frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 29 August 2023
DOI 10.3389/fsufs.2023.1241077

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OPEN ACCESS

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RECEIVED 16 June 2023
ACCEPTED 15 August 2023
PUBLISHED 29 August 2023

CITATION
Sarwar S, Ross H, van Bommel S, Polack S, Waschka M, Lubcke K, Bryceson K, Cooper TL, Butler DW and Macintosh A (2023) Developing a new technology for demonstrating environmental sustainability in the Australian grassfed beef industry.
Front. Sustain. Food Syst. 7:1241077.
doi: 10.3389/fsufs.2023.1241077

Developing a new technology for demonstrating environmental sustainability in the Australian grassfed beef industry

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Meeting the increasing consumer and market expectations for sustainably produced beef requires measurement and demonstration of the producers' sustainability practices. Typically, demonstration of sustainable production relies on time consuming and costly on-ground audits. Online tools using combinations of remotely sensed data and other information sources could offer a cost-effective alternative. However, there are also concerns about the merits and risks of such tools. This paper presents a case of the development process of an online platform for Australian beef producers to demonstrate their sustainable production practices, connected with learning opportunities for continual improvement of their sustainability performance. The project is led by an innovative cross-sectoral collaboration of beef industry, non-government organisation and university partners. Our approach combines producer and market perspectives; focusing on the "value proposition" of the proposed technology for producers, and value chains' priorities in sustainability markets and in having the ability to demonstrate sustainability in a cost-effective manner. The development process adopted co-design at three levels: (1) the "Consortium" of project partners (2) collaborative co-design through small online groups with producers and value chain representatives; and (3) consultative co-design through producer testing of the platform as it is built by software developers. The design process focused on five themes: tree cover, ground cover, biodiversity stewardship, carbon balance, and drought resilience. We present the main platform design characteristics sought by the co-design groups, and the indicators and measures they considered important for each of the five themes. We then discuss a set of key issues and their implications for technology development, according to a framework expressing interactions between people and their properties, processes and technology. This case shows the importance of taking a "demand-led" rather than a "supply-driven" approach, for the best possible fit of new technology to its users. Since co-design is more often consultative than treating users as equals or leaders in a technology design process, our case highlights the desirability of a fully collaborative approach to co-design.

KEYWORDS

technology, process, sustainability, environment, red meat, beef, co-design

1. Introduction

Consumer and market demand for sustainably produced agricultural products is increasing (Sánchez-Bravo et al., 2021; Zamuz et al., 2021). Meeting these expectations for sustainable production of foods requires demonstration that environmental expectations are being met, and hence measurement of the sustainability practices and achievements of the producers (Gardner et al., 2019; Meemken et al., 2021). Currently, demonstration of sustainable practices within individual enterprises relies on time consuming and costly on-ground audits (Cosby et al., 2021). However, on-ground auditing by third party specialists is not a realistic proposition for many agricultural businesses. There is also a desire to find methods to credibly demonstrate environmental performance more consistently, economically and inclusively (Meemken et al., 2021). Online tools using combinations of remotely sensed data and other information sources could offer a cost-effective alternative for some circumstances, and a useful complement for others (Sadlier, 2018; Andries et al., 2021). There has been a substantial increase in the use of digital technologies for monitoring, measuring, and reporting environmental change, and verifying environmental practices and outcomes. Remote sensing, drones and smartphone applications (apps) are increasingly used for these purposes, linking local practices on the ground to digital information in the cloud (Urzedo et al., 2023). Despite some limitations in accuracy and user trust in online tools, they have potential to be more affordable to use, and more scalable and inclusive than on-ground audits (Gardner et al., 2019; Sellare et al., 2022).

Internationally, there is increased attention to measuring, monitoring, reporting and verification, also referred to as "measurementality" (Turnhout et al., 2014; Lippert, 2015) as a pathway towards sustainable development. This is intended to produce transparent and objective information which can be used to verify the situation on the ground and assess it against an external standard which defines a desired level of attainment. Incentives such as market access or a price premium are expected to influence production practices towards increasing sustainability. The increase in measurementality has coincided with increased academic attention to the merits and risks of this digital accounting of environmental performance (Turnhout et al., 2016; Turnhout, 2018; Kloppenburg et al., 2022).

Critical scholars give insights into the increasing trend of digital environmental accounting, and its effects (Bakker and Ritts, 2018; Bernards et al., 2020; Dauvergne, 2020; Gabrys, 2020; Gupta et al., 2020; Scoville et al., 2021). Although digital technologies have the capacity to make large amounts of data available in real-time, this does not automatically lead to a better representation of environmental challenges. The remotely sensed data that is used to create digital representations of the environment are not neutral and "objective". Remote sensing requires satellites, sensors and servers that generate data. Then this data is stored in databases and processed by certain types of software. Finally, it is given comprehendible form in terms of numbers, images or text. The process of collecting and processing digital data is thus underpinned by restrictions of what is technologically possible (e.g., resolution), as well as human selection and interpretation based on the questions asked and purposes for which the data is used. Software developers and platform builders can tend to emphasise points that can be measured at the expense of those that cannot, and unless developers and users are wary, digital accounting for environmental performance has the potential to privilege some people and marginalize others (Kloppenburg et al., 2022). Accordingly there is a call for research on monitoring, reporting and verification systems that are designed to be responsive to local needs and where local contexts are taken into account (Turnhout et al., 2014).

Recognizing the concerns about the social risks inherent in digital technologies and the need for locally responsive reporting and verification systems, this paper presents a case of design and development of a user-focused online platform by the "Environmental Credentials for Australian Beef" project. This platform will allow Australian beef producers to demonstrate their sustainability performance within specified parameters in order to ensure access to capital and commodity markets and take advantage of the emerging market demand for sustainably produced beef (Faulkner et al., 2022). It builds on earlier insights from, and experiences with, Reflexive Interactive Design (Klerkx et al., 2012; Elzen and Bos, 2019). That approach consists of system and actor analysis, structured design based on collaborative and interactive learning, and anchoring (see Elzen and Bos, 2019). As Eastwood et al. (2022) point out, this is one of the few co-design methods (besides their own) that was created for agricultural contexts. It has been used in the pork industry, laying hen industry, dairy industry, broiler industry, rabbit industry and goat industry (Elzen and Bos, 2019).

The online platform will enable grassfed beef producers to measure and report on environmental performance to their value chains and consumers and will provide supporting resources towards continual improvement. By enabling grassfed beef producers to demonstrate their sustainable practices, the online platform will complement and enhance the industry's sustainability efforts such as the Australian Beef Sustainability Framework (ABSF) and Carbon Neutral 2030 (CN30) target (explained in Section 2).

The paper documents the background, the approach taken in developing the online platform, the users the platform is intended for, the technology development process (to the time of writing), and the proposed characteristics of the platform. It shares key issues considered during that process and their implications for the evolving platform design. In doing so, we reflect on issues raised in the literature about measurement of sustainability: (1) how the verification approaches incorporated in the digital platform shape visibility (through the technology, indicators and measures chosen), and (2) the influences of those who are creating the platform, i.e., who does the counting, how and for whom (the people and the process). The paper offers guidance for future developers of online platforms. It seeks to contribute to knowledge on use of digital platforms as a tool for demonstrating environmental stewardship; and on development of monitoring, reporting and verification systems by producers, for producers, to document their constructive environmental practices. In so doing it offers an example of technology that seeks to overcome the risks of digital technologies empowering some parties relative to others (Kloppenburg et al., 2022).

