Coordination of International Research Cooperation on soil CArbon Sequestration in Agriculture (CIRCASA)

Horizon 2020

Call: H2020-SFS-2016-2017 (Sustainable Food Security – Resilient and resource-efficient value chains)

Type of action: CSA (Coordination and support action)
Grant Agreement: 774378-CIRCASA

DELIVERABLE TYPE: Report

DELIVERABLE NUMBER: D2.2

DELIVERABLE TITLE: **"Assessing barriers and solutions to the implementation of SOC sequestration options"**

Abstract: Report on the key barriers and solutions for the implementation of SOC sequestration options across different geographic zones and what knowledge gaps need to be filled to overcome barriers.

Start date of the project: November 1, 2017

Due date of deliverable: M16

Actual submission date: M20

Organisation name of lead contractor: IITA

Dissemination level: PU/~~PP~~/~~RE~~/~~CO~~

AUTHORS:

Claessens, L.; Frelih-Larsen, A.; Ittner, S.; Tarpey, J.; Olesen, J.E.; Graversgaard, M.; Emoke Madari, B.; Razafimbelo, T.; Kontoboytseva, A.; Nciizah, A.; Swanepoel, C.; Katto, C.; Verchot, L.; Baldock, J.; Grundy, M.; Hongmin, D.; Li, Y.; McNeill, S.; Arias-Navarro, C.; Soussana, J.-F.

CITATION:

CIRCASA, 2019. Deliverable D1.1: "*Assessing barriers and solutions to the implementation of SOC sequestration options".*[Claessens, L.; Frelih-Larsen, A.; Ittner, S.; Tarpey, J.; Olesen, J.E.; Graversgaard, M.; Emoke Madari, B.; Razafimbelo, T.; Kontoboytseva, A.; Nciizah, A.; Swanepoel, C.; Katto, C.; Verchot, L.; Baldock, J.; Grundy, M.; Hongmin, D.; Li, Y.; McNeill, S.; Arias-Navarro, C.; Soussana, J.-F.]. European Union's Horizon 2020 research and innovation programme grant agreement No 774378 - Coordination of International Research Cooperation on soil CArbon Sequestration in Agriculture. https://doi.org/10.15454/SYP4PE

DISCLAIMER OF WARRANTIES

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement **No 774378**.

Table of content

GLOSSARY

Carbon sequestration	Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide in plants, soils, geologic formations, and the ocean.
SOC	Soil organic carbon (SOC) is one part in the much larger global carbon cycle that involves the cycling of carbon through soil, vegetation, oceans, and the atmosphere. SOC is the main component of soil organic matter.
SOM	Soil Organic Matter (SOM) also includes nutrients such as nitrogen, phosphorous and sulphur. It is divided into living and dead components and can range from very recent inputs such as roots and stubble to largely decayed materials that are thousands of years old.
SDGs	The Sustainable Development Goals (SDGs) are a collection of 17 global goals set by the United Nations General Assembly in 2015 for the year 2030. The SDGs are part of Resolution 70/1 of the United Nations General Assembly, the 2030 Agenda.

FIGURES

TABLES

Executive Summary

There is an increased awareness and interest in the potential of agricultural soils to contribute to climate change mitigation, adaptation and food security through improved Soil Organic Carbon (SOC) management. Streamlining research collaboration and informing policies on soils for SOC sequestration requires common understanding by stakeholders of the current status of soils and the options for enhanced carbon storage. WP2 of the CIRCASA project aims to carry out a dialogue with stakeholders on challenges and opportunities related to SOC. We gathered stakeholders' perspectives on the potential for soil carbon management to contribute to climate change mitigation and adaptation, sustainable intensification of agriculture, multiple Sustainable Development Goals (SDGs), and on the barriers to implementation and potential solutions to these barriers.

Towards this effort, a mixed method was applied, combining quantitative and qualitative data gathering. This included workshop dialogues with key stakeholders on SOC management and two online surveys (one global and one for Denmark specifically). The surveys consisted of seven main sections: 1) Background questions on SOC, 2) Current management in relation to SOC, 3) Barriers for implementing SOC management options, 4) Solutions to address the barriers to implementation, 5) Knowledge needs, 6) Contribution of SOC management - sustaining and enhancing agricultural crop production and ecosystem services, 7) Contribution of SOC management to climate and sustainable development. This report focuses on the analysis of sections 3 and 4 (barriers and solutions), while sections 1, 2, 6 and 7 are reported in D2.1 (Ref).

The global survey consisted of both open-ended and closed-ended questions and was disseminated through 11 regional hubs and their networks, as well as through the network of the European Soil Plenary, the EIONET NRC Soil network and the 4 per 1000 initiative. The survey was available online from July 2018 until March 2019. In total, the global survey was visited 2057 times, of which 1369 answers can be used for the analysis after data cleaning. The data cleaning excluded those responses, where no questions or only the background questions were answered. The results were analysed and visualised with the help of cross tabulations. The analysis considers differences in relation to a) geographical regions, b) stakeholder type, c) specific farming system and d) farm size. Due to the different number of responses for different regions as well as the different participation of different stakeholder types, the results are biased and must be interpreted carefully. This is especially relevant when only (very) few responses were received from a certain region/country or stakeholder type. To account for these biases, the quantitative survey results (rankings of barriers and solutions) were complemented with more qualitative information from the open-ended questions in the surveys and outcomes of 9 regional stakeholder workshops. In general, the qualitative information was very consistent with the observations from the cross tabulations largely confirming the ranking of barriers and solutions for different regions and stakeholder types. In addition, it provided some more subtle insights in regional differences (globally and at the EU level) and differences by stakeholder type (farmers vs other stakeholders).

In terms of barriers, in summary, at both the global and EU level and across stakeholders, from the surveys and workshops, economic barriers are ranked very highly, followed by knowledge barriers (e.g. advisory services) and political priorities (also mostly related to financial incentives like carbon credits, subsidies etc.). The economic barriers of potential benefits and incentives for longer-term investment point to the tradeoffs that often exist between short term gains and longer-term sustainability and profitability of SOC management options. Biophysical

conditions and availability of machinery and land tenure, are, with a few exceptions, not ranked as important. In general, multiple barriers are ranked as most important or important, so there is a challenge and need for addressing barriers simultaneously.

In terms of solutions, in summary, at both the global and EU level and across stakeholders, from the surveys and workshops, advisory services and knowledge exchange (in a variety of formats) are seen as the most important solution to barriers to implementation of SOC sequestration. This contrasts a bit with the knowledge barriers identified which only ranked as fifth most important. Indicators and tools for measuring SOC storage in time and space, as well as improved awareness about options for both public and policy makers are also seen as very important solutions to overcome barriers to implementation of SOC sequestration. It is interesting to note that solutions related to financial incentives for SOC sequestration (e.g. financial support, credit and trading schemes) are 'only' regarded important, while economic constraints were ranked as the most important barriers.

In conclusion, based on the quantitative survey results complemented with open-ended stakeholder feedback from the surveys and workshops, there seems to be a consensus that economic constraints (financial incentives and/or risks) are the most important barrier for implementation of SOC sequestration. However, advisory services and knowledge exchange are regarded as the most important solution.

There are subtle geographic differences in response, and it is notable that there are many 'don't know' responses from Africa for the most importantly ranked barriers and solutions. This could point to a lack of knowledge and awareness, both in the public and policy context, of issues surrounding SOC sequestration.

Comparing responses from stakeholder types (farmers and other stakeholders) only reveals very little differences, pointing to a general agreement of all stakeholders on the most important barriers and solutions to the implementation of SOC sequestration options. Based on this report (and D2.1.. Olesen et al., 2019) knowledge needs will be distilled to guide the way forward.

1. Introduction

There is increased awareness of the importance of soils among policy makers, research communities, other stakeholders and the general public. The public profile of the issue of soil management has recently been raised by the Global Soil Partnership (GSP), the global soil week and the 4 per 1000 Initiative on Soils for Food Security and Climate (Minasny et al., 2017). The societal debate on soil management in the context of climate change spans multiple policy areas and a wide range of stakeholders with different, and in part converging, agendas. Most directly, soil management is a key issue for climate mitigation and adaptation and for coping with increased demands on food production.

Agricultural soils carry a large potential for carbon sequestration, especially in degraded soils (Paustian et al., 2016). On the one hand, world soils contain a total organic carbon stock of about 1,500±230 gigatons carbon (GtC) (up to 1 m depth) (Scharlemann et al., 2014), equivalent to twice the amount of carbon as CO_2 in the atmosphere (i.e. 829 GtC in 2015) (Quèrè et al., 2015). On the other hand, close to half of all agricultural soils are estimated to be degraded, which raises threats for food production, because climate change is likely to accelerate land

degradation. Therefore, preserving Soil Organic Matter (SOM), restoring degraded agricultural soils and raising Soil Organic Carbon (SOC) stocks provides adaptation to climate change (less variable yields) and sustainable intensification (higher productivity). Indeed, improved efforts for SOC management are central for achieving several sustainable development goals (SDGs), and they also play an important role in meeting the objectives of the UN Framework Convention on Climate Change (UNFCCC), the UN Convention to Combat Desertification (UNCCD) as well as the Convention on Biological Diversity (CBD). These different but related foci create potentially synergistic drivers to advance societal action to advance SOC sequestration action.

Agricultural soil carbon preservation and enhancement appear as both a no-regret and an indispensable climate action. It is no-regret for its contribution to climate change adaptation, food security, and to wider ecosystem service benefits adding to overall climate resilience. It is indispensable for its climate mitigation and negative emissions characteristics, helping undo historical carbon emissions.

Given the recognized biological, economic, social, political and institutional constraints on the implementation of SOC management measures, the scale of carbon sequestration in agriculture will rely more upon overcoming these constraints than upon filling in gaps in our scientific and technical knowledge (Smith et al., 2008). There has not been a research effort focused on the cultural and policy complexities of soil carbon sequestration that matches the level of the effort that has been made on the technical issues. These social science challenges are as challenging as the physical science side of the climate problem itself (Amundson and Biardeau, 2018). To date, there is no systematic review of these constraint and barriers, especially the non-bio-physical ones, and potential solutions to overcome them, this is very much an emerging research area, which is key to improving uptake of management options. To contribute to this effort, WP2 of the CIRCASA project aims to carry out a dialogue with stakeholders on challenges and opportunities related to SOC. The analysis focuses on the implementation of SOC sequestration options (D.2.1. Olesen et al., 2019) and this report more specifically on the barriers to implementation and potential solutions (D.2.2.).

The Chapter is structured as follows: after this introductory chapter 1, chapter 2 describes the methods used for this study (this chapter is the same as for D.2.1.), and both online surveys and workshops are discussed in more detail. Chapter 3 analyses the barriers to the uptake of SOC management options based on the surveys and workshops. Chapter 4 analyses the potential solutions for increasing the adoption of SOC management options based on the surveys and workshops. Chapter 5 contains some more discussion and conclusions. There are 5 Annexes to the report with more details on the surveys, open-ended questions, and outcomes from the workshop discussions.

2. Methods

A mixed approach was applied to identify stakeholder's views on the role of SOC for climate change mitigation, adaptation and SDGs, and on barriers and solutions to SOC sequestration, combining quantitative and qualitative data gathering. This included workshop dialogues with key stakeholders on SOC management and two online surveys. One survey was distributed globally to a diverse group of stakeholders working or having knowledge on SOC management

(the global survey), and another survey was directed specifically to farmers in Denmark (Danish farm survey).

To ensure that a broad range of perspectives was captured around the globe, 11 regional/national hubs were facilitated by regional/national coordinators (Table 1). Each hub identified key stakeholders in their region and motivated them to participate in the global online survey and the regional workshops. The approach for interacting with stakeholders differed across the hubs, depending on the context and the resources available.

Moreover, a Stakeholder Advisory Board (StAB) was established, consisting of 12 representatives from farmers' organizations, conservation agriculture and land conservation interests, technical, business and industry, landowners and land users, foundations, investment funds and NGOs. The StAB was involved in the piloting of the online survey, assisted by identifying and reaching stakeholders, and reflected on the results of the survey at a physical meeting in January 2019.

2.1. Online surveys

The global online survey was translated into seven languages: English, German, Danish, Portuguese, Spanish and Russian, and it was disseminated via the regional hubs. The survey consisted of both open-ended and closed-ended questions. A summary of the survey structure and the full list of questions is shown in Annex 1. In the global survey, questions were phrased around "SOC", rather than "carbon sequestration" as this can be an unfamiliar term for some stakeholders.

The survey consisted of seven main sections:

- Background questions on SOC
- Current management in relation to SOC
- Barriers for implementing SOC management options
- Solutions to address the barriers to implementation
- Knowledge needs
- Contribution of SOC management - sustaining and enhancing agricultural crop production and ecosystem services
- Contribution of SOC management to climate and sustainable development.

Two versions of the global survey were prepared: one for farmers and one for other stakeholders. Many questions overlapped, but there were also some differences. For example, farmers were asked for information on their social-economic background (specify primary farming system, ownership and employment conditions) and their knowledge about the SOC (e.g. SOC concentration of their soils). Section 7, on the other hand, was only included in the questions to "other stakeholders". The questions in the survey were selected based on expert's opinions followed by a pilot test with partners and the StAB.

In this report on Task 2.2, the analysis will mainly focus around the sections 3 and 4. Task 2.1 focuses on sections 1, 2, 6 and 7 and is reported in deliverable D2.1., whereas the results on knowledge needs are reported in D2.3.

2.1.1. Global survey

The global survey was disseminated through all 11 regional hubs and their networks, as well as through the network of the European Soil Plenary, the EIONET NRC Soil network and the 4 per 1000 initiative. The survey was available online from July 2018 until March 2019. In total, the global survey was visited 2057 times, of which 1369 answers can be used for the analysis after data cleaning. The data cleaning excluded those responses, where no questions or only the background questions were answered.

We can observe a variable response rate from different stakeholder groups and geographic regions. One third of responses came from "Research institute or university", another third from "Farmers" followed by "Public / government authority" with 9% (see Table 3 in Annex 2).

The highest number of answers come from EU stakeholders (678), followed by Latin America (227), Africa (196) and Asia (112) and a limited number of answers for North America (76), Australia (44), Russia (16) and New Zealand (6). The answers in different regions vary with respect to different stakeholder types and specific farming system. For farmers in Europe the proportion of farms with grain and root crops were greater than for the global survey (Figure 1).

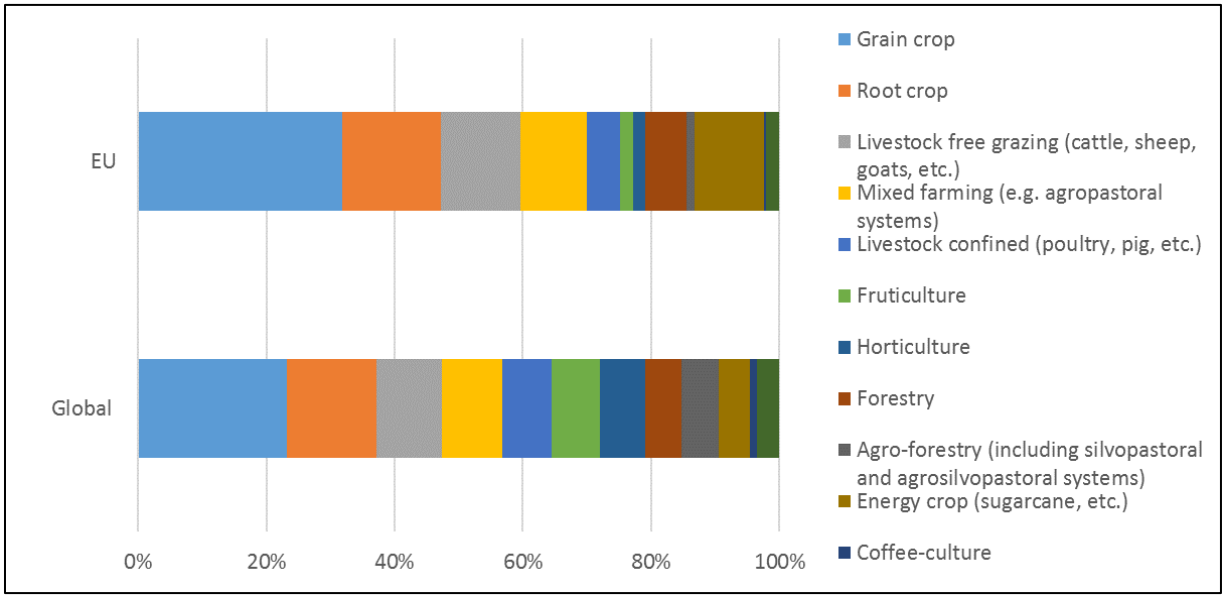

Figure 1: Overview of responses from EU and global farmers to their primary farming system.

The results were analysed and visualised with the help of cross tabulations. The analysis considers differences in relation to a) geographical regions, b) stakeholder type, c) specific farming system and d) farm size. Due to the different number of responses for different regions as well as the different participation of different stakeholder types, the results are biased and must be interpreted carefully. The results of the survey for the different regions were validated with the results of the regional workshops (see chapter 2.2).

2.1.2 Farm survey in Denmark

Danish farmers' views and perceptions on SOC management were surveyed using the same design as for the global survey. The survey was translated into Danish, with some amendments

that adapted it to Danish farming and agricultural conditions. For example, the farm type coffee-culture is not a production form in Denmark, so this option was excluded from the Danish farm survey.

