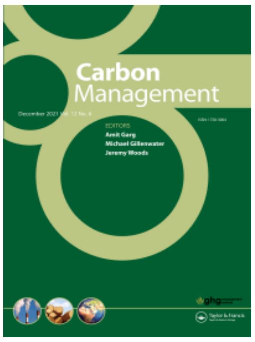

Carbon Management

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tcmt20

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To cite this article: Cara Stitzlein, Jeffrey A. Baldock, Stephen H. Roxburgh, Martijn Mooij, Daniel Smith & Peter Fitch (2023) Facilitating entry to land sector carbon abatement projects: the LOOC-C tool, Carbon Management, 14:1, 2265156, DOI: 10.1080/17583004.2023.2265156

To link to this article: https://doi.org/10.1080/17583004.2023.2265156

CARBON MANAGEMENT
2023, VOL. 14, NO. 1, 2265156
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Facilitating entry to land sector carbon abatement projects: the LOOC-C tool

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ABSTRACT

Carbon farming presents an opportunity for the land sector to generate income and transition to more sustainable land management practices. In Australia, establishing a carbon project and earning carbon credits is complex, with project proponents needing to satisfy eligibility requirements and adhere to rigorous measurement, verification, and reporting protocols of approved methods. To address these challenges, a human centered design (HCD) approach was used to deliver a digital solution, serving landowners' needs related to method discovery and reconfiguring how the methodological and scientific complexity of abatement potentials was delivered. The solution, called LOOC-C (pronounced "Look-see"), supports the discovery of abatement methods that are available for a given land area and provides an initial estimate of the potential quantum of carbon sequestered/emitted and the nature of co-benefits associated with each eligible method. Reporting on LOOC-C development and its observed impact demonstrates the role that human centered digital tools have in promoting land management actions that are both sustainable and reasonable to undertake. It equally demonstrates the power of integrating environmental market and user requirements with a robust design methodology. With similar opportunities in environmental markets globally, additional applications of an HCD approach are proposed.

KEYWORDS
Carbon abatement potential; land sector methods; human centered design; digital tool; emissions reduction fund; Australia

POLICY HIGHLIGHTS

- In 2012, the Australian government established the Emissions Reduction Fund (ERF) to reward landowners (*via* awarding Australian Carbon Credit Units, or ACCUs) for the implementation of management practices that either sequester carbon and/or reduce emissions of greenhouse gases.
- Rigorous eligibility and method requirements are intended to provide confidence in abatement outcomes, but they introduce significant complexity that participants must overcome.
- 11 years later, uncertainties in the implementation and ACCU generation potential of ERF projects and implications on productivity/co-benefits have limited uptake and the quantum of ACCU generation of land sector enterprises.
- Digital tools that support the discovery of options and provide estimated potential outcomes, such as the LOOC-C tool described in this paper (https://looc-c.farm/), can generate interest and empowerment, helping to initiate decisions toward market participation.

VIDEO ABSTRACT
Facilitating Entry to Land Sector Carbon Abatement Projects: The LOOC-C Tool

Introduction

Carbon abatement projects have the potential to reduce greenhouse gas emissions and/or sequester carbon from the atmosphere. Implementing a market mechanism helps to achieve this change by incentivizing different land management practices. In 2012, the Australian government established a carbon trading mechanism with the Emissions Reduction Fund (ERF) and Australian Carbon Credit Units (ACCUs), whereby one ACCU equates to one ton carbon dioxide equivalent (*t* CO_2-e) that can be sold to the Australian government or into a secondary market. ERF projects must be implemented in accordance with approved methods that set out the rules and methods and must comply with a set of "Offsets Integrity Standards" defined in the

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Supplemental data for this article is available online at https://doi.org/10.1080/17583004.2023.2265156

"Carbon Credits (Carbon Farming Initiative) Act 2011" [1]. The methods determine eligible management activities and how abatement is to be measured, verified, and reported. A range of methods have been approved for all sectors of the economy. Within the land sector, agricultural, vegetation, and savanna fire management methods are available.

While the land sector can potentially contribute to national abatement [2], uptake into the ERF has been modest. Facilitating entry into any carbon market requires overcoming multiple barriers that include meeting significant regulatory obligations and managing uncertainty about participation and possible outcomes [3–5]. Uncertainties related to the trade-offs between emission abatement and farm production are important considerations [6,7]. Incentives must outweigh the costs of participation, especially in situations where the economics of carbon farming are marginal and, by necessity, landowners are more concerned with the "main game" of productivity and business viability.

Any co-benefits associated with implementing an ERF project should also be considered and these are well documented both in agronomic terms and more broadly from social, environmental, economic, and policy perspectives [3,8–10]. Examples include improved soil health and productivity, improved water holding capacity and management of erosion and salinity, as well as biodiversity and conservation outcomes. Whilst each of these are positive outcomes, dis-benefits can also arise [11], such as the potential for decreased catchment runoff with extensive reforestation. Given the range of possible co-benefits, they should be considered as a component of the decision-making process when the potential of initiating an emission abatement project is evaluated. Indeed, including an assessment of co-benefits could re-invigorate how emission abatement projects are perceived and adopted [3].

Carbon brokers and aggregators provide expert advice services and considerable administration support, which can reduce barriers to market entry. Aggregators can achieve scale, spread the risk of low or negative abatement, and spread some of the project costs by linking individual projects into a portfolio. However, how such benefits translate to individual landowners will be subject to the terms in the contract agreed to by the landowner and aggregator. If carbon prices are low $<\$30\,t$ CO_2-e, transaction costs can consume a significant proportion of the value created by a project, especially where project areas are small [2]. Where margins are small, a project may not be considered economically attractive unless significant co-benefits are created for the landowner (e.g. increased productivity is achieved by implementing the management practice change required to provide emissions abatement). Secondly, landowners can be suspicious about whether advice provided by an aggregator is aligned with aggregator interests or represents the best option for the landowner [12].

In consideration of the challenges associated with carbon market participation, this paper asks whether a digital solution could provide a quick, independent, and location-specific estimate of the potential quantum of abatement associated with land sector ERF methods. One hypothesis is that success is possible if the tool provides a positive user experience (UX), which "encompasses all aspects of the end-user's interaction with the company, its services, and its products" [13]. The design of UX is often achieved through the application of human centered design (HCD) methods, some of which are captured as an International Organization for Standardization (ISO) standard [14], and thus are recognized as an important part of ensuring that new tools are considered usable. Increasingly, the need for end user input is recognized and reported as part of an optimum technology development process [15]. There is a recent uptake of HCD in various Agri-technology solutions [16–18].

This paper presents the Landscape Options and Opportunities Carbon abatement Calculator (LOOC-C) web-based tool designed to facilitate entry to Australian land sector ERF projects (available at https://looc-c.farm/). The paper focuses on how applying HCD methods produced a user-friendly tool underpinned by robust scientific models of potential carbon abatement. The application of HCD demonstrates how barriers to environmental market entry can be mitigated by meeting user requirements for an appropriate level of decision support: here, by leading users through the process of identifying options and providing the estimates of the potential outcomes of these options [19] and providing a good "fit" between people, their current technology and tools, and to the context of use [20]. By supporting ERF method discovery and responding to a user need for co-benefits information, the tool empowers landowners with farm specific insights and helps promote scheme participation by providing scientific estimates of carbon abatement potential.

Methods

In this section, a two-phased HCD process is described with subsections addressing how science, engineering, and design activities were conducted.

The human centered design (HCD) process

HCD provides a structure and set of methods that focuses problem solving on people's needs and abilities. The HCD process is historically represented with two phases of activity in a "double diamond" structure: phase 1 discovery and definition (left diamond), and phase 2 development and delivery (right diamond) [21]. Shown in Figure 1: In the first phase, a problem area is scoped after an exploration of people's experiences and context.

