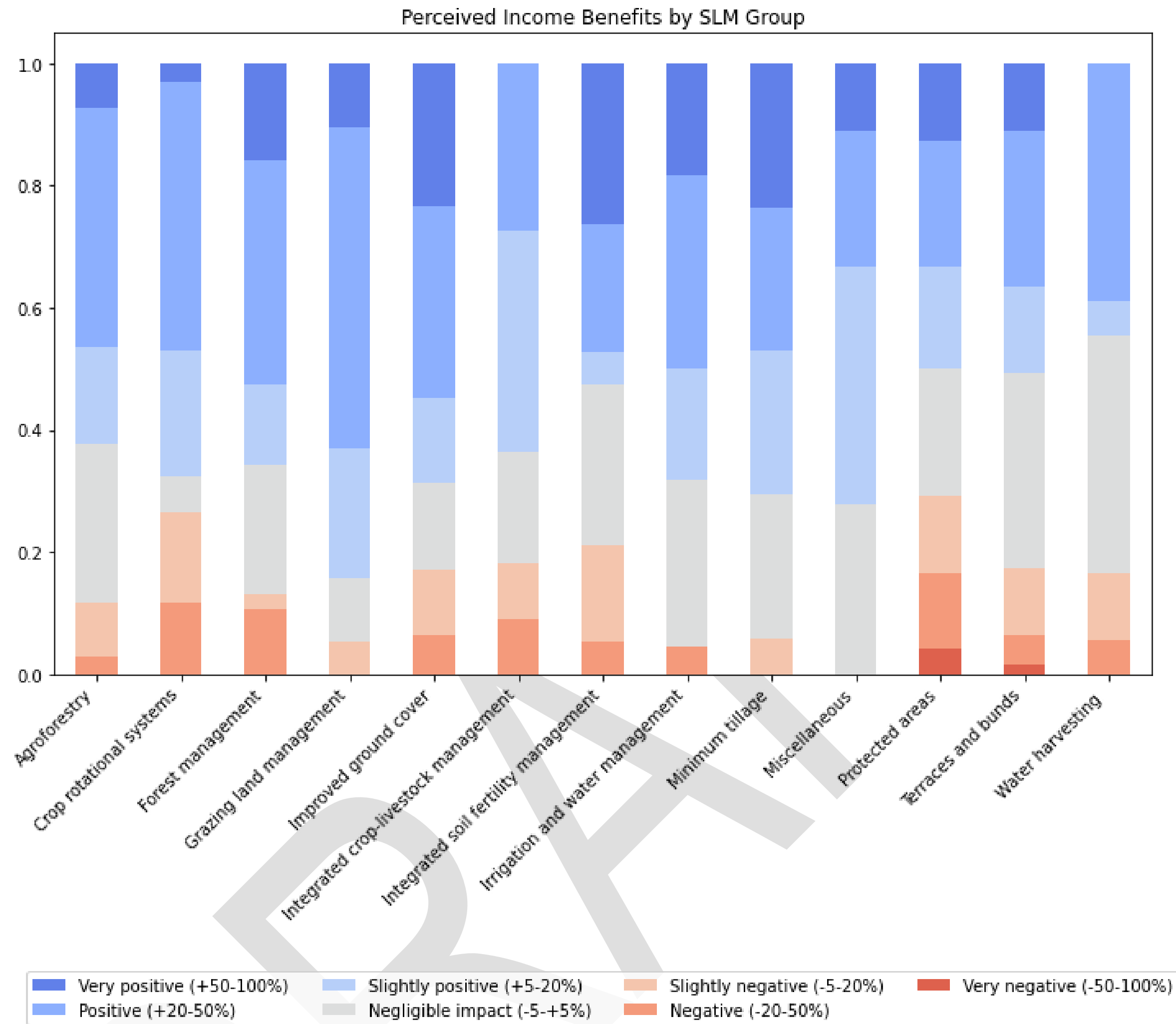

Figure 11: Income Benefits by SLM Group

4.6. Other analytical possibilities

When using the ECON-WOCAT Dataset, users can also make further breakdowns, and analyse for example, the spread of costs of individual technologies, within a given region. Combining this with perceived benefits (see figure 10 for production benefits), the dataset user can search for the most cost-effective technologies for the impact item of interest. For example, a given user may wish to implement one or several SLM technologies that have a positive impact on water quality and availability, but at reasonable cost within a given region. In that case, the dataset user will firstly select the region of interest, then filter on impacts on water, and finally, on SLM strategy. This would allow a ranking of SLM technologies in terms of perceived impact on water per $ spent over a 10-year time-period.

