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Soil-based carbon farming: Opportunities for collaboration

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ABSTRACT

Soil-based carbon farming has been identified in previous research as a win-win for farm productivity and the mitigation of climate change through carbon sequestration. However, it faces numerous barriers to adoption, including low carbon prices, high transaction costs, information barriers and high uncertainty around future outcomes, markets and policy conditions. Collaboration between landholders and other stakeholders has been proposed as a potential means of overcoming some of these barriers, while maximising the benefits of soil-based carbon farming.

In this article, we present the results of a two-stage process investigating collaborative soil-based carbon farming in Australia, involving national-scale key informant interviews and a regional-scale Participatory Rural Appraisal. Fifty-three interviews were undertaken with key carbon farming stakeholders, including landholders, landholder groups, carbon service providers, government, researchers and the financial sector. Collaboration was seen to offer the greatest advantages in relation to knowledge-sharing and social support, followed by its potential to increase carbon income through enhanced bargaining power and the optimisation of co-benefits. The advantages of collaboration were less clear in relation to reducing costs or maximising farm productivity and collaboration also presents new challenges around risk and complexity. Under current conditions, informal collaboration models were seen to offer the best balance between the benefits and risks, with existing co-operatives also well-placed to diversify into carbon. Alternative conditions in the future or in other locations would be needed to facilitate models involving joint projects, pooled credits, shared land management and/or the creation of new carbon-specific cooperatives.

1. Introduction

Carbon farming has become increasingly prominent within national and international climate change mitigation strategies, with pathways emerging for landholders to earn money by storing carbon in their soils and vegetation in diverse jurisdictions such as the European Union (Paul et al., 2023), China (Tang et al., 2019), India (Jat et al., 2022), Canada (Government of Alberta, 2023) and Australia (Baumber et al., 2019). However, landholders seeking to engage in carbon farming face numerous barriers, including lack of knowledge around program rules and market conditions, challenges around the measurement of carbon, lack of adequate scale and risks of future policy changes. Greater collaboration between landholders has been proposed as a response to these challenges (Bamanyisa et al., 2019; Baumber et al., 2020; Johansson et al., 2022; Macintosh et al., 2019; Mattila et al., 2022; Paredes et al., 2023). This requires a consideration of past experiences with collaboration and cooperation in agriculture worldwide, which can involve formal and informal models underpinned by diverse goals relating to economic gain, environmental conservation and community benefit (Wynne-Jones, 2017).

The term "carbon farming" can be used in different ways. The European Union favours a broad definition that involves all farm-level

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management of carbon pools, flows and greenhouse gas fluxes for the purpose of mitigating climate change (EC, 2021). Conversely, researchers such as Lin et al. (2013), Tang et al. (2019), Jassim et al. (2022) and Leifeld (2023) employ a narrower definition that focuses specifically on carbon sinks in vegetation and soils and the practices to maintain or increase them, such as afforestation or reforestation to increase above-ground biomass and the alteration of grazing or cropping regimes to increase soil organic carbon. We follow the narrower definition in this article.

Australia was an early global leader in carbon farming policy through its 2011 Carbon Farming Initiative and 2015 Emissions Reduction Fund (Baumber et al., 2019). The European Union has embraced the language of carbon farming more recently under its Green Deal (Bumbiere et al., 2022) and investigation of results-based payment schemes for carbon (EC, 2021). Carbon farming is also incentivised under the Emissions Offset Scheme in Alberta, Canada (Government of Alberta, 2023) and public-private partnerships for trading farm-based carbon credits have emerged in India (Jat et al., 2022). China has also experimented with a range of market-based, regulatory and technology-driven policies that may be classed as carbon farming (Tang et al., 2019). Overlapping terms have also emerged in other contexts, including “nature-based solutions” within UN agencies (Seddon et al., 2020) and “climate-smart agriculture” in the USA (Buck and Palumbo-Compton, 2022; Gosnell, 2022).

Forms of carbon farming that focus on soils have been experiencing a particular surge in interest, including from private companies “experimenting” with different ways to offset their emissions (Buck and Palumbo-Compton, 2022). While soil-based carbon farming is less developed than vegetation-based approaches, it may offer additional advantages by not only generating carbon credits but also enhancing the productivity of grazing or cropping enterprises via increased ground cover, soil fertility and water-holding capacity (Amin et al., 2023; Buck and Palumbo-Compton, 2022; Gosnell, 2022; Jat et al., 2022; Li et al., 2013). Counteracting this is the additional complexity and uncertainty associated with soil-based approaches. Uncertainties around technologies, costs, locations (e.g. soil types and rainfall), practices, carbon prices and landholder interest lead to wildly divergent estimates of the potential for soil carbon increases, such as the range of 17–103 Mt CO_2-equivalent per annum that White (2022) cites for Australia. While new tools are emerging to model and predict changes in soil carbon (Gray et al., 2022; Gutierrez et al., 2023; Mandal et al., 2022), accurate monitoring and verification is hampered a lack of simple indicators and precise measurement tools, slow rates of change and uncertainty about long-term persistence (Wiese et al., 2021).

For landholders embarking on a soil carbon project, the challenges they may need to consider include accurately quantifying soil carbon, understanding the impacts of specific land management practices, managing side-effects and navigating complex rules designed to ensure additionality and permanence that could potentially change in the future (Paul et al., 2023). In a review of studies looking at farmer attitudes towards the management of soil carbon as a climate change solution, Buck and Palumbo-Compton (2022) found the most common barriers to be a lack of knowledge or understanding about how to engage in a soil carbon project, followed by policy uncertainty. This aligns with recent findings from Australia that complexity around markets, governance and stakeholder roles is the most significant barrier to participation in carbon and ecosystem service markets (Cotton and Witt, 2024). Other barriers include the high costs of monitoring and verifying soil carbon increases (EC, 2021), transaction and compliance costs involved in setting up and managing a carbon project (White, 2022), concerns about loss of land use flexibility (Baumber et al., 2020) and eligibility rules that prevent some landholders from participating in carbon markets (Thompson et al., 2022).

Collaboration between landholders has been proposed as a potential means of overcoming carbon farming barriers, including by increasing scale (Macintosh et al., 2019), streamlining processes (Paredes et al., 2023) and collectively marketing carbon credits (Bamanyisa et al., 2019). While some of these options are likely to require formal commercial structures such as cooperatives, other collaborative models might involve less formal networks of farmers sharing knowledge and supporting one another (Kragt et al., 2017; Johansson et al., 2022; Mattila et al., 2022), or helping governments to co-design incentive schemes (EC, 2021). Coordinated cross-property management between neighbouring properties could also help to maximise some of the co-benefits that have been identified in previous Australian studies (Baumber et al., 2019), including erosion control (Dumbrell et al., 2016), habitat provision for biodiversity (Paul et al., 2016) and the creation of social and economic development opportunities for local communities (Robinson et al., 2016).

In this article we explore the different forms that landholder collaboration could take around soil-based carbon farming in the Australian context, including the opportunities and challenges they present. The key research questions underpinning this study are:

1. To what extent can landholder collaboration reduce barriers and enhance opportunities around soil-based carbon farming?
2. What challenges might collaboration create that need to be managed or addressed?
3. How do these opportunities and risks vary across different collaborative options and business models?

Section 2 reviews the policy landscape for carbon farming in Australia, while Section 3 summarises the key opportunities for collaboration. Section 4 presents the methodology for the social research undertaken for this study, with results presented in Section 5 and discussed in Section 6.

2. Carbon farming in Australia

The primary driver of carbon farming in Australia since 2015 has been the Australian Government’s AUD4.5 billion Emissions Reduction Fund (ERF), which employs a reverse auction mechanism to direct government payments to lowest-cost forms of emissions abatement. Private sector demand for offsets has also been growing due to Safeguard Mechanism obligations on large emitters (Clean Energy Regulator, 2023b) and voluntary targets. The ERF and Safeguard Mechanism are supported by the ACCU Scheme, which provides methods and processes for creating, registering and trading government-verified Australian Carbon Credit Units (ACCUs).

While the ACCU Scheme covers many practices apart from carbon farming (e.g. energy efficiency, landfill gas), methods relating to the management of carbon in vegetation and soils account for more than half of the ACCUs that have been issued under the ERF (Clean Energy Regulator, 2023a). In particular, carbon farming projects based on the ERF methods for Avoided Deforestation (i.e. foregoing an existing right to clear trees in return for payment) and Human Induced Regeneration (i.e. altering grazing regimes or other activities to assist tree growth) have provided some of the lowest-cost forms of abatement at successive ERF auctions.