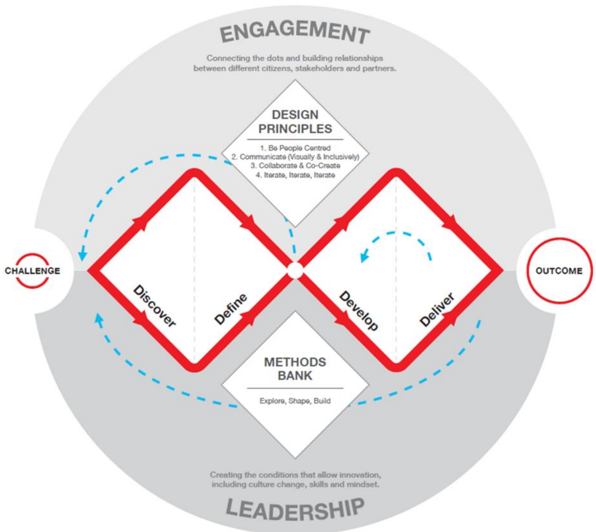

Figure 1. **Framework for innovation (reproduced from Ref. [21]). The HCD process starts with a challenge and finishes with an outcome. The double diamond within is supported by design principles and methods. Activities are influenced by stakeholder engagement and leadership.**

This allows for the development of a solution concept that is informed by a deep understanding of the people being designed for. In the second phase, the solution concept is iteratively tested and is refined as more is learned about its efficacy and usability for solving the problem.

The identified design challenge was to provide a digital solution that reduced barriers faced by landowners, mainly uncertainties regarding method regulation and project consequences. The primary outcome of the work was the LOOC-C tool, delivered directly to the Australian land sector and supporting an initial evaluation of carbon abatement potential of land sector ERF methods applicable to a defined land area, plus additional decision support information. As shown in Figure 2, the scientific and design activities were executed in parallel and informed one another.

- In phase 1, activities identified requirements for user experience and applicable ERF land sector methods, helping to define and scope the design challenge.
- At the end of phase 1, a journey map technique [22] helped the team generate a solution concept and a set of questions for user testing in phase 2.
- In phase 2, iterative testing cycles refined and improved the solution concept, from both a science delivery and UX perspective. The solution matured from a prototype to a product and was ultimately delivered as a web-based tool.

The translation of requirements into features of the LOOC-C tool is presented in the Results. Details of the social scientific and scientific approaches as well as the ERF methods included in LOOC-C are found in the Supplementary Material.

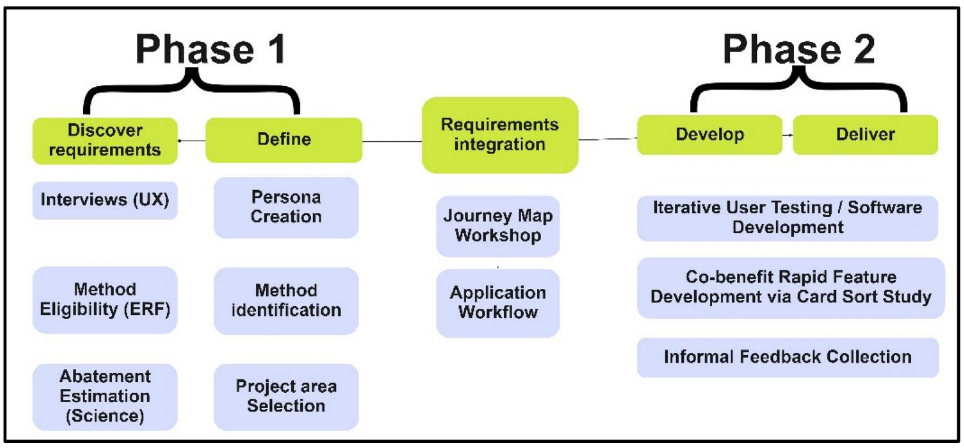

Figure 2. **Conceptual diagram capturing two phases of HCD research activities. The progression toward a more mature solution is shown in green boxes (top row) with activity descriptions in blue boxes (bottom rows).**

Phase 1: Discover and define solution requirements

In phase 1, an investigation of the regulatory framework and market mechanism determined how scientifically derived abatement estimates could be calculated and what methods were required to calculate that abatement. In parallel, social science activities were undertaken to identify the most likely users and their needs for decision support.

Requirements for determining ERF methods, eligibility, and site-specific estimates

To support the delivery of abatement estimates, four design requirements needed to be met. First, a subset of ERF land sector carbon abatement methods was identified. Australian land sector ERF methods available at the time the LOOC-C project was initiated included agricultural, vegetation, and savanna burning methods. This set of methods was reviewed based on the feasibility of their implementation, how easily they could be applied to a specific land area, and whether existing solutions existed already. Second, a way of tailoring method discovery to a specific land area was needed to allow site specific abatement estimates to be derived given the diversity in environmental conditions and soil characteristics that exist across Australia. Third, eligibility information from the regulatory framework required integration. The eligibility requirements of each ERF method were derived from the associated Australian government legislative method determinations. Eligibility of a particular ERF method to a selected project area depended on a combination of geographic location and/or land use and the management practices applied before initiating a project. Finally, an estimation of the potential quantum of emission abatement for each applicable ERF methodology was required. A summary of each land sector ERF method included in LOOC-C and the calculations used to derive the estimated abatement potential are provided in the Supplementary Material.

Requirements for decision making and market information

Interviews were used to identify user requirements (for a review of social methods, see Chasanidou et al. [23] and IDEO.org [22]). This participatory research activity captured aspects of UX including ERF method literacy, land management decision making, and motivations for participating in the carbon market. After completing a content analysis, a series of user personas were developed, which captured the key characteristics of anticipated users of the digital tool [24].

Requirements integration

Journey mapping is an HCD method that provides structure and process for solution generation by representing activities, experienced feelings, and the interactions that end users might experience [22]. The technique draws design attention to points of decision making and key uncertainties that then become focal areas for development efforts. The journey map technique captured a potential "carbon abatement journey" focusing on how a landowner may consider, plan for, register, and implement a carbon farming project. An example of a journey map approach is provided in the Supplementary Material.

This HCD activity sought to integrate various requirements into a workflow of how the entry of data by users would interact with the underlying model architecture and produce potential abatement estimates. A set of UX issues was also identified: one being the trade-off between the effort required by the user to enter data about farm operations and the precision of the carbon abatement potential estimate provided. To test this trade-off, two modes were developed in a prototype:

1. A complex, scientific mode requiring significant data entry to provide project-specific estimates of potential outcomes, and
2. A simpler approach requires minimal data entry and the use of generic data to estimate potential outcomes.

In phase 2, these two modes of providing abatement estimates were compared in user testing supported by a prototype.

Phase 2: Develop and deliver solution with an iterative testing approach

In the context of facilitating entry into the ERF, a usable tool would promote informed decision-making and reduce transaction costs for the landowner. Rose et al. [25] identified a range of factors considered important to the design of digital tools for supporting landowners including performance, ease of use, trust, and relevance. In phase 2, these factors were assessed in iterative user testing cycles that formatively evaluated the quality of the interaction between a targeted end user and a prototype. The main UX issues tested included user's tolerance of data entry, their intent to use the tool, and overall usability.

Iterative testing cycles

Rounds of user testing and refinement took formal and informal formats. The formal testing was executed by an experienced practitioner and a functional prototype [26]. Informal testing was completed by the entire project team at industry conferences and agricultural events, where user feedback was gathered conversationally through prototype demonstrations. The feedback was aggregated and discussed by the team. Tests of the prototype's overall usability indicated an acceptable UX, based on participants' self-report of not needing further instruction to use (demonstrating intuitiveness) and not making errors while using the tool (demonstrating ease of use). Other features required additional development; these are described in the next section.