The interested reader is referred to the guidance document for more information on how the dataset can be used.

5. Caveats and limitations

As with any dataset there are a number of caveats and limitations to be aware of when analysing and interpreting results. First and foremost, the WOCAT questionnaire has been populated by different people with diverse backgrounds and in multiple languages, which may introduce differences in interpretation and the ways that the data has been collected within the land use communities.

In harmonising the ECON-WOCAT it was assumed that the questions have been answered as intended, but there may be hidden bias, especially with regards to the perceived benefits, due to potential differences in the appreciation of what is asked for within a given question. For example, *Q6.1 onsite impacts of the Technology* asks about the perceived increase in crop productivity, crop quality, fodder production, wood production, etc… for a total of 14 categories, using a 7-point likert scale, from -100% to +100%. In this regard, some users may have paid attention to the percentages (and calculated the actual quantification of the benefits), whilst others have been more focused on the ranking of the benefits. In a similar fashion, depending on who has entered the data, e.g. a researcher versus a project manager, there may be differences in regards to how the perceived benefits have been assessed. There may likewise be a self-selection entry bias, in that projects that were successful are more likely to be recorded relative to unsuccessful projects. As such, the data may be skewed towards successful projects.

As the majority of database entries do not record the total intervention area the technology was implemented in[33], we used the *Average area of land owned, leased or used (with user rights) by land users applying the Technology* (average land size) to assess the scale within which the technologies were implemented. As over 70% of the dataset concerns land users applying the technology on areas less than 5 hectares we can assume the costs and benefits are relevant to smallholders, but may not scale directly to thousands of hectares.

Finally, the dashboard and dataset allows users to filter the data to answer questions relevant to their interests. In doing so users can encounter scenarios with limited data available. Caution must therefore be exercised when extracting results from small sample sizes and careful consideration of the filters that can be used to expand a search to include other comparable landscapes is recommended to increase the sample size.

6. Conclusion and Outlook

[33] Only 8% (45/507 entries) contain area data in Q2.5 in the WOCAT Questionnaire

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The WOCAT Database has been extracted and systematically harmonised to produce the new ECON-WOCAT Dataset and Dashboard. The dataset has detailed quantitative information on the costs of implementing and maintaining a diverse range of SLM technologies across the globe. However, at present, the benefits procuring from the SLM technologies are primarily described in qualitative terms. For this reason, it would be important to enhance the ability of the WOCAT questionnaire to capture easily quantifiable benefits – such as crop yields and other provisioning ecosystem services - that can be assessed with field data. Coupled with data on input costs, revenues, incomes and returns on investments can easily be estimated. This could in turn help mobilise more reliable and affordable finance for smallholders. Indeed, one of key constraints to greater integration of biodiversity, nature and ecosystem conservation in investment decision-making by development finance institutions and impact investors, is the ability to monitor and verify changes that are directly attributable to specific SLM investments and technologies. Today, there is a lack of reliable baselines to work from, and the costs of establishing monitoring, reporting and verification (MRV) systems to understand the positive or negative impacts of technology are considered prohibitive in already low-margin settings, such as smallholder farming[34]

Secondly, it would also be of interest to expand the database to allow for repeated observations that can capture the evolution of SLM costs and benefits over time. Moreover, increasing the geographic granularity of the future versions of the ECON-WOCAT dataset would increase the value added for location-specific sub-national LDN activities and allow for coupling field based measurements with earth observations.

Thirdly, research on land degradation neutrality must increasingly draw on comprehensive transdisciplinary conceptual frameworks, such as the nexus between land-climate-biodiversity. Reaching net-zero by 2050 and avoiding a climate catastrophe requires a transformation of the agriculture and forestry sectors from greenhouse gas sources to sinks within 30 years. Efforts to conserve and restore soil health must start immediately, if we are achieving the Paris climate target, the Convention on Biological Diversity, Land Degradation Neutrality and broader global sustainability targets embedded in the United Nations Sustainable Development Goals[35].