The following section presents background on the Australian beef industry and relevant initiatives. Subsequent sections explain the technology development process, including the sequence of project activities and co-design process adopted, then the results, discussion and conclusions.

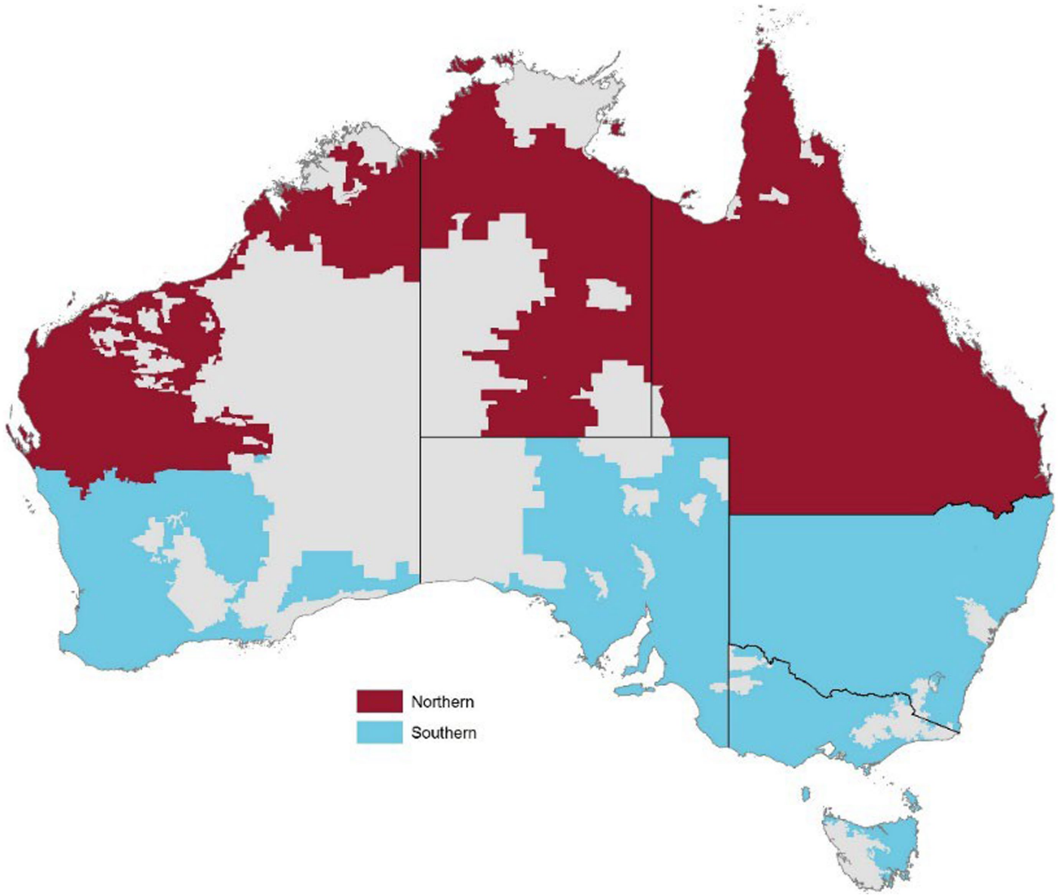

FIGURE 1
The northern and southern beef production systems in Australia (Harper et al., 2019).

2. Background—the Australian beef industry

Beef is a significant agricultural industry for Australia. Over half of the Australian landscape is used for livestock production, employing approximately 428,000 people,[1] with the beef and veal industry worth $15.9 billion in 2021–2022 (ABS, 2022; MLA, 2022). Australia exports around two-thirds of the beef produced and was the world's fourth largest exporter of beef and veal in 2021 (MLA, 2022). The global demand for beef has increased significantly in recent decades, and the global consumption of beef is projected to increase from 70 million tonnes in 2021 to 76 million tonnes in 2031 (OECD, 2022).

Australia's beef production systems are diverse owing to wide variation in climatic conditions, soil types, different pasture species, genetics of cattle, ownership and scale of cattle enterprises and the management systems adopted by the producers (Bell et al., 2011; Greenwood et al., 2018; Bell and Sangster, 2022). The Australian beef industry can be categorized broadly into the northern and southern production systems (see Figure 1), with sub-systems. Northern Australia has a hotter climate with monsoonal rainfall and relies largely on natural tropical pastures with lower carrying capacities. This region therefore involves extensive production systems, often on very large land holdings with large herds. The southern region typically has milder temperatures and higher yearly rainfall. The types and quality of pasture available generally allow more intensive production with higher stocking rates than in the north (Harper et al., 2019).

International and Australian beef consumers and value chains are increasingly seeking evidence that the beef they purchase is produced sustainably (Hocquette et al., 2018; Metzger et al., 2018). Thus, demonstrating practices and outcomes to the customers and value chains is becoming increasingly important. There is a similar emerging dynamic within the finance sector, where banks and other investors are seeking assurances about the sustainability of pastoral production systems (Taskforce on Nature-Related Financial Disclosures, 2023).

The Australian beef industry is pioneering a range of sustainability initiatives such as the ABSF and a target to achieve carbon neutrality as an industry by 2030 (CN30). These industry initiatives aim to minimise its environmental impact by adopting sustainable land management practices while maintaining high levels of industry productivity and profitability (ABSF, 2022). The ABSF, launched in 2017, sets out sustainability priorities and the key indicators of performance in sustainability for the beef industry. The framework reflects and encourages the industry's commitment to environmental stewardship through best practices towards improving biodiversity,

1 The number includes beef cattle and sheep farming, and feedlots.

soil health, groundcover, and reducing greenhouse gases attributable to the industry. The ABSF is also pioneering use of online technology, e.g., an online "balance of tree and grass cover" dashboard, that enables the industry and producers to analyse trends in woody vegetation and seasonal trends in ground cover at a regional level. CN30 is an industry target to achieve carbon neutrality through reducing attributable emissions across the industry, and by increasing carbon storage in soils and vegetation under the custodianship of red meat industry stakeholders.

Beef producers accomplish multiple benefits by improving their environmental stewardship, through enhanced productivity, landscape restoration, and drought resilience. Through the ABSF and other initiatives, the Australian beef industry has shown improvement in its environmental sustainability performance (Witt et al., 2020; ABSF, 2022). Nevertheless, there remain continued challenges in terms of consumer perceptions pertaining to the beef industry's environmental sustainability (Gerber et al., 2015) and communicating it effectively with the public and within the Australian beef industry (Faulkner et al., 2022). The industry is seeking further opportunities to design and develop practical tools to demonstrate its environmental sustainability to their markets and the value chains, including the online platform documented here.

3. Materials and methods

This section presents an overview of the technology development process, phase by phase, then further details the approach taken to co-design.