Rapid feature development and refinement: co-benefits

To provide insight into the range of co-benefits associated with the ERF methods included in the LOOC-C tool, a survey of the literature was undertaken, with co-benefits (and dis-benefits) categorized into four classes: farm profitability, farm resilience, environmental/social benefits, and dis-benefits. From this mapping of co-benefits to methods, a HCD card sort technique was used to reorganize the information in a user friendly way [27]. The card sort activity required landowners and farm advisors to group the suggested set of co-benefits in a way that was meaningful to them. Supported by a questionnaire, participants described how they valued co-benefits as part of a broader farming enterprise and commented on the completeness of the suggested set of co-benefits [17]. Findings from this activity led to the refinement of how co-benefits were presented, going from the initial concepts determined from an expert review to the consensus found within a group of users.

Solution delivery

The LOOC-C tool was designed to provide a simple workflow of identifying Australian land-sector ERF emission abatement methods applicable to a specified land area and to estimate the potential quantum of abatement associated with applying a method. Abatement potentials were confirmed through the development of a series of validation protocols specific to each method. Optimizing the UX was facilitated by user testing accompanied by re-design based on feedback and retesting. After a year of incrementally building and testing the proposed solution, the LOOC-C tool was launched publicly in December 2019.

Results and discussion

A digital tool was envisioned to require minimal data entry, provide reliable insights, and support the discovery of as many of the land sector emission abatement options as were relevant given the land use history of the identified area. In conjunction, a desirable UX was envisioned to be free of jargon, support simple interactions (intuitiveness), and offer a unique way of learning about the potential outcomes of applying emission abatement options *via* a digital interface.

The subsequent sections of this paper focus on how the problem of facilitating carbon market entry with a digital tool was resolved. The key outputs of phase 1 and phase 2 are described, with a summary of participation details and a description of the key features of the LOOC-C tool. A final section on tool usage is provided. An overview of the architecture of the LOOC-C tool that identifies all data sources and how they were processed and linked *via* application programming interfaces (APIs) is provided in the Supplementary Material.

HCD activities: stakeholder participation and outputs

The details of human participation in HCD activities are summarized in Table 1, each managed through a human research ethics protocol approved by the sponsoring research organization. The intention was to recruit from a range of geographical locations, farming enterprises, and farm advisory roles so that results would reflect views from a diverse population. Landowners operating forestry, grazing, and mixed farming systems from across Australia participated. Farm advisory officers and environmental consultants also participated in the interviews and user testing activities. Phase 1 activities focused on requirements identification so

Table 1. Summary of HCD activities, participation details, and main outputs.

	Participant details	Activity description/research output
Phase 1 (discover and define)		
Interviews	$n = 14$, Australian landowners, farm consultants, and scheme operators[a]	Conducted online, 60 min duration, subject to content analysis
Personas	n/a based on interview data	4 personas: aggregator, traditional farmer of an older generation, traditional farmer of a younger generation, and a farm advisor
Journey map technique (requirements integration)		
	Multidisciplinary team activity[b]	2 maps: corporate farmer and family farmer, plus an initial workflow diagram developed at 2-day workshop
Phase 2 (develop and deliver)		
User testing, formal	$n = 8$, Australian landowners and farm consultants[c]	Conducted online and in person, 45 min duration, supported by functional prototype
User testing, informal	~100, including policy makers, carbon project developers, aggregators, and landowners[d]	Demonstrations and trials at industry events over 12-months, supported by prototypes
Card sort study	$n = 33$, Australian landowners and farm consultants	Conducted with web-based tool including questionnaire, thematic analysis, and similarity comparison to identify groupings

aInterview participants included family farmers (mixed farming), farm advisors and researchers, industry stakeholders, and experts/aggregators working in the carbon industry.
bResearch team included scientific expertise in greenhouse gas accounting, soil and vegetation management, software engineering, market economics, and user experience.
cFormal testing participants included farm advisors, environmental project managers, and farmers (mixed farming). Some identified with multiple roles.
dInformal testing took place at multiple Agritechnology and Carbon industry events where the prototype tool was available at an exhibition booth, numbers are approximations.

that design decisions could be made before any software code being written.

In the interviews, 14 landowners, farm consultants, and scheme operators described what mattered to them when considering land management decisions broadly, and the economic viability and practical feasibility of implementing a carbon farming project. This activity enabled a diverse set of views to be considered regarding the problem of how to facilitate entry to land sector ERF projects. Participants responded to a set of open-ended questions: (1) their actions and decisions related to managing the farm business (e.g. tools and information use), (2) their awareness and understanding of the carbon farming program (e.g. abatement methods and requirements), and (3) the perceived costs and benefits of participating in the scheme.

The videorecorded interviews were reviewed and common themes were identified through an emergent content analysis. Most participants reported poor financial incentives and a lack of clarity about how the scheme operated. When asked if they had knowledge about the carbon market, landowners responded with their own questions asking, "What was on offer?" and "How will it fit into what I'm already doing?" The interviews also identified the importance of farm advisors in the decision-making process. When asked about the benefits of participating, a farm advisor replied, "It comes as no surprise to me whatsoever that farmers are just viewing this as sceptical and getting on adopting other technologies that are seen as more relevant and a better bet with their investment dollar." The combination of not knowing how to participate and the inability to estimate participation costs and returns was a common theme in the data. The resultant content analysis indicated that landowners struggled to effectively consider the carbon farming opportunity, for example, being unable to estimate costs associated with making the land management change, feeling overwhelmed by regulatory requirements, and uncertainty about the market carbon price [28].

Four personas were created, representing potential market participants: a traditional farmer, a progressive farmer, a farm advisor, and a carbon project developer or aggregator [29]. The personas informed questions, such as "who is being designing for?" and "what (personal) challenges or frustrations are being solved by the solution?" Examples of two (of the four) personas are provided in Figure 3.

The journey map workshop was the most pivotal HCD activity in the LOOC-C tool development process. The journey map workshop defined the early version LOOC-C tool and encouraged consideration of the broader context within which the LOOC-C tool would be used. Using the journey map as a solution blueprint, an application workflow diagram was created to specify the underlying model architecture, the software engineering requirements, how potential abatement estimates were to be processed based on data provided by the user and other available data sources, and the

Figure 3. Two of the four personas developed from interviews: a carbon project developer/aggregator (left) and traditional farmer (right).

criteria for evaluating the proposed UX. More information about the journey map activity is in the Supplementary Material; see also Ref. [29].

User testing during phase 2 provided evidence that informed final design decisions for LOOC-C functionality. Having a tangible prototype meant that the team could get user feedback before significant investment in software engineering. The testing of two modes of estimating abatement potential provided a "reality check" about what would be acceptable for targeted users in terms of data entry required and receiving information on potential abatement in a meaningful way. Although a complex scientific solution with significant data entry was envisioned for the tool initially, the influence of the HCD method led to a tool that relied solely on a simpler estimation technique (e.g. "quick and useful").

Consistent with interview data collected in phase 1, user testing in phase 2 indicated that estimates of carbon abatement alone were insufficient to incentivize project consideration, and information about co-benefits and transaction costs was highly desirable. The card sort study ensured that the co-benefits information was presented in a way that made sense to the target audience [17]. Table 2 shows the difference between those co-benefits proposed by the expert review (which were focused on physical and financial aspects of the farm/farm business and separated physical components, such as soil and water) and those based on farmers and advisors' groupings (which distinguished between benefits found on the farm *vs.* the ones that were distributed in the broader community and landscape).