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[34] Jonathan Casey, Alexander Bisaro, Alvaro Valverde, Marlon Martinez and Martin Rokitzki (2020). Private finance investment opportunities in climate-smart agriculture technologies. The CASA programme under the UK Foreign, Commonwealth and Development Office (FCDO). https://www.casaprogramme.com/wp-content/uploads/2021/10/Private-finance-investment-opportunities-in-climate-smart-agriculture-technologies.pdf

[35] Johan Rockström and Tim Beringer and David Hole and Bronson Griscom and Michael B. Mascia and Carl Folke and Felix Creutzig (2021). We need biosphere stewardship that protects carbon sinks and builds resilience. Proceedings of the National Academy of Sciences. V(18) n38, pages 2115-2181. URL https://www.pnas.org/doi/abs/10.1073/pnas.2115218118

This will also require advances in cross-sectoral ecosystem service valuation, to demonstrate the impact of the SLM adoption. In this regard, enhancing linkages between ECON-WOCAT dataset to other relevant data sources such as The Ecosystem Services Valuation Database (ESVD) and case studies under the Economics of Land Degradation (ELD) initiative and TEEB for agriculture.

Whilst there are many interesting improvements in perspective, as the first dataset of its kind, the ECON-WOCAT dataset has significant and timely value today - in terms of providing readily available information, on the actual costs, and perceived benefits of adopting and maintaining wide-ranging sustainable land management practices, across 11 land use types, 9 climates, 75 countries and 14 regions of the world.

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Annex

A. Dataset contents

	Question or Question data is derived from	Added	Description
code	N/A		Questionnaire ID
Continent	Q2.5	Y	Continent in which the technology is implemented
Sub-region Name	Q2.5	Y	Region in which the technology is implemented
Intermediate Region Name	Q2.5	Y	Sub Region in which the technology is implemented
Country	Q2.5		Country
Main purpose	Q3.1		What is the main purpose of the technology? Up to 5 answers per technology. examples include: Improve production, preserve/ improve biodiversity
Degradation addressed	Q3.7		Main types of land degradation addressed by the Technology. Examples include; soil erosion by water, soil erosion by wind, biological degradation
Land use	Q3.2		Current land use type(s) where the Technology is applied
Land use Simplified	Q3.2	Y	A simplified grouping of the Land use for easier analysis. (Reduces the land use list from 36 unique combinations of values to 11)
Mixed land use type	Q3.2		Is land use mixed within the same land unit (following ICRAF definitions)? Mixed land use: a mixture of crops, grazing, and trees within the same land unit, e.g. agroforestry, agro-silvopastoralism.
Cropland sub-category	Q3.2		Cropland land use sub category: Annual cropping Perennial cropping Tree and shrub cropping Other
Grazing extensive sub-category	Q3.2		Grazing land use sub category: Extensive grazing Nomadism Semi-nomadic pastoralism Transhumant pastoralism Ranching

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Grazing intensive sub-category	Q3.2		Grazing land use sub category: Intensive grazing Cut-and-carry/ zero grazing Improved pasture
Forest type	Q3.2		Forest/ woodlands land use type: (Semi-)natural forests/ woodlands Tree plantation, afforestation
Forest (Natural) sub-category	Q3.2		Forest/ woodlands land use sub type (Semi-)natural forests/ woodlands: Selective felling Clear felling Shifting cultivation Removal of deadwood or cuttings Non-wood forest use
Forest (Plantation) sub-category	Q3.2		Forest/ woodlands land use sub type Tree plantation, afforestation: Monoculture local variety Monoculture exotic variety Mixed varieties
Settlement sub-category	Q3.2		Settlements, infrastructure sub categories: Settlements, buildings Traffic: roads, railways Energy: pipelines, power lines
Waterways sub-category	Q3.2		Waterways, waterbodies, wetlands sub categories: Drainage lines, waterways Ponds, dams Swamps, wetlands Rivers and riparian zone Lakes and lakeshores Sea and seashores
Original landuse changed?	Q3.3		Has land use changed due to the implementation of the Technology?
Original landuse	Q3.3		The original land use
Watersupply	Q3.4		Water supply for the land on which the Technology is applied
Annual rainfall	Q5.1		Annual rainfall in mm
Agroclimatic zone	Q5.1		Agro-climatic zone Humid: length of growing period (LGP) > 270 days Sub-humid: LGP 180-269 days Semi-arid: LGP 75-179 days Arid: LGP < 74 days