3.1. Overview of the technology development process

In 2019 the Australian Government, under its National Landcare Program, sought innovative partnerships to promote environmental sustainability in new ways. This opportunity encouraged three organisations, Meat & Livestock Australia (MLA),[2] World Wide Fund for Nature Australia (WWF-Australia) and The University of Queensland (UQ) to form a consortium to develop an online platform to simplify measurement and demonstration of environmental performance by "grassfed beef"[3] producers seeking to participate in emerging environmental markets. At the same time, the platform is intended to enable greater understanding by, and education of, producers to encourage continual improvement through learning and adaptation that is underpinned by best practice management.

Concurrently, the Australian National University (ANU) was working with the Australian Government on the development of a farm biodiversity certification scheme as part of its Agriculture Biodiversity Stewardship Package. Hence an opportunity was identified to include ANU (from 2021) in the collaboration to contribute their expertise, and ensure the alignment of approaches and exchange of technical knowledge.

The platform is intended to enable Australian grassfed beef producers to demonstrate their position and pursue continual improvement in five of its sustainability (and resilience) priorities: carbon balance, biodiversity stewardship, maintaining tree cover, maintaining ground cover, and resilience to drought. The platform is being developed through a comprehensive co-design process with beef producers and industry stakeholders. The project was funded from late 2019 to the end of 2023.

The project has four main phases, as illustrated in Figure 2.

1. Scoping phase.
2. Intense co-design phase.
3. Platform development phase.
4. Release and adoption of the platform.

At the time of writing the first two phases are complete, and the third is underway.

3.1.1. Scoping phase

The scoping phase commenced in early 2020 (following pre-project discussions with the funding body before the collaboration could commence work in earnest). At the outset of this project, it was necessary to devote considerable meeting time to forming relationships and developing shared understandings and common language for the project. A lengthy formation period, concurrent with making preliminary decisions about project structures and administrative arrangements, role sharing and approach, helped in developing a smooth collaboration between the three very different Consortium partners, and other contributing organisations. The scoping phase was ramping up just as Australia settled into extended arrangements for managing COVID-19, including lengthy lockdowns and closures of state borders. Therefore, all meetings apart from a single face-to-face team workshop, to strengthen relationships and enable deeper discussion on project direction, had to be held online. This simplified costs and travel, although it made development of relationships more difficult. Since the main project personnel were based in five locations, online meetings were retained throughout the life of the project, even after state borders were opened in early 2022.

An advisory group was established to provide strategic input and advice to the project team, to ensure the project meets the needs of producers and value chain stakeholders. The advisory group was structured to cover all aspects of the beef value chain, from beef producers, processors, retailers, to food production companies, and included independent stakeholders with relevant expertise.

Background research was essential to inform refinements to the methodology, and the design of the platform itself. A business analysis was conducted during 2021–2022 to gather detailed information on the business context and demand for the proposed platform (Bryceson and Sarwar, 2022). This was conducted through in-depth interviews with value chain actors and producers and explored market interest in sustainable production and an online platform, and the need and opportunity for the industry to demonstrate sustainability. Meanwhile, a literature review on approaches to co-design and online group-based research underpinned decisions about the co-design process.

Once team roles were decided, with each partner choosing one to three themes to specialize in, and one partner (UQ) also specializing

2 Australia's red meat and livestock industry's service body which invests in research, development and adoption projects.

3 Grainfed producers use feedlots, and are excluded from the work.

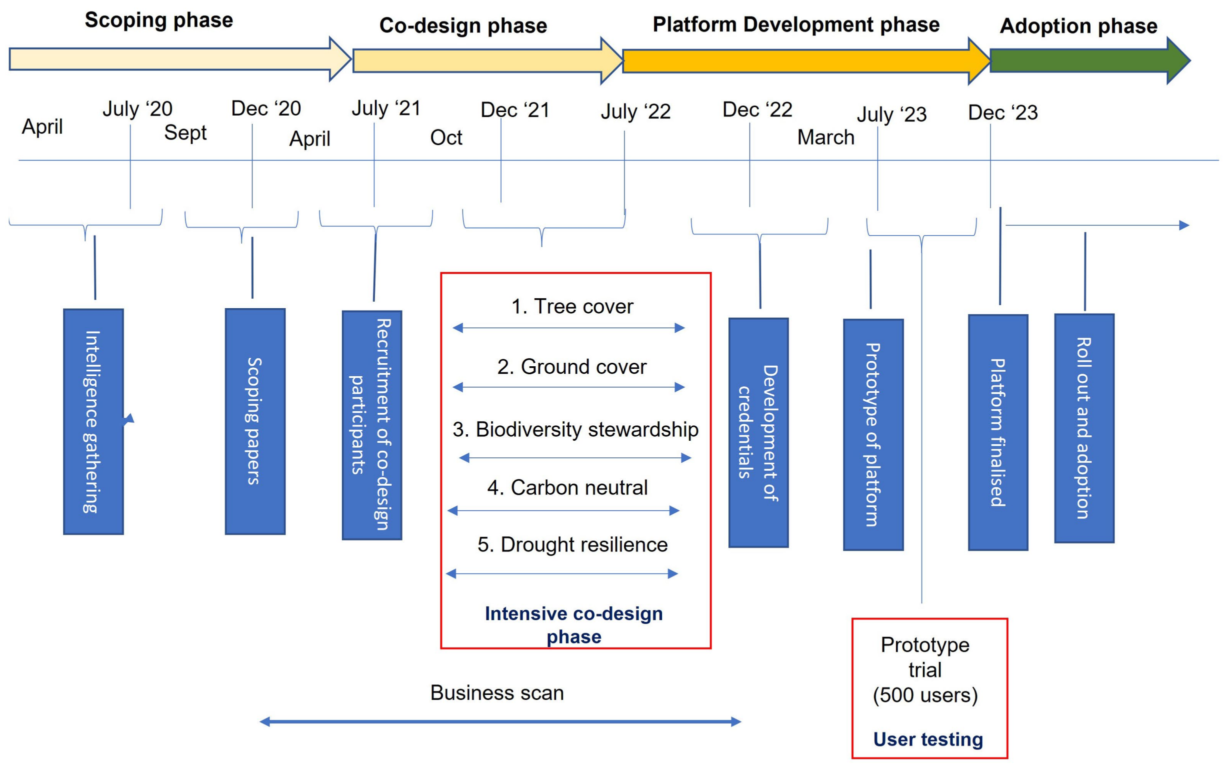

FIGURE 2
Timeline of the development of the platform.

in the co-design process, scoping papers were researched and written. These provided essential background information for the choices needed for the co-design approach, and for each of the five themes. They helped to frame discussion priorities for the second phase, intensive co-design. Through a systematic analysis of other relevant initiatives and developments for each of the themes, and the key actors involved, the theme scoping papers sought to avoid any potential for duplication with existing programs or platforms.

3.1.2. Intensive co-design phase

Producers of grassfed beef will be the users of the platform. Where producers are willing to voluntarily share results pertaining to their properties, value chain organisations will be beneficiaries (and "customers") of the information synthesized on the platform. Accordingly, both producers and value chain organisations were involved in the co-design (and represented in the project's advisory group).