In order to ensure that questions were comprehensible the Danish farm survey was tested with a small group of farmers, as well as with researchers that have knowledge of farm surveys. The questions were then edited, taking into account comments from participants in the pilot group. This pilot resulted in some useful corrections for the final survey. To increase the response rate and for dissemination purposes a newspaper article was written and published in the national Danish farmers magazine (Landbrugsavisen), which introduced the project and stated that the survey would be distributed to Danish farmers (Olesen, 2018).

The survey was distributed, via email, to a representative sample of 9434 farmers across Denmark through a web-based questionnaire survey via the online platform SurveyExact. The sample were extracted randomly among farmers registered in the Danish fertilization register (Gødningsregistret) that include all Danish farms[1]. In the database, 10% of the farmers from each region in Denmark was randomly chosen. In the register-database of Danish farmers, approximately 25.000 farmers were registered with email-addresses in 2018. Therefore, our sample distribution was around 40 percent of all farms in Denmark[2]. The survey was distributed from September 2018 – December 2018 with two email-reminders. In total, 2108 respondents started the questionnaire and 1807 completed it (19 percent). This means that we have responses from a little more than 5 percent of all farmers in Denmark. The response rate of around 19 percent of the sample is normal for web-based surveys (Hansen & Pedersen, 2012).

In total 1807 complete responses are included in this analysis. When comparing the farmer responses with national agricultural statistics from 2017 (2018 not available before summer 2019), we can see the survey was representative of Danish farms (see Table in Annex 3). The survey are representative of Danish farms both in terms of farm characteristics (farm type, farm size and agricultural practices), demographics (age and gender), and geographically distributed over the five regions in Denmark.

2.2. Workshops

Ten regional workshops were organised between July 2018 and March 2019 by Hub-Partners with a total number of 202 participants (Table 1). The overall aim of the workshops was to engage with regional stakeholders' in order to gather their perspectives on SOC management, in particular their views on SOC management options, barriers and solutions for the implementation, as well as knowledge and research needs to increase uptake of SOC management practices in their region.

[1] All Danish farmers are obliged to report fertilizer plans and accounts every year, to get payments and subsidies and for complying with Danish and European legislation.

[2] According to Danish national statistics, there were 34731 farms in total in Denmark in 2017. The number for 2018 are not officially reported yet.

Table 1: Regional workshops and number of participants.

Workshop	Number of participants
Brazil	23
Madagascar	33
Russia/Eurasia	13
South Africa	18
Colombia	16
EU	31
Australia	24
China	35
New Zealand	9

The CIRCASA WP2 team provided a guideline for the workshops and briefed the partners. The guideline included a detailed description on the aim of the workshop, who should be involved, steps to select and invite participants, guidance on selecting the timing and the venue, the role of the facilitator as well as a detailed programme for internal use and an agenda. In order to ensure the quality and consistency in reporting, a report template was provided. The workshops were organized as full-day or half-day workshops, depending on capacities and nature of the event (e.g. side-event to conference). The aim was to have at least 15–20 stakeholders present at the workshops to ensure that a range of perspectives were included. A third of the participants came from the research, followed by government representatives, whereas agricultural advisory services, international research initiatives/programs, NGO´s, farmers and farmer´s and landowner´s associations each were represented with about 5% (Figure 2).

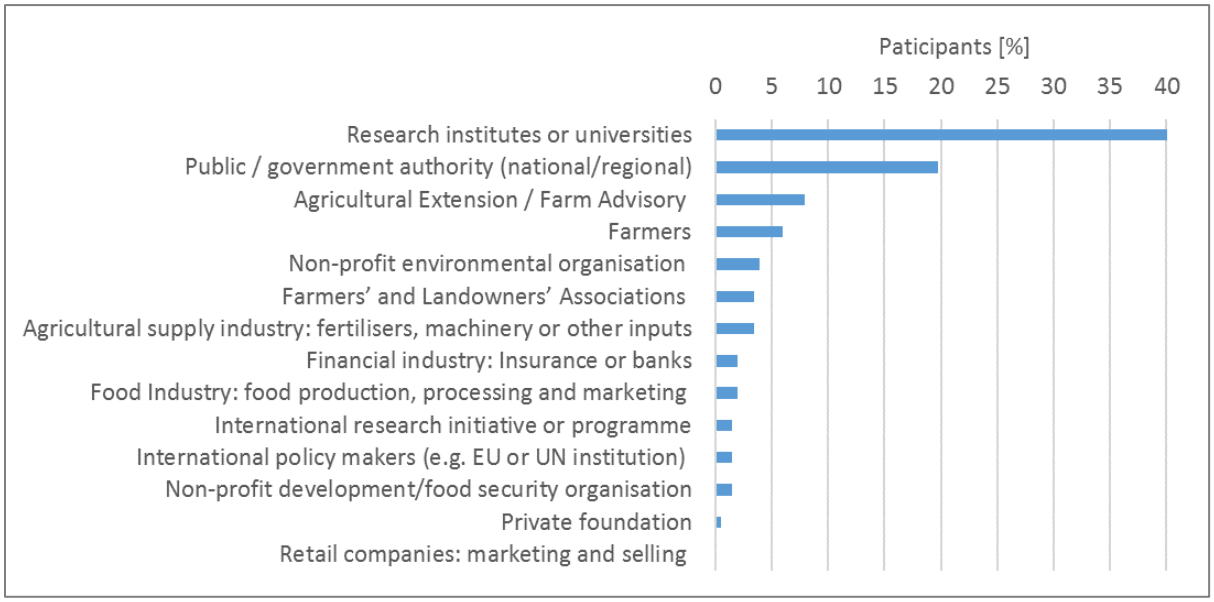

Figure 2: Stakeholder participation in the 9 regional workshops.

The workshop covered two main thematic blocks with two sessions each (Table 2). Based on the workshop reports the results of all workshops were summarized in a spreadsheet. In session 1 voting was applied to identify most effective, most applied and most interesting but not well-known management options per region and global. The pros & cons were categorized, and most important arguments analyzed for the most important practices. The barriers and solutions were

categorized in political, economic, social, financial and knowledge issues and analyzed by region. The results of the workshops complement the results of the global survey (Annex 4).

Table 2: Structure of the workshops.

Block	Session	Content
Current SOC management and barriers to implementation	1	First all management options identified for the online survey were presented to the participants. Stakeholders were asked to complete the list of management options for their region. In a second step participants prioritized options according to: i) most effective, ii) most applied and iii) interesting but not implemented or not known. In smaller groups, participants discussed pros and cons of options in terms of the effect on SOC of the most relevant options identified before.
	2	After presenting the type of barriers from the survey, stakeholders discussed specific barriers to the uptake of SOC management in their region and prioritized these barriers by voting.
Solutions and knowledge needs for implementing SOC management options	3	After presenting the types of solutions identified in the online survey, stakeholders discussed which solutions for enabling the uptake of SOC management options are most important to address in the context of their region and how solutions can be effectively organized. All solutions were prioritized by voting.
	4	After presenting the types of solutions identified in the online survey, stakeholders discussed which solutions for enabling the uptake of SOC management options are most important to address in the context of their region and how solutions can be effectively organized. All solutions were prioritized by voting.

3. Barriers to the implementation of SOC sequestration options

In the online survey (Chapter 2.1), stakeholders were asked the question: 'Which are the most important barriers to the uptake of SOC management options?'. They were asked to rank the following 14 potential barriers in order of importance (not important - minor importance – important - most important - don't know).

1. Lack of funds to access technology or machinery
2. Lack of funds to access inputs (e.g. fertilizer)
3. Additional costs are too high
4. The right machinery is not available (e.g. suppliers or contractors do not have equipment)
5. Lack of incentive for medium/long-term investment due to lack of successor
6. Land is leased
7. Not convinced by productivity and economic benefits (e.g. concern about yields)
8. SOC sequestration is not rewarded financially (e.g. no subsidies or carbon credits)

9. Technical solutions are not mature (additional research is required)
10. Information and knowledge support is not available
11. Farm extension services do not have knowledge and capacity to train farmers on technical solutions
12. Biophysical (unsuitable climate or soil)
13. SOC management is not a political priority
14. Other (please rank here and specify in the box below)

3.1 Global

At the global level, the fact (or impression) that SOC sequestration is not rewarded financially (8), e.g. in the form of subsidies or carbon credits, is ranked as the most important barrier. However, the response is slightly biased towards Europe, North and Latin America, and for Africa there is a high response of 'don't know', pointing to the lack of (awareness of) financial compensation systems and/or policies in place on the continent. In terms of stakeholder types, it is remarkable that farmers and farmers' associations, as well as financial industry, don't rank this as the most important barrier compared to others.

Globally ranked as second most important, the fact or impression that SOC management is not a political priority (13) again shows a high 'don't know' response for Africa, pointing to a lack of awareness and presence of SOC issues in the policy context. This barrier is ranked most important by the majority of international policy maker (UN, EU) respondents.

Globally ranked as third most important, not being convinced by productivity and economic benefits (7) again shows a high 'don't know' response from Africa (and Russia, though largely ranked as important). All landowners' associations respondents rank this as the most important barrier. This barrier stresses the trade-offs that often exist (or are perceived) between short term economic gains and longer-term sustainability and profitability in many SOC management options/investments.

Other open-ended responses on barriers to SOC management options are ranked fourth most important and are summarized in Annex 5.

Information, knowledge support and extension (10, 11) are seen as the fifth most important barrier globally. This clearly points to the relevance of the CIRCASA project developing international synergies concerning research and knowledge transfer.

The importance of barrier 5 (lack of incentive for medium/long-term investment due to lack of successor), again points to the trade-offs that often exist between short term gains and longer-term sustainability and profitability in SOC management.

Lack of funds and/or access to technology and inputs, and too high additional costs (1-4) are seen as relatively low barriers to the uptake of SOC management options. This is consistent among stakeholder categories, although farmers still see it as of (minor) importance.

Biophysical barriers (unsuitable climate or soil) (12) are globally seen as least important (exceptions are Russia, Australia and Asia), this might point to a knowledge need in terms of agro-ecosystem (soil, climate) specific potential for SOC sequestration, as there are certainly biophysical limitations in many parts of the world.

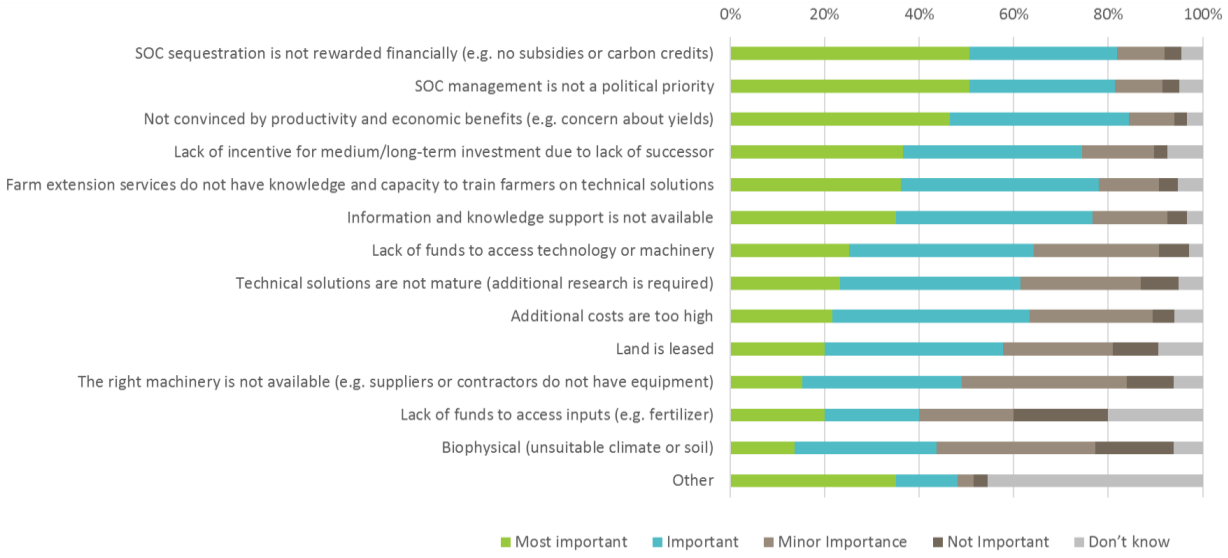

Figure 3: Ranking of importance of barriers at the global scale for other stakeholders.

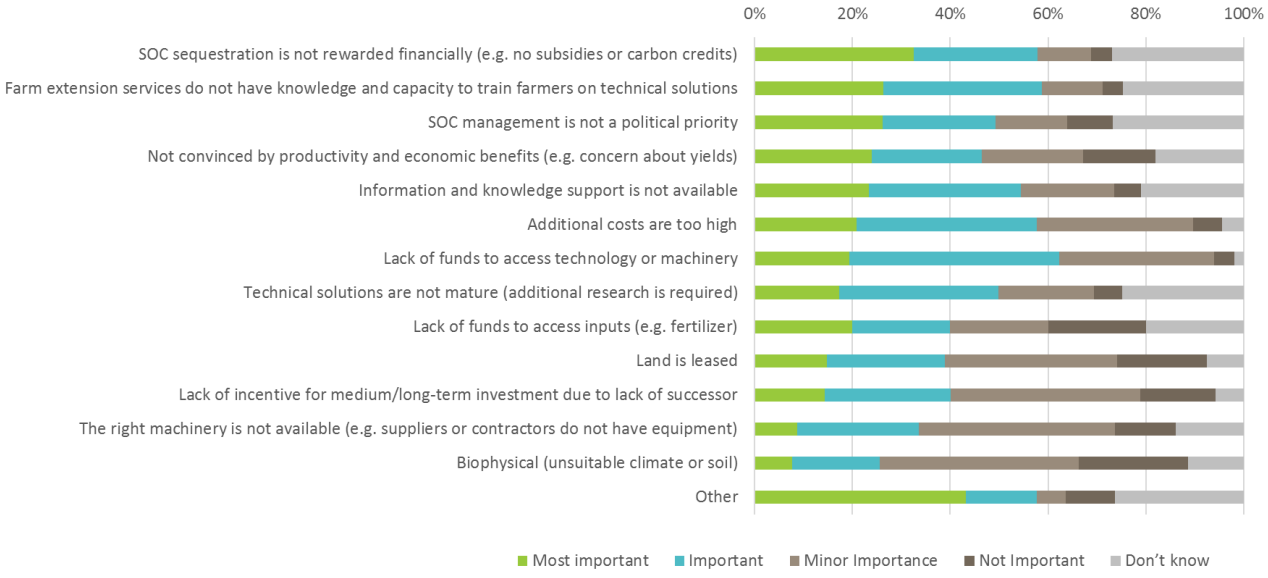

Figure 4: Ranking of importance of barriers at the global scale for farmers.

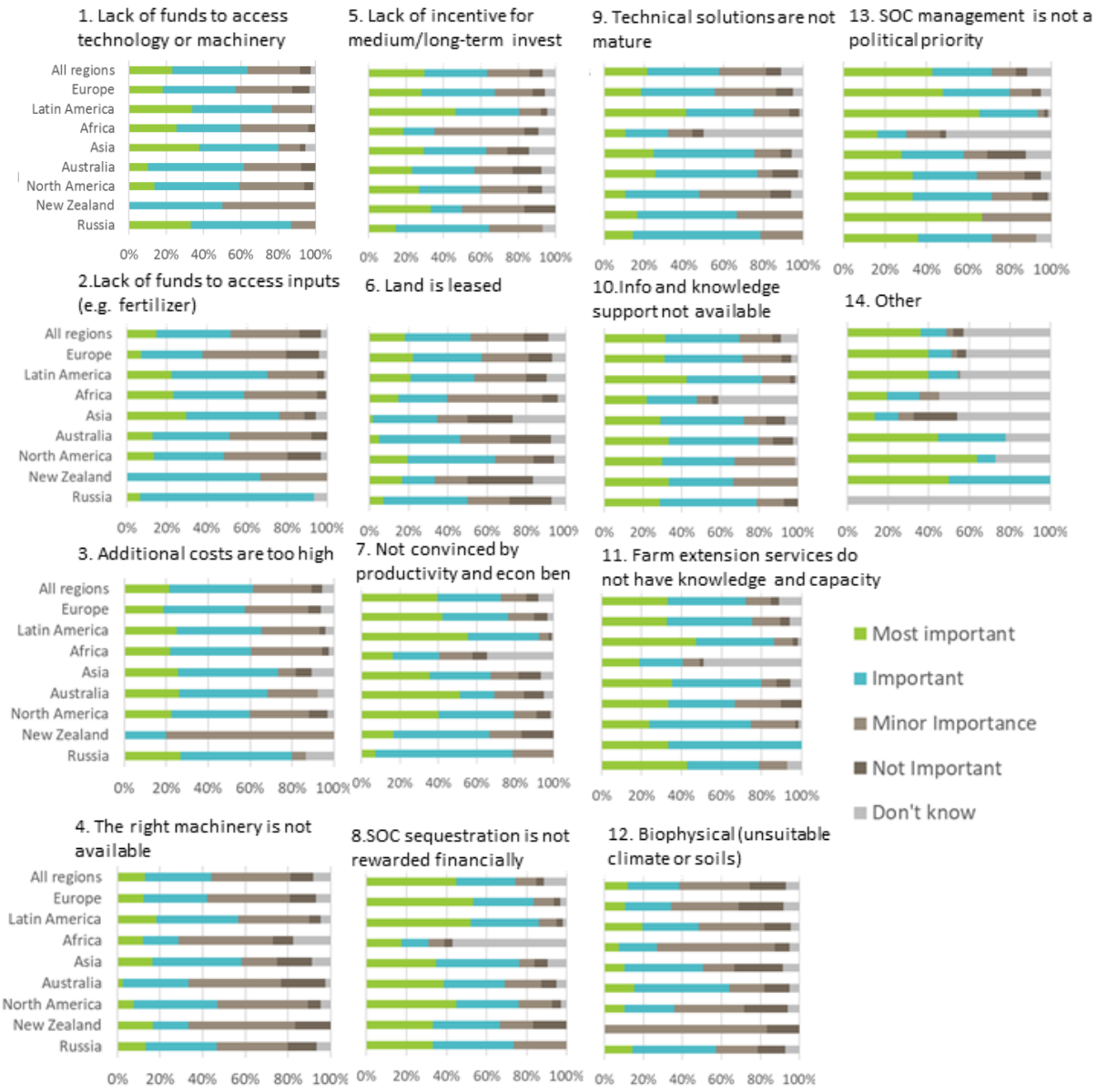

Figure 5: Ranking of importance of barriers by geographical region at the global scale.