The key difference between the two groups was that the categories developed by study participants

Table 2. Co-benefit categories developed by the research team (left) *vs.* participants of the card sort study (right).

Research scientist categories	Farmer and advisor categories
Farm productivity	Farm profitability
Soil health	Farm resilience
Biodiversity and conservation	Broad environmental and social benefits
Water quality and quantity	Dis-benefits
Socio-economic	

reflect an arguably more integrated and holistic conceptualization of co-benefits. When designing digital tools for farmers, technology developers should consider that collecting feedback from farmers can be used to present information in a useful and relevant way [30,31]. The co-benefit feature implemented in the LOOC-C tool is described in the next section.

In summary, with each testing opportunity, the tool's UX and approach of emulating ERF methods were assessed and improved. This iterative approach helped to identify data gaps in the models, errors in the software code, and increased robustness of these approaches before launching the tool publicly.

Features of the LOOC-C tool

LOOC-C was designed to emulate ERF emission abatement methods as closely as possible, minimize the amount of data entry required by users, and rapidly return abatement estimates for the land sector methods eligible for application to an area of land defined by the user. The features of the web-based tool are described in the sequence of the user's workflow: first, identifying a project area followed by answering questions about land use history. Then, the presentation of the eligible method, abatement potential, and co-benefits

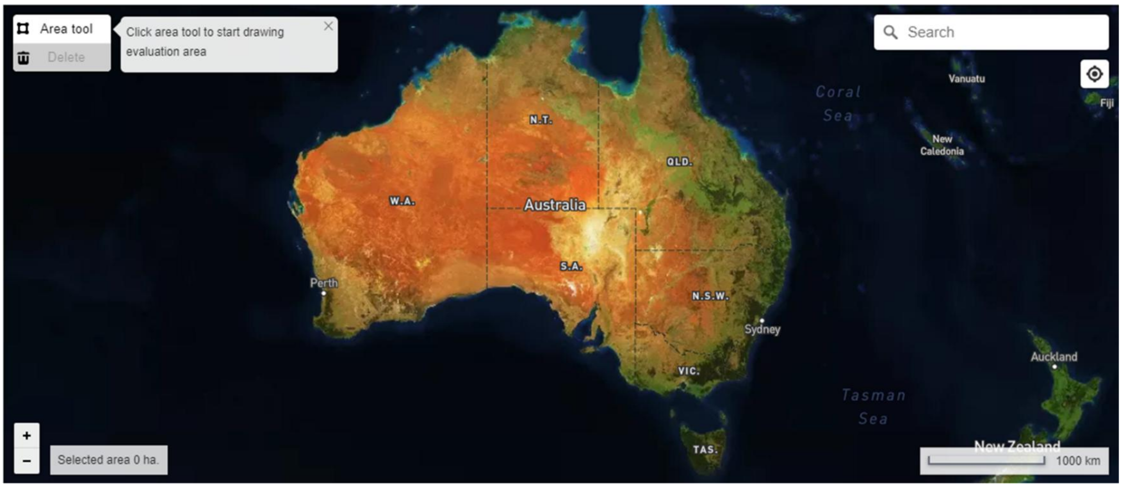

Figure 4. **Project area selection tool within the LOOC-C tool (http://mapbox.com).**

through interactive cards is described. Additional features are summarized.

Project area selection tool

A project area selection tool (Figure 4), covering the entirety of Australia, supported users to identify a physical project area so that the relevant methods could be identified. This tool was created using data and software libraries from Mapbox (http://mapbox.com). Users could zoom in and out and select a project area based on paddock boundaries, landform features, infrastructure, or other visible features. The tool was customized to support the polygon definition workflow of LOOC-C.

For all methods included in the LOOC-C tool, the total potential abatement at the end of 25 years over the entire selected area in units of *t* CO_2-e was derived as well as the annual average abatement over the 25 years in units of *t* CO_2-e ha^{-1} y^{-1}. Identification of the specific project area was required for a range of reasons, including:

- methods may only be applicable to defined geographic regions (e.g. *Human-induced regeneration of a permanent even-aged native forest*),
- methods rely on the use of spatially explicit parameter values and/or data (e.g. *Estimating sequestration of carbon in soil using default values*, *Beef cattle herd management*), or
- methods may use spatially explicit values derived from the application of the Full Carbon Accounting Model (FullCAM) modeling system (e.g. all vegetation methods) (https://www.dcceew.gov.au/climate-change/publications/full-carbon-accounting-model-fullcam).

Participants throughout user testing indicated a strong preference for a satellite view compared to a map view because it provided visual feedback with regard to landscape features and land management zones. Participants reported that the personalized experience of seeing the farm provided a sense of familiarity.

Defining method eligibility

After identifying the project area, method eligibility was assessed by soliciting land use and management information from the user and comparing it to the regulatory requirements of each method. This comparison was based on a cluster analysis of the seven ERF method eligibility requirements, with relevant information gathered through the following workflow. The workflow starts with the selection of the main production system used in the project area over the last five years (radio button). Once a prior land use is selected, the user answers a series of additional yes/no questions (radio buttons). For example, if Native Forest is selected, no additional questions are posed because the only eligible method for land previously under Native Forest is *Avoided clearing of native regrowt*h. Alternatively, if Crop is identified as the major prior production system, a series of four additional questions related to applied management practices appear. This approach minimized user input by only soliciting information when required based on the information previously provided, and by reducing the redundancy of overall eligibility requirements. In user testing, participants were able to answer the questions required to identify method eligibility without difficulty [26]. With this solution, users were presented with results for ERF methods that could be implemented in the defined project area.

Presenting emission abatement potentials and method information

The tool was designed for landowners to become familiar with the scheme and the potential of implementing an ERF project on their land. To the greatest extent possible, the approach taken in LOOC-C is consistent with what would happen in an ERF project (e.g. forestry methods and default soil carbon sequestration). In other methods (e.g. soil carbon measurement and beef herd management), the user is asked to define (estimate) a management induced change in a parameter (e.g. soil carbon content or herd emission intensity). The potential ACCUs associated with this change are

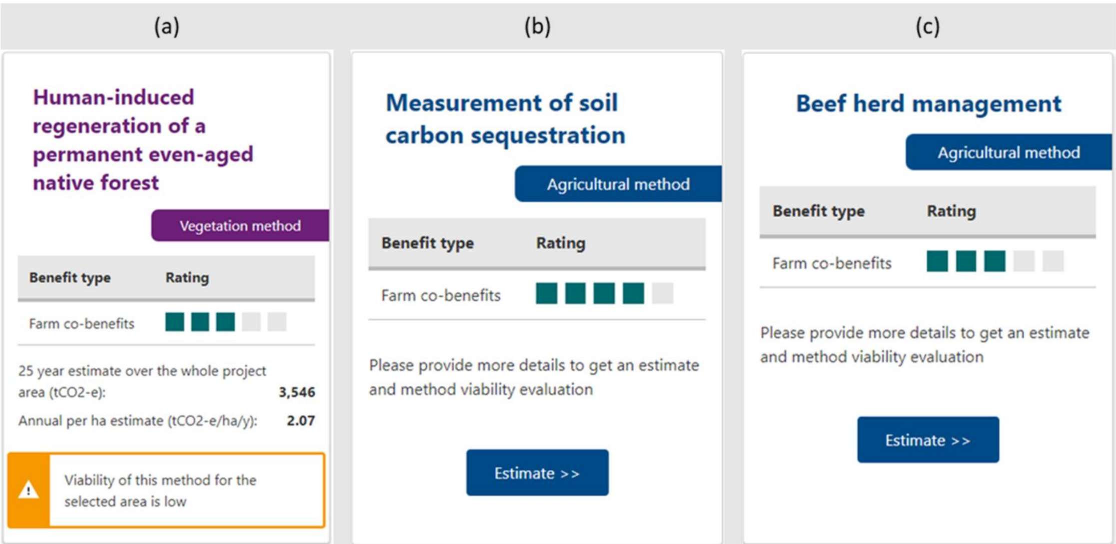

Figure 5. **Examples of the front of three LOOC-C cards obtained for the application of methods to a project area.**