To ensure relevance to grassfed beef producers and value chains, an intensive, collaborative, co-design approach was adopted (see Section 3.2 below for further detail). Five co-design working groups, one for each project theme, were formed through a combination of open call to producers through MLA's networks, and invitations to major beef processors. Crucially, this entire process was conducted online. Originally, face to face meetings were considered, but would have presented considerable problems in inclusion given travel distances for many producers and hence time away from their production. The onset of COVID-19 and Australia's response—involving high uncertainty about interstate travel—made the decision to hold online meetings inevitable. It was reliable, provided groups were kept small, reduced the time burden on participants and enabled wider geographic inclusion.

Following the series of co-design meetings, the theme leaders edited the deliberations, with some refinements based on their research, into "design briefs" for each theme, for the platform developers. The briefs included the definition of each theme, and its scope, indicators and metrics for measurement, benchmarks appropriate for producers to compare performance, and the types of learning materials preferred to support continual improvement in sustainable production. These documents were peer reviewed by independent technical experts prior to being presented to the platform developers in the next phase.

During this phase a recruitment and contracting process was conducted through MLA's tender process for technical experts to build the platform. A combination of specialists in overall platform design, remote sensing, and learning materials was appointed.

3.1.3. Platform development phase

Following the recruitment and contracting of software developers, the platform development phase began with orientation of the development team. This included discussions between the project team and platform builders to interpret and synthesise the five theme-based design briefs, and to incorporate the platform builders' expertise. Close consultation continues between the project team and platform builders.

Conscious that the platform developers had been asked to work mainly from separate design briefs for each theme, the project team created two overarching documents explaining common points across the five themes. These were a list of "design principles" expressed by all or most of the co-design groups,[4] and a matrix of interdependencies among the themes, particularly with respect to remotely sensed information. For example, biodiversity stewardship and tree cover have close linkages with the carbon balance theme, and ground cover is an important aspect of drought resilience.

The steps in the design and build phase involve planning and design, system architecture, data ingestion and developing the learning modules. The platform will be refined through user acceptance testing during a pilot testing phase, involving consultative co-design (see Section 3.2 below).

3.1.4. Adoption phase

Before and after the release date, the platform will be promoted through communication and dissemination among members of the Australian beef industry, including grassfed beef producers and wider networks. This will include engagement with various value chain stakeholders to ensure they have a strong understanding of the platform and its capability to drive adoption.

3.2. Detail on approaches to co-design

A co-design approach was vital to the development of the technology. Co-design enabled active involvement of the users in the process of identifying the requirements, so that it would best meet their needs and attain their trust. We elaborate our approach to co-design, given the opportunity to illustrate how different models of co-design can be applied in technology development.

Where new technologies are co-designed with prospective users, there is a range of possibilities, from developers consulting representatives of users about key decisions and actual technology prototypes that the developers have prepared first (which we will call "consultative co-design") to a much more "bottom-up" approach, led by typical users or created jointly by typical users and a project team (which we will call "collaborative co-design"). These roughly align with the International Association for Public Participation's spectrum of participation (IAPP, 2018), in the segments from "consult" to "collaborate" and "empower". Issues for decision concerned the best models of co-design to use at different stages in the project, and the specifics of how to apply them. Under an overarching collaborative approach by the three project collaborators, we chose a sequential approach with producers (see Figure 3), from collaborative (supported by "inform" in the preparatory materials) in the intensive co-design groups in phase 2, to consultative co-design in the platform prototype testing in phase 3.

In principle the project team sought to "empower" producers in the design process (*cf* IAPP, 2018). However, given expertise was also needed from the theme leads, our approach is best described as collaborative, with the prototype testing phase being consultative. A collaborative co-design process cannot, however, be information free. It is also important to brief participants before discussions, at least on topics they may not already (all) know well, hence aspects of "inform" (IAP2) support collaborative discussions.

The co-design process chosen for this project involves three levels: (1) the cross-sectoral collaboration of Consortium members, explained previously; (2) collaborative online co-design groups consisting of producers, some value chain representatives and content experts; and (3) later consultative co-design through producer testing of the platform as it is built by software developers. Figure 3 illustrates the three levels of the co-design process.

The first level of co-design, which continues throughout the project, is the collaboration between the Consortium members: MLA, WWF-Australia, and UQ. This is more than a management structure: the combination of unusual partners was sought under the grant scheme and enabled combination of different perspectives and expertise to the process and problem solving.

In the second level of the co-design process, collaborative co-design, five co-design groups were formed, one to focus on each theme. To cater for the challenges of online meetings and allow all members plenty of time to participate, each group was kept as close as possible to ten members each: eight to nine producers, and up to two value chain representatives (except in the drought resilience group which comprised only producers; one group had 11 members). The producers, 48 in all, were unique to each group. Given fewer organisations and people available, three individuals represented value chains, participating in two groups each. Each group met online six to eight times, for 90 min to 2 h per meeting. Thus, while there were few participants relative to the size of the industry, each individual participated for 9.5 to 12.5 h online, with some three additional hours in preparation between meetings. This represents unusually intensive input.

Each meeting was convened by the theme lead (a member of the Consortium, or their representative[5]), and jointly facilitated with an independent contractor skilled in online facilitation, and a member of the project's co-design team. The meetings were supported by background information prepared by the theme leads: the scoping paper at the start of the series and new information (and sometimes tasks for participants) between each meeting. The process followed a "flipped learning" approach (Bergmann and Sams, 2012), in which participants prepared between meetings so that the meetings could concentrate on discussion rather than presentation of information. Through their sequence of meetings, each group developed relationships, and conducted discussions gradually evolving from a broad perspective on what their theme should offer and achieve, to the specifics of definitions, scope, indicators and measures, and other design requirements including the nature of learning materials.

In the third level of the co-design process, using consultative co-design, some 500 grassfed beef producers will test the features and useability of the platform and its layout and design. After further iterations based on the feedback from this testing, the fully functional platform will be widely promoted through communication among grassfed beef producers and the industry networks.

At the time of writing the intensive co-design process (see Section 3.1.2 above) is complete. Technical and educational specialists have begun building the platform's conceptual prototype (see Sections 3.1.3

4 E.g. catering for low internet bandwidth in remote areas, diversity of production systems, data integrity, privacy and confidentiality issues.

5 The Australian National University worked with WWF-Australia to coordinate three of the five co-design groups: biodiversity stewardship, tree cover and ground cover.