Comparing results from the survey with the workshops (comments from workshops, by region and stakeholder type, are in Annex 4)

OTHER STAKEHOLDERS

For Africa, the most important issues from the survey ranked somewhat lower in the workshop. The most frequently cited barriers in the survey were a lack of funds and knowledge issues/a lack of training in SOC management. Issues surrounding short-term land leases were mentioned in the survey, though this did not rank highly in the workshop. However, there were some overlaps: the lack of political will was cited as an important both in the survey and in the workshops. One survey respondent summarized:

> "Weak farm extension services go hand in hand with low political priority. Governments have invested in alternatives to SOC management for a long time and have become path dependent. Shifting to SOC management needs political will followed by a major overhaul of training,

> extension, investments etc. It should be cost effective for farmers, but the playing field is not level"

Australia and New Zealand also had few responses. A common theme in survey responses in Australia was biophysical concerns: "Environmental conditions (low rainfall 240 mm GSR) and alkaline calcareous soils make increasing SOC a hard process." – a barrier that ranked particularly low in the workshop. However, survey responses from both Australia and New Zealand note the lack of political will for SOC management, which was ranked highly in the workshop.

For Latin America, the predominant barrier from survey responses was the lack of knowledge among farmers, closely followed by inadequate extension services. These both ranked relatively highly in the workshop, showing some overlap. Other barriers highlighted in the survey were financial: expensive machinery, focus on productivity, and lack of funds:

> "Little knowledge and incentive of the technical assistance to convince the producers about the economic and environmental benefits of SOC the management. Technical assistance is more concerned with selling products."

The most cited barrier for North America was economic – primarily the lack of incentives for SOC management, but also concerns surrounding land costs. This is reflected in the results from the workshop. Multiple responses also mentioned the focus on short-term returns, which also ranked highly in the workshop:

> "Small-scale farmers living in poverty have to prioritize food security and the next harvest as well as their overall resilience. The short-term costs can be prohibitive for households without extra resources to invest, and farmers are risk averse when the quality/quantity of their next harvest is the most important factor. This also means that medium- and long-term benefits are of less importance. And insecure land tenure (whether leased or land not directly titled/owned) is a disincentive to invest time and money into making soil health better."

The predominant issues cited in the survey from China were financial barriers, a lack of political will, and lack of knowledge surrounding SOC, strongly reflecting the workshop results. Some responses to the survey specifically noted that that young people are moving to cities for work, leading to a labor shortage, and a difficulty for older villagers to learn new techniques.

FARMERS

In Africa, the predominant barrier cited in the survey was lack of funds to access inputs, technology, or machinery. Further, respondents stated that additional costs were too high. From the workshop, these barriers ranked 6th, 7th and 8th, in terms of being "most important". Survey respondents also highlighted that the leasing of land presented a barrier, though again, this is not reflected strongly in the workshop results. Barriers that ranked more highly in the workshop – particularly those tied to information and knowledge support, as well as being unconvinced by productivity – were not mentioned as frequently by survey respondents from Africa.

In Australia and New Zealand, the primary barrier noted in the survey responses was tied to awareness and training, reflecting the results of the workshop.

From Latin America, survey respondents highlighted a lack of policies surrounding SOC management, which also ranked highly in the workshop.

North American survey respondents mentioned the lack of demonstration of successful practices, as well as general awareness of the subject.

Finally, from China, the most cited barriers in the survey were lack of knowledge and financial limitations, generally reflecting the important barriers from the workshop.

3.2 EU

Like at the global level, economic benefits (yields, subsidies) (7-8) are seen as the most important barrier consistently across the EU (exception is Ukraine). The response is also consistent among all stakeholders (unfortunately, we don't have responses from financial and agricultural supply industry).

SOC management not being a political priority is ranked as the second most important barrier consistently across the EU. This points to the importance of agricultural policies in the EU. It is important for all stakeholders, but especially for international policy makers (EU, UN), pointing to awareness of the low priority (and willingness to prioritize more?).

Other open-ended responses on barriers to SOC management options are ranked third most important and are summarized in Annex 5.

Information, knowledge support and extension (10-11) are seen as the fourth most important barrier in the EU. Interestingly, this is not the opinion of research institutes and universities (though still seen as important).

No incentive for longer-term investment (5) is seen as an important barrier. This again points to the trade-offs that often exist between short term gains and longer-term sustainability and profitability in the SOC management context.

Biophysical suitability (12) is seen as one of the least important barriers in the EU. Stakeholders seem to be convinced about biophysical suitability for SOC management. Like at the global level, this might point to a knowledge need in terms of agro-ecosystem (soil, climate) specific potential for SOC sequestration, as there are certainly biophysical limitations in parts of the EU (but then these unsuitable systems might not be under agriculture in the first place).

Lack of funds to access inputs (2) seems to be the least important barrier in the EU. Agriculture seems to be economically viable, but this contrasts a bit with the concerns about economic benefits seen as the most important barrier.

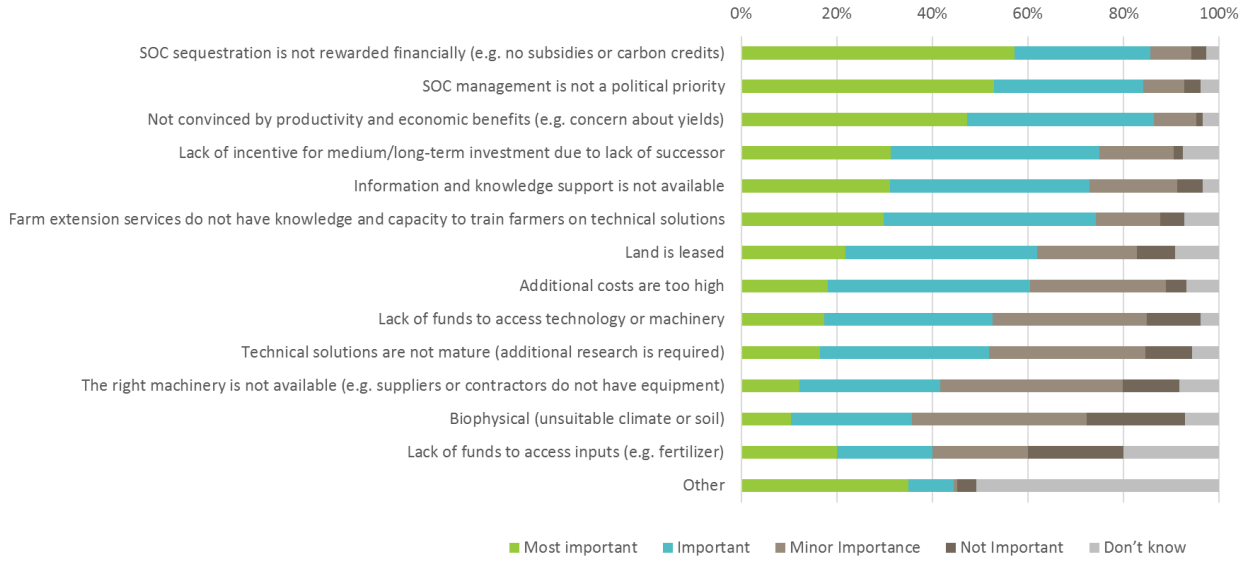

Figure 6: Ranking of importance of barriers by other stakeholders in the EU.

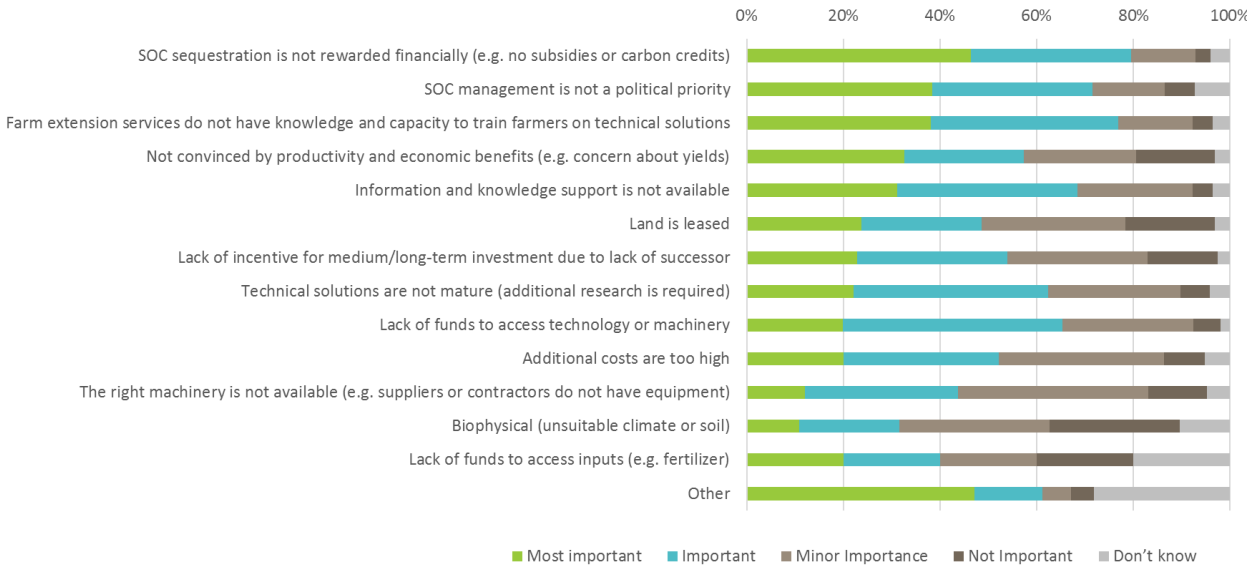

Figure 7: Ranking of importance of barriers by farmers in the EU.

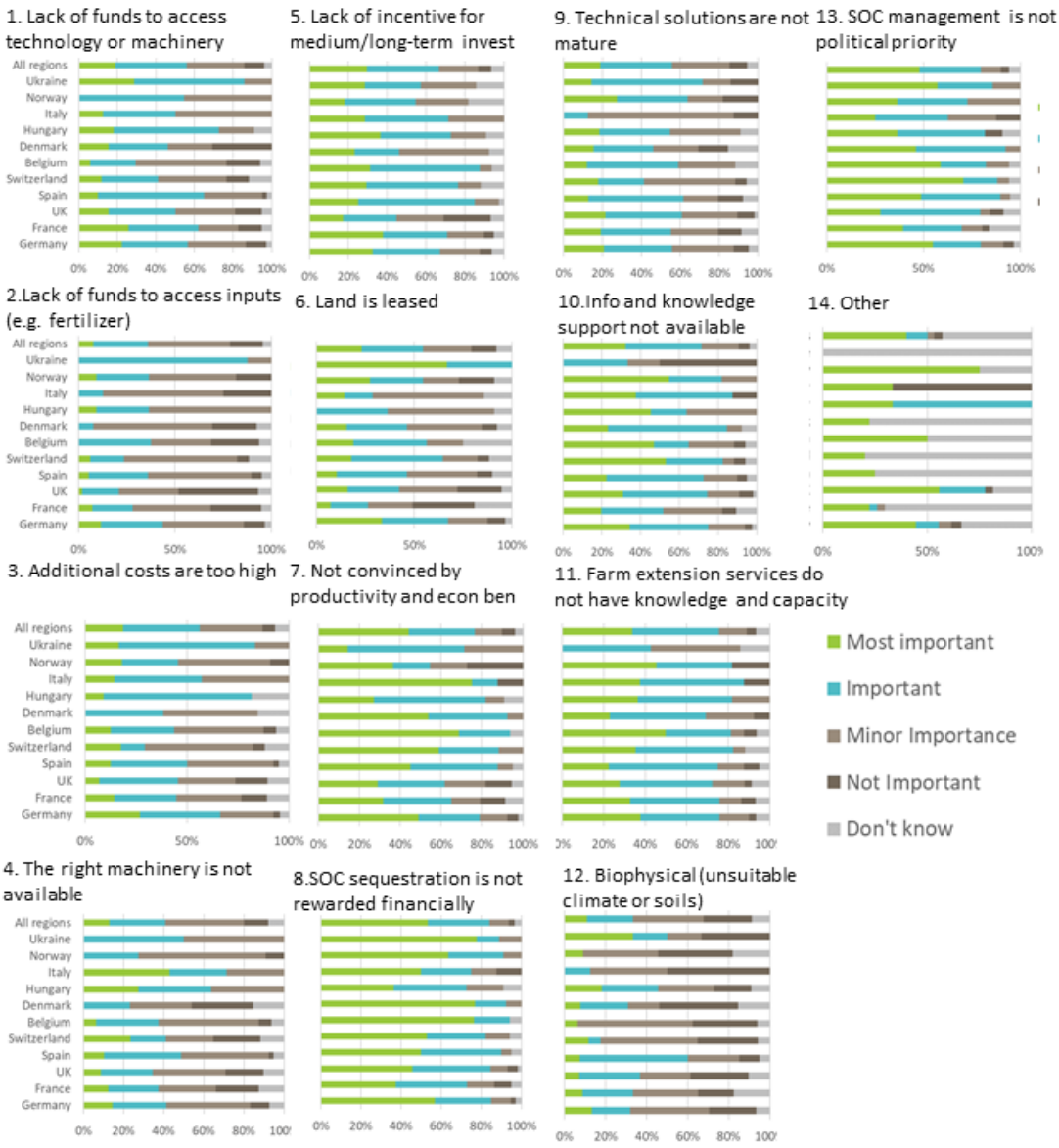

Figure 8: Ranking of importance of barriers by geographical region for the EU.

Comparing results from the survey with the workshops (comments from workshops, by region and stakeholder type, are in Annex 4)

OTHER STAKEHOLDERS

Survey responses from other stakeholder largely reflected the results from the workshops. As with the workshop, the lack of regulatory incentives and political will were the most mentioned barriers.

Further, the short-term vision vs. long-term investment was a concern mentioned often by both the survey respondents and workshop participants. One survey respondent noted: ““There is little evidence that increasing SOC contents has an economic benefit, unless the SOC is low (<1%?), so farmers need an incentive to build SOC. That could be payment or a cross-compliance penalty. The knowledge and technical means are already available.”

Barriers linked to training and advisory services were noted in the survey, with specific concerns surrounding availability and quality of extension services varying strongly between regions; agricultural

consultants are mostly still very traditionally oriented; farm extension services and schools are very 'chemical' oriented. This

One difference was noted in the view on the need for more research and awareness raising. This was frequently mentioned in the survey, though neither were mentioned as highly in the workshops.

Further, few responses from the survey cited issues surrounding access to or costs of machinery, though this was mentioned as a barrier of moderate importance in the workshops.

FARMERS

The results from the workshop are generally similar to the responses received in the survey. While there were slight variations in how frequently specific barriers were mentioned in the survey, the general concerns surrounding economic constraints and lack of knowledge were the most frequently cited.

On the economic side, the survey responses highlighted a shortage of funds to dedicate to SOC management, uncertainty about yields/performance, as well as the need for carbon credits to increase interest.

From a knowledge perspective, many farmers expressed their lack of awareness on SOC, as well as the availability of suitable advisory services training on SOC.

Reflecting the workshop results, several farmers responded to the survey on negative impacts of agricultural policy (negative effect of area payments and bureaucracy): e.g. “Confidence/need to make the change to a system when financial (Single farm payment) encourages the status quo, why change a system that financially works!”

Generally, the results of the workshops with regards to the less frequently mentioned items was also reflected in the survey responses. Access to machinery and biophysical constraints were not brought up frequently.

In contrast, issues surrounding land leasing and the lack of incentives for the long term were cited in the survey. One comment nicely summarized many of the issues facing European farmers:

> “Due to the decline in the number of farms, many farmers no longer have a successor. Long-term investments (e.g. in agroforestry systems) are too risky on leased land. There are hardly any practical research data available for humus-building cultivation systems, which prove the possible effectiveness of these systems. Humus development and site-adapted humus contents are currently not promoted, making overexploitation of soil financially more attractive at present. Humus-building cultivation systems have hardly been systematically researched so far, most of the research investigates individual aspects of humus-building systems, not the whole system. As a result, most of the research results are not relevant for practice. The knowledge of soil-conserving cultivation systems lies with innovative farmers and spreads through agricultural circles. As a result, it often remains very regional and spreads only very slowly. Official bodies have hardly any contact with the industry associations. Agricultural consultants and schools have little soil knowledge that they can pass on to farmers. The development of humus is not an issue for the state institutions. Often the necessary knowledge about the work and challenges in practice is also lacking”.