Support for carbon farming has also been provided through the development of new ACCU Scheme methods and research funding to reduce soil carbon measurement costs towards a target of 3AUD per hectare (Commonwealth of Australia, 2021). The rapid growth in carbon farming has also attracted criticism from some quarters, most notably around the integrity of the Avoided Deforestation (AD) and Human Induced Regeneration (HIR) projects in rangeland areas (Macintosh et al., 2023). While an independent review concluded that arrangements were “essentially sound” (Chubb et al., 2022 p. 2), changes were recommended to separate responsibilities for government procurement of credits from ACCU Scheme regulation and to improve transparency around project reporting and method development.

The creation of credits through soil carbon projects in Australia has been slow compared to methods based on tree growth. The first large-scale issuance of soil carbon credits under the ACCU Scheme occurred in June 2023, with two Queensland properties together awarded over 150,000 ACCUs for increasing soil carbon through time-controlled grazing and changes to pasture type (Beef Central, 2023). Grazing-related changes such as these are among the most common soil carbon project activities, along with cropping-related measures such as crop diversification and the use of cover crops (S&P Global, 2023). Soil carbon projects in higher rainfall zones have been identified as an area of future growth (Badgery et al., 2021), with potential gains in soil organic carbon in the state of New South Wales (NSW) estimated to be around four or five times higher in the eastern regions than in the drier western areas where most HIR projects have been established (Gray et al., 2022).

In contrast to HIR, which is typically framed as a trade-off between carbon sequestration in trees and livestock production from grass growth (Baumber et al., 2020; Berry et al., 2019; Jassim et al., 2022), soil-based carbon farming is often framed as a “win-win” between carbon sequestration and agricultural productivity. Co-benefits such as increased water-holding capacity, pasture nutrition and soil fertility have been cited as key motivations for adoption of soil carbon methods by Australian farmers (Dumbrell et al., 2016; Kragt et al., 2017), echoing research findings from Europe, North America, Africa and Asia (Buck and Palumbo-Compton, 2022). However, despite this “win-win” narrative, commentators in Australia and elsewhere have warned that trade-offs and integrity issues may emerge around soil carbon projects as the industry matures (Jat et al., 2022; Macintosh et al., 2023; Paul et al., 2023).

Several soil carbon methods for generating ACCUs have been introduced and revoked in Australia since 2014, with the current method employing a combination of direct measurement and modelling to estimate baseline carbon levels and changes over time (Clean Energy Regulator, 2021). Landholders must introduce at least one new management practice to demonstrate additionality (Fig. 1). A default value method is also available with fewer eligible activities and conservative estimates of soil carbon increases, but no projects are currently registered under that method.

The use of models and default values is aimed at addressing the costs of directly measuring soil carbon, which is one of the key barriers to the greater adoption of soil carbon projects (Commonwealth of Australia, 2021). Soil measurement contributes to the broader transaction costs related to carbon farming, which include information gathering, project registration, reporting, auditing and marketing of credits. These costs can be a particular barrier for smaller properties with minimal credits and are exacerbated by the fact that many costs need to be covered upfront before credit income is received (Macintosh et al., 2019).

3. Evaluating the potential for collaboration

“Collaboration” is used here to refer to circumstances in which landholders cooperate through exchanges and interactions to achieve a mutual benefit, including both formal and informal models with differing combinations of collective and individual interest (Wynne-Jones, 2017). While collaboration between landholders may offer potential economic, social and environmental benefits in agricultural settings, it can also face barriers and introduce new challenges for participants (Riley et al., 2018). Much early research into farming collaborations focused on the performance of formal cooperatives from an agricultural economics lens, with additional factors such as farmer identity, network analysis, social capital and human rights progressively incorporated through consideration of sociology, politics, philosophy and development studies (Emery et al., 2017). Motivations for collaborating can include economic gain, environmental conservation, risk minimisation, resilience, farm continuity and community benefit, with collaboration success influenced by factors such as relative advantage, trust, identity, history of collaboration, compatibility with farm plans and impact on landholder autonomy over management decisions (Emery, 2015; Ingram et al., 2013; Wynne-Jones, 2017; Riley et al., 2018).

A range of potential benefits from landholder collaboration around carbon farming have been identified or theorised through previous research. These include information-sharing through trusted networks of landholders (Kragt et al., 2017), reduced transaction costs per landholder (Macintosh et al., 2019), more efficient sharing of land and equipment (Johansson et al., 2022), maximising of co-benefits relating to soil health, biodiversity, erosion control, water quality and community development (Baumber et al., 2019), obtaining market premiums related to these co-benefits (Clean Energy Regulator, 2022) and social support with transitions to carbon farming (Mattila et al., 2022). Fig. 2 links these potential benefits to collaborative models with relevance to the Australian context.

When considering collaborative models for the Australian context, it is important to note that the ACCU Scheme provides for a very limited form of collaboration through “aggregation”. Most commonly, this involves the bundling of credits from unrelated projects (“credit-related aggregation”) by carbon service providers (or “aggregators”) who provide advice, cover upfront costs and act on behalf of individual landholders in return for a share of the credits, typically 20–30% (Carbon Carbon Count, 2022). While it is also possible to undertake more complex “project-related aggregation”, whereby abatement activities across multiple properties are bundled into a single registered project, this does not require any active collaboration between participating landholders and is mostly used for properties under common ownership (Macintosh et al., 2019). As such, while the ACCU Scheme does not prevent landholders from collaborating with one another, it offers minimal incentives or pathways for doing so.

Collaborative business models utilised for other agricultural activities may have relevance for the emerging carbon farming sector in Australia. Agricultural cooperatives, which first emerged in Western Europe in the 1800s (Luo et al., 2020), are particularly prominent in Australia’s grain and dairy sectors (Mazzarol et al., 2013). Many early cooperatives had “defensive” motivations (Cook, 1995), such as

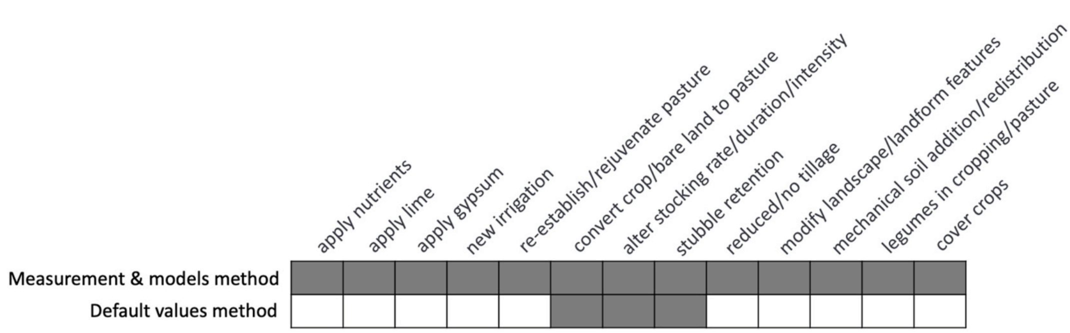

Fig. 1. Eligible new activities to qualify for the measurement and models method and default values method relating to soil carbon under the ERF (Clean Energy Regulator, 2021).