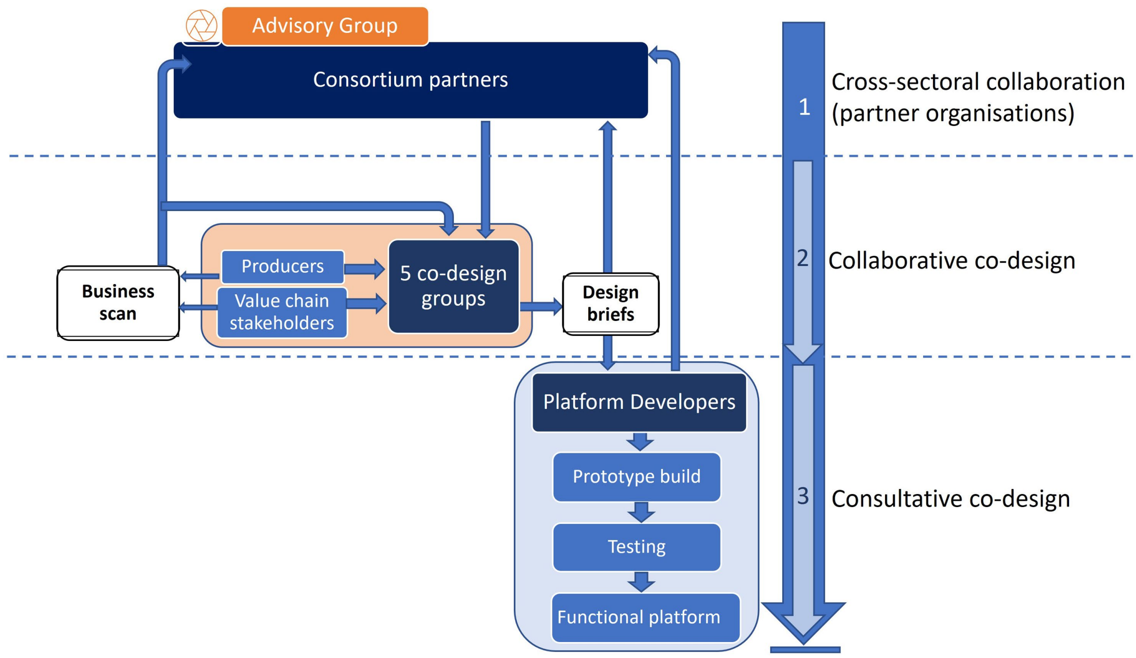

FIGURE 3
The three levels of co-design used in development of the platform.

and 4.1), informed by the design briefs. The prototype testing will commence in late 2023.

4. Results

In this section we share the conceptual design of the platform, and then explain the general design characteristics sought by the co-design working groups, theme by theme, then the indicators they considered important and how to measure them. We then comment on issues faced in the technology development process, and their implications.

4.1. Platform design

A conceptual design of the platform has been developed based on the design briefs (Figure 4). This will evolve as the platform developers proceed, and user feedback is offered. The main aspects planned are an entry page providing explanations, mechanisms to assure privacy, and then major sections for learning resources, and for demonstration of sustainability performance. Meanwhile work is underway to develop environmental credentials under two of the project's five themes: carbon balance and biodiversity stewardship. This is anticipated to be a further opportunity for landholders to demonstrate their environmental performance under these two themes. Detail about the nature of these environmental credentials and how they will be achieved is yet to be agreed. Based on the business analysis, there is no current market indication to support development of stand-alone tree cover, ground cover or drought resilience credentials. Hence for these three themes, the platform will enable user information and learning opportunities, and sharing of information with value chains should they choose, without being directed towards credentials.

4.1.1. Specific characteristics sought

The producers emphasised that the platform should serve as a *practical tool* for beef producers to measure and demonstrate their sustainability performance and efforts, where applicable, and that reporting and learning through the platform should be *simple and user friendly*.

Equally, *privacy and control of data* about their properties is highly important to the producers. The project team agreed with them from the outset that strict sign-in requirements, associated with delineation of property boundaries, are essential to enable producers to maintain privacy of data synthesized about their own properties. To assure this, users will be required to enter their individual Property Identification Code (PIC) which is a code that is allocated by each state government to ensure each land holding can be referenced to a business. Some primary producers may have several PIC numbers across multiple properties. The use of this code ensures producers are only able to view and provide information relative to their land parcels and businesses. They alone should decide on and control any sharing for market purposes. The platform will thus provide the ability and choice to opt in to share data (or not), to allow a producer to demonstrate to their markets that they are meeting the biodiversity stewardship and/or carbon balance credential sought by that value chain or market (where these exist).

While the platform was originally conceived as an opportunity to demonstrate sustainability performance to markets, the producers were also enthusiastic about the idea of using the platform to *inform their management*, without necessarily sharing information. They were equally keen that the platform provide producers with an information base and learning resources to improve their sustainability practices and gave rich advice as to how to do this. With this in mind, they asked that the self-guided learning modules be both *specific* to a theme (e.g., how to improve ground cover), and *integrative* across themes

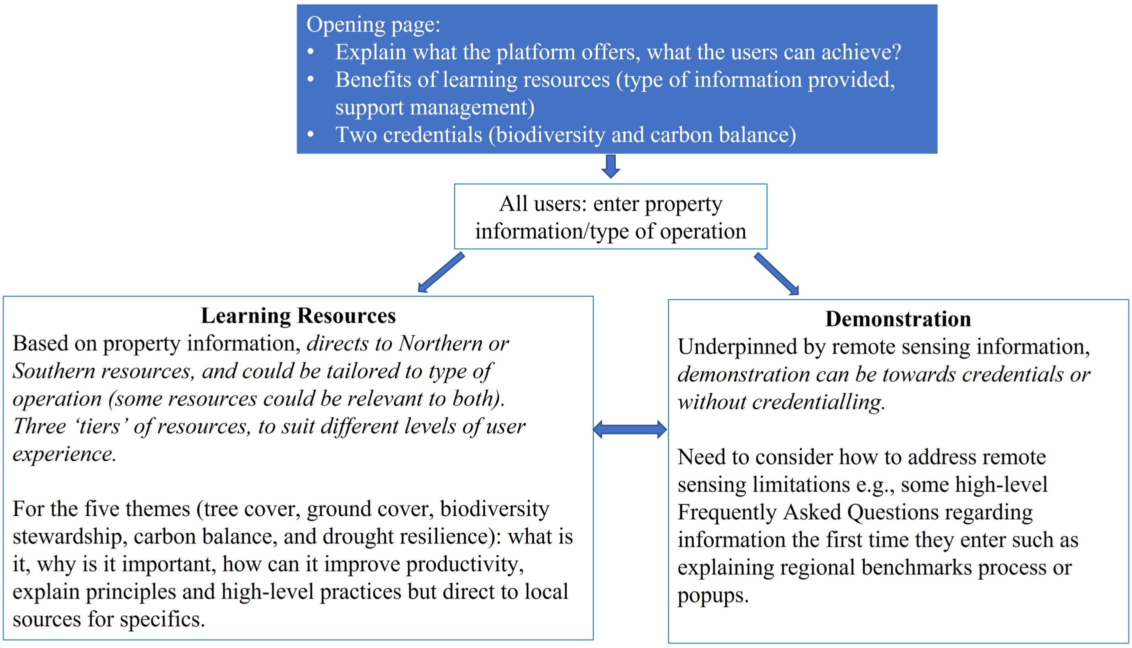

FIGURE 4
Conceptual design of the platform.

(how to improve ground cover in ways that also enhance biodiversity and drought resilience).

Given concerns discussed about the accuracy of remote sensing data, the co-design groups suggested incorporating the capability for *user input* of biophysical data, alongside the primary reliance on remote sensing data. They suggested this feature will be important when remote sensing cannot cover a specific indicator or measure, or when users believe the remote sensed data is incorrect, e.g., vegetation loss after a bushfire. (This feature will not be incorporated in the first version of the platform but may be considered in future).