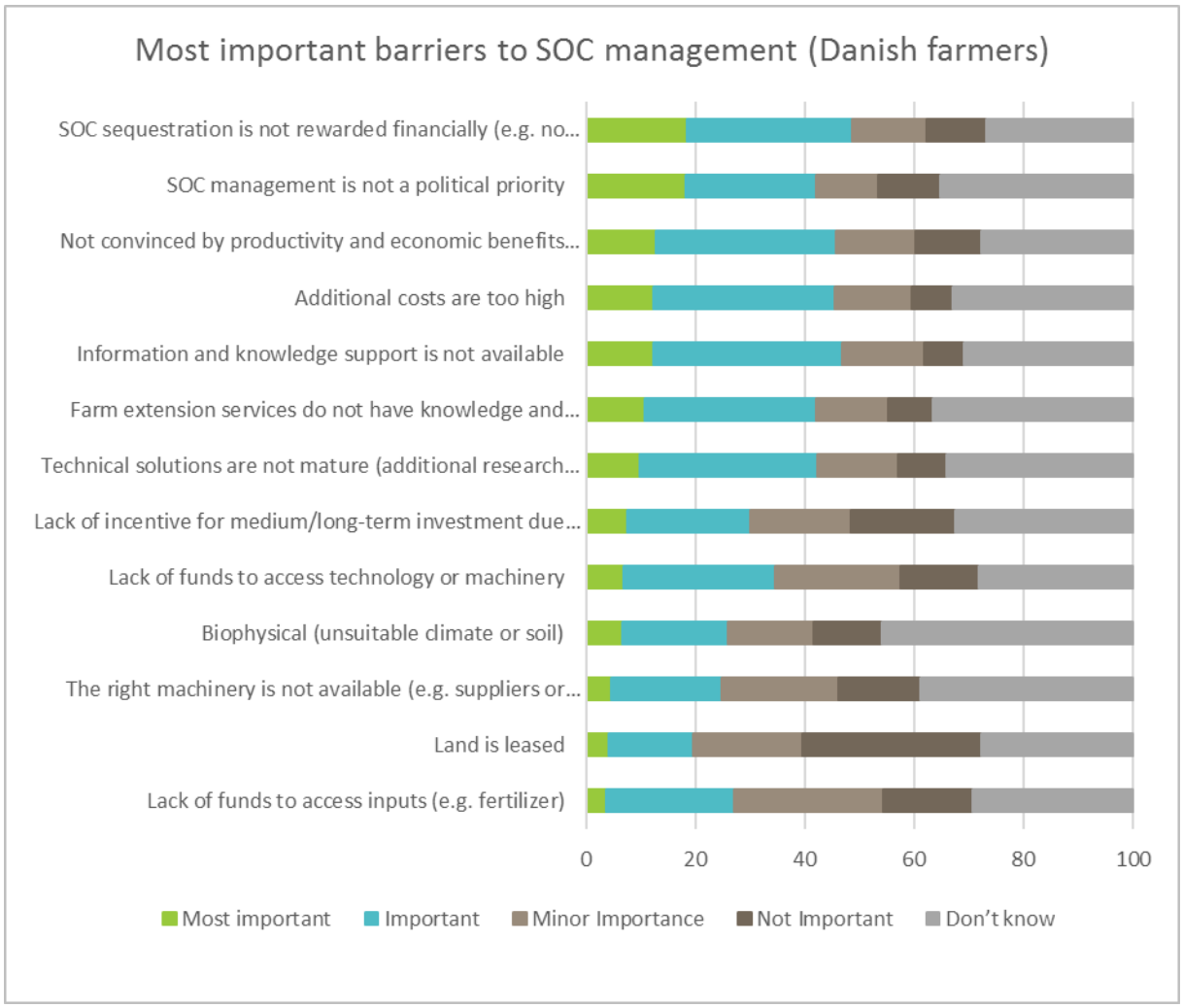

Figure 9: Ranking of importance of barriers by farmers in Denmark.

When we compare the ranking of barriers by farmers in the EU (Fig. 6) with the ranking by farmers in Denmark (Fig. 8), there is a remarked similarity. Economic barriers (financial incentives, additional costs, investment risk) are ranked very highly, followed by political priorities (also mostly related to financial incentives like carbon credits, subsidies etc.) and knowledge barriers (e.g. advisory services). This is also confirmed by the more detailed feedback received from farmers in Denmark (Annex 7): economic barriers were mentioned >30 times, (with a special emphasis and call for financial incentives for incorporating straw), knowledge issues (for farmers but also for policy makers) 17 times, and political and legislative barriers 12 times. The only barrier that does not seem to be important in Denmark as compared to the EU is the leasing of land.

4. Solutions to the implementation of SOC sequestration options

In the online survey (Chapter 2.1), stakeholders were asked the question: 'Which solutions are most important for increasing the adoption of SOC management options?'. They were asked to rank the following 13 potential solutions in order of importance (not important-minor importance-important-most important-don't know) to overcome the barriers to the uptake of SOC management options.

1. Tailored guidance and advice for farmers on how to increase soil organic carbon
2. Strengthen farm advisory services and knowledge exchange (e.g. workshops, demonstrations)
3. Payments for ecosystem services (usually public subsidies)
4. Other financial support to transition to SOC practices (e.g. loans or grants for investments)
5. Carbon certification schemes (product labels)
6. Compulsory standards set by food companies
7. Development of carbon credit schemes
8. Include SOC in emission trading schemes
9. Improve infrastructures to access inputs and technologies
10. Set mandatory targets and regulatory requirements for SOC sequestration
11. Information to policy makers on where and how to target SOC sequestration policy
12. Indicators and tools for farmers and policy makers to measure progress in improving carbon storage in soils
13. Improved awareness among the public

4.1 Global

Advisory services and knowledge exchange (in a variety of formats) (1,2) are seen as the most important solution to barriers to implementation of SOC sequestration globally and consistently across regions and stakeholders. This contrasts a bit with the knowledge barriers identified which only ranked as fifth most important.

Indicators and tools for measuring SOC storage in time and space, as well as improved awareness about options for both public and policy makers (11-13), are seen as the second most important solution to overcome barriers to implementation of SOC sequestration globally and consistently across regions and stakeholders.

All solutions related to financial incentives for SOC sequestration (3-10) are regarded important. It is remarkable to note again the large 'don't know' response from Africa, pointing to the lack of (awareness of) financial compensation systems and/or policies in place in the continent. Standardization and certification schemes (5-6) are highly ranked, especially by retail companies and international policy makers. It is interesting to note that solutions related to financial incentives for SOC sequestration (e.g.

financial support, credit and trading schemes) are 'only' regarded important, while economic constraints were ranked as the most important barriers.

Open-ended responses on solutions to SOC management options are summarized in Annex 6.

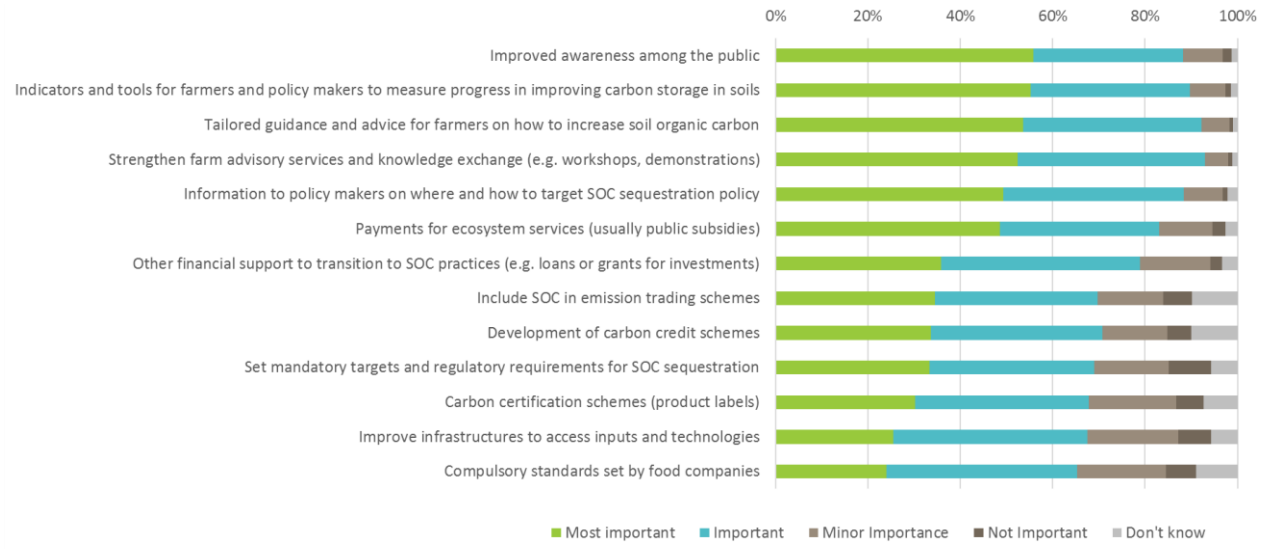

Figure 10: Ranking of importance of solutions at the global scale by other stakeholders.

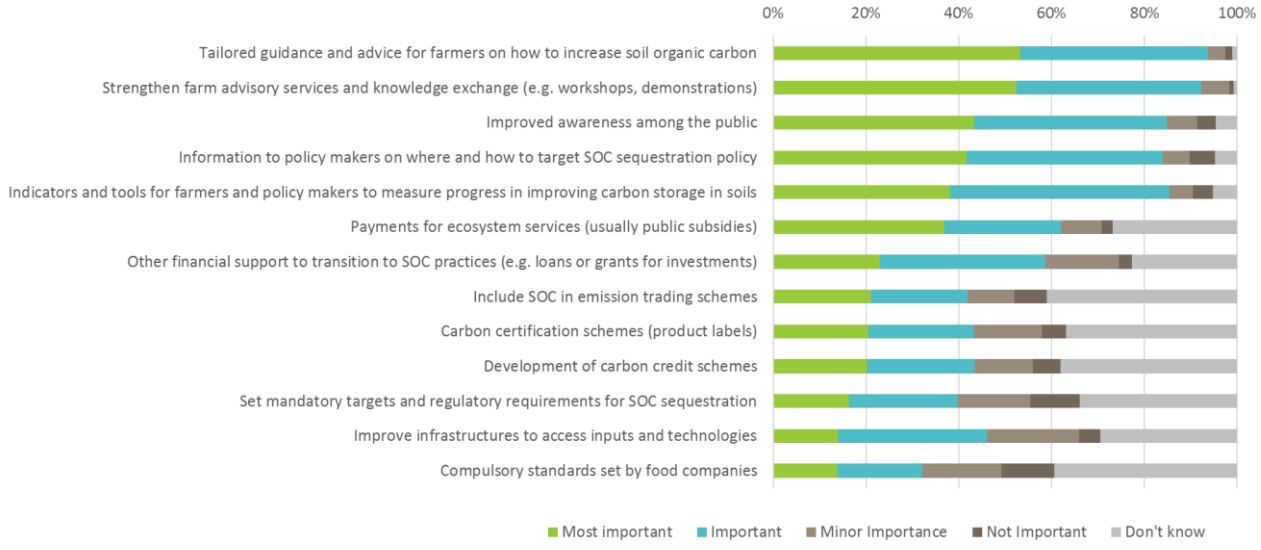

Figure 11: Ranking of importance of solutions at the global scale by farmers.

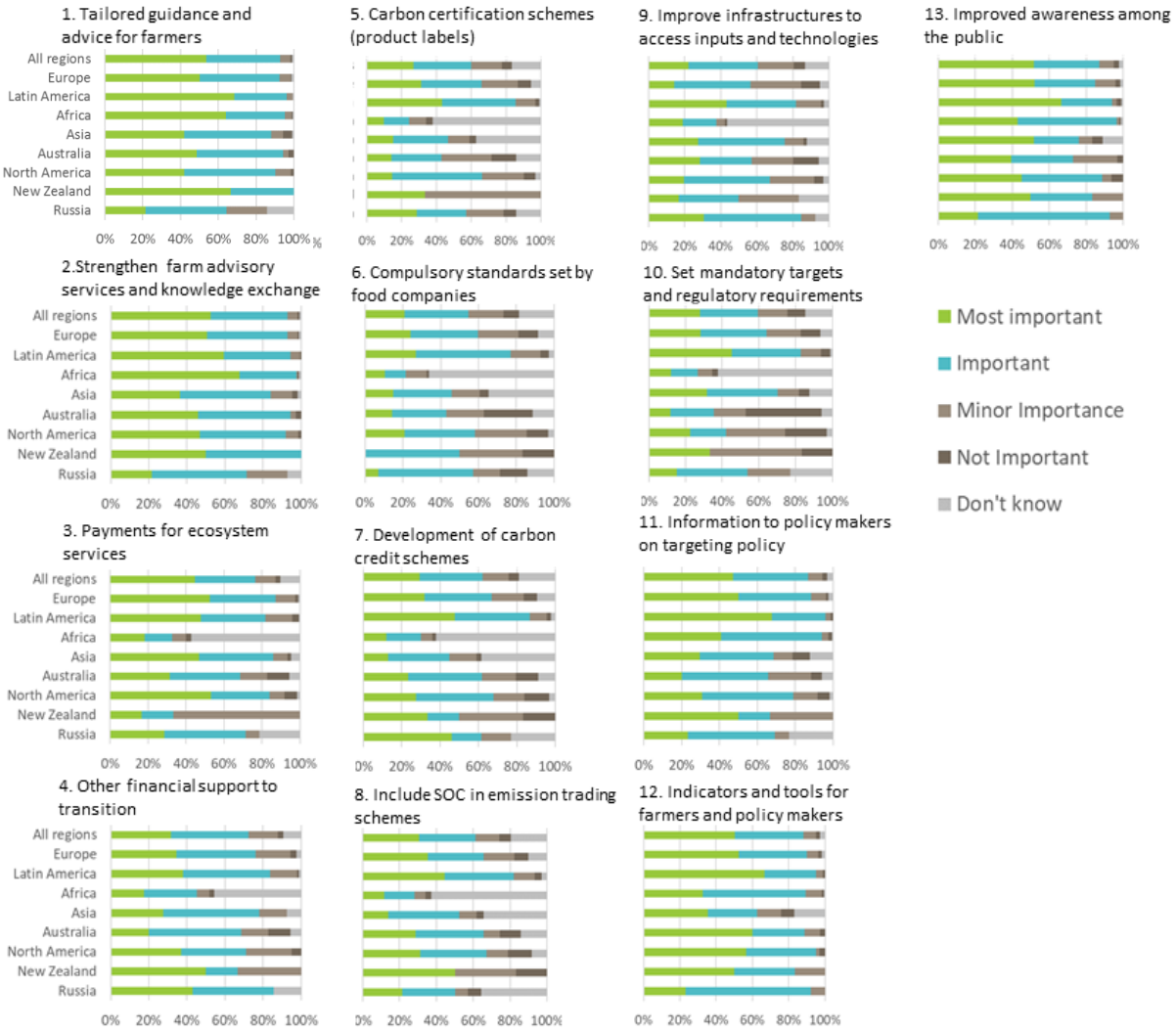

Figure 12: Ranking of importance of solutions by geographical region at the global scale.

Comparing results from the survey with the workshops (comments from workshops, by region and stakeholder type, are in Annex 4)

OTHER STAKEHOLDERS

For Africa, education and awareness were most frequently mentioned in the survey (though more for farmers than the public), followed by financial incentives. This is generally in line with the workshop results. However, the need for indicators and tools was not mentioned often in the survey, diverging from the preferences cited in the workshop.

For Asia, the responses to the survey offered a mixed bag. In Jordan, guidance for farmers and subsidies were cited, while in Nepal financial incentives, policies, location-specific technologies, and certified organic products were mentioned. Responses from Japan noted the need for increased public awareness and a carbon credit system, a response from India noted the need for financial support for ecosystem services, and one response from Kyrgyzstan noted that the government needs to get researchers to conduct a soil survey. It is difficult to contrast this with the workshop results, though we see that public awareness and guidance for farmers emerges as a common theme.

For Oceania, the predominant solutions mentioned in the survey responses were tied to a need for education and improved extension services. Financial incentives were also cited, partially reflecting the workshop results. Multiple survey responses from Australia noted the specificity of the Australian situation and biophysical constraints: "Adaptation of techniques for building OC defined for local environments and farming systems so farmers have realistic expectations of the amount and rate of change in OC is vital for them to make informed decisions" – this was not apparent in the workshop results.

For Latin America, the predominant issues in emerging from the survey were tied to awareness and training, as was noted in the workshop results: ""Farmers have sufficient knowledge about the main management practices of the SOC, but for reasons related to logistics, convenience and lack of technical advice, they abandon the main practices emphasizing only productivity and profit." Further issues were related to financial incentives and the need for indicators, though indicators were ranked notably higher in the workshop results.

North American survey responses were focused on the need for financial incentives and payments for ecosystem services. This did not rank as highly in workshop results, though it was fairly frequently cited, nonetheless. Increased awareness of SOC issues was also one of the more frequently mentioned solutions, in line with the workshop results. One response linked the need for financial incentives with the productivity of the measures, and policy requirements: "if the measures allow for increased productivity, and therefore income, it'll be adopted without any policy program. If it lowers productivity, policies can attempt to alleviate the loss, but adoption will slow considerably, because knowledge of the policy needs to be created, farmers have to apply for it, there need to be controls, etc..."

Finally, the key solution that emerged from Chinese survey responses was farmers' awareness of SOC management, which was also one of the most important issues from the workshop. "The key to improve SOC is to raise agricultural producers' awareness to the importance of improving soil SOC. If the awareness of agricultural producers is not improved, good technology, policy and capital investment will not play its role." Further survey responses mentioned public awareness and support through financing and investments.