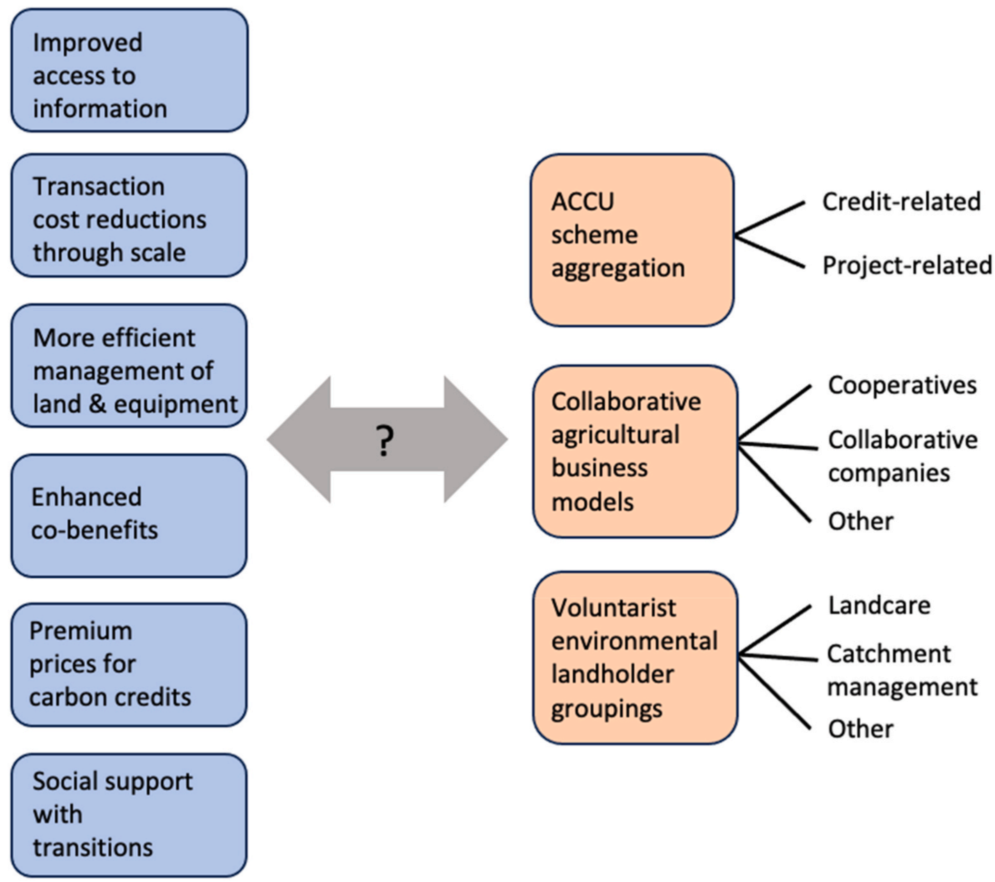

Fig. 2. Potential benefits of collaboration (left) and possible collaborative models for realising these benefits (right).

reducing transaction costs (Iliopoulos and Valentinov, 2018) and removing "middle men" to provide greater returns to producer members (Australian Bureau of Statistics, 2012). Co-operative Bulk Handling (CBH) is a prominent Australian example, having emerged during the Great Depression to alleviate growers' financial burdens through more economical and efficient bulk handling of wheat (CBH Group, 2021).

Macintosh et al. (2019) argue that the creation of new cooperatives for the marketing of carbon credits could reduce information barriers and lower marketing costs. There is also the potential for existing co-operatives to diversify into carbon, something that has also been proposed for cooperatives overseas (Bamanyisa et al., 2019). Drawing on results from Southern Queensland, Paredes et al. (2023) contend that creating a new cooperative specifically for carbon is likely to be more difficult than joining one that has already been established or diversifying an existing cooperative into carbon.

Outside of the commercial sphere, there is a strong presence of "voluntarist" groups made up of local landholders in Australia that could become involved in carbon farming collaborations. The Landcare movement is a prominent example, emerging in the mid-1980s to address both conservation and production objectives though diverse activities such as afforestation, erosion control, pest and weed management and fencing riparian zones (Compton and Beeton, 2012; Curtis et al., 2014; Lockwood, 2000). Analogous examples in other countries include Germany's Landcare movement (Prager and Vanclay, 2010) and the Farmer Cluster Model in the UK (Jones et al., 2023). Later developments in Australia included integrated catchment management programs supported by state governments (Bellamy et al., 2012), community forestry (Lawrence et al., 2007), collaborative biodiversity governance (Cosby et al., 2022) and food hubs (McKay and Dunn, 2015; Rose, 2017; Smith, 2019).

Macintosh et al. (2019) argue that regional groups focused on natural resource management could play an important extension role around carbon farming as a trusted source of information or even provide project establishment and marketing services to landholders. Such groups could also help to increase social acceptance and ensure a "just transition" to carbon farming by helping to identify and maximise regional outcomes (Dumbrell et al., 2024). Concerns about a lack of "social licence" for carbon farming in Australia's rangelands highlight the economic, social and regulatory risks that can arise if broader community objectives are not considered (Baumber et al., 2022).

The diversity of modern collaborative initiatives among landholders in Australia reflect the nuanced and multifaceted nature of contemporary agricultural challenges and opportunities. Barriers to collaboration are also multifaceted and include differing land uses and values, individualistic or "property-centric" mindsets, exposure to financial or land management risks, unfamiliarity with collaborative business models, lack of time and the absence of group leaders or champions (McKiernan and Gill, 2022; McLeod and Hine, 2023; Pfeiffer et al., 2017). Policy-driven initiatives to amplify collaboration and overcome barriers include the $15 million-dollar Australian Government funded Farming Together program that supported over 28,000 primary producers to implement collaborative business solutions between 2016 and 2018 (Clear Horizon, 2018). This tradition of collaboration and the breadth of models present in Australian agriculture provides a critical resource for stakeholders investigating carbon farming to draw on.

4. Methods

In order to inform the research questions through stakeholder knowledge of soil-based carbon farming and collaboration, two stages of social research were undertaken: (1) national-scale key informant interviews and (2) participatory rural appraisal within a selected case study region. Human research ethics approval was obtained through the University of Technology Sydney (reference number ETH21-6399).

4.1. Key informant interviews

Twenty-eight semi-structured interviews were undertaken across seven stakeholder categories between September and June 2022 (Table 1). All interviews were conducted online using Zoom due to the impact of Covid-19 travel restrictions. A “snowballing” approach was used to recruit participants, starting with prominent businesses, agencies and organisations involved in agriculture and carbon farming, with each participant then asked to nominate other people we should interview. Following Kirchherr and Charles (2018), the diversity of perspectives was maximised by starting with multiple “seeds” (initial participants), allowing for multiples “waves” of snowballing and persisting with difficult-to-reach participants by contacting them at least twice and extending the interview period to suit their availability. All participants were de-identified and are referred to using stakeholder category codes.

While landholders were not specifically recruited as key informants, several representatives of farmer groups or agricultural service providers were also landholders. Agricultural service providers differed from carbon service providers in that they provided advice or training in areas other than carbon markets (e.g. regenerative farming, grazing management). Government participants and researchers specialised in either agriculture or climate change. Markets and finance participants included specialists in carbon markets as well as more conventional finance sector stakeholders who were beginning to engage in carbon markets.

Interview questions covered roles and experience, opportunities and barriers to carbon farming, benefits and risks of collaboration, perspectives on different collaboration models and factors that could enhance collaboration success (see supplementary information). As interviews were semi-structured, follow-up questions varied depending on an interviewee’s initial response. Collaborative models suggested by previous interviewees were used as prompts for follow-up questions to ensure that participants considered a broad range of options. Thematic analysis was undertaken on the key informant interview transcripts using NVivo 12 software. An *in vivo* approach was employed, whereby thematic codes emerged from the interviews (King, 2008), rather than predetermining codes based on the literature (i.e. *in vitro* coding).

4.2. Participatory rural appraisal

The second stage of the study sought to understand how the national-scale issues identified in the key informant interviews might play out at the regional scale. The region of focus was the Central West of New South Wales (NSW) (Fig. 3), which was selected for a range of reasons, including the mix of grazing and cropping, positioning between higher and lower rainfall areas of NSW (mean annual rainfall 500–750 mm across study zone), recent recruitment of local landholders by carbon service providers and proximity to the rangeland areas of NSW where carbon farming projects are already underway.

Participatory Rural Appraisal (PRA) treats rural people as co-producers of knowledge that can be used to inform participatory planning and action (Chambers, 1994). The PRA involved pairs of interviewers (one researcher and one local stakeholder) spreading out across the region to visit landholders on their properties. The interview pairs gathered each evening to share results and again at a final sense-making workshop after all interviews were completed.

Twenty-five interviews with twenty-seven landholders (two involved a pair of interviewees) were undertaken across three days in late March 2022. A snowballing approach similar to the key informant interviews was employed, starting with contacts provided by local landholder groups and suggestions from key informants. All participants were graziers running cattle and/or sheep, with ten also engaging in cropping (e.g. canola, wheat, fodder crops), similar to the overall regional breakdown between grazing and cropping enterprises (NSW DPI, 2020). The median area of land managed by participants was 1150 ha (~2800 acres), ranging from 150 ha to 7000 ha. Participants were also categorised in terms of readiness to establish a carbon project, with a diverse spread from “sceptical” at one end of the spectrum to “carbon farmer” at the other (Fig. 4).