4.1.2. Indicators and measures chosen

Defining the concept underlying each theme, crystallising the purpose for each theme, then choosing indicators and measures of sustainability were difficult tasks, involving iteration over several meetings for each theme. Table 1 lists the definitions, purpose, and indicators and measures decided by each of the co-design groups. Some were refined by the theme leads.

Remote sensing is preferred as the most widely available and cost-effective basis for measuring and demonstrating sustainability performance, with a focus on outcomes rather than processes. However, the working groups and theme leaders recognised that remote sensing varies in capabilities and limitations for certain themes (discussed in detail in Section 4.2.3.1). For the tree cover and ground cover themes, the desired outcome and use of remote sensing to measure it is relatively straightforward. For biodiversity stewardship, which is conceptually complex, an outcome-based approach focused on the condition of grazing properties to support native biodiversity is recommended. Ecosystem condition has emerged as a central concept in environmental accounting through the United Nation's system of environmental economic accounting and its recommendation as an indicator by the Taskforce on Nature-Related Financial Disclosures (2023). Condition of grazing lands to support biodiversity can be modelled using a range of available data including land use and remotely sensed land cover classes. Spatially explicit estimates of local ecosystem condition can also be compared to regional "benchmarks" to develop a measure that is responsive to the local context. This approach seeks to achieve a balance between scientific rigour and practical limitations, especially where comprehensive on-ground audits are not possible. For some themes, it is difficult to measure and demonstrate sustainability by relying heavily on remote sensing. For example, the carbon balance theme needs to rely largely on carbon calculators for emissions, and indicating carbon sequestration is difficult. For the drought resilience theme, many remote sensed indicators are relevant, but interpretation is necessary to infer *resilience*. Further, remote sensing can contribute to understanding the resilience of the land, but not of the business and the people.

4.2. Key issues faced, and implications

The issues faced in the design process are reported according to a framework expressing interactions among people and their properties, processes and technology. This framework is adapted from a model by Leavitt (1965), originally developed for analysing organisational change according to people, process and technology (PPT). The PPT framework has been applied in different contexts including cyber security organisational management, process improvement, product development, knowledge management, information technology and customer relationship management among others (Chen and Popovich, 2003; Pee and Kankanhalli, 2009; Morgan and Liker, 2020). In this study, involving technology development for the agri-food sector, we necessarily incorporate different considerations under each

TABLE 1 Definitions, purposes, indicators and measures decided for the themes.

	Tree cover	Ground cover	Biodiversity stewardship	Carbon balance	Drought resilience
Definition	Areas containing forests or sparse woody vegetation, including revegetation.	The organic material covering the soil surface.	Conserving and enhancing native plants and animals and ecological communities.	The difference between amount of greenhouse gases emitted when raising beef, and the amount carbon sequestration on-farm.	The ability for land, livestock, enterprise and people to prepare for and adapt successfully when faced with droughts and related challenges.
Purpose	To demonstrate environmental performance in relation to forest and woodland stewardship on-farm, by providing data to help producers better understand the correlation between tree cover and productivity; and support development of carbon balance on farm.	To demonstrate that ground cover is being retained and/or improved in grassfed grazing systems.	To demonstrate that biodiversity is being retained and or improved in grassfed grazing systems.	To lift the collective awareness, understanding and knowledge of beef producers about the opportunities and risks associated with carbon. Enable beef producers to measure on-farm emissions and sequestrations, and to demonstrate actions and benefits in managing carbon balance.	To support awareness and sound management for drought through cycles of before, during and after droughts. Enable demonstration of sound management for drought.
Indicators and measures[a]	Extent (ha) of each class of tree cover (area-based measure) Percentage (%) change in tree cover (change ± measure) Area cleared or regenerated by type.	Percentage of farm achieving healthy ground cover thresholds (aligns with the ABSF) Percentage of area in groundcover classes, e.g., 0%–30% (low), 30%–70% (medium), >70% high Percentage of groundcover meeting the 3P criteria (palatable, perennial, productive)—would require field verification	Vegetation condition score as a proxy for biodiversity condition, compared to regional benchmarks Land (ha) or % of farm with native vegetation	Total annual emissions (kg CO_2e/year emitted) from beef production system. Also presented as emissions per kg liveweight to account for differences in herd size. Carbon stocks (total kg CO_2e) and fluxes in soil (kg CO_2e/year). Carbon stocks (total kg CO_2e) and fluxes in trees (kg CO_2e/year). Annual carbon balance (total annual emissions minus total annual sequestrations).	Land management—Stocking rate relative to carrying capacity, LSU/ha/100 mm rainfall Enterprise management—Economic diversity, Farm profit vulnerability, Farm HH income vulnerability Individual/ Family—Stress level, Optimism, Empowerment, Physical health

[a]Terminology for indicators and measures can be confusing. For our purposes, an 'indicator' indicates something, while a measure gives as precise as possible a measure of it. Indicators are often used as suggestions, e.g., the presence of particular plants may indicate that soil is frequently waterlogged, or the presence of certain species in a soil sample can indicate soil health. Many indicators can be calculated from combinations of data.

main heading. We treat the framework in a "systems" way, emphasizing the interactions and hence mutual influences among people, process and technology (see Section 4.2.4).

People and their properties—This focuses on the types of people the technology is developed for, primarily grassfed beef producers. Since the nature of their properties and business operations is intimately associated, we include their properties.

Process—This covers the processes involved in the development of the platform, including decisions about the forms of collaboration to use, wider participation, and pathways to adoption.

Technology—This focuses on the use of technology, e.g., remote sensing, to produce further technology (the online platform), and ultimately the features of the technology sought.

4.2.1. People and their properties

Any new technology should meet the needs of the types of people for which it is being developed. Several key issues related to the people and their properties are explained below.

4.2.1.1. Remote locations of properties

Beef producers are located throughout much of Australia, from remote savanna areas across Australia's north, arid regions of central Australia, to higher rainfall areas on the east coast and south. Many properties are very extensive and the majority of the producers are located in rural and regional areas (MLA, 2022) which suffer from unreliable internet connectivity, bandwidth issues, slow speeds, and generally less access to technologies. Hence, a platform with heavy bandwidth requirements needing high speed internet will be problematic especially for many remote producers. According to the Australian Digital Inclusion Index, which measures digital inclusion across the dimensions of access, affordability and digital ability (Thomas et al., 2021), people living in rural areas and remote locations (including a proportion of Australian beef producers) have low levels of digital inclusion, which can be attributed to lack of infrastructure (Marshall et al., 2020). This has implications for our platform development choices, between catering for those with unreliable internet, and the potential power that could be offered in the platform for users in areas of more reliable internet. Some producers experience unreliable internet even in southern regions where there are pockets of weak service.

Meanwhile, the more remote properties have least access to the existing option for demonstration of an environmental credential, since travel costs for third party audits are higher, and the areas of property to be covered are so much larger.

4.2.1.2. Practical people and diverse user experience

Generally, the producers are "hands on" and busy, with the majority spending most of their time out on their properties rather than at their desks and telephones. They tend to be "time poor", especially since production costs and profit margins limit capacity for employing others. The users also vary in computer use in their businesses, and range from beginners to advanced users, i.e., those who may not use computers much beyond their business financial recording or may prefer to rely on agronomists for environmental information, to those who are comfortable with looking up information on the web, and are inclined to use some of the complex tools available.