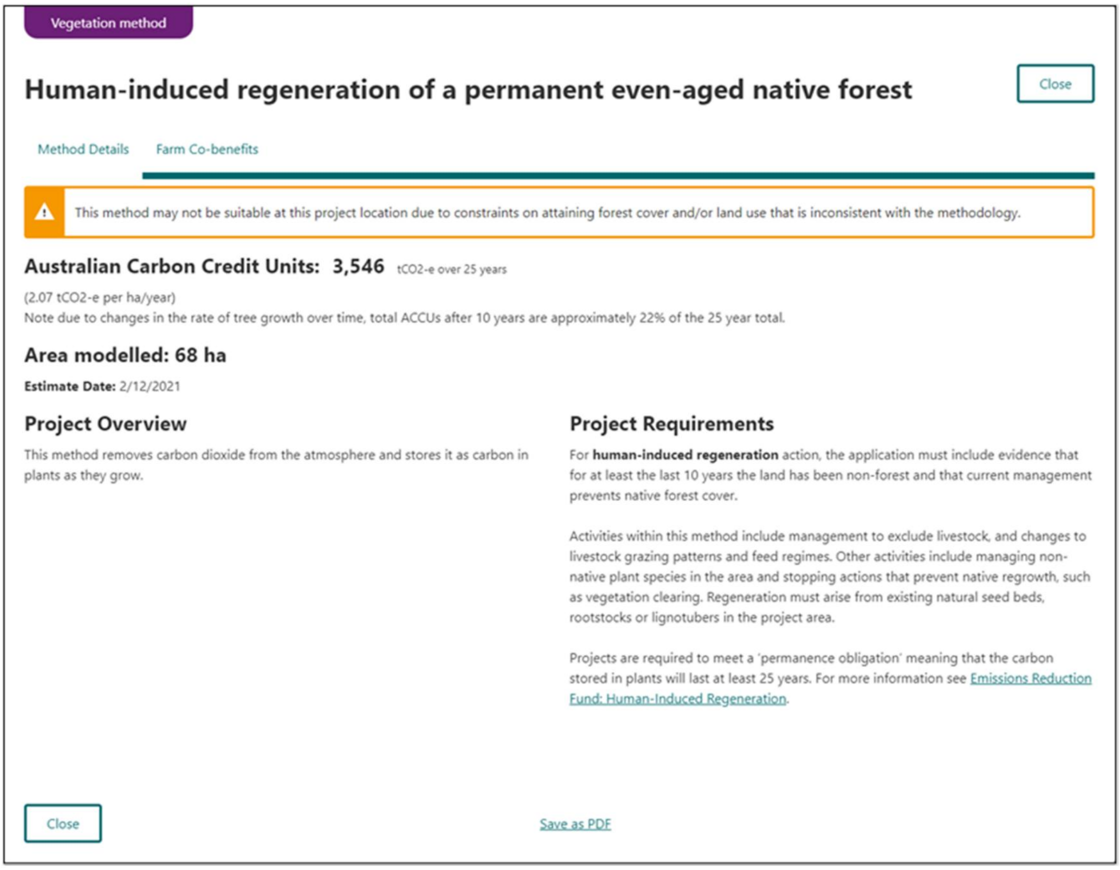

Figure 6. **The back of the human-induced regeneration of a permanent even-aged native Forest method card with the "method details" tab active, but also showing the selectable "farm Co-benefits" tab below the method title.**

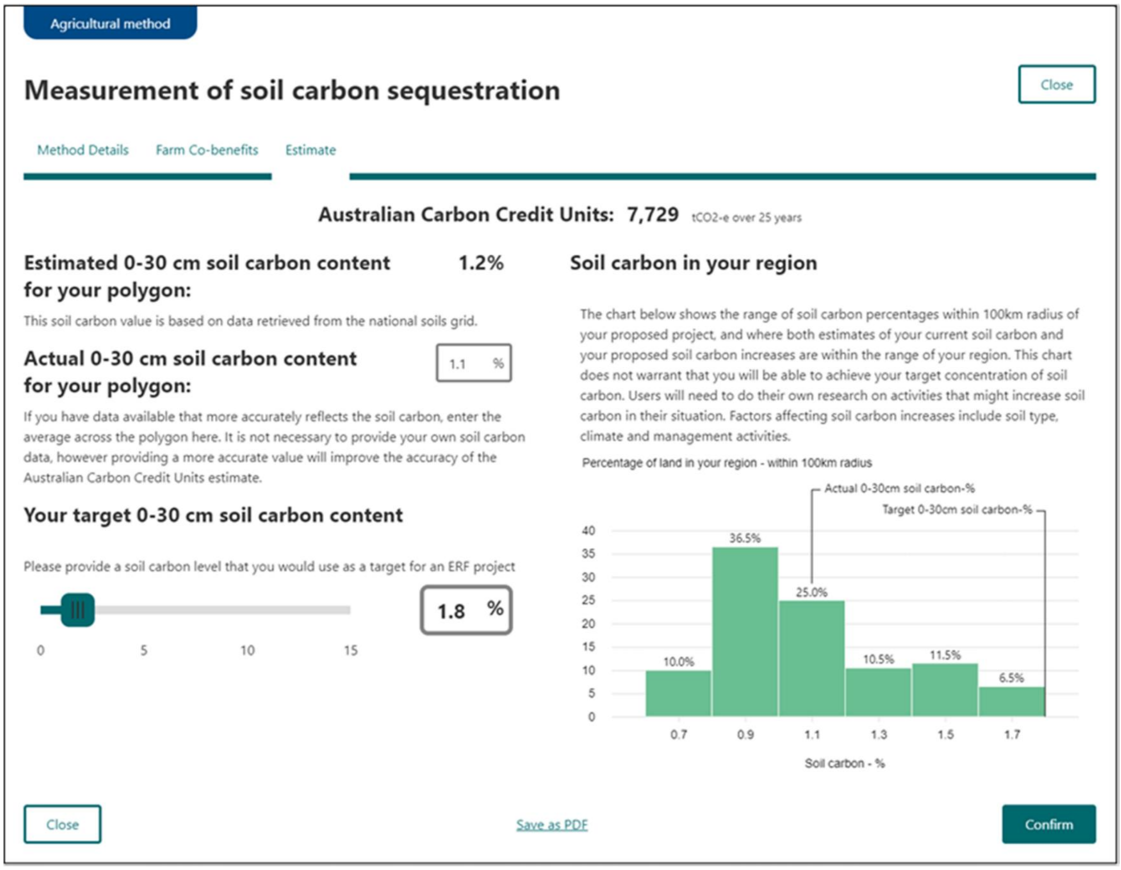

Figure 7. The back of the measurement of soil carbon sequestration method card with the "estimate" tab active but also shows the selectable "method details" and "farm co-benefits" tabs below the method title.

calculated using the best available data; however, there is indeed a risk that the values provided by LOOC-C would be different from those measured if the proposed ERF project was implemented.

Once eligible methods for the project area were defined, the emission abatement potential associated with each method was calculated using the approaches defined in the Supplementary Material, based on decades of soil and vegetation research and development. The output was presented as a series of double-sided virtual cards: the front side provided the abatement potential and other method-specific information for the project area (Figure 5) and the reverse side presented detailed information arranged in tabs located below the method title (Figure 6).