FARMERS

For Africa, the most frequently cited responses in the survey were directly in line with the workshop results: tailored guidance and advice for farmers and strengthened farm advisory services. The next most cited were also in line with the workshop results: awareness among the public, information to policy makers, and indicators and tools.

No survey responses were collected from farmers in Asia.

One survey response from Australia was focused on financial incentives for farmers, which was not especially high in the workshop results, but did get some attention.

For Latin America, survey responses were focused on the importance of training technical staff (similar to the workshop results), and the need to eliminate personal interests from political decisions.

For North America, the focus was on financial incentives: ""Need outcome based strategies and reward structure for conservation of existing SOC" and the need to increase public awareness about SOC. This is partially reflected in the workshop results, although financial incentives were not ranked as especially important.

In China, the most common survey responses covered knowledge issues among farmers and the public, as well as the lack of technical staff and experts. This is directly in line with the workshop results.

4.2 Europe

Indicators and tools for measuring SOC storage in time and space, as well as improved awareness about options for both public and policy makers (11-13), are seen as very important solutions to overcome barriers to implementation of SOC sequestration in the EU (like at the global level). This response is consistent among all stakeholders.

PES (3) is seen as a very important potential solution in the EU. It is more important than at the global level, maybe pointing to higher awareness about the concept in the EU.

Advisory services and knowledge exchange (in a variety of formats) (1-2) are seen as very important solutions to overcome barriers to implementation of SOC sequestration (like at the global level). This is consistent for all stakeholders (so not only for farmers).

Solutions related to financial incentives for SOC sequestration (financial support, credit and trading schemes (4, 7-8) are regarded important.

Standardization and certification schemes (5-6) are also ranked as important potential solutions, especially retail companies regard these as the most important.

Open-ended responses on solutions to SOC management options are summarized in Annex 6.

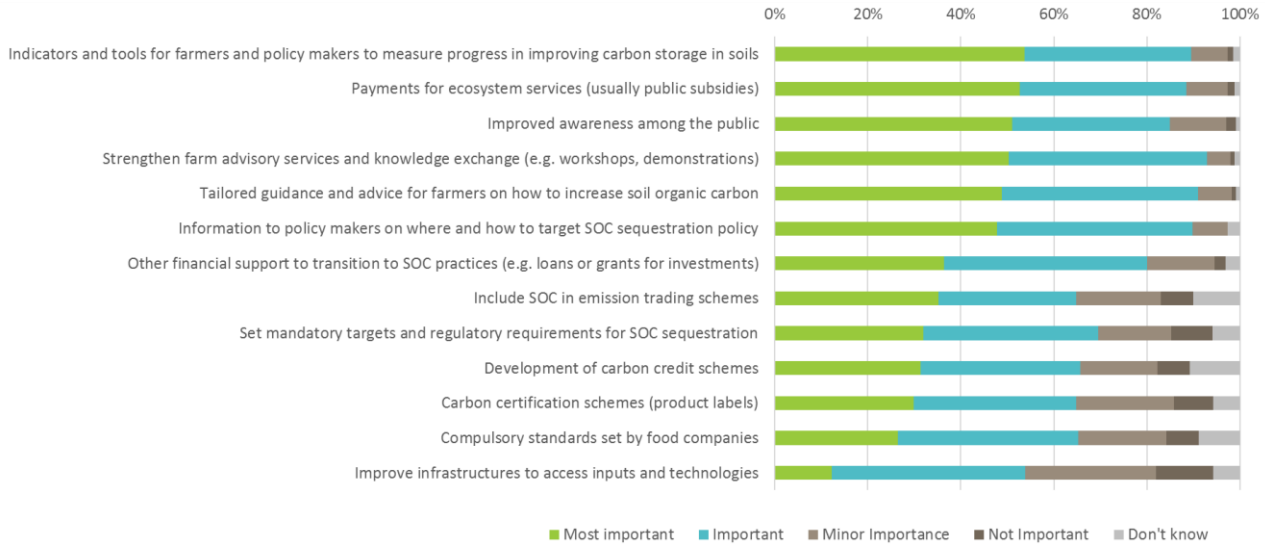

Figure 13: Ranking of importance of solutions by other stakeholders in the EU.

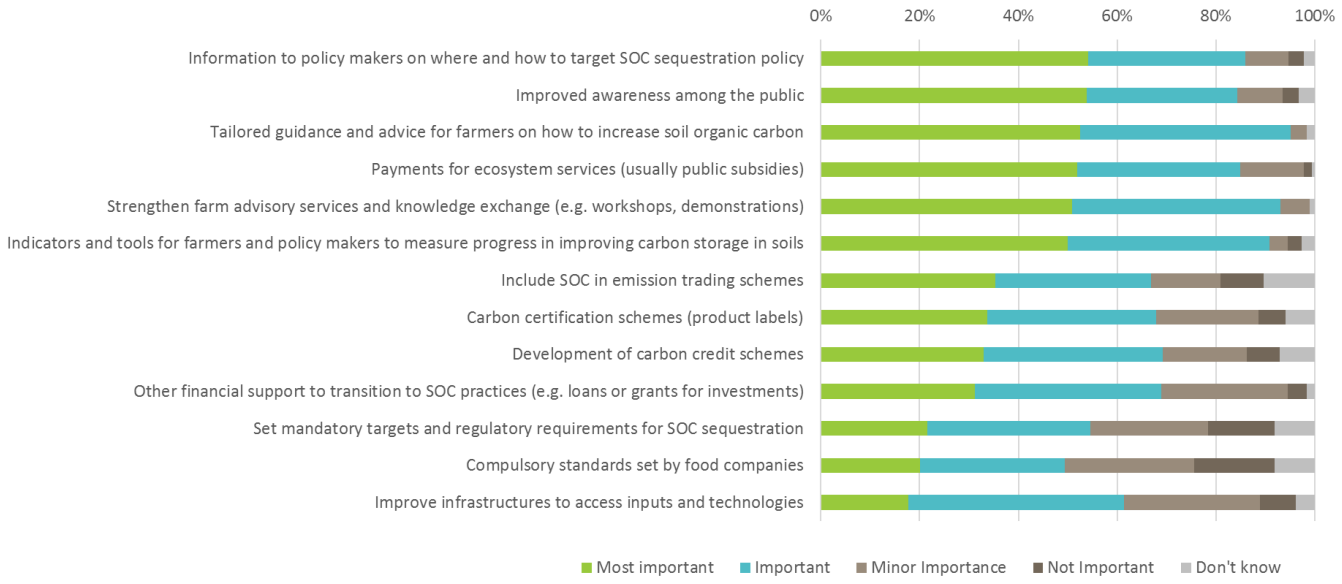

Figure 14: Ranking of importance of solutions by farmers in the EU.

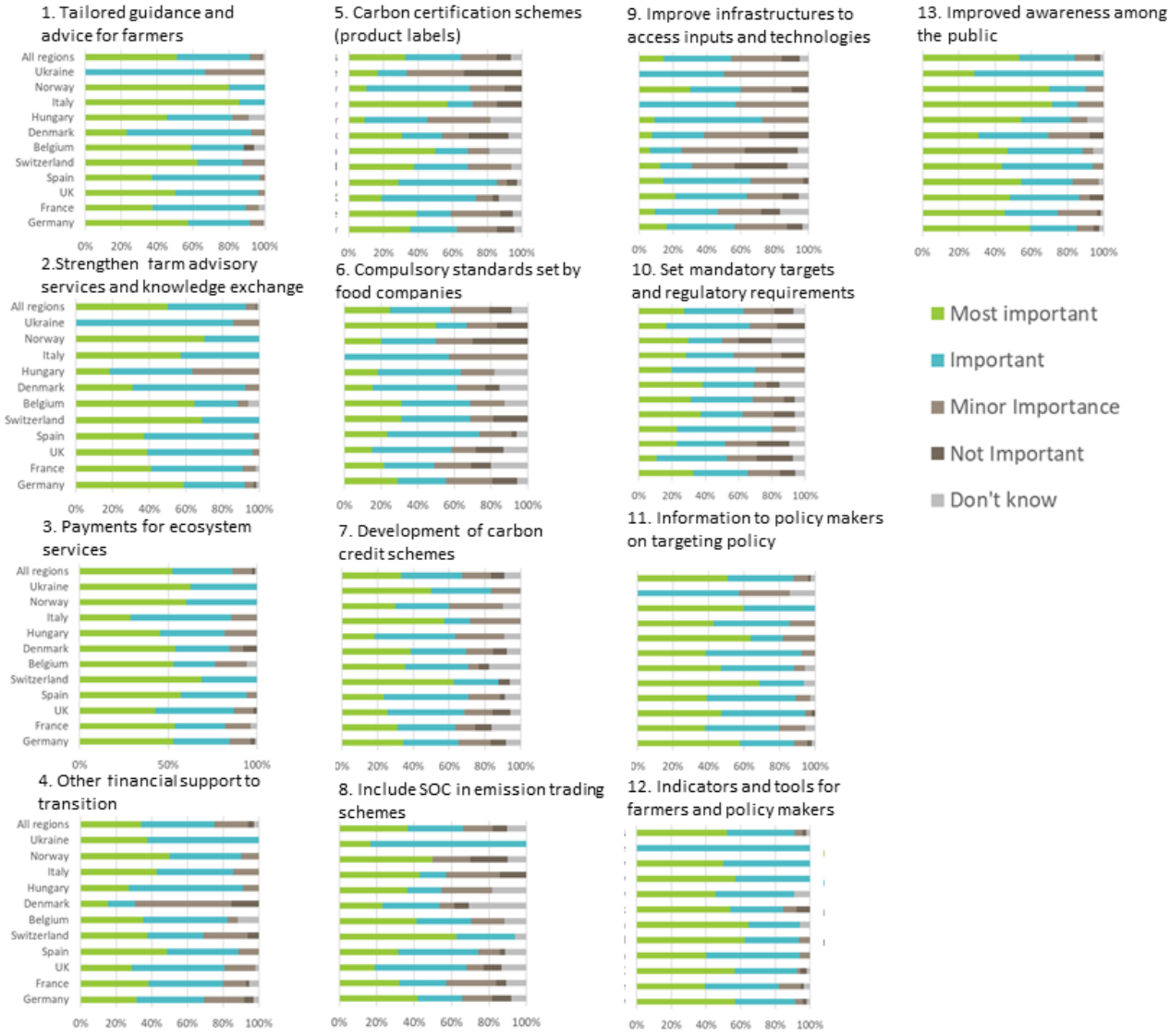

Figure 15: Ranking of importance of solutions by geographical region for the EU.

Comparing results from the survey with the workshops (comments from workshops, by region and stakeholder type, are in Annex 4)

OTHER STAKEHOLDERS

From the survey responses, the frequently mentioned solutions were financial incentives; awareness raising among policymakers and the public; and improved advisory services, training, and farmer-to-farmer knowledge sharing. This is generally reflected in the workshop results.

Multiple survey respondents noted that consumers should be prepared to pay more for food products: "Subsidies might encourage farmers to change behaviour but until the consumer is obliged to pay the environmental cost of food at the point of sale, nothing is going to change much." – but this was not reflected in the workshop results, where product labels and food standards ranked especially low.

Some survey respondents mentioned the mentioned the need for improved tools (such as nitrogen balance analysis, humic balance calculation) as well as indicators to encourage adoption of measures: "Indicators and tools for farmers and policymakers to measure soil organic carbon increase: operational indicators and diagnostics for farmers; observation and reporting for decision-makers based on national or even international monitoring networks (funding to be sustained over long time)." However, it was not as frequently mentioned as in the workshop results, where it is the most frequently cited solution.

FARMERS

The top results from the workshop were tied to information and awareness raising (among farmers, public, and policy makers), payments for ecosystem services, improved advisory services, and indicators and tools for farmers. This was almost directly reflected in the survey: financial incentives, subsidies, and investments were the most frequently cited solutions. One response noted "Structure land tenure to encourage long term occupation through tax breaks and incentives" and another: "There must be support/subsidy for reduced tillage, as it will be an expense in the beginning."

Improved information for all actors was also often cited, with a specific emphasis on educating the public about organic foods: "The awareness of non-agriculturists, first and foremost political opinion leaders, must be strengthened so that the issue reaches society and is practically taken into account in daily life." It is worth noting that the workshop results again place consumer-oriented solutions, like product labels and food standards, somewhat lower in the rankings.

However, few survey responses noted the need to strengthen farm advisory services, which contrasts the workshop result.

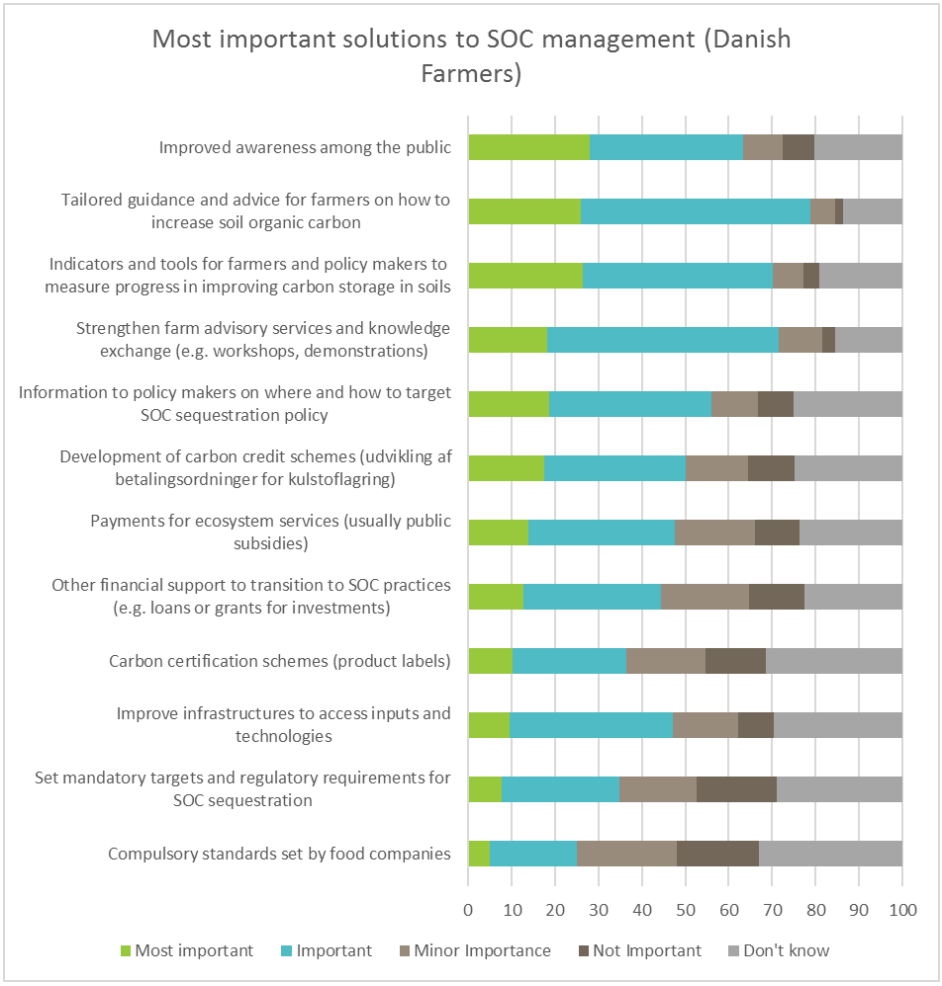

Figure 16: Ranking of importance of solutions by farmers in Denmark.

When we compare the ranking of solutions by farmers in the EU (Fig. 10) with the ranking by farmers in Denmark (Fig. 12), there is again a remarked similarity. Advisory services and knowledge exchange for awareness creation (for both farmers and policy makers) are seen as the most important solutions. Danish farmers rank the need for indicators and tools to measure progress in improving carbon storage in soils higher than at the EU level. On the other hand, they rank payments for ecosystem services (public subsidies) as not so important. This is also confirmed by the more detailed feedback received from farmers in Denmark (Annex 7): knowledge issues were mentioned 26 times, with a specific call to improve consumer/public awareness of sustainability concepts. Advisory services in the form of demonstrations are suggested and the need for indicators and tools to monitor the success of measures (instruments for measuring/monitoring SOC) are often mentioned. Economic incentives, subsidies, and financing were mentioned 18 times, but these should be seen in conjunction with other solutions. Political and legislative solutions were rarely mentioned, besides increasing the awareness of politicians.

5. Discussion and conclusions

Due to the different number of responses for different regions as well as the different participation of different stakeholder types in the surveys, the results are biased and have to be interpreted carefully. This is especially relevant when only (very) few responses were received from a certain region/country or stakeholder type. To account for these biases and uncertainties, the quantitative survey results were complemented with more qualitative information from the open-ended questions in the surveys and outcomes of 9 regional stakeholder workshops. In general, the qualitative information was very consistent with the observations from the cross tabulations largely confirming the ranking of barriers and solutions for different regions and stakeholder types. In addition, it provided some more subtle insights in regional differences (globally and at the EU level) and differences by stakeholder type (farmers vs other stakeholders).

In terms of barriers, in summary, at both the global and EU level and across stakeholders, from the surveys and workshops, economic barriers are ranked very highly, followed by knowledge barriers (e.g. advisory services) and political priorities (also mostly related to financial incentives like carbon credits, subsidies etc.). The economic barriers of potential benefits and incentives for longer-term investment point to the trade-offs that often exist between short term gains and longer-term sustainability and profitability of SOC management options. Biophysical conditions and availability of machinery and land tenure, are, with a few exceptions, not ranked as important. In general, multiple barriers are ranked as most important or important, so there is a challenge and need for addressing barriers simultaneously.