The co-design participants noted several implications for platform design. The technology should be easy to use, intuitive, and avoid complexity for the users. However, it is important to cater for different levels of users, from those who are skilled with information technologies, to those who are less so. Designing for a single skill and interest level risks either not offering value to more advanced users or deterring and confusing beginner users (or both). Further, some producers see returns on their time investments in engaging with technology, while others will not be willing to invest long in learning and using such a tool. While this may or may not be possible, co-design group members also suggested making it possible to use parts of the platform in the field, i.e., on tablets and mobile phones, in addition to desktop computers. Further, to cater for weak internet connectivity, they suggested making offline use possible. The co-design participants preferred the platform to be free to users: ways of achieving this remain under discussion but it may not be feasible to make the entire platform free to users, especially indefinitely.

4.2.1.3. Diverse landscapes and production systems

Australian production systems are extremely diverse and complex, involving interactions among different types of landscapes, climatic conditions, soil types, different pasture species (Greenwood et al., 2018; Bell and Sangster, 2022). The co-design participants across different themes noted that what is desirable and achievable differs regionally, for example ground cover levels in low and high rainfall areas. The possible management practices differ across the production systems. For example, for the carbon balance theme, there are regional differences in sequestration opportunities and emissions reduction activities. Similarly, levels of tree cover are different due to diverse climates, soil and vegetation types. Drought pressures, and strategies for being resilient, vary by region. The co-design process helped to identify the needs of users in the diverse production systems, across the themes.

The implication is that a "one size fits all" solution is inappropriate. The minimum differentiation needed is between low and high rainfall areas, reflected in the northern and southern production systems. The platform will need to cater for regional differences in setting benchmarks associated with measures, and in learning resources and management practices. The co-design participants suggested that ideally the platform should cater for the wide range of production types, small to large scale, organic and otherwise, land uses and types, breeding versus standard production, at least in benchmarking (if not in all information and learning resources provided).

4.2.1.4. Users' purposes

Producers will have diverse objectives for using the platform. Some will have a single primary objective, such as carbon balance, biodiversity stewardship or drought resilience. Others manage holistically, across several themes. This will guide the information they require from the platform, and which (if any) objectives they choose to work towards. Therefore, the platform needs to be flexible to cater for these different needs. For instance, if a producer is focused entirely on carbon balance, the species of trees planted may be less important than if they are focused on biodiversity stewardship, in which case locally relevant species would be used. The same applies in ground cover. If the producer's purpose is solely to prevent erosion many species will do, but for production purposes the producer may seek Perennial, Productive, Palatable (3Ps) and diverse drought resistant species.

4.2.2. Process

Despite much literature over many decades recommending working closely with the prospective users of a new technology (Brhel et al., 2015; Taherdoost, 2018), the reality is that the majority of programs and platforms in the agricultural field have been "supply-driven" by the developers, creating advances in the technical possibilities, often with little consideration for the natures and capacities of the users. The project team recognised a need to be "demand-led", with focus on the interests of the markets for sustainable beef and the producers seeking to participate in those markets. Market context was explored through business research, and co-design was a natural choice for having producers lead the design process so far as possible.

The next subsections highlight important aspects of the process of developing the technology and discuss their implications.

4.2.2.1. Market analysis

Given that an important aspect of the platform is to facilitate access to sustainability markets, a comprehensive market analysis was conducted to get sustainability context from a business perspective. The analysis explored the current and growing need for sustainability performance from the perspective of beef producers and other value chain players. Those interviewed see value in demonstrating environmental sustainability performance to the market and indicated that there is significant potential value in doing so in both the domestic and overseas markets. The analysis indicated that all five themes of the project were considered to be important by the participants. The information derived from the analysis provided valuable stakeholder perspectives on the value proposition of the platform.

4.2.2.2. Approaches to co-design

While co-design was the logical choice to ensure that the technology meets the needs of its users, the approaches to co-design required detailed consideration. We explained in Section 3.2 how this project combined collaborative and consultative approaches to co-design. Overall, the approach sought to "empower" users (*cf* IAPP, 2018). The sequenced approach allows strong influence over the design, followed by checking (the consultative co-design aspect) during the platform build phase.

Following initial decisions about the broad approach to co-design (primarily collaborative) a set of design decisions was necessary.

4.2.2.3. Selection of participants

Diversity across Australia's major beef producing regions and types of property within those was an important issue in selection of participants for online co-design. This raised questions as to whether the co-design group members should be "representative", especially should they be typical of all producers, or focus on those most interested in sustainable practices and potential use of a technology platform. The co-design participants were not a representative "sample" of all producers but were aware of the nature and concerns of other producers, often providing specific examples.

4.2.2.4. Managing complexity in the co-design discussions

The potentialities for the platform design could have been approached from many possible angles. Some structuring was necessary to simplify discussions and explorations for the project team and for the co-design working groups, when recruited. After much deliberation, the project team decided to focus on the five sustainability and resilience themes, which had been promised in the grant application but not necessarily with the intent of organising the design discussions in that way. This enabled the Consortium members to share out the theme leads roles, and the theme leads and co-design groups to focus in depth on background investigations and discussions towards specific themes. This enabled concentration, but carried the risk of designing five parts, putting the onus on the platform builders to create the "whole" from the parts.

Meanwhile, the technical requirements for building the platform pointed to needing a team that incorporated overall management and platform structure and approach towards a rewarding user experience, remote sensing capabilities, and learning aspects. The organisations and individuals contracted brought their own expertise and experience to interpret the design briefs, and to suggest approaches to fulfil them.

4.2.3. Technology

The success of technology, i.e., the platform being developed, needed consideration of the aspects of remote sensing, to produce technology, data integrity and ultimately the features of the technology sought.

4.2.3.1. Remote sensing

Remote sensing has great power and cost effectiveness, and the platform relies primarily on remote sensing. However, it has stronger potential relevance and accuracy for some themes than others. For example, remote sensing can measure ground cover but can only indicate in terms of green vegetation and non-green vegetation cover etc., and cannot distinguish among the types of cover with certainty. Similarly, the carbon balance theme needs calculators for emissions, as these cannot be remotely sensed. For the drought resilience theme, drought can be indicated, but the aspect of resilience cannot be measured through remote sensing. Also, there are issues for remotely sensed data in terms of resolution, as the larger scale data is generally available for free, while finer scales are more useful for the purposes, but come at a cost.

There are implications for platform design in terms of using remote sensing, so that all themes draw similarly on the remote sensing data to give the platform a coherent information framework. For example, drought resilience will rely on other themes (e.g., ground cover, tree cover). Likewise, biodiversity stewardship draws on sub-indicators involving tree cover, ground cover and land use. Where two themes share indicators, they should ideally also draw on the same data to inform those indicators.

4.2.3.2. Integrity of data sources and calculation processes

Integrity of data sources and the processes used to calculate measures were seen as key issues by the co-design participants. Data integrity is also critical for producer and market confidence. The implication is to ensure data integrity so far as possible by using high-quality and reliable data with transparency about the data sources and the processes used to calculate measures. The trustworthiness of the data sources used and integrity of the calculation process can be shown by providing a "further information" link to enable those who so wish to check the detail. It should be acknowledged that no data source is error free, and that some potential applications may require further verification or refinement of data presented through the platform, rather than building expectations of infallible data sources.