The front side of each card provides the method name, type of method, a summary rating of on-farm co-benefits associated with implementing the method, any warnings applicable to the application of the method on the project area selected (e.g. Figure 5(a)), and either the calculated abatement potential or an "Estimate" button. For default soil and vegetation ERF methods, only a single value is generated, or emulated in the LOOC-C tool. To maintain consistency in presentation in how information was provisioned, a single value was delivered for the other methods. The "Estimate" button appears if additional information is required to calculate an abatement potential (e.g. Figures 5(b,c)).

An example of additional information required to obtain an estimate associated with a *Measurement of soil carbon sequestration* method is provided in Figure 7.

This approach provided relevant information only so as not to overload the user. The interaction of "flipping the card over" by clicking on content was discoverable during informal user testing. The cards enabled users to quickly assess the total quantum of potential abatement and the annual rates of potential abatement per hectare for each method deemed applicable to the project area. The simplicity of the front of the card ensured that the users were only exposed to the key outputs required to make an informed comparison of abatement potentials across the eligible methods. The presentation of all eligible methods on one screen and the use of different colors supported such a comparison. The linkages through to the detailed information provided on the tabs on the back of the card ensured that more detailed information was available if desired. Additional data input is only required where the user is interested

Table 3. **Summary of co-benefits and dis-benefits associated with carbon farming activities, divided into four main classes: farm profitability, farm resilience, environmental/social benefits, and disbenefits.**

Co-benefit class	Description	Beef herd management	Native forest from managed regrowth	Environmental plantings	Human-induced regeneration	Avoided clearing	Soil carbon methods: default and measurement
Farm profitability							
Optimized Yield	Undertaking this activity can help you achieve maximum value for what is primarily produced on the farm.	strong	none/negligible	slight	none/negligible	none/negligible	strong
Optimized land use efficiency	Undertaking this activity can help you achieve the best possible outputs given the inputs across the farm.	slight	slight	slight	slight	slight	slight
Optimized soil health *via* soil organic carbon	As part of the natural carbon cycle, increasing soil organic carbon (SOC) also increases soil fertility that is good for all types of farms. Increasing carbon storage in the soil can reduce the effects of global warming.	none/negligible	none/negligible	none/negligible	none/negligible	none/negligible	strong
Product diversification	For some farms, this activity may provide optimized revenue streams that include carbon offsets or alternate products.	strong	strong	strong	strong	strong	strong
Farm resilience							
Improved water quality	Undertaking this activity can improve the amount and condition of the local water supply.	none/negligible	slight	slight	slight	slight	slight
Improved soil stability	Undertaking this activity helps to protect and enhance the farm's ground cover, leading to a range of benefits including soil health.	slight	slight	strong	slight	strong	strong
Reduced chemical runoff	Undertaking this activity helps to reduce the movement of pollutants into the local water supply.	none/negligible	slight	slight	slight	strong	strong
Reduced dryland salinity	Most relevant to cropping regions, this activity can mitigate excess salt being absorbed into plants' root structures in times of heavy rains.	none/negligible	slight	strong	slight	slight	none/negligible
Environmental/social benefits							
Optimized biodiversity/conservation	This activity may promote positive outcomes for both biodiversity (presence of healthy microbes, bugs, plants, etc.) and conservation (preserving natural resources, preventing destruction of habitats, etc.).	slight	strong	strong	strong	strong	strong
Optimized animal welfare	Animal health and stress levels can be improved with activities that provide access to shade, fresh water, and habitat.	strong	none/negligible	slight	none/negligible	none/negligible	none/negligible
Climate adaptability	This activity promotes a reduction in greenhouse gas emissions, helping to mitigate the effects of global warming	none/negligible	slight	strong	slight	slight	slight
Disbenefits							
Land use conflicts	The proposed activities are intended as long-term management options that may prevent alternate land use strategies from being implemented.	none/negligible	slight	slight	slight	slight	none/negligible
Reduced water yield	This activity may result in reduced local water availability.	none/negligible	slight	slight	slight	slight	none/negligible

A three-tier classification was derived to provide an indication of the relative strength/importance of each benefit for each methodology (strong, slight, none/negligible). This information is provided to the user on the abatement report card for each applicable methodology.

Table 4. Values assigned to the "farm co-benefits" score before adjustment for any disbenefits.

		Number of strong benefits							
		0	1	2	3	4	5	6	7
Number of slight benefits	0	0	1	1	2	2	3	3	3
	1	1	1	2	2	3	3	3	4
	2	1	2	2	3	3	3	4	4
	3	2	2	3	3	3	4	4	4
	4	2	3	3	3	4	4	4	5
	5	3	3	3	4	4	4	5	5
	6	3	3	4	4	4	5	5	5
	7	3	4	4	4	5	5	5	5

The colored values indicate a range of values from negligible (captured by 0 None / negligible value, 1 Low value, 2 Low-moderate value, 3 Moderate value) to positive (captured by 4 Moderate - positive value, 5 Positive value). This color coding is meant to indicate 'magnitude of benefit'.

in a particular method, and entering such data ensures that the abatement potentials derived are specific to the area and conditions associated with a particular project.

Co-benefits

The LOOC-C tool provided a summary co-benefit rating on the front of the card and detailed information on the back. The four classes of co-benefits and the individual items within each class that appear on the "Farm Co-benefits" tab LOOC-C are provided in Table 3. Table 3 also provides the ratings assigned to each item for each emission abatement method.

The overall "Farm Co-benefits" rating was calculated based on the number of individual benefits that received a rating of "strong" and "slight" (Table 4) and then adjusting that value by subtracting a value of one from the score where "strong" or "slight" disbenefits were identified. This approach resulted in "Farm Co-benefit" scores associated with implementing an emissions abatement project that was independent of location, indicative of the trend in co-benefits, but not necessarily indicative of the potential magnitude of co-benefit change. The magnitude of co-benefit change will be influenced by their initial status and the environmental characteristics of the project area.

Additional features

An "About" feature provided a general description of the LOOC-C tool, web links to the detailed documentation about each ERF method, a description of how estimates were calculated, and an instructional video. This feature enabled users to become confident in the tool's operation and if desired, they could delve deeper into the approaches used to calculate abatement potentials.

In addition to providing an independent and unbiased assessment of what might be possible for a landowner within the carbon scheme, the LOOC-C tool provided resources to support the user in taking additional steps toward project registration. A "Next Steps" feature was framed as a series of questions, where general background and Internet resources were provided. This feature included descriptions of relevant programs beyond the ERF where carbon activities were recognized within Australia.

A "Save" feature allowed an analysis to be exported as a Portable Document Format (PDF). This met an important UX requirement of users being able to share and discuss the results in the absence of the tool.

Future proofing

During development, a range of features were included to help future proof the LOOC-C tool. Australian ERF emission abatement methods are not static, and the set of methods has been modified since their creation in 2012. The compartmentalization of data and calculations required for each method and the use of separate cards to display potential abatement estimates ensured that a particular method could be modified, removed, or replaced without impacting the performance of other methods. Where new abatement methods are added to the scheme, a new card with method specific estimates and supporting information can be created using the same formatting approach to maintain the visual style. The compartmentalized approach also allows LOOC-C to be extended to cover other schemes and methods beyond those included as components of the Australian ERF (e.g. Verified Carbon Standard methods). The decision to provide LOOC-C as a web-based tool, as opposed to a stand-alone application, provided complete version control and ensured that the most current version was available for use.