From the open-ended questions in the survey ('other') and the regional stakeholder workshop outcomes, some subtle variations in rankings by region/country can be observed. At the global level, it is notable that there are many 'don't know' responses from Africa for the most importantly ranked barriers. This could point to a lack of awareness, both in the public and policy context, of issues surrounding SOC. Biophysical barriers (unsuitable climate or soil) are globally seen as least important but are mentioned in the open-ended questions and workshop discussions for Australia, Russia and Asia. Comparing the Danish with the EU survey, it can be noted that leasing of land is not as important in Denmark as it is in the EU in general.

In terms of solutions, in summary, at both the global and EU level and across stakeholders, from the surveys and workshops, advisory services and knowledge exchange (in a variety of formats) are seen as the most important solution to barriers to implementation of SOC sequestration. This contrasts a bit with the knowledge barriers identified which only ranked as fifth most important. Indicators and tools for measuring SOC storage in time and space, as well as improved awareness about options for both public and policy makers are also seen as very important solutions to overcome barriers to implementation of SOC. It is interesting to note that solutions related to financial incentives for SOC sequestration (e.g. financial support, credit and trading schemes) are 'only' regarded important, while economic constraints were ranked as the most important barriers.

Also for the solutions, from the open-ended questions in the survey ('other') and the regional stakeholder workshop outcomes, some subtle variations in rankings by region/country can be observed. At the global level, it is remarkable to note again the large 'don't know' responses from Africa for the highest ranked solutions, pointing to the lack of (awareness of) advisory services, financial compensation systems and/or policies in place in the continent. Comparing the Danish with the EU survey, Danish farmers rank the need for indicators and tools to measure progress in improving carbon storage in soils higher than at the EU level. On the other hand, they rank payments for ecosystem services (public subsidies) as not so important.

In conclusion, based on the quantitative survey results complemented with open-ended stakeholder feedback from the surveys and workshops, there seems to be a consensus that economic constraints (financial incentives and/or risks) are the most important barrier for implementation of SOC sequestration. However, advisory services and knowledge exchange are regarded as the most important solution. Based on this report (and D2.1.) knowledge needs will be distilled to guide the way forward.

6. References

Amundson, R., & Biardeau, L. (2018). Opinion: Soil carbon sequestration is an elusive climate mitigation tool. Proceedings of the National Academy of Sciences of the United States of America, 115(46), 11652–11656. doi:10.1073/pnas.1815901115.

Olesen, J.E. 2018. Forskere borer hul i 450 marker og sender 10.000 spørgeskemaer. Landbrugsavisen. 14. september. 2018.

Olesen, J.E.; Graversgaard, M.; Frelih-Larsen, A.; Ittner, S.; Tarpey, J.; Madari, B.E.; Razafimbelo, T.; Kontoboytseva, A.; Nciizah, A.; Swanepoel, C.; Katto, C.; Verchot, L.; Baldock, J.; Grundy, M.; Hongmin, D.; Li, Y.; McNeill, S.; Claessens, L.,; Arias-Navarro, C.; Soussana, J.-F. (2019). "Assessing barriers and solutions to the implementation of SOC sequestration options". Coordination of International Research Cooperation on soil CArbon Sequestration in Agriculture. CIRCASA Project Deliverable 2.1. . DOI XX.XXX/XXXXXXX

Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G.P., Smith, P., 2016. Climate-smart soils. Nature 532, 49-57.

Quéré, C. L., Moriarty, R., Andrew, R.M., Canadell, J.G., Sitch, S., Korsbakken, J.I., Friedlingstein, P., Peters, G.P., Andres, R.J., Boden, T.A., Houghton, R.A., House, J.I., Keeling, R.F., Tans, P., Arneth, A., Bakker, D.C.E., Barbero, L., Bopp, L., Chang, J., Chevallier, F., Chini, L.P., Ciais, P., Fader, M., Feely, R.A., Glritzalis, T., Harris, I., Hauck, J., Ilyina, T., Jain, A.K., Kato, E., Kitidis, V., Klein Goldewijk, K., Koven, C., Landschützer, P., Lauvset, S.K., Lefèvre, N., Lenton, A., Lima, I.D., Metzl, N., Mellero, F., Munro, D.R., Murata, A., Nabel, J.E.M.S., Nakaoka, S., Nokiri, Y., O'Brien, K., Olsen, A., Ono, T., Pérez, F.F., Pfeil, B., Pierrot, D., Poulter, B., Rehder, G., Rödenbeck, C., Saito, S., Schuster, U., Schwinger, J., Séférian, R., Steinhoff, T., Stocker, B.D., Sutton, A.J., Takahashi, T., Tilbrook, B., van der Laan-Luijkx, I.T., van der Werf, G.R., van Heuven, S., Vandermark, D., Viovy, N., Wiltshire, A., Zaehle, S., Zeng, N., 2015. Global carbon budget 2015. Earth System Science Data 7, 349-396.

Scharlemann J.P., Tanner, E.V., Hiederer, R., Kapos, V., 2014. Global soil carbon: understanding and managing the largest terrestrial carbon pool. Carbon Management 5, 81-91.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M., Smith, J., 2008. Greenhouse gas mitigation in agriculture. Philos. Trans. R. Soc. Lond. B Biol. Sci. 363, 789–813. http://dx.doi.org/10.1098/rstb.2007.2184.

Annex 1: Questions of the global survey

1. Background questions

Are you female/male?

What is your age?

Which stakeholder group describes you best?

Where do you live?

Background questions - Farmer

- Specify primary farming system
- Which soil type categorizes your soils?
- Do you own the land that you farm?
- How much land do you own?
- How much land do you farm?
- Please specify the type of labour used on your farm
- How much labour do you hire?

Background questions on SOC - Farmer

- Do you know the SOC concentration of (your) soil or of the soils in your region?
- Do you consider SOC of (your) soil to be increasing or decreasing?
- Do you consider SOC of (your) soil to be critically low?
- How do you view SOC of (your) soil to be different from soils in your region?

2. Current management in relation to SOC

Which management options do you apply or consider applying? – Farmer

Which options do you think farmers are using for SOC management in your region at present?

In your opinion, how effective are the following management options for enhancing and conserving SOC compared to current levels?

3. Barriers for implementing SOC management options

Which are the most important barriers to the uptake of SOC management options (most important, important, minor important, not important)?

For highly important and important, please give specific examples.

4. Solutions to address the barriers to implementation

Which solutions are most important for increasing the adoption of SOC management options (most important, important, minor important, not important)?

For highly important and important, please give specific examples.

5. Knowledge needs

What additional information (knowledge) do you think farmers need to increase adoption of management options that conserve or enhance SOC?

6. Contribution of SOC management - agricultural crop production and ecosystem services

To what extent (to a large extent, to some extent, to a low extent, not at all) does SOC?

- Enhance the yield potential
- Enhance the yield stability
- Improve product quality (e.g. higher value)
- Improve soil quality
- Improve soil workability, e.g. for seedbed preparation
- Improve biodiversity
- Improve soil water holding capacity
- Improve water infiltration and drainage
- Reduce irrigation demand
- Reduce demand for fertiliser
- Reduce crop protection needs (pest and diseases)
- Prevent soil erosion
- Prevent nutrient leakage

7. Contribution of SOC management - climate and sustainable development

To what extent do you agree (strongly agree, agree Disagree, strongly disagree) with the following?

- SOC management affects GHG emissions from soils
- Reducing GHG should be a concern for SOC management
- SOC management compensates other agricultural GHG emissions (nitrous oxide and methane)
- SOC management compensates emissions from fossil fuels (energy and transport in society)
- Higher SOC would protect against soil degradation under climate change
- SOC management is relevant to climate change adaptation
- SOC management is relevant to food security

Annex 2: Responses by stakeholder type in the global survey

Table 3: Answers of the global survey by stakeholder for all countries (global) and for the EU in percentage

STAKEHOLDER TYPE	ANSWERS - GLOBAL [%]	ANSWERS - EU [%]
RESEARCH INSTITUTE OR UNIVERSITY	33,5	25,3
FARMER	30,1	34,0
PUBLIC / GOVERNMENT AUTHORITY	9,1	11,6
AGRICULTURAL EXTENSION / FARM ADVISORY	5,9	6,7
OTHER	5,3	6,8
NON-PROFIT ENVIRONMENTAL ORGANISATION	4,1	4,5
AGRICULTURAL SUPPLY INDUSTRY: FERTILISERS, MACHINERY OR OTHER INPUTS	2,8	3,1
NON-PROFIT DEVELOPMENT/FOOD SECURITY ORGANISATION	2,0	1,0
FARMERS' ASSOCIATION	1,8	1,3
GENERAL PUBLIC	1,7	1,6
FOOD INDUSTRY: FOOD PRODUCTION, PROCESSING AND MARKETING	0,8	0,9
INTERNATIONAL RESEARCH INITIATIVE OR PROGRAMME	0,7	0,6
PRIVATE FOUNDATION	0,5	0,6
INTERNATIONAL POLICY MAKER (E.G. EU OR UN INSTITUTION)	0,5	0,7
RETAIL COMPANIES: MARKETING AND SELLING	0,4	0,3
FINANCIAL INDUSTRY: INSURANCE OR BANKS	0,4	0,0
LANDOWNERS' ASSOCIATION	0,2	0,4
PUBLIC FUNDING MECHANISM	0,2	0,4

Annex 3: Representativeness of Danish farm survey responses

Table 4: Characteristics from the Danish farm survey compared with the national statistics regarding farm type, farm size, agricultural practice and farmer demographics

FARM CHARACTERISTICS (YEAR OF STATISTICS)	CHARACTERISTIC RESPONSE	SURVEY (% OF RESPONDENTS)	NATIONAL STATISTICS (% OF GROUP)
PRIMARY FARM ACTIVITY (2017)	Livestock[3]	37%	40%
	Cattle	20%	29%
	Dairy	8%	8%
	Pigs	8%	6%
	Poultry	1%	1%
	Mink	1%	4%
	Arable[4]	59%	48%
	Horticulture	1%	2%
	Fruit- and viticulture	1%	1%
AGRICULTURAL PRACTICES (2017)	Conventional	80%	90%
	Organic	14%	10%
	Biodynamic (2016)	0,2%	0,1%
	Conservation agriculture	2%	NA
	No till	1%	NA
FARM SIZE (2017)	0-5 ha	6%	6%
	5-10 ha	11%	21%
	10-20 ha	13%	17%
	20-50 ha	21%	20%
	50-100 ha	19%	13%
	100-200 ha	15%	11%

[3] Other livestock types reported from the survey include Mink, horses, sheep/goats. Information on cattle types is also available in the dataset.

[4] Respondents also reported on other land use types in the survey including; forestry, mixed farming, which is also available in the dataset.

	200-300 ha	7%	5%
	300-400 ha	3%	2%
	Over 400 ha	6%	3%
REGIONAL DISTRIBUTION (2017)	North Denmark Region	14%	19%
	Central Denmark Region	36%	31%
	Region of Southern Denmark	26%	27%
	Region Zealand	20%	17%
	Capital Region of Denmark	4%	6%
AGE (2017)[5]	18-39	6%	6%
	40-54	29%	33%
	55-74	56%	47%
	over 75	9%	7%
GENDER (2013)[6]	Female	6%	8%
	Male	94%	92%

[5] The official statistics have a category with undisclosed age, in 2017 it was 7% of farms that was in this category.

[6] Eurostat statistics: http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do

Annex 4: Comments from workshops

Table 5: Summary of different barriers out of nine regional workshops (Brazil, Madagascar, South Africa, Colombia, Europe, Australia, New Zealand, Russia and China). The number in bracket indicate the number of regions mentioned the barrier as being important.

CATEGORY OF BARRIER	EXAMPLES
ECONOMIC [9]	• SOC sequestration is not financially rewarded; only status vs. c sequestration (for example, no subsidies or carbon credits) [5] • Lack of incentive for medium/long-term investment due to lack of successor; No immediate returns or incentives to change; Farm productivity and profits are typically examined on a short (1-2 years) time frame. On such a time frame building soil carbon does not come into the picture [6] • Lack of funds to access inputs (e.g. Fertilizer, high volume of raw material) [3] • Physical absence of manure due to the lack of livestock in some regions • Lack of funds to access technology • Additional costs are too high; High cost-benefit ratio (productivity and other economic benefits do not justify the application of practices); For some of the new soil engineering options, availability of suitable equipment can be an impediment and initial investment may be high. Proof of future returns is required to justify use. [5] • Competition on land; nutrient; water [2] • Land is leased [2] • Land tenure insecurity [2] • Cost of C analysis • Future liabilities associated with maintaining soil carbon stocks and decreased flexibility in farming options once carbon credits are awarded. • Society does not pay the full cost of food production. The cost of maintaining the resource base is often omitted. • Market access [2] • Not convinced by productivity and economic benefits [5] • More chemical used for weed control • Reduce livestock population [2] • Organic fertilizer is not as effective as mineral fertilizer for the improvement of crop yield • The right machinery is not available (e.g. suppliers or contractors do not have equipment) [3] • Labour consuming [3] • Lack of staff, low share of young employees in industry research and production structures

SOCIAL [5]	• Conservation of ancestral practices, attachment to traditional practices; Mindsets hard to change/ Slow adoption to new technologies and technology [3] • Social problem: tradition, insecurity, vandalism, bushfire • Social recognition (What do the neighbours think?); Social pressure "good farmers" = active and tidy • Soil carbon is not a mainstream concern for most farms; Lack of raising awareness [3]
KNOWLEDGE [9]	• Support for information and knowledge is not accessible or in an appropriate form for farmers; Farm extension services do not have knowledge and capacity [10] • Lack of easy and tailored guidelines for farmers, Guidelines not aligned with needs: lack of geographic targeting • Technical solutions are not mature (additional research is required) [5] • Lack of experience in terms of management; Inadequate technical handling; Complex technical choice in management [2] • Lack of education or correctly trained [2] • Knowledge transfer: lack of farmer to farmer initiatives; lack of demonstration farms and success stories to convince farmers [2] • Local knowledge are not taken into account • Need for geographical specification of information (C, yield, margin) [2] • knowledge gaps in measuring SOC for policy efficacy • Lack of information about Carbon <-> yield <-> margin • Uncertainty and variability in the quantum of soil carbon change that is possible and how this varies across soil by climate combinations. • Little understanding of threshold values of soil carbon for attaining adequate contributions to soil function and how this varies with soil type and climate • Demonstrated effects not clear [2] • Unresolved unified state registry and cadastre of agricultural land categories.
POLICY [6]	• Institutional autonomy not effective • SOC management is not a political priority; Political will: lack of government incentive, poor investment from government, and thus lack of supporting policies [5] • Lack of local initiative • Lack of credibility to the proposal of changes in production processes (of communities and institutions) • Need for certification and standardization for C analysis; methodology to assess C sequestration (robust and cheap to implement)

	• Phosphate/Nitrate regulation (can act as a barrier if the regulation puts limits to P application.) • Monitoring protocols (local, regional and national scale) • "Lack of need to change not forced" Misleading policy signals: lack of a need to change as a barrier, which is supported by the current structure of the subsidy scheme." • Lack of an easy-to-understand and implement low cost system to reward farmers for building soil carbon stocks. Current approaches are complex and have high transaction costs. • Constantly changing programs as governments change and adopt new priorities. Soil carbon stock change is a long term process. How can consistency be built into a system.
BIOPHYSICAL [2]	• unsuitable climate or soil [2]

Table 6: Summary of different solutions out of nine regional workshops (Brazil, Madagascar, South Africa, Colombia, Europe, Australia, New Zealand, Russia and China). The number in bracket indicate the number of regions mentioned the barrier as being important

CATEGORY OF SOLUTION	EXAMPLE
POLICY [8]	• Payments for ecosystem services; Putting a value on carbon that competes with commercial cropping [6] • Other financial support for transition to practices that favour SOC increase (eg, public subsidies, loans or grants for investments) [4] • Development of carbon credit schemes; Include SOC in emission trading schemes [5] • Carbon certification schemes; SOC certification as part of environmental labelling, Certification of practices/products (product labels; low carb label) [4] • Certification of amendments • Effective incentives, such as tax/fiscal incentives for private actors (to develop incentives for payments for ecosystem services) [4] • Development of regional, national and international policies and agreements towards SOC sequestration • Set mandatory targets and regulatory requirements for SOC sequestration; Objective based regulation – show economic risks for new practices [4] • Compulsory standards set by food companies [3] • Strategies need to be developed to provide farmers/farm consultants with tools needed to manage risk and make informed decisions about entry into carbon accounting programs. • Change regulation (if it is a barrier) • Implementation in Cross compliance • Effective programs of land formalization • Public funding mechanism to provide support; Legal support for Farmers; Financial support to farmers for data collection of SOM content on farm [3] • Law enforcement to individual safety and their assets protection • Insuring and making accessible Land tenure security, making possible global request to appropriate land titles, applying contract farming, establishing national agricultural insurance schemes • government-private partnership funding mechanisms • Facilitation innovations for SOC locally • Provide subsidies for the application of biochar • Government provide subsidies for the preventing erosion • Initial involvement of government may be required to kick start the process, but it should be set up in a manner that it transitions into the private sector. However, a demand needs to be created either through

	government policy (emission reduction/tax/financial penalties) or public pressure to consume goods with a low emission footprint. • Inclusion of a high frequency of temporal measurement within a soil monitoring program to define the underlying management effects on soil carbon in the presence of noise induced by variations in climate [2]
ECONOMIC [8]	• Carbon Market directly accessible for farmers • Improve infrastructure to access inputs and technologies [3] • Enhancement of offered products quality • Enhancing income in order to increase farmers' purchasing power • Interest-free financing with zero-per-cent interest rate • desectorialisation of Public market • Facilitating credit access • Capacity building on marketing • Use biochar in cascade (to improve animal food -> save medicine + doctor cost; co-compost the dung -> use it as long lasting fertilizer , reduction of leaching + capture of nitrate -> more c in the soil) • Reduce the cost for producing biochar • Economic management tools • "Financial institutions could enhance the use of natural capital associated with the soil in the valuation of properties and development of lending criteria (provides incentives for farmers to invest). New programs are in development. Society recognises maintenance of the soil resource as an important component in food production and becomes willing to pay premiums to farms maintaining soil carbon and the soil resource." • Diversification of regional agriculture through introduction of livestock and poultry in the food systems.
KNOWLEDGE [9]	Awareness • Improve awareness of the public; what is SOC, healthy land, role of management and farmers -> public reward of farmers [4] • Knowledge spreading (media, facebook, newspaper, radio reports) [2] • Information to policy makers on where and how to target SOC sequestration policy [4] • Improve farmer awareness on SOC ecosystem services; Increasing awareness within farming community; Awareness campaigns on farmer level, NGO and government extension office level, including demonstration trials, training and showcasing best management practices [3] Knowledge exchange and advisory • Strengthen farm advisory services; Training should include field schools, on-farm experiments, discovery learning [7]