The PRA interview questions were similar to those asked of key informants, with additional questions asked on land size, land use and history of land management. Follow-up questions were dependent on each landholder’s experiences with carbon farming to date and, relative to the key informant interviews, they had more of a focus on how they personally might view an opportunity, barrier or collaborative model. As with the key informant interviews, thematic analysis was undertaken on the PRA interview transcripts using NVivo 12 software.

Table 1
Key informants listed by stakeholder category. Note that several participants are listed under more than one stakeholder category.

Category	Code	No. of Participants
Landholder	LH	6
Farmer group	FG	6
Agricultural service provider	AS	8
Carbon service provider	CS	5
Government (3 states & federal)	GV	4
Researcher	RS	6
Markets & Finance	MF	3

5. Results

5.1. Potential benefits of enhancing soil carbon

Across both the key informant interviews and the PRA, interviewees tended to frame soil carbon increases as a win-win for agriculture and the environment. PRA participants generally cited productivity benefits for their farming enterprise before discussing income from carbon or broader environmental benefits. The types of benefits cited were similar between the two interview groups (Table 2), with the most-commonly cited benefits being increased water-holding capacity of soils, followed by income from carbon credits.

When asked about opportunities to increase soil carbon, key informants tended to focus more on market opportunities, such as rising credit prices or increasing demand. In contrast, PRA participants focused more on land use practices, such as time-controlled grazing, composting or minimal till cropping. Both groups regarded grazing practices as holding greater potential to enhance soil carbon than cropping, with this being particularly pronounced for the PRA interviews (Fig. 5).

5.2. Barriers to engaging in carbon farming

Across both the national-scale key informant interviews and the regional-scale PRA interviews, the two most commonly-cited barriers were the same: complexity of rules and processes and high project set up costs (Table 3).

Responses to information barriers and complexity ranged from attempts seek out information to inertia to mistrust (“farmers are inherently suspicious of any government schemes” - Key Informant AS1). Some participants were sceptical that the hype around soil carbon credits would be fulfilled while a small minority in both the key informant and PRA interviews were opposed to the idea that farmers should be expected or encouraged to store carbon in their soils as an offset for other emitters (“provide cover for the fossil fuel industry to continue business as usual” - Key Informant FG/LH2).

The most commonly-cited cost barrier was for soil sampling. Many landholders saw the carbon service provider model of retaining a proportion of credits in return for covering upfront costs as unfair and

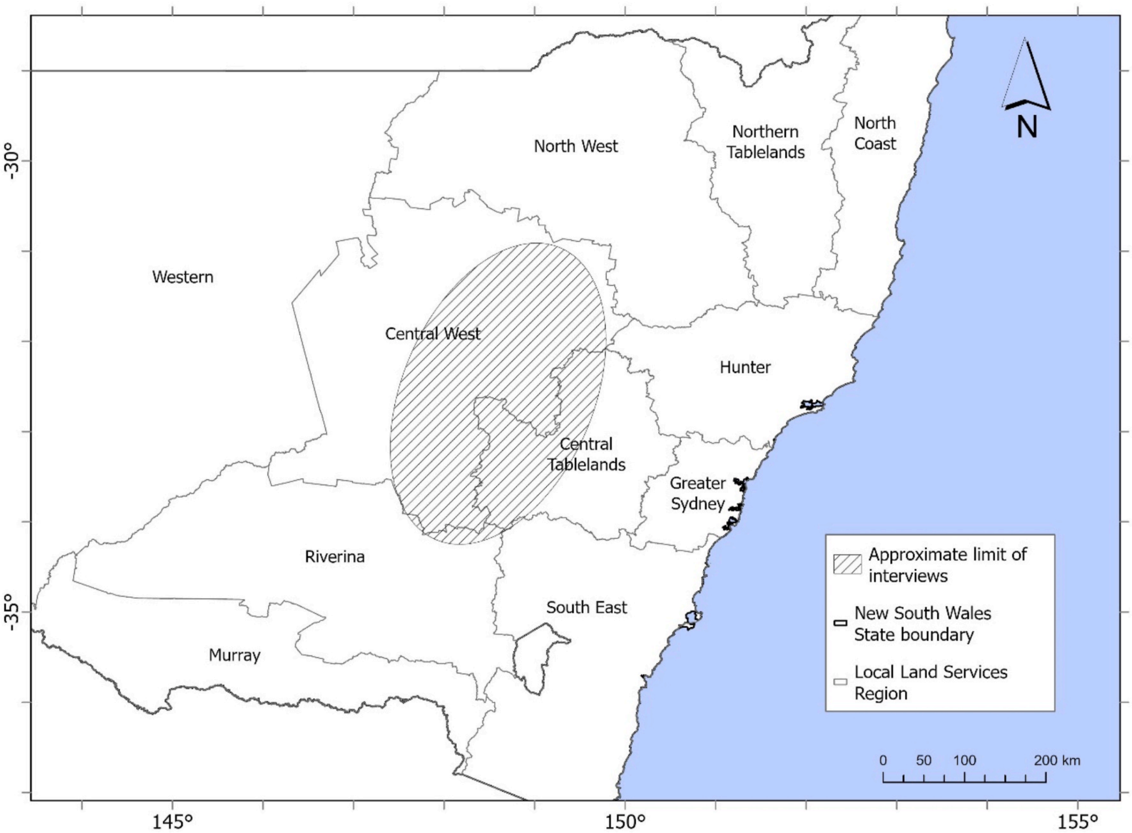

Fig. 3. Location of the PRA exercise in the NSW Central West.

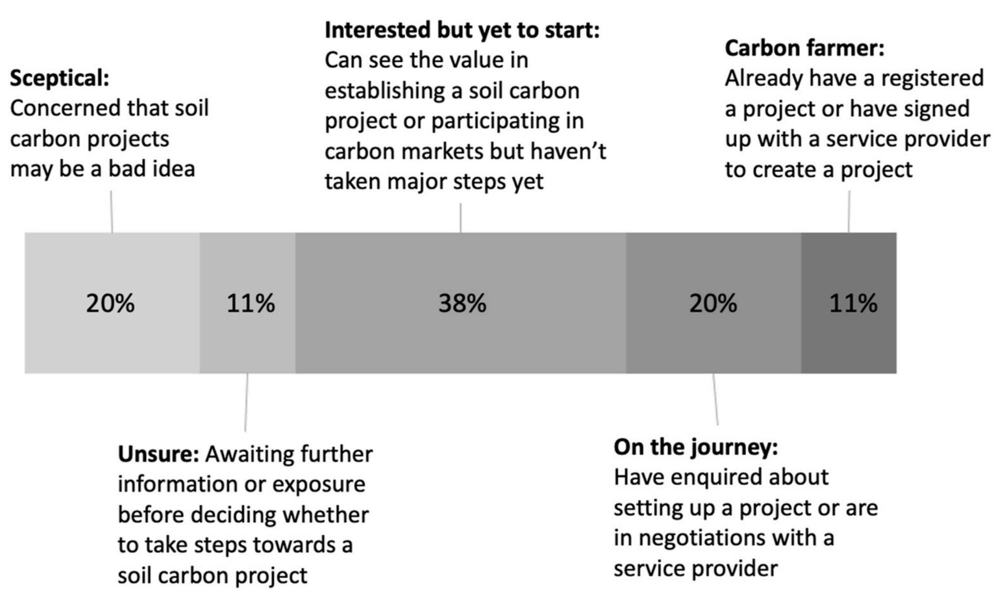

Fig. 4. Readiness of PRA participants to engage in soil-related carbon farming.

excessive (with the term "sharks" used by multiple participants). Others felt this was reasonable given the costs and risks involved. Scale was a related factor, with several participants indicating that small properties lacked sufficient scale to offset the transaction costs of setting up a project by themselves.

Other barriers identified across the two groups included:

- Risks that expected sequestration would not be achieved
- Farmers unable to get paid for having increased soil carbon prior to registering a project
- Loss of flexibility around future land use due to a 25 or 100 year commitment period (potentially impacting the future sale of land)
- Low price of carbon at present relative to other farm produce (and risk that it could fall)
- Traditional/conservative/risk-averse mindsets amongst some farmers

Table 2
Most commonly-cited benefits of enhancing soil carbon across both sets of interviews.