Slope angle	Q5.2		Slopes on average flat (0-2%) gentle (3-5%) moderate (6-10%) rolling (11-15%) hilly (16-30%) steep (31-60%) very steep (> 60%)
Altitude	Q5.2		Altitudinal zone < 100 m a.s.l. 101-500 m a.s.l. 501-1,000 m a.s.l. 1,001-1,500 m a.s.l. 1,501-2,000 m a.s.l. 2,001-2,500 m a.s.l. 2,501-3,000 m a.s.l. 3,001-4,000 m a.s.l. > 4,000 m a.s.l.
Landforms	Q5.2		Landforms (modified from ISRIC 1993): Plateau/ plains: extended level land (slopes less than 8%). Ridges: narrow elongated area rising above the surrounding area, often hilltops or mountaintops. Mountain slopes (including major escarpments): extended area with altitude differences of more than 600 m per 2 km and slopes greater than 15% Hill slopes (including valley and minor escarpment slopes): altitude difference of less than 600 m per 2 km and slopes greater than 8% Footslopes: zone bordering steeper mountain/ hill slopes on one side and valley floors/ plains/ plateaus on the other side Valley floors: elongated strips of level land (less than 8% slope), flanked by sloping or steep land on both side
Gender	Q5.6		The gender characteristics of the average/ typical land users who applies the Technology
Average land size	Q5.7		Average area of land owned, leased or used (with user rights) by land users applying the Technology
Land ownership	Q5.8		Land ownership state company communal/ village group individual, not titled individual, titled

			other
Land user rights	Q5.8		Land use rights: Open access: means free for all Communal (organized): means subject to community-agreed management rules Leased: right to use land for a limited period of time against payment (contract) Individual: right of use pertains to single user
Water user rights	Q5.8		Water use rights: Open access: means free for all Communal (organized): means subject to community-agreed management rules Leased: right to use land for a limited period of time against payment (contract) Individual: right of use pertains to single user
How does the technology survive storms?	Q6.3	Y	The median response from how the technology survives meteorological disasters
How does the technology survive fires?	Q6.3	Y	The median response from how the technology survives fire disasters
How does the technology survive floods?	Q6.3	Y	The median response from how the technology survives flood disasters
How does the technology survive temperature variation?	Q6.3	Y	The annual temperature exposure sensitivity
How does the technology survive rain variation?	Q6.3	Y	The annual rainfall exposure sensitivity
How does the technology survive droughts?	Q6.3	Y	The drought exposure sensitivity
How does the technology survive landslides?	Q6.3	Y	The landslide/ debris flow exposure sensitivity
How does the technology survive pests?	Q6.3	Y	The insect infestation exposure sensitivity
SLM Group (WOCAT)	Q3.5		WOCAT SLM group to which the Technology belongs. Up to 3 can be selected
SLM Groups Simplified (WOCAT)	Q3.5	Y	A simplified grouping of the WOCAT SLM Groups for easier analysis. (Reduces the SLM Group list from 251 unique combinations of values to 12)