- Tailored guidance and advice for farmers on how to increase soil organic carbon [5]
- Provision of training programs for consultants. Focus would be on consultants to increase the number of farmers reached; The agricultural extension plans must include guidelines for the Agricultural Extension Service Providers (EPSEAS) to ensure that they have knowledge and capacity [4]
- Knowledge exchange; Partnership: to overcome working in isolation, learn from each other, coordinate work effort. Also strengthen the relationships between different stakeholders; Integration of knowledge/ knowledge transfer; Farm-to-farm knowledge transfer: need for demonstration farms (working farms and not at a research facility). Find frontrunner farmers who are doing things well and disseminate their best practices. Link farmers with researchers and establish a network to reach farmers. Would be a cost-effective method to promote uptake of practices and lead to better policy implementation. conveying farmer2farmer networks, have more focus on integrating information and sensitivity to carbon and nutrient cycling; "Farmers want to learn from farmers." -Benefits of peer-to-peer diffusion of knowledge: within established network and thus trust of the communicator and greater willingness to accept and act upon the information received. [6]
- Living labs, which are place-based, focused on both technical and social innovations. Seek to co-design innovation(s) within a particular landscape with stakeholders)
- Education at schools

Tools

- Tools to demonstrate the effect; Development of quantitative relationships between soil carbon stocks and productivity to demonstrate the financial benefits of enhancing soil carbon stocks. [2]
- Create an implementation framework that include management, methodologies; Proposing technological solutions adapted to local context and economically viable (local methods); Establishment of a soil monitoring program across a diverse range of soil by climate by farming enterprise combinations. The program should be set up in a manner to deal with the impacts of the variance in carbon stocks imposed by naturally derived spatial and temporal variability. [3]
- Farm carbon calculation (Need for a simple and relatively cheap method of analysis for SOM content)
- Propose indicators / tools to measure progress in improving SOC storage for farmers and policy makers [3]
- Quantification of the potential enhancement of soil carbon possible through the modification of soil condition. Definition of the impact of soil engineering options on productivity and the duration required to gain a return on investment.
- develop suitable regional/national models for the complex system

Research

	• Research and develop new machine for the complex system • Research and develop options to control CH4 emissions from rewetted organic soil • Need for large-scale studies • Long term implications of management practices require examination. Building soil carbon does not occur over short time frames. An example would include the provision of N to growing crops. On an annual budget, it will always be most favourable to mine N from the soil resource; however, in the long term this approach would reduce the future capacity of the soil to support crop production without increased need for fertiliser additions. • A range of approaches including direct measurement through to remote sensing should be developed and applied where most appropriate. Where spatial variance of soil carbon stock over the area being assessed is low, direct measurement methods could be used; however, as spatial variance increases, sacrificing analytical certainty to obtain better spatial coverage may result in improved estimates. • To maintain the integrity of carbon credits derived from enhancing soil carbon stocks, confidence in the magnitude of change is required. Aggregated multiple measurements over time are required to account for spatial variance and seasonal variations in carbon flow and define the uncertainty – associated with each of the potential methods. • Conduct research to define threshold levels of soil carbon for maintaining critical functions noting that the functions required of soil carbon and the threshold will vary across soil types and climatic conditions [2]

Annex 5: Summary of open-ended survey responses on barriers to implementation of SOC management options.

FARMERS:

Africa

A total of 61 responses were gathered from farmers in Africa, with all but one of these from Madagascar. The outlier included one response from Kenya. The predominant issue for the region was a lack of funds to access inputs or technology and machinery (mentioned 85 times). Next, many responses noted that additional costs are too high (50 times), this includes the use of non-traditional inputs, the labor costs of new practices, or the cost of more fertilizer. Another important barrier is related to the leasing of land (17 mentions); contracts are often between 2-5 years, and the land could be returned to the landowner at any time, thus removing the incentive to take care of the soil. The availability of information and knowledge support was mentioned 14 times, with multiple respondents noting that they live in remote areas and are unable to afford transport to formations. Twelve respondents noted being unconvinced by productivity and economic benefits, with further responses pointing to biophysical concerns or the availability of machinery.

Asia

Only one response came from a farmer in Asia (Japan), who highlighted farmers understanding of the importance of humus.

Australia/NZ

Two farmers responded from Australia. One highlighted the need for farmers to talk to farmers ("extension staff have no farming experience), the other highlighted the lack of subsidies, labor/capacity shortages to take on new trial projects and methods.

In New Zealand, one response noted the lack of awareness of the importance of SOC.

Europe

Risk management in transition to more sustainability was mentioned as a barrier. [3]

A number of comments on the risks associated with taking glyphosate of the market, and the open question about whether conservation agriculture is possible without it. [5]

Economic constraints [30]: Lack of profitability in conventional systems and associated lack of money to invest, lack of competitiveness , uncertainty about yields, high prices for leasing land and long-term investments being too risky on leased land (agro-forestry systems), price performance ratio of catch crops as poor (expensive seeds). Need for carbon credits with higher than normal price to increase interest [12].

Lack of knowledge [65] (on effective methods, how to keep the ground covered) and availability of farm advisory service (i.e. advisors able to provide advice on SOC, compulsory farm courses don't contain training on SOC); [12]

Lack of linking research and practice: "Humus-building cultivation systems are hardly explored by the sciences. The majority of humus research is basic research or modeling. Research with (!) the practice takes place very little."[3]

Several also commented on negative impacts of agricultural policy [18] (negative effect of area payments and bureaucracy): e.g. "Confidence/need to make the change to a system when financial (Single farm payment) encourages the status quo, why change a system that financially works!"
Several farmers from Germany criticized the Fertiliser Regulation for being too restrictive and a hindrance for SOC build up. E.g.: [5]

> "To form one percent humus, 1500€ are needed and according to my information about 2500Kg N and also carbon in the form of compost or wood chips - wood must be introduced into the soil. According to the current fertilizer regulation, this is not possible, although with proper advice and execution the soil stores everything and no leaching threatens. The advice on this is also inadequate from the responsible AELF. There is still a lot of research to be done and implemented together with the farmers. The politicians are obviously not interested in the fact that something is changing here. At least nothing is published here."

A nice summary in one commentary:

> "Due to the decline in the number of farms, many farmers no longer have a successor. Long-term investments (e.g. in agroforestry systems) are too risky on leased land. There are hardly any practical research data available for humus-building cultivation systems, which prove the possible effectiveness of these systems. Humus development and site-adapted humus contents are currently not promoted, making overexploitation of soil financially more attractive at present. Humus-building cultivation systems have hardly been systematically researched so far, most of the research investigates individual aspects of humus-building systems, not the whole system. As a result, most of the research results are not relevant for practice. The knowledge of soil-conserving cultivation systems lies with innovative farmers and spreads through agricultural circles. As a result, it often remains very regional and spreads only very slowly. Official bodies have hardly any contact with the industry associations. Agricultural consultants and schools have little soil knowledge that they can pass on to farmers. The development of humus is not an issue for the state institutions. Often the necessary knowledge about the work and challenges in practice is also lacking".

Biophysical constraints:

> "have put in biophysical because we are on chalklands with high biodiversity on wildflowers, therefore conflicting priority between deeper soils vs higher biodiversity"

Latin America

Only two responses; both focused on lack of policies and carbon credits

North America

Only 8 responses. The themes: Lacking demonstration of what works, Opportunity cost (more profitable to rent land to grain farmers than to graze for SOC management), need for carbon credits, and general awareness

China

There were 11 responses from farmers in China, these covered: lack of knowledge surrounding SOC (4 mentions), financial limitations (4 mentions), lack of suitable fertilizer (3 mentions), labour shortage/cost (2 mentions), and the absence of a model to demonstrate for farmers (mentioned once).

SCIENTISTS:

Africa

A total of ten responses were gathered from the scientific community in Africa. The responses reflected the concerns of farmers: lack of funds (6 mentions), lack of training in SOC management practices (4 mentions), and the focus on short-term yields (mentioned twice). Additional concerns included illiteracy (financial literacy specifically noted) and biophysical issues (mentioned twice).

Asia

Five responses were gathered from Asia. In Japan, traditional farming practices are forgotten, such as rotation and recycling, as well as composting and "humanure". In Lebanon it was mentioned that "public awareness is weak". In Jordan, the barriers are "available data, cost-benefit advantage and machinery availability and accessibility". In Thailand, "lack of mindset of scientists and experts" was highlighted. In Nepal, there is limited research into the topic, as well as a need for financial benefits for farmers.

Australia/NZ

For Australia, two out of four responses mentioned biophysical concerns: "Environmental conditions (low rainfall 240 mm GSR) and alkaline calcareous soils make increasing SOC a hard process." One noted the focus on yield and productivity, and one noted a lack of awareness on SOC.

One response in New Zealand highlights the vest interests of agribusinesses, and the lack of political priority of SOC management.

Europe

Gap between actual and short-term constrains and the perception of benefits of changes in practice, short term vision - concern about yields [11]

> E.g. "There is little evidence that increasing SOC contents has an economic benefit, unless the SOC is low (<1%?), so farmers need an incentive to build SOC. That could be payment or a cross-compliance penalty. The knowledge and technical means are already available."

Transition period

> "The transition period! It takes a long time from you implement carbon storage measures before the soil becomes workable with (and the weeds are manageable) - patience there is no room for this in modern agriculture."[5]

Lack of regulatory incentives, CAP political framework, incentives, lack of political will [23]

More investment in RD

"If land is leased (depending on the terms), less care is taken and the tendency is towards mining;" [4]

Training and lack of education [5]

More research needed/awareness rising [20]

Quote examples:

> "Subsidies are based on policy objectives. On the one hand, neither climate change mitigation nor sustainable agriculture is a political goal. Therefore, there are no subsidies that specifically aim to increase SOC (e.g. target value SOC in soil is promoted, this is also a matter of framing measures) or the subsidies are lower than the yield loss would be (e.g. brownfields/strips). Furthermore, market pressure is very high, especially for small and medium-sized farms. This also means that the succession of farms has not been clarified, but also that all measures that

> mean a reduction in yields are less accepted (in particular fallow land, permanent grassland options)."
>
> "We monitor every field in Geneva since 1993. Different projects have surveyed the soils at federal level. We see very contrasting results between farms, corresponding to the major points raised above. Notably, a minority of farmers, but not so rare, is uptaking CO2 by 2% a year. And the economy of the farm is good. The contrasts between cropping systems and results lead to the questions raised above."

Biophysical:

> "The 'biophysical' argument is only perceived as constraint and used as an excuse for: "This does not work under my conditions";"

Access to land: "* Farm succession is a complicated thing due to a policy towards market-driven competition and upscaling of farms. Access to land for young farmers is further complicated by speculation and investment by corporations and fonds."

Latin America

Lack of knowledge, particularly among farmers, is a significant issue: mentioned 13 times. The lack of training or inadequate extension services was mentioned 7 times.

> "Little knowledge and incentive of the technical assistance to convince the producers about the economic and environmental benefits of SOC the management. Technical assistance is more concerned with selling products."

Financial barriers were mentioned 6 times:

> "The machinery to accelerate the implementation of ICL (integrated crop-livestock), ICLF (integrated crop-livestock-forestry), zero-tillage system and other integrated systems is specific and expensive. There are financial resources to encourage the adoption of this type of systems, but to have access to it is extremely difficult and bureaucratic, which discourages agronomists and producers."
>
> "Lack of financial resources by small farmers to access: plant genotypes that are more productive and resistant to pests, diseases and lack of water; seeds of cover crops, crop rotation.:

Additionally, farmers focus on productivity and yields was mentioned 5 times:

> "One of the main causes of farmers not adopting practices aimed at increasing the SOC is the low productivity of these systems at the beginning, that is, when changing from the conventional system to another, generally the productivity is not immediately high (or comparable) to the productivity before, in the conventional system."

Lack of support for research was mentioned by 5 respondents:

> "Lack of public policies for incentivizing, lack of information at the level of academia and research centers."

Two responses highlighted biophysical barriers. One response noted: "Due to the distinct edaphoclimatic conditions found in different regions in Brazil, the management of each type of this system is also different by region, so I believe that there is a lack of extension in the sense of transmitting knowledge to the producers and technicians/agronomists about the particularities of each system proposed in function of the reality of a specific region."

North America

Three responses were gathered from North America. One mentioned the need for better policy, another highlighted the importance of education for farmers and landowners. The other response combined

multiple barriers: farmers' focus on yields, policies and extension services prioritizing fertilizer access, no valuation for SOC, issues surrounding leased land, and a lack of funds or availability of inputs.

China

Among scientists in China, financial barriers were mentioned 5 times, lack of knowledge was mentioned 3 times, and political barriers were brought up 3 times. One respondent summarized:

> "There are few policy supports and financial subsidies about improving SOC by government or agriculture organizations. If farmers can get profits by improving SOC, they will be more active to adopt technologies and managements to improve SOC."

OTHER STAKEHOLDERS:

Africa

The 24 responses gathered from the remaining stakeholder groups covered the full range of barriers. Knowledge and training issues were mentioned 17 times, while the lack of political will was mentioned 7 times; one respondent noted:

> "Weak farm extension services goes hand in hand with low political priority. Governments have invested in alternatives to SOC management for a long time and have become path-dependent. Shifting to SOC management needs political will followed by a major overhaul of training, extension, investments etc. It should be cost effective for farmers, but the playing field is not level"

Furthermore, economic issues surrounding a lack of funds or focus on yields were mentioned 15 times, while concerns over short-term land leases was brought up 6 times.

Asia

Five responses collected. In India, following barriers were mentioned: the quantity of Organic Manure is very high; Non-Availability in Adequate quantity is a problem; Yield benefit in Organic farming with conventional varieties need to be established." In Kyrgyzstan the agricultural system is outdated and the main barrier is "small-scale farming due to small plots of land." Three responses were gathered from Japan: one response highlighted "vermicomposting", another on the lack of carbon crediting in the country, and one response said "to add more high value to harvested vegetables and crop through carbon sequestration in farmland"

Australia/NZ

For Australia, three responses highlighted the lack of government support for increasing SOC in agricultural systems, with one noting that "Commercial fertiliser manufacturers are blocking R&D funding and or imposing bias in R&D organisations." And another that "All institutions in Australia that serve agriculture are deeply rooted in the industrial agriculture. This paradigm can not deliver SOC outcomes." Three respondents also mentioned the lack of knowledge surrounding practice changes or poor extension services.

For New Zealand, one respondent noted that "There are proficient producers, educators and consultants out there who are not being supported by current structures. Desperately need funds for extension services." Another highlighted the farmers poor understanding of the benefits of SOC.

Europe

Farmers are in a difficult economic position. They are often obliged to choose for short term benefits although they are aware of long-term benefits of carbon [7]
Better and more Advisory [15]: Availability and quality of extension services varies strongly between regions; Agricultural consultants are mostly still very traditionally oriented; farm extension services and schools are very 'chemical' oriented, they focus on mineral fertilizer, pesticides etc.

More awareness and better knowledge [47]

More incentives are needed is mentioned by 11 stakeholders:

> "additional carbon production has a financial cost (more seed, more work, reorganization of the farm, etc.)"
> "A promotion of humus build-up via Co2 certificates is, as far as I know, only available in Austria around the ecoregion Kaindorf".

Other good quote:

"Lack of model projects to facilitate knowledge transfer from farmer to farmer, public but also political awareness of the resource soil

"Farms that are already organically managed use cultivation techniques on the shelves that require more manpower. However, labour is the resource that is most heavily taxed by the state. This means that these farms are disadvantaged by the market, while farms that save labour and squander natural resources are rewarded. Also the land management is an investment in manpower, know-how, machines that are "punished" under the current competition. In order to promote and experiment with such forms of cultivation, farmers need backing and not existential worries.

Politics and the public: Consumers and politicians need more information about the importance of carbon management. This also means questioning outdated thought patterns and making new perspectives visible and tangible. This is an educational mission

Knowledge transfer: Added to this is the very slow transfer of knowledge from advisors to farmers and from farmer to farmer. Transformation requires know-how and time. This is not the case at present. Both training at universities and training at agricultural schools continues to follow the techno-efficiency principle. Here world views must be questioned and tangible alternatives must be visible. We need a network of demonstration companies and new curricula."