Benefit	No. of participants citing the benefit	
	Key informants	PRA
Water-holding capacity of soils	17	19
Income from carbon credits	15	16
Biodiversity (including soil biota and pasture diversity)	15	12
Improved pasture growth/productivity	9	13
Improved ground cover (including erosion control)	9	11
Social or community benefit	5	12
Improved water quality (i.e. runoff into streams)	3	3

5.3. Potential for collaboration

The potential advantages and disadvantages of collaboration cited by interviewees were similar amongst both the key informants and PRA participants: increased access to information and technical support, social support and learning together, increased bargaining power, enhanced co-benefits and potential premiums based on credit provenance. However, these potential advantages were highly dependent on the collaborative model that a participant had in mind, as were the potential disadvantages or risks from collaboration. While all interviews involved an open question around models for collaboration, three main models emerged early on from key informant responses and were raised with later participants for feedback:

1. Informal knowledge-sharing and project establishment: This involves landholders coming together to share knowledge and potentially some costs, but retaining the option to have independent carbon projects for each property.
2. Joint management of projects: This model involves tighter integration between landholders, potentially including shared management responsibilities and the pooling of carbon credits
3. Joint marketing of credits: This model does not require landholders to share land management or ownership of credits, but involves coming together to market their credits collectively.

By far the most popular model across both the key informant and PRA interviews was informal knowledge sharing and support with project establishment (Model #1). It did not offer the same benefits in terms of bargaining power, price premiums or co-benefits as the other two models (Fig. 6a), but was seen to offer considerable flexibility in decision-making while gaining the benefits of information-sharing and social support. Moreover, it was seen to have far fewer disadvantages or risks than the other models (Fig. 6b). It was often cited as suitable for existing landholder groupings like Landcare groups, farming systems groups, neighbours with a history of working together or extended family units managing multiple properties.

The second model (joint management of projects) was the least-preferred model across both key informants and PRA participants due to its legal, commercial and social complexity, regulatory challenges around establishing joint projects, exposure to risk and the need for complex rules around entry and exit, shared management practices and the distribution of revenue and costs. Two of the carbon service providers involved in the study reported that they had previously trialled "project-related aggregation" involving the bundling of multiple properties into a single registered project, but had moved away from this due to the additional stakeholder liaison, administrative burden and transaction costs involved.

The third model (joint marketing of credits) received widespread

Table 3
Sample quotes relating to carbon farming barriers.

Complexity and information access	High project set up costs
"I think the biggest prohibitor is the lack of education and the confusion around carbon farming" – Key Informant FG/LH1	"To fund the baseline studies usually requires selling some credits to pay for it because it's quite expensive to do the soil tests" – Key Informant FG/LH2
"I think the main barriers are understanding it, exactly what is involved" - PRA Landholder M	"how much would it probably cost me? You know, maybe 30, 50 grand to do the baselining … that's a fair bit of money. Then I'd have to recoup that in a sale." – PRA Landholder A
"The ones that are really progressive probably just go and read more and will fill their knowledge gaps or seek more information. But some might get a little jaded and say, oh, I don't understand this, I'm just going to wait and see how it plays out." – Key Informant CS1	"We know some methods are more expensive than others and especially for things like soil measurement, for example, which can be expensive. And how does a landholder assess those costs and benefits or find good advice to help them assess those costs and benefits as well?" – Key Informant GV3

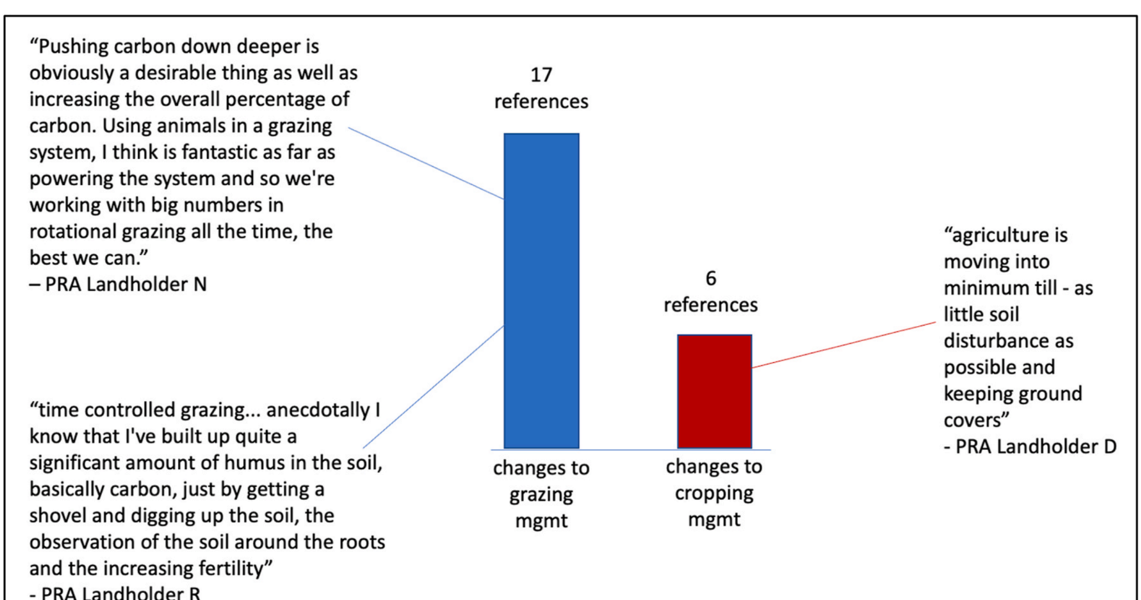

Fig. 5. Number of references and sample quotes related to opportunities around grazing versus cropping in the Central West PRA interviews.

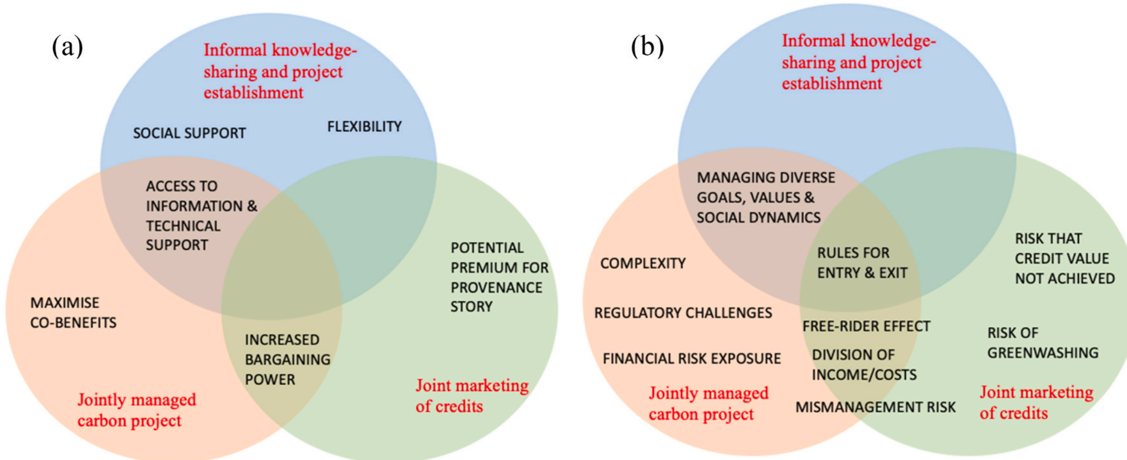

Fig. 6. Most frequently cited advantages (left) and disadvantages/risks (right) for each of the three main models discussed in the interviews.

support, but was seen as somewhat speculative. The key benefits it offered were increased bargaining power and the potential to obtain a market premium for credits from farmers with a shared vision, However, obtaining these benefits would require landholders to retain future sale rights over their credits (i.e. not assign them to a service provider on project establishment), a business structure to market credits and distribute income, and a carbon price premium that was high enough to justify the added complexity. Existing co-operatives set up to market other products (e.g. beef, dairy, wheat) were seen to have the structures already in place to capitalise on this opportunity, with a company structure also suggested as an option. Participants were more sceptical about establishing new co-operatives specifically around carbon credits.