LOOC-C use to date and usability

In an independent review, RTI International analyzed how the reduction of information barriers and information asymmetries possible with the LOOC-C tool would impact emissions abatement within Australia between 2021 and 2030. In a cost-benefit analysis of four scenarios varying carbon prices and possible technology impact, they estimated that the use of LOOC-C would enhance the magnitude of emissions abatement by 11–36 million tons of CO_2-e relative to what would occur in the absence of the tool [32].

Google Analytics shows a steady upward trend in use with up to 1000 instances per month, with a peak usage of 1500 users during October 2021 and a steady growth of about 14% over 6 months from January to July 2022. Usage is not limited to Australia, LOOC-C is being used by North American companies with agricultural interests in Australia to support the assessment of abatement projects. Twenty-seven percent of users discover the tool *via* web search and the others from embedded links on other websites including Australian agricultural groups.

Some states require a PDF of a LOOC-C assessment to accompany applications for funding through their schemes. The LOOC-C tool has also been used as an independent and objective assessment of carbon abatement potential by carbon project aggregators when discussing opportunities with clients as a mechanism to lower the barrier of entry into carbon farming and accounting projects for Australian producers. In the future, a retrospective account of LOOC-C use linked to scheme uptake could provide further evidence of the impact of this tool.

Meeting criteria of use and acceptance

There are many criteria identified in the literature that comprise an optimal UX [15,20,25]. The LOOC-C tool achieved a high degree of user friendliness by providing a simple workflow with a logical progression to identify options and their merits in a carbon abatement project decision. Requiring a modest amount of data entry, the user receives information through cards that present options with high visibility and accessibility. Efforts to reduce legislative jargon and implement co-benefit classes informed by target users contributed further to the tool being usable.

Ease of use is supported through careful design of the tool's navigation. First, a user can quickly explore opportunities for a potential project area that is of interest to them without creating an account or needing to log in. The workflow supports forward and backward navigation with "back" and "close" buttons. If a mistake is made in data entry at any point, it can be corrected without requiring a "restart." As a web-based application, it is browser agnostic and does not require software installation. In a comparison of other carbon calculators, the LOOC-C tool was identified as one of the best regarding the data entry required and regional relevance [33].

The tool was built by Australia's national science agency which has a public reputation of being objective and trustworthy. Created independently of carbon project managers and advocates, the LOOC-C tool was not biased by private interests. In addition, LOOC-C abatement estimates were generated by a strong evidence base founded on decades of soil and vegetation research and development. The team members involved in developing the abatement estimates had a strong understanding of the various ERF methods given their contributions to ERF method development. The relevance of LOOC-C potential abatement estimates lies in the fact that the tool is estimating, as closely as possible, the abatement outcomes that would be achieved if available ERF methods were applied to the project area selected. Where the applicability of an estimate for a particular method to a defined project area was less certain, warning messages provided direct advice.

In summary, HCD helped the research team navigate a complex problem space and produce a solution that met the requirements for UX and ERF eligibility. Undertaking activities to understand the context in which landowners made decisions (interviews), reflect on those insights to articulate a clear design problem (personas and journey map), and refine the solution based on user feedback (user testing) proved influential to the multidisciplinary science team. The team's initial focus on a traditional technology transfer delivering complex abatement knowledge shifted toward developing a digital solution that catered to a range of information needs identified by users during the double diamond process. We assert that this shift—from traditional technology transfer toward formatively evaluating solutions—should be explicitly included in frameworks governing agricultural technology development and innovation [34].

Conclusion

A lack of information about options, concern about the feasibility of implementation, and the uncertainty of the value of ACCUs potentially produced, have contributed to the modest engagement of the land sector in registered carbon abatement projects to date. This work demonstrates that when a design process considers users' needs for information, resultant digital solutions like the LOOC-C tool help to clarify opportunities in environmental markets and emerging land stewardship schemes [32]. Feedback collected during user research identified what information was relevant and desirable when considering undertaking a carbon project (e.g. tolerance to data entry when using the tool, benefiting from co-benefit information in addition to estimates). The example of LOOC-C illustrates how a digital solution might balance needs related to scheme complexity, the science underpinning the qualification/quantification of greenhouse gas emissions or co-benefits, and what constitutes a useful digital experience. The inclusion of a co-benefits assessment within the LOOC-C tool may provide an additional motivation for landowners to participate in emission abatement projects by identifying additional positive outcomes on their land alongside abatement potential. If carbon trading programs included the broader economic narrative of co-benefits within the regulatory process, it could revitalize the conversation around farm productivity and sustainability. Achieving such a transformation toward valuing a greater range of benefits—social, environmental, and economic—is a key issue for agriculture and communities around the world to address.

In this example, a good UX was to meet the needs of landowners attempting to understand the potential impacts associated with implementing emissions abatement projects in a particular area. The chosen approach of having quick and useful information presenting complexity in simplified ways, driven by an HCD methodology has been shown to be an effective awareness raiser, a conversation starter, and a mechanism to facilitate landowner entry into a regulated carbon market. Our experiences show how HCD helps shape science delivery for real world impact. It does so by aligning research from the social and natural scientists, a disciplinary divide that can be difficult to close [35]. In this case, HCD offered a useful way of working: assisting in the discovery of challenges associated with participating in the Australian carbon market and an effective process for reducing them with a digital solution.

The inclusion of the Land Restoration Fund co-benefits was a collaboration with the Queensland Government Land Restoration team.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Ethical approval

Research ethics approval was granted by the CSIRO Human Ethics Research Committee (086/18 and 125/17). The authors appreciate the contribution of each research participant.

Funding

This work was funded by the CSIRO Digiscape Future Science Platform, Australia (https://research.csiro.au/digiscape/). The Clean Energy Regulator provided funding for the LOOC-C update during July 2020 to FullCAM 2020 modeled results.

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Data availability statement

The LOOC-C tool described in this paper uses a combination of existing and generated datasets to provide the estimates of carbon sequestration associated with each of the methods included. The vegetation methods were based on the 2020 release of the Full Carbon Accounting Model (FullCAM; ver 6.20.03.0604) available at https://www.dcceew.gov.au/climate-change/publications/full-carbon-accounting-model-fullcam, and as such are amenable to replication.

The measured soil method within LOOC-C used publicly available soil data held within the Soil and Landscape Grid of Australia (https://esoil.io/TERNLandscapes/Public/Pages/SLGA/) for the gravimetric organic carbon content (g C 100 g^{-1} soil) and dry bulk density (g soil cm-3 soil) of the 0–5, 5–15, and 15–30 cm soil layers was extracted and manipulated as described in the Supplementary Material to create spatial layers for gravimetric soil carbon content and dry bulk density of the 0–30 cm soil layer. All equations and subsequent calculations to derive estimates of soil carbon stock and stock change are provided in the Supplementary Material. The estimation of sequestration of carbon in soil using the default values method used predefined sequestration rates produced by the Australian government. No data was created to perform the calculations of sequestration within LOOC-C. The total carbon sequestration and rates of sequestration were derived by applying the default values to the area identified by the LOOC-C user. The collated and generated data for LOOC-C is available subject to commercial terms on a subscription basis. Should researchers want access to the data for reasonable non-commercial purposes, the authors will consider the request, and if reasonable, make it available.

Acknowledgments

The authors would like to acknowledge the contributions of the software development team for their dedication and commitment to the LOOC-C project—Rob Bridgart, Will Cheung, Owen Harvey, Jevy Wang, Cathy Lill, Alex Bunday, and Roger Butler. Contribution to team discussions, perspectives on carbon market design, and participation in industry events by Andy Reeson and Todd Sanderson are acknowledged. The authors also acknowledge the contribution of Michael Battaglia for the project vision and inspiration, and Andrew Moore for his unwavering support for this work.