On Agroforestry:

Please see the results of the AFINET project (www.agroforestry.eu/afinet), on which farmers explain the lack of technical knowledge, policy adequacy, public knowledge and are important reasons not to implement agroforestry.

Latin America

Lack of knowledge surrounding SOC was mentioned three times. The "broken" rural extension system in Brazil was mentioned twice: "Rural extension is broken in Brazil. We do not have a law on the use and conservation of agricultural land at the federal level, only São Paulo and Paraná are supervising the use and conservation of the soil." In Bolivia there are no extension services offered by the state. Economic concerns were highlighted 4 times, specifically the lack of resources among farmers to implement SOC measures.

North America

Multiple (11) responses noted economic barriers, including lack of incentives for SOC management, as well as a focus on yields, and land costs (specifically mentioned 5 times):

> "Everything for a grain farmer is pretty much about highest return right now. Land cost means more land is getting rented with absentee landlords that demand the highest returns. If not the self competiveness of farmers (shrewd businessman-economies of scale) will take land away from those farmers who manage for the future through added cost and soil health. Agri-business actively rewards this and low cost food policies may play into it as well."

> "Small-scale farmers living in poverty have to prioritize food security and the next harvest as well as their overall resilience. The short-term costs can be prohibitive for households without extra resources to invest, and farmers are risk averse when the quality/quantity of their next harvest is the most important factor. This also means that medium- and long-term benefits are of less importance. And insecure land tenure (whether leased or land not directly titled/owned) is a disincentive to invest time and money into making soil health better. Farmers may not have access to quality extension services because of their remoteness; women likely have less access because they may not be seen as the farmers in the household."

The influence of chemical companies or agribusiness was noted by three respondents.

Three responses mentioned socio-cultural barriers, such as:

> "It's a matter of culture--a desire to do things the way they've always been done--and the fact that there are subsidies that basically prop up a malfunctioning system"

China

Lack of knowledge surrounding SOC was mentioned by 3 respondents, with the absence of government policies and incentives mentioned twice "It is hard to popularize practices which can increase SOC without political regulations by government." Two responses noted the focus on yields, as well as two responses pointing out that young people are moving to cities for work, leading to a labour shortage, and a difficulty for older villagers to learn new techniques.

Annex 6: Summary of open-ended survey responses on solutions to implementation of SOC management options.

FARMERS:

Africa

Tailored guidance and advice for farmers on how to increase soil organic carbon mentioned 89 times. This was generally mentioned in the context of updating/deepening knowledge, through workshops, demonstrations, trainings, or booklets/pamphlets.

Strengthen farm advisory services and knowledge exchange mentioned 89 times – same issues as above: trainings, workshops, etc.

Information to policy makers on where and how to target SOC sequestration policy mentioned 48 times. Frequently mentioned in conjunction with the creation of new laws related to SOC management, but also to promote and encourage vulgarization.

Improved awareness among the public mentioned 35 times. Often noted: so that all villages can enjoy the benefits of SOC management.

Indicators and tools for farmers and policy makers to measure progress in improving carbon storage in soils mentioned 18 times. Frequently mentioned in order to "take better decisions at the right time," as well as the need for easier tools for farmer to measure and monitor.

Improve infrastructures to access inputs and technologies mentioned 2 times.

Asia

No responses collected from farmers.

Australia/NZ

Single response from Australia, highlighting the importance of financial incentives: "If everyone benefits, then everyone should contribute to the success of implementing and ensuring a journey towards success. We should at least be directed by the science and then supported by all the beneficiaries. Give us the tools, including finance incentive to do what the larger public expects, but not us to bear the whole load."

Europe

Improved knowledge and awareness in all domains was frequently mentioned – farmers (9), policy makers (8), public (11). Specifically educating the public about organic/healthy food was frequently cited: "The awareness of non-agriculturists, first and foremost political opinion leaders, must be strengthened so that the issue reaches society and is practically taken into account in daily life." / "Serious investment is needed in educating the public about healthy, wholesome foods from sustainable farming practices - this is currently wholly absent in the UK"

Specific references to advisory services and demonstration were infrequent, only appearing three times.

Financial incentives, subsidies, and investments were mentioned 22 times. One response noted "Structure land tenure to encourage long term occupation through tax breaks and incentives" and another: "There must be support/subsidy for reduced tillage, as it will be an expense in the beginning.".

One response highlighted the need for a unified approach to SOC management:

> "A critically important factor in enabling soil carbon gain at scale will be agreement on a harmonised framework for SOC measurement. Ideally this will form part of an ongoing annual on farm sustainability assessment, with international agreement on the best means of reliably measuring soil carbon outcomes. This is likely to be a combination of outcome based individual field

measurements and incentives based on assumptions of soil carbon gains from the adoption of specific management practices/farming systems."

Some responses were tied to more specific measures:

> "It is not possible to change over to No-Till throughout the whole area, favourable locations must remain available for potatoes, vegetables and sugar beet cultivation, the (reduced) tillage associated with this must not be a disadvantage of the FOOD PRODUCTS. Cereals and fodder production can perhaps be trimmed to NoTill by restructuring "subsidisation"."
>
> "A blanket ban on glyphosate would lead to strong SOC degradation through intensified tillage. Restricting the use of glyphosate to no-till systems with an application only shortly before or after sowing would create a strong incentive for farmers to try out this no-till system "permanent green" and thus also increase SOC contents in the soil."

Latin America

The responses from Latin America noted the importance of training of technical staff, as well as the need to eliminate personal interests in political decisions: "This well-formed technical staff will be the shield that will prevent this projection of personal interests." Another response noted that agroforestry is not yet supported in politics, so farmers cannot afford to apply it.

North America

Responses highlighted the need for financial incentives (three mentions): "Need outcome based strategies and reward structure for conservation of existing SOC" as well as the importance of increasing public awareness about SOC and the importance of soil health (two mentions). One respondent noted: "policy makers refuse to consider management and practices that already protect and enhance SOC, and instead focus on new technology and practice change."

China

Multiple responses covered knowledge issues among farmers (seven mentions), as well as the public (two mentions); the lack of technical staff and experts was mentioned twice. Two responses highlighted that farmers' incomes are too low, and one more noted that the improvement of infrastructure is important.

SCIENTISTS:

Africa

Education and awareness was by far the most frequent response (six mentions). Financial incentives were mentioned three times, while two responses noted the importance of a science-policy dialogue to promote stakeholder involvement in the implementation of policies.

Asia

Two responses from Japan highlighted the importance of earthworms in fields, with one noting that "Agricultural colleges know nothing of soil biology as they are mainly chemical franchises to profit driven companies." In Jordan, both guidance for farmers as well as subsidies were mentioned, while in Nepal financial incentives, policies, location-specific technologies, and certified organic products were mentioned.

Australia/NZ

The one response from NZ noted that "We need an international mandate for the inclusion of SOC as either carbon credits or included somehow in the ETS."

From Australia, one response highlighted the need for indicators demonstrating improvements to soil conditions, as well as the need for financial support for new practices and equipment. Three response were tied to biophysical constraints, and the need for location-specific information on SOC management.

Europe

Only 5 responses mentioned a need for financial incentives. One respondent noted that "Payment for environmental services is utopian. An increase in carbon taxes is a redistribution in exchange systems seems more economically realistic, in the long run."

Awareness of SOC management among farmers does not seem to be a particularly important issue, but rather updating their knowledge to newer practices:

> "Novel sustainable intensification techniques are seldom presented and as they lack research funds (which goes more into precision farming and similar, corporate-targeted research fields), the experience of progressive farmers cannot be upscaled easily."

Awareness raising among policy makers and the public was mentioned 4 times, especially in the context of consumer being prepared to pay more for food products.

> "Subsidies might encourage farmers to change behaviour but until the consumer is obliged to pay the environmental cost of food at the point of sale, nothing is going to change much."

> "Unless and until adequate policy support measures are put in place to reward farmers for the range of services provided - water quality improvement and maintenance, soil health enhancement, climate change adaptation, climate change mitigation, land stewardship, biodiversity enhancement and a range of other ecosystem services(e.g. flood prevention) there will be haphazard and scattered adoption of SOC management practices that benefit society in general."

Advisory services, training, and specifically farmer-to-farmer knowledge sharing was frequently mentioned (5 times):

> "I think it would be important to promote a network of practical demonstrations supported by the most sensitized farmers, with their help to promote both knowledge and overcoming barriers. Support for counselling would be another highly effective measure in this regard"

Latin America

Issues surrounding awareness of SOC management and training on new practices were mentioned 7 times; one response specified: "Farmers have sufficient knowledge about the main management

practices of the SOC, but for reasons related to logistics, convenience and lack of technical advice, they abandon the main practices emphasizing only productivity and profit." Three responses highlighted the need for information for policy makers.

Financial incentives were mentioned 5 times, including bonuses/subsidies for farmers using SOC management practices, reducing taxes on products produced in these systems, as well as carbon credit schemes.

Some responses (3) mentioned the need for indicators to monitor soil quality, as well as benchmarking tools

One response stated: "Improving infrastructure reduces the cost of purchasing inputs and, with more balanced nutrition, reduces the amount of pesticides, and increases biomass production, influencing the management of SOC."

North America

All three responses noted the importance of strong policy in place, with one pointing out that farmers will often be driven by seeing their neighbor's success. Two responses mentioned payments for ecosystem services. Another response noted the need for improved advisory services, grants/loans, carbon credits, and the importance of change driven by policy makers and the public.

China

The key issue in China appears to be tied to farmers' awareness of SOC management and its benefits (mentioned 5 times). One response specifically mentioned the need for demonstrations as well as government policy and financial support.

"The key to improve SOC is to raise agricultural producers' awareness to the importance of improving soil SOC. If the awareness of agricultural producers is not improved, good technology, policy and capital investment will not play its role."

OTHER STAKEHOLDERS:

Africa

Financial concerns are common. The development of a carbon market was mentioned 6 times, and payments for environmental services and other financial incentives were mentioned 6 times.

Knowledge and training issues among farmers were frequently mentioned (10 times), as well as for policy makers (4 times), and the public (2 times).

With regards to policy makers, one response noted: "often policy makers are still strongly oriented in the green revolution (rapid production) and forget the harmful effects, hence the importance of information / awareness."

The need for indicators and tools for both farmers and policymakers was mentioned 3 times

Two responses mentioned the need for agro-industry standards, while one noted biophysical concerns: "Technical people need to learn which green manure/cover crop systems are best for each cropping system, climate, etc"

Asia

Two responses from Japan mentioned the need for increased public awareness, with one noting that a carbon credit system is needed. One response from India noted the need for financial support for ecosystem services, and one response from Kyrgyzstan noted that the government needs to get researchers to conduct a soil survey.

Australia/NZ

For Australia, the importance of education, and specifically extension services, was mentioned 4 times. Financial incentives were mentioned 4 times, with one response noting "The offset payments under the emissions reduction fund have led to some excellent science not supporting the activity. There have been few, if any, applications for projects for sequestering soil carbon under the Australian governments emission reduction fund."

Multiple (2) responses noted the specificity of the Australian situation: "Adaptation of techniques for building OC defined for local environments and farming systems so farmers have realistic expectations of the amount and rate of change in OC is vital for them to make informed decisions"

One response tied together the limited role of soil in education, causing a lack of public push and no government activity: "Indicators and tools for farmers such as land management within capability already exist but there is little traction as government is not interested. This is perhaps because there is little public push and this is because there is limited education in science - starting from decline in extension services and withdrawal of soil conservation in curriculum"

Europe

Finance: 7 mentions, 2 mentions of carbon credit market.

> "It is clear that a carbon credit market would encourage all sectors and organizations to put in place measurement tools and practices to create value for farmers and thus push them towards measured and measurable practices in carbon sequestration."

Awareness raising was 9 times mentioned. Multiple responses highlighted the importance of public awareness in order to push policy on the issue, often tied to labelling: "Increased awareness with public will influence policies and guidance on SOC management. In particular if sustainable labels for crops are introduced."

Improved advisory and extension services were mentioned 4 times. Introduction of targets/objectives was mentioned by 4 respondents:

> "Establishment of binding targets and regulatory requirements for the sequestration of soil organic carbon: cf. eco-conditionality of the CAP, leases with environmental clauses (easements on the preservation of stocks)"

A total of 4 responses mentioned the need for improved tools (such as nitrogen balance analysis, humic balance calculation) as well as indicators (4 mentions) to encourage adoption of measures:

> "Indicators and tools for farmers and policymakers to measure soil organic carbon increase: operational indicators and diagnostics for farmers; observation and reporting for decision-makers based on national or even international monitoring networks (funding to be sustained over long time)."

Latin America

Awareness of SOC issues was mentioned for farmers (2 times), policy makers (2 times), and the public (2 times). Demonstrations for farmers and technology transfers were mentioned 4 times. Three responses specifically mentioned scientific tools tied to monitoring: one mentioned a tool to assess how soil is used and degraded, while another called for mathematical models of carbon accumulation at specific locations over time. One response mentioned including SOC in the emissions trading scheme.

North America

The most frequently mentioned response in North America is tied to financial incentives (7 times). One response linked the need for financial incentives with the productivity of the measures, and policy requirements: "if the measures allow for increased productivity, and therefore income, it'll be adopted without any policy program. If it lowers productivity, policies can attempt to alleviate the loss, but adoption will slow considerably, because knowledge of the policy needs to be created, farmers have to apply for it, there need to be controls, etc..." While another response indicated that legislation of SOC sequestration was simply a bottleneck to action: "Wherever possible minimize the role of ENGO's and government in EGS payment schemes - build programs to pay producers directly...Do not legislate SOC sequestration. Incentivize!"

Addressing knowledge gaps was mentioned 3 times: "We need financial assistance in educating farmers and the public about the importance of carbon sequestration."

China

One response mentioned improvement of public awareness, another highlighted support through funding, investments, and technology. Another response stated that farmers in China are more concerned with crop yield, input costs, and ease of techniques than improvement of soil health and SOC.

Annex 7: Feedback from farmers in Denmark

BARRIERS

Knowledge issues were mentioned 17 times, primarily concerning farmers, but also policy makers and the public.

> "lack of experience, knowledge and focus on the topic from our agricultural association"

A need for increased research was mentioned 3 times.

Economic barriers were mentioned more than 30 times. These included a lack of subsidies or incentives for farmers, focus on short-term yields, and high machinery costs:

> "It would be a huge plus if there were subsidies for the purchase of machinery, or even better if you were financially rewarded for storing carbon in the soil."

Political and legislative barriers were mentioned 12 times.

Issues surrounding the use of straw on soil, and the sale of straw, were mentioned 16 times:

> "Political / financial incentive to secure a relatively "easy" storage of huge amounts of carbon and CO2 in the Danish agricultural land. Here I think of a kind of reward for the incorporation of straw into the soil and the establishment of catch crops. Establishing catch crops and straw incorporation into the soils are effective measures to store carbon in the soil, but there is no economic incentive to do so - on the contrary. The cost of the above can quickly cost over DKK 1000 / ha. Lack of income on straw and expense for catch crops. These measures are not compensated for by agriculture. There are not many farms that can "afford" these measures. Conflicting interests regarding biofuel and straw incorporation into the soils"

Multiple farmers highlighted concerns about surrounding fertilizer and chemical use, as well as nitrogen fixing catch crops:

> "Nitrogen-fixing plants are not permitted in statutory catch crops"
>
> "Carbon storage requires fertilizer but we are not allowed to use that extra"
>
> "Afraid that there will be an accumulation of perennial weeds in reduced tillage practices, when we in the organic farming can not use round up"

Some responses highlighted biophysical and climatic concerns:

> "Own soil conditions mean that the soil's nature fluctuates greatly from year to year. Experiments with depth harrowing (not sure how to translate this correct) prior to establishing winter rape were unsuitable due to big tubers in 2012 and perfect in 2018"
>
> "I started on reduced tillage for 2-3 years ago. Hard to know what is right / wrong with harrowing / solution / time assessment of the soil"

SOLUTIONS

Knowledge issues were mentioned 26 times, primarily concerning farmers, but also policy makers and the public. Specifically, the need for improved consumer/public awareness was mentioned 12 times.

> "Information and knowledge sharing must be the driving force that can convince about economic sustainability in the actions to be implemented"
>
> "Consumer awareness and sustainability requirements will also be an incentive for carbon storage"
>
> "If we do not have the rest of Denmark's population with us, everything else does not matter"

Some responses highlighted the need for improved advisory services and demonstrations:

> " Advice in the field / stable school is more effective than ordinary advice. We hear more about each other's experiences, but lack practical things and concepts"
>
> "The regenerative agricultural practice lacks support at all stages of the agricultural sector, ranging from the advisory area to the handling of roughage companies by, for example, companion cropping. Purchasing and overview of available products is too cumbersome, and here the agri-business are also no help"

Economic incentives, subsidies, and financing were mentioned 18 times.

> "There must be an economic incentive to increase the content of C. It has to be seen in conjunction with other factors as well. The best way is to motivate cultivation practices so you get the greatest overall gain on the various parameters. We must continue to produce and make money from it"

Political and legislative solutions were rarely mentioned, outside of increasing the awareness of politicians.

Many responses (12) mentioned the need for indicators and tools to monitor the success of measures, and specifically measure carbon content in the soil

> "instrument that can measure the carbon content out in the field which can be purchased at an affordable price"
>
> "It is important to get an idea of how the carbon content of the soil changes. How is the carbon content measured? Coherence between carbon content and soil fertility must be apparent. How is the soil structure affected by the carbon content?"

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement **No 774378**