Variations on the models were also suggested by participants. Several referred to a hybrid model that was being promoted by a group called Regen Farmers Mutual during the interview period (Regen Farmers Mutual, 2021). This model features elements of Model #1 and #2, with some pooling of credits and collaborative natural resource management via a Landcare or other local group, while allowing each member to retain independence over their farming enterprises and the bulk of the credits they generate. Other variations suggested by participants included:

- Combining Model #1 and Model #3, potentially through a co-operative or other entity involved in both project setup and the marketing of credits
- Retaining credits to offset on-farm or supply chain emissions rather than selling them
- Partial pooling of credits (e.g. some retained by individual farm, some pooled across local group, some issued to service provider)
- A family-owned entity pooling carbon credits from properties owned by family members
- Shared management of grazing herds across properties (e.g. an entity that could provide grazing services or bid for access rights to multiple properties)
- Conservation covenants, whereby landholders could enter into cross-property conservation convenant with a third party that covers carbon, biodiversity and other ecosystem services

5.4. Factors for successful collaboration

Views were mixed with regards to the types of groups that could evolve into collaborative carbon farming groups. Amongst the key informants, Landcare groups and farming systems groups were most commonly cited, with trust, social bonds and history of collaboration cited as enabling factors. Conversely, a lack of commercial collaboration between members was a key barrier for Landcare groups and several participants cited the need for "independence" or a "fresh start". Government-instigated groups were not favoured as a means of setting up collaborative carbon farming, with participants indicating that government processes were overly bureaucratic or that government agencies had pulled back from offering these kinds of extension services.

Existing co-operatives were identified as a potential vehicle for collaborative carbon farming, but there was a lack of experience with co-operatives amongst PRA participants in the NSW Central West. One example cited from a different region was a pilot project run by the beef-oriented Casino Food Coop in northern NSW that is exploring the potential for soil-based carbon to offset farming emissions across the co-operative's activities (Farming Together, 2023a).

Social factors were cited as particularly important for collaboration. Shared values and shared practices were cited as factors that could be important for telling a provenance story (e.g. a group of farmers managing their land in a certain way based on common values being able to obtain a market premium for their carbon credits). In addition, shared practices (e.g. time-controlled grazing of cattle) could make it easier for landholders to share relevant knowledge. Shared values (e.g. around regenerative farming) was seen as important for ensuring the longevity of any collaboration.

In terms of trust, other landholders were the most commonly cited source of trusted information, particularly where there was a history of collaboration. Specific examples included neighbours, family, members of a Landcare group or farming systems group or respected local champions of particular land use practices. Other trusted sources included government agencies (e.g. Local Land Services, agriculture department), as well as accountants, solicitors and financial advisors. Carbon service providers were trusted by some participants, especially those who had entered into carbon farming agreements with them, while others expressed distrust, especially where a large share of future credits (e.g. 30%) was being sought in exchange for their services.

Interview participants had mixed views on the importance of geographic proximity as a factor in effective collaboration. Some argued that it was important, particularly for maximising co-benefits and making joint measurement easier. However, most participants indicated that being direct neighbours wasn't essential and could even be problematic due to the need to maintain good relationships and not become too invested in one another's land management. Some suggested that having similar soil types was an important characteristic that could make measurement (and potentially modelling) of soil carbon easier. Others suggested catchment boundaries were important for managing run-off, erosion and water quality.

6. Discussion

The social research undertaken for this study affirmed many of the benefits and barriers around soil-based carbon farming identified in previous studies. Moreover, returning to the three research questions for this study, the results showed that: (1) collaboration between landholders has the potential to enhance some of these benefits and overcome some barriers, (2) collaboration also introduces additional complexities and requires certain enabling conditions for it to succeed, and (3) the advantages, disadvantages and likelihood of success vary with the choice of model. Each of these findings are explored below.

6.1. Potential for collaboration to enhance opportunities and reduce barriers

The interview results showed that collaboration does offer the potential to enhance some of the benefits motivating landholders to adopt soil-based carbon farming, while also reducing some of the barriers. However, it is important to distinguish between the significance of a given benefit or barrier in driving adoption overall and the potential for collaboration to further increase adoption by enhancing benefits and reducing barriers (Fig. 5).

In terms of benefits, the most significant drivers of adoption, particularly in relation to grazing enterprises, were found to be productivity increases related to water-holding capacity, microbial activity, pasture diversity and ground cover. This is consistent with Buck and Palumbo-Compton's (2022) global review of soil carbon sequestration studies and supports the idea that soil-based carbon farming can offer a win-win between climate action and agricultural productivity (Amin et al., 2023; Gosnell, 2022). Our findings further challenge the framing of these outcomes as "co-benefits" when they are often a landholder's primary motivation for adopting practices that enhance soil carbon. While this can incentivise the adoption of carbon farming, it also has the potential to diminish the value of collaboration, as productivity gains are largely driven by actions on individual properties (unlike landscape-scale co-benefits relating to biodiversity or water quality).

Fig. 7 demonstrates the importance of separating out property-scale and landscape-scale co-benefits. Our results suggest that property-scale co-benefits offer a stronger motivation for landholders to increase soil carbon, but the opportunities for collaboration are more significant for landscape-scale co-benefits such as biodiversity or water quality/flood mitigation, where coordinated efforts could enhance outcomes beyond the property scale and contribute to regional objectives (Dumbrell et al., 2024).

Income from carbon credits tended to fall in between property-scale and landscape-scale co-benefits as a carbon farming motivation for landholders in this study and was also a mid-ranking factor with regards to the potential for collaboration to enhance it. Collaboration could increase bargaining power with carbon service providers or prices obtained for credits through joint marketing, particularly if the group can demonstrate environmental or social co-benefits beyond their properties (Clean Energy Regulator, 2022). However, this is dependent on landholders being willing to enter into complex commercial relationships (discussed further in section 6.3). The final benefit in Fig. 5 relates to the social aspects of collaboration. Our results support the findings of Kragt et al. (2017) and Mattila et al. (2022) that collaboration can offer support with transitions and create a sense of community, but do not suggest that this is likely to be a major driver of adoption.

The barriers to carbon farming identified in this study were consistent with those identified by other researchers exploring carbon farming in Australia, Europe and North America. A lack of knowledge and confusion about the rules and processes for engaging in carbon farming was widely-cited as a barrier, consistent with the findings of Buck and Palumbo-Compton (2022), Wiese et al. (2021) and Cotton and Witt

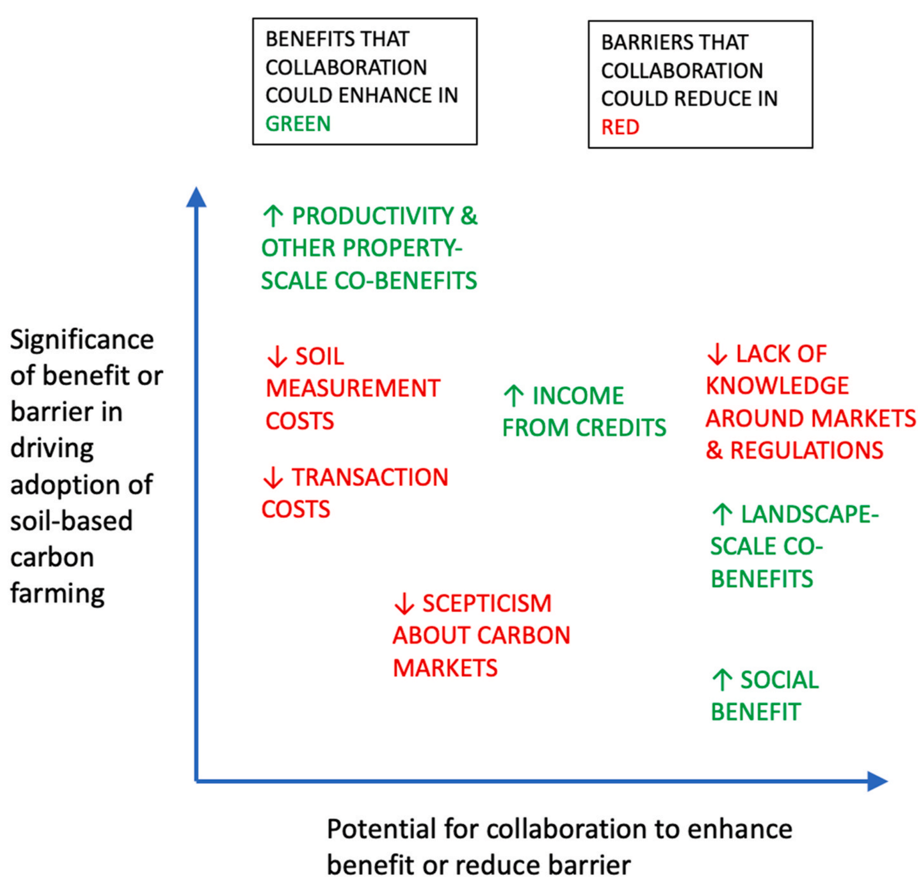

Fig. 7. Potential for collaboration to overcome barriers and enhance benefits of carbon farming.