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Type of measure	Q3.6	Y	SLM measures comprising the Technology, simplified into 8 options
Total establishment costs ($/ha)	Q4.3	Y	The total establishment costs in 2020 USD/ha
Total maintenance costs ($/ha)	Q4.4	Y	The total maintenance costs in 2020 USD/ha
Total present value 0% ($/ha)	Q4.3, Q4.4	Y	The total present value costs in 2020 USD/ha using a 0% discount rate
Total present value 2.5% ($/ha)	Q4.3, Q4.4	Y	The total present value costs in 2020 USD/ha using a 2.5% discount rate
Total present value 5% ($/ha)	Q4.3, Q4.4	Y	The total present value costs in 2020 USD/ha using a 5% discount rate
Annuity costs 0% ($/ha)	Q4.3, Q4.4	Y	The annuity costs in 2020 USD/ha using a 0% discount rate
Annuity costs 2.5% ($/ha)	Q4.3, Q4.4	Y	The annuity costs in 2020 USD/ha using a 2.5% discount rate
Annuity costs 5% ($/ha)	Q4.3, Q4.4	Y	The annuity costs in 2020 USD/ha using a 5% discount rate
Est. labour costs ($/ha)	Q4.3	Y	The establishment labour costs in 2020 USD/ha
Est. equipment costs ($/ha)	Q4.3	Y	The establishment equipment costs in 2020 USD/ha
Est. plant materials costs ($/ha)	Q4.3	Y	The establishment plant material costs in 2020 USD/ha
Est. fertilizer costs ($/ha)	Q4.3	Y	The establishment fertilizer costs in 2020 USD/ha
Est. construction costs ($/ha)	Q4.3	Y	The establishment construction costs in 2020 USD/ha
Est. other costs ($/ha)	Q4.3	Y	The establishment other costs in 2020 USD/ha
Maint. labour costs ($/ha)	Q4.4	Y	The maintenance labour costs in 2020 USD/ha
Maint. equipment costs ($/ha)	Q4.4	Y	The maintenance equipment costs in 2020 USD/ha
Maint. plant materials costs ($/ha)	Q4.4	Y	The maintenance plant material costs in 2020 USD/ha
Maint. fertilizer costs ($/ha)	Q4.4	Y	The maintenance fertilizer costs in 2020 USD/ha
Maint. construction costs ($/ha)	Q4.4	Y	The maintenance construction costs in 2020 USD/ha
Maint. other costs ($/ha)	Q4.4	Y	The maintenance other costs in 2020 USD/ha
Est. labour (days)	Q4.3	Y	The establishment labour days
Maint. labour (days)	Q4.4	Y	The maintenance labour days

Est. costs perceived short term benefits	Q6.4		The establishment costs perceived short term benefits (1-3yrs)
Est. costs perceived long term benefits	Q6.4		The establishment costs perceived long term benefits (10yrs)
Maint. costs perceived short term benefits	Q6.4		The maintenance costs perceived short term benefits (1-3yrs)
Maint. costs perceived long term benefits	Q6.4		The maintenance costs perceived long term benefits (10yrs)
Tech adoption percentage	Q6.5		How many land users in the area have adopted/ implemented the Technology?
Tech adoption spontaneously	Q6.5		Of all those who have adopted the Technology, how many have did so spontaneously, i.e. without receiving any material incentives/ payments?
Socio economic production benefits	Q6.1	Y	The median response of the socio-economic production impacts
Socio economic water benefits	Q6.1	Y	The median response of the socio-economic water impacts
Socio economic income benefits	Q6.1	Y	The median response of the socio-economic income impacts
Socio cultural benefits	Q6.1	Y	The median response of the socio-cultural impacts
Ecological water benefits	Q6.1	Y	The median response of the ecological water impacts
Ecological soil benefits	Q6.1	Y	The median response of the ecological soil impacts
Ecological biodiversity benefits	Q6.1	Y	The median response of the ecological biodiversity impacts
Ecological climate and disaster risk resistance benefits	Q6.1	Y	The median response of the ecological climate and disaster risk impacts
Offsite benefits	Q6.1	Y	The median response of the offsite impacts
Socio Economic Production (Numeric)	Q6.1	Y	The median response of the socio-economic production impacts
Socio Economic Water (Numeric)	Q6.1	Y	The median response of the socio-economic water impacts
Socio Economic Income (Numeric)	Q6.1	Y	The median response of the socio-economic income impacts
Socio Cultural (Numeric)	Q6.1	Y	The median response of the socio-cultural impacts
Ecological Water (Numeric)	Q6.1	Y	The median response of the ecological water impacts
Ecological Soil (Numeric)	Q6.1	Y	The median response of the ecological soil

			impacts
Ecological Biodiversity (Numeric)	Q6.1	Y	The median response of the ecological biodiversity impacts
Ecological Climate / Disaster Risk (Numeric)	Q6.1	Y	The median response of the ecological climate and disaster risk impacts
Offsite (Numeric)	Q6.1	Y	The median response of the offsite impacts
Technology Name	Q1.1		Name of the SLM Technology
Link	N/A		Link to the WOCAT Database and individual case study