References

1. Office of Parliamentary Counsel. Carbon Credits (Carbon Farming Initiative) Act 2011 [Internet]. Fed. Regist. Legis. Office of Parliamentary Counsel; 2011. Available from: https://www.legislation.gov.au/Details/C2020C00281
2. Roxburgh SH, England JR, Evans D, et al. Potential future supply of carbon offsets in the land sector in Australia [Internet]. CSIRO; 2020. p. 380. Available from: http://hdl.handle.net/102.100.100/369113?index=1
3. Fleming A, Stitzlein C, Jakku E, et al. Missed opportunity? Framing actions around co-benefits for carbon mitigation in Australian agriculture. Land Use Policy. 2019;85:230–238. doi: 10.1016/j.landusepol.2019.03.050.
4. Kragt ME, Dumbrell NP, Blackmore L. Motivations and barriers for Western Australian broad-acre farmers to adopt carbon farming. Environ Sci Policy. 2017;73:115–123. doi: 10.1016/j.envsci.2017.04.009.
5. Macintosh A, Waugh L. An introduction to the Carbon Farming Initiative: key principles and concepts; 2012 [cited 2022 Aug 15]. Available from: https://ageconsearch.umn.edu/record/249393
6. Gil JDB, Daioglou V, van Ittersum M, et al. Reconciling global sustainability targets and local action for food production and climate change mitigation. Glob Environ Change. 2019;59:101983. doi: 10.1016/j.gloenvcha.2019.101983.
7. Bryan BA, Crossman ND, Nolan M, et al. Land use efficiency: anticipating future demand for land-sector greenhouse gas emissions abatement and managing trade-offs with agriculture, water, and biodiversity. Glob Chang Biol. 2015;21(11):4098–4114. doi: 10.1111/gcb.13020.
8. Bustamante M, Robledo-Abad C, Harper R, et al. Co-benefits, trade-offs, barriers and policies for greenhouse gas mitigation in the agriculture, forestry and other land use (AFOLU) sector. Glob Chang Biol. 2014;20(10):3270–3290. doi: 10.1111/gcb.12591.
9. Deng H-M, Liang Q-M, Liu L-J, et al. Co-benefits of greenhouse gas mitigation: a review and classification by type, mitigation sector, and geography. Environ Res Lett. 2017;12(12):123001. doi: 10.1088/1748-9326/aa98d2.
10. Verspecht A, Vandermeulen V, Avest ET, et al. Review of trade-offs and co-benefits from greenhouse gas mitigation measures in agricultural production. J Integr Environ Sci. 2012;9(sup1):147–157. doi: 10.1080/1943815X.2012.698989.
11. Ürge-Vorsatz D, Herrero ST, Dubash NK, et al. Measuring the co-benefits of climate change mitigation. Annu Rev Environ Resour. 2014;39(1):549–582. doi: 10.1146/annurev-environ-031312-125456.
12. Jakku E, Taylor B, Fleming A, et al. "If they don't tell us what they do with it, why would we trust them?" Trust, transparency and benefit-sharing in smart farming. NJAS-Wagening J Life Sci. 2019;90-91(1):1–13. doi: 10.1016/j.njas.2018.11.002.
13. Norman D, Neilsen J. The definition of user experience (UX) [Internet]. Available from: https://www.nngroup.com/articles/definition-user-experience/
14. International Organization for Standardization. ISO 9241-210:2019(en) ergonomics of human-system interaction—part 210: human-centred design for interactive systems; 2019.
15. Rossi V, Salinari F, Poni S, et al. Addressing the implementation problem in agricultural decision support systems: the example of vite.net®. Comput Electron Agric. 2014;100:88–99. doi: 10.1016/j.compag.2013.10.011.
16. Lawes R, Hochman Z, Jakku E, et al. Graincast™: monitoring crop production across the Australian grain belt. Crop Pasture Sci. 2022;74(6).
17. Stitzlein C, Fielke S, Fleming A, et al. Participatory design of digital agriculture technologies: bridging gaps between science and practice. Rural Ext Innov Syst J. 2020;16(1):14–23. Available from: http://www.apen.org.au/rural-extension-and-innovation-systems-journal
18. Vilas MP, Thorburn PJ, Fielke S, et al. 1622WQ: a web-based application to increase farmer awareness of the impact of agriculture on water quality. Environ Model Softw. 2020;132:104816. doi: 10.1016/j.envsoft.2020.104816.
19. Dicks LV, Walsh JC, Sutherland WJ. Organising evidence for environmental management decisions: a '4S' hierarchy. Trends Ecol Evol. 2014;29(11):607–613. doi: 10.1016/j.tree.2014.09.004.
20. Norman DA, Draper SW, editors. User centered system design. Boca Raton, FL: CRC Press; 1986.
21. Framework for innovation: Design Council's evolved double diamond [Internet]. [cited 2022 Aug 15]. Available from: https://www.designcouncil.org.uk/our-work/skills-learning/tools-frameworks/framework-for-innovation-design-councils-evolved-double-diamond/
22. IDEO.org. The field guide to Human-centered design [Internet]; 2015. Available from: https://www.designkit.org//resources/1
23. Chasanidou D, Gasparini AA, Lee E. Design thinking methods and tools for innovation. In: Lecture notes in computer science. Switzerland: Springer International Publishing; Vol. 9186; 2015. p. 12–23.
24. Blomkvist S. Persona-an overview [Internet]; 2002. Available from: https://www.researchgate.net/publication/242401053

25. Rose DC, Sutherland WJ, Parker C, et al. Decision support tools for agriculture: towards effective design and delivery. Agric Syst. 2016;149:165–174. doi: 10.1016/j.agsy.2016.09.009.
26. Stitzlein C, Mooij M. Design for discovery: helping Australian farmers explore their options in a government sustainability program through user centred design. Proc Hum Factors Ergon Soc Annu Meet. 2019;63(1):1173–1177. doi: 10.1177/1071181319631312.
27. Wood J, Wood L. Card sorting: current practices and beyond. J Usability Stud. 2008;4:1–6.
28. Stitzlein C. Digiscape carbon interview report. Canberra, Australia: CSIRO; 2018. p. 13.
29. Stitzlein C, Mooij M. Design thinking workshop report: customer journey mapping in Digiscape-Carbon; 2018 [cited 2022 Aug 15]. doi: 10.25919/h32z-mx15.
30. Lindblom J, Lundström C, Ljung M, et al. Promoting sustainable intensification in precision agriculture: review of decision support systems development and strategies. Precision Agric. 2017;18(3):309–331. doi: 10.1007/s11119-016-9491-4.
31. Rose DC, Bruce TJA. Finding the right connection: what makes a successful decision support system? Food Energy Secur. 2018;7(1):e00123. doi: 10.1002/fes3.123.
32. Austin K, Love E, Reingold B, et al. Prospective analysis of the LOOC-C carbon app. RTI International; 2021. p. 26. Available from: https://www.csiro.au/en/about/corporate-governance/ensuring-our-impact/impact-case-studies/future-industries/looc-c-carbon-app
33. GrainGrowers. Carbon calculators compared for Australian grain growers [Internet]; 2020. p. 13. Available from: https://www.graingrowers.com.au/policy/sustainability-climate-change-and-natural-resource-management/graingrowers-carbon-calculator-report
34. Rose DC, Wheeler R, Winter M, et al. Agriculture 4.0: making it work for people, production, and the planet. Land Use Policy. 2021;100:104933. doi: 10.1016/j.landusepol.2020.104933.
35. Moon K, Blackman D. A guide to understanding social science research for natural scientists. Conserv Biol. 2014;28(5):1167–1177. doi: 10.1111/cobi.12326.