(2024). The other major barrier was cost, particularly the high cost of measuring soil carbon and the transaction costs involved in setting up and administering a project, also consistent with previous results from Europe (EC, 2021) and Australia (White, 2022).

Of the two main barriers, this study found that collaboration offered the greater advantage in relation to overcoming confusion, misinformation and the lack of trusted information sources, supporting the findings of Kragt et al. (2017) and Johansson et al. (2022) around the importance of knowledge-sharing between landholders. In contrast, it is less likely that collaboration would reduce soil measurement costs or transaction costs, as combining properties under a single project in Australia is complex (Macintosh et al., 2019) and likely to create additional legal, financial and social costs, according to project participants. Carbon service providers interviewed for the study also rejected the notion that combining properties would reduce the number of soil measurements per landholder, as the 2021 soil carbon measurement and model method sets a minimum number of measurement points per Carbon Estimation Area (CEA), with each property divided into multiple CEAs and all land in a CEA required to be owned by the same landholder (Clean Energy Regulator, 2021).

While the barrier relating to carbon trading scepticism is consistent with previous findings from Queensland (Jassim et al., 2022), collaboration is unlikely to make much difference for landholders concerned about providing "cover for the fossil fuel industry". A number of the other barriers identified by our participants and by previous studies would not be reduced by collaboration in any meaningful way, such as the risk that sequestration will fall short of expectations (Buck and Palumbo-Compton, 2022), eligibility rules that prevent landholders from generating credits from past sequestration (Thompson et al., 2022) and concerns that committing to carbon farming reduces future land use flexibility (Baumber et al., 2020).

Notably, our study participants affirmed the "win-win" narrative between agricultural productivity and soil carbon sequestration reported in previous research (Amin et al., 2023; Buck and Palumbo-Compton, 2022; Gosnell, 2022). This contrasts with the "trade-off" narrative that is typically applied to assisted regeneration in Australia, whereby carbon income from trees needs to compensate for lost grazing income (Baumber et al., 2022; Jassim et al., 2022) and with some overseas cases where practices that enhance soil carbon have been linked to reduced agricultural income (Jat et al., 2022; Paul et al., 2023).

6.2. Challenges associated with greater collaboration

While a group of landholders working together may be able to help one another overcome knowledge barriers, obtain higher returns on their credits and optimise landscape-scale co-benefits, the processes required to do this can also create their own challenges. Concerns raised by study participants around the potential loss of independence, exposure to risk, social conflict around differing values and personality types, and the need to manage specific processes like entry and exit rules echo concerns found in previous studies on landholder collaboration in Australia (McKiernan and Gill, 2022; McLeod and Hine, 2023; Pfeiffer et al., 2017), as well as other countries such as the UK (Jones et al., 2023; Riley et al., 2018). Joint marketing approaches and attempts to optimise landscape-scale co-benefits could also reduce autonomy in relation to land management. Long-term arrangements could further impact on the ability to change practices, sell land or succession arrangements within families, exacerbating concerns around loss of land use flexibility cited in previous studies (Baumber et al., 2020).

Balancing the challenges and risks that collaboration can present against its potential benefits is likely to require both the selection of appropriate legal and business models and careful consideration of social and behavioural factors. While the pros and cons of different models are discussed further in section 6.3, the Farming Together program has developed a set of social principles based on previous studies and experiences supporting collaborative farming ventures businesses in Australia (Table 4). The interviews provided a number of key insights into how these principles might be operationalised around soil-based carbon farming in the Australian context. Non-commercial collaborations such as Landcare or farming systems groups often possess strengths in relation to trust and shared values, but lack the structures and experiences to manage some of the additional complexities that arise from commercial collaborations, including division of costs and revenue, conflict resolution and managing entry and exit processes. The recent study of landholders in Southern Queensland by Paredes et al. (2023) also shed light on potential behavioural interventions that may influence views on carbon trading and collaboration, including the ways that issues are framed (e.g. enhancing a positive versus minimising a negative) and social nudges that create peer pressure to join in.

6.3. Models for collaboration

The study results indicate that, given the current state of soil-based carbon farming in Australia, informal collaborations based on knowledge sharing and social support (Model #1) offer the best balance between the potential benefits and challenges of collaboration. Beginning with informal collaboration does not preclude later expansion into joint marketing arrangements (Model #3) or joint projects (Model #2), which may appeal to certain landholders who are highly motivated to generate carbon credits or have greater familiarity and comfort with formal collaborative legal and business structures such as co-operatives. An informal landholder group that does not extend into joint projects or collective marketing of credits may still gain a number of advantages from collaboration through pathways such as:

- Speaking to one or more service providers together before making individual decisions (Farming Together, 2023a)
- Jointly negotiating with a single provider to cover project costs in return for an agreed share of credits under a credit-related aggregation approach (Macintosh et al., 2019)
- Collectively hiring consultants to provide the advice they need for a do-it-yourself (DIY) project in which landholders cover their own upfront costs (Carbon Carbon Count, 2022).

Table 4
Factors enabling successful collaborations from Farming Together (2023b) and insights from participants in this study.

Principles for successful collaborations (Farming Together, 2023b)	Insights from study participants
Build strong and trusting relationships	Trust and social bonds are higher for landholders with a history of collaboration (e.g. through Landcare and farming systems groups)
Establish a clear collective purpose, goal/s and an agreed way forward together	Shared values are more important for successful collaboration than shared practices or geographical proximity.
Set the conditions and processes to support working together effectively	Landholders are often a more trusted source of information than government, agribusiness or carbon service providers.
Establish clear but flexible roles and responsibilities	Landholders lack knowledge of carbon markets and rules, so support is needed from other stakeholders (carbon service providers, government).
Support conflict resolution	Neighbours often avoid close collaboration on commercial, legal or land management matters due to the risk of conflict.
Cultivate relationships strategically and match structure to purpose	Landcare groups generally lack a history of commercial relationships so other structures (e.g. cooperatives) may be better for commercial collaboration.
Know if/when to end things …	Managing entry and exit to a group will add to the complexity of carbon farming. Cooperatives have clearer processes for this than informal groups.

One of the key reasons why informal collaborations were favoured by study participants appears to be the importance of individual productivity gains as a motivation for adoption of practices that enhance soil carbon, relative to landscape-scale co-benefits or income from carbon credits. This is consistent with the findings of Buck and Palumbo-Compton (2022) around the importance of productivity gains, as well as other researchers who have cited low carbon prices, high costs and/or uncertain sequestration potential as a barrier to widespread adoption of soil-based carbon farming (Jat et al., 2022; Macintosh et al., 2019; Paul et al., 2023; Thompson et al., 2022; Wiese et al., 2021).

The preference for informal collaboration reflects UK results from Riley et al. (2018) and Jones et al. (2023) that formal collaboration models for landscape-scale environmental schemes can create concerns regarding impacts on a farm business and loss of control over decision-making. Discussing US farmers, Klein et al. (2019) argues that large commercial gains may be required for landholders to overcome underlying aversions to working together in formal arrangements that limit their individual rights. Emery (2015) draws a distinction between individualism (a desire to work alone) and independence (desire for control and autonomy), noting that collaboration can actually increase a farmer's independence if it opens up new opportunities while allowing them to maintain control over land management decisions. In our case study, most participants saw informal collaborations as striking the best balance between farmer autonomy and the benefits arising from interdependencies (e.g. knowledge-sharing and social support).

A key factor working in the favour of informal collaboration on carbon farming is the experience that many Australian farmers have with "voluntarist" landholder groups that combine conservation and production, such as the Landcare movement (Compton and Beeton, 2012; Curtis et al., 2014; Lockwood, 2000). Such groups offer a starting point for landholders who wish to capitalise on the benefits of knowledge-sharing and social support, without having to take on the financial, legal and land management risks associated with tighter integration. However, case study participants also suggested that Landcare or similar groups lack the commercial dimension needed to take a collaboration beyond the informal stage. Curry et al. (2022) also found mixed views on the potential role for Landcare groups in Southern Queensland to lead a carbon farming collaboration, with such groups regarded as superior to local government authorities, but inferior to farmer associations or more commercial structures such as a "landholder body corporate".

While landholders with a history of working together non-commercially may be well-placed to capitalise on existing levels of trust, shared values and contextual knowledge, they are not necessarily well placed to inform one another of the nuances of carbon farming rules and processes or reduce costs relating to project setup and soil monitoring. As such, successful collaborations are also likely to require the involvement of carbon service providers or consultants. This is supported by the recent study of Southern Queensland landholders by Paredes et al. (2023), which found that even though the majority of surveyed landholders had a positive view of collaboration around carbon trading, the most-preferred option involved outsourcing tasks related to project establishment, aggregation and trading to a specialist firm with the necessary expertise rather than rely on other farmers for the required knowledge and skills.

The case study results showed that some landholders may be willing to explore more formal collaboration options, particularly if they already belong to a cooperative or other body that is able to offer carbon farming support services to its members and manage the commercial and legal aspects of collaboration. Existing collaborative businesses such as beef, dairy or grain cooperatives are well-placed to begin offering services to their members around project establishment, soil carbon measurement and joint marketing of credits, as shown by the example of the Casino Food Coop in Northern NSW (Farming Together, 2023a). Farmers belonging to such cooperatives are also likely to have already navigated questions of interdependence and autonomy (Emery, 2015), opting to collaborate on matters that increase opportunities and returns (e.g. joint marketing and shared infrastructure), while retaining control over farm management practices and decisions.

By virtue of their pre-existing rules and processes, cooperatives can avoid many of the challenges faced by new collaborative businesses, including the need for legal arrangements, governance processes, conflict resolution, entry and exit rules, investment in upfront costs and the division of income and expenses. This may also enhance willingness to experiment and adaptability for participating cooperatives, which can be a key factor in their longevity (Iliopoulos and Valentinov, 2018). Similar opportunities may also exist in other regions with a strong tradition of agricultural cooperatives, such as Europe and North America (Candemir et al., 2021).

While diversifying into carbon farming may be an option for existing cooperatives in sectors such as beef, dairy or grains, this study found little support for the suggestion of Macintosh et al. (2019) that new co-operatives could be formed specifically to market agricultural carbon credits and provide support services around carbon farming. Key challenges for the creation of new cooperatives include the relatively low value of carbon credits for each landholder, the nature of project establishment as a one-off process and the desire amongst many landholders to sell credits upfront to pay for soil monitoring and other setup costs (rather than having recurring sales as is common for marketing cooperatives). These results are supported by the recent findings of Paredes et al. (2023) that creating a new cooperative specifically for carbon is likely to be more difficult than diversifying an existing cooperative into carbon due to the need for new skills, resources, advice and consultation. Furthermore, some of the weaknesses observed for co-operatives in previous research (Candemir et al., 2021) could be exacerbated for a carbon farming cooperative, including differing motivations between members (e.g. those at setup phase and those with an established project), heterogeneity of production systems (e.g. grazing vs cropping), differing attitudes to risk (e.g. desire to sell credits upfront vs hold out for higher prices) and the free-rider effect (if seeking to maximise landscape-scale co-benefits).

The unpopularity of Model #2 (joint projects with pooling of credits and shared land management) highlights the importance of land management independence and concerns about risk exposure through collaboration with neighbours within the project case study. This evidence supports the finding of Riley et al. (2018) that perceived loss of independence is a key barrier to greater cooperation within agri-ecological schemes in the UK, while countering the suggestion of Johansson et al. (2022) that landholders in Sweden may wish to share equipment and land as part of a carbon farming collaboration. However, it is important to recognise that preferred models are likely to differ within and across different countries due to differences in production systems, farming cultures, policy environments and experiences with collaboration (Riley et al., 2018), highlighting the importance of further studies on collaborative carbon farming in different contexts.

It is also notable that, while Model #2 was the least-preferred amongst participants, it was also most commonly associated with the term "collaboration" when each interview began. In cases where participants had this model in mind from the start of the interview, they tended to focus first on the disadvantages of collaboration, with advantages only discussed after being prompted with other models. Future research could explore how landholders to differing terminology around collaboration and carbon farming. The term "regenerative agriculture" similarly generated differing responses, with some PRA participants self-identifying as regenerative farmers and others rejecting the label. Other terms that could be explored include "independent" and "individual", which have also been found to generate nuanced responses amongst participants in previous studies (Emery, 2015).

Government support is crucial to enabling further development of collaborative models and providing user-friendly pathways for collaboration that align with ACCU Scheme rules and processes. This work should draw insights from policy experimentation underway in diverse jurisdictions, including the European Union (Paul et al., 2023), China (Tang et al., 2019), India (Jat et al., 2022) and Canada (Government of Alberta, 2023). The recent proposal by Cotton and Witt (2024) for "multi-stakeholder roundtables" to address "wicked problems" in Australian carbon and ecosystem markets could also offer a pathway for landholders, scientists, regional communities, carbon service providers and purchasers of carbon credits to work constructively with government agencies to identify and support new collaborative models for carbon farming.

7. Conclusion

In this article, we set out to address three key questions around soil-based carbon farming. These related to: (1) the potential for landholder collaboration to reduce barriers and enhance opportunities, (2) the challenges that might arise and (3) the different models that could be applied.

Our case study results highlight the potential for collaboration to address barriers around confusion, misinformation and a lack of trusted information sources, particularly through less formal collaborations that can build on the presence of "voluntarist" landholder groupings within Australian agriculture (Bellamy et al., 2012; Compton and Beeton, 2012). Such groupings may also help landholders to maximise landscape-scale co-benefits and engage more efficiently with the specialised carbon service providers who can provide the group with more detailed advice and help them manage complex processes relating to project registration, measurement and credit generation. Similar groupings in other countries may offer a starting point for collaboration as soil-based carbon farming options continue to emerge, including in the UK (Jones et al., 2023), Sweden (Johansson et al., 2022) and the EU (EC, 2021).

Our finding that agricultural productivity can be a stronger driver of soil-based carbon farming than carbon credit income supports recent overseas research (Buck and Palumbo-Compton, 2022). However, we also found that this can work against collaboration, as productivity gains are largely driven by actions on individual properties and the status of carbon as a minor income stream may reduce the significance of collaborative efforts to enhance bargaining power or jointly market credits. The relatively low value of carbon credits and the increased social, financial and legal complexity of managing a collaborative carbon farming venture also mitigate against formalised models that involve the pooling of credits or shared land management. Exceptions to this may include collaborative models that have already been set up for other purposes, such as agricultural cooperatives that could adapt existing mechanisms for landholder support and joint marketing to diversify into the nascent carbon farming sector.

As the carbon farming sector matures, new models for collaboration may emerge, particularly if carbon prices rise, transaction costs fall and certainty increases around credit generation from specific land use practices. This may reduce the importance of individual productivity gains for the adoption of soil-based carbon farming and increase the attractiveness of collaboration around joint marketing and credit premiums linked to landscape-scale co-benefits. It may also make new collaborative models viable, including dedicated carbon cooperatives or hybrid models involving partial pooling of credits and shared land management to optimise landscape-scale impacts. As carbon markets and the regulatory environment surrounding them continue to evolve, the results of this study will need to be revisited and combined with further research involving other locations, practices and models for collaboration.

CRediT authorship contribution statement

Alex Baumber: Writing – original draft, Supervision, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Rebecca Cross:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Peter Ampt:** Methodology, Investigation. **Cathy Waters:** Writing – review & editing, Resources, Investigation. **Jennifer Ringbauer:** Writing – review & editing, Project administration, Investigation. **Isabella Bowdler:** Investigation, Formal analysis, Data curation. **Amanda Scott:** Writing – original draft, Investigation. **Lorraine Gordon:** Writing – review & editing, Supervision, Resources. **Andres Sutton:** Writing – review & editing, Investigation. **Graciela Metternicht:** Writing – review & editing, Resources, Funding acquisition.

Declaration of competing interest

Cathy Waters is employed by GreenCollar, a provider of carbon farming services (employment commenced after this research project concluded).

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jrurstud.2024.103268.

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