4.2.3.3. User friendliness

The co-design participants emphasized repeatedly that the online platform must be user-friendly, or it would not be used. They made a number of suggestions for achieving this, while catering to varied levels of user experience.

4.2.4. Systemic interactions

We argued earlier that the technology design process should be viewed as systemic. This requires attention to the mutual influences among people, process and technology. Figure 5 summarises the points already raised with respect to each part of the framework and shows the main interactions. At the centre of Figure 5 is the ultimate purpose, development of an online platform that suits producers and their needs to demonstrate the sustainability of their production practices to particular markets, and to have convenient access to learning materials, tailored to their circumstances, to support continual improvement.

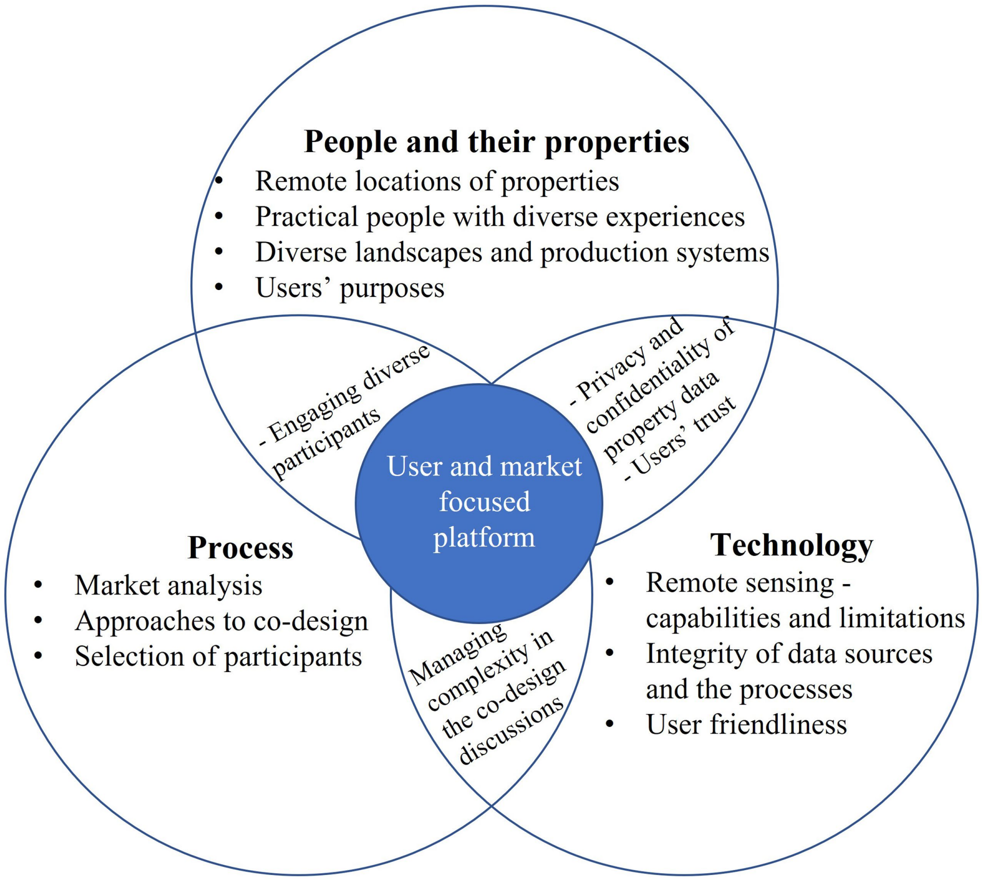

FIGURE 5
Systemic interactions between people, process, and technology.

4.2.4.1. Interactions between people and process

The process needed to suit two sets of people—producers, and value chain participants. A market analysis based on individual interviews and document analysis was best for value chain participants. That analysis could then be supplied into the collaborative co-design process, to inform it. Some value chain members also participated in the collaborative co-design, and some on the advisory group along with some beef producers and other stakeholders. The nature of the people and their properties (including property locations, remote or otherwise, and internet bandwidth in their regions) had a strong influence over the co-design process required. Although COVID-19 travel restrictions and uncertainties originally determined the decision on online co-design, it also made sense in terms of geographical inclusion, and using online methodology for an online platform.

4.2.4.2. Interactions between people and technology

The key issues in the interactions between people and technology, beyond the obvious intention that the technology serve the people's needs, is the very high concern for privacy and control. Producers recognise the widespread availability of remotely sensed data, and how it can be linked and used to support well informed decision making on-farm. However, data privacy is of high importance to producers to ensure sensitive business information is not accessible to those outside of their business, including data such as property locations. Trust in the privacy controls, so that only producers—and those they choose to share information with—can see the information collated about their property is thus vital. The producers also emphasized that the limitations of the technology, particularly remote sensing, needed to be communicated clearly to users, in ways they could understand readily. Further, they requested the ability to review their data, input additional data and flag errors.

4.2.4.3. Interactions between process and technology

As we have mentioned above, the decision to use online co-design meant that online technology was used to develop further online technology. Less obviously, the collaborating partners were faced with very difficult choices about how to structure the online co-design process (and overall design process) to simplify a complex set of interactions. The choice to separate discussions by themes enabled that simplification and allowed each co-design group to focus intensively on a single topic. The consequence was a challenge in integration across the themes. That was addressed by further information being provided to the platform builders, to point out the synergies and overarching design principles inherent in the separate design briefs. The producers had no such problem with synthesis. In their discussions under their single themes many explained how they managed their properties, often for several theme purposes at once, and hence the information and considerations they took into account.

5. Discussion

Online technologies will be used increasingly, for many purposes that include demonstration of sustainable practices in agricultural production, and assembly of information to improved market access. While every approach to creating a new technology is probably unique, certain points can be learnt and shared.

We have explained our approach to developing an online platform for demonstrating sustainability and learning in an agri-food industry. In doing so we have argued that active participation of the users in the design process helped in identifying their purposes and requirements, to ensure the platform's relevance, and should encourage better trust and adoption by the users after it is developed (Treasure-Jones and Joynes, 2018; Durall et al., 2019; Villatoro Moral and De Benito, 2021).

This section reflects on the findings according to the three dimensions of the framework, and their interactions, to suggest implications and learnings for others. It then returns to points raised in the introduction, to comment on how this project has addressed the critiques about "measurementality" in environmental information systems.

First, while developing new technology, the dimensions of people, process and technology, and their consequences for one another, need to be considered together. Traditionally, the people and process aspects tend to be ignored. In contrast to common approaches in which the potential inherent in technology is used to drive the process of developing it, and people are assumed to want to use it, our procedure puts the people and their requirements first, matched with a suitable process (Meynard et al., 2012; Berthet et al., 2018). Building on earlier work on Reflexive Interactive Design (Bos and Grin, 2012; Elzen and Bos, 2019), we engaged the people as users through a carefully considered, highly collaborative, co-design process which helped to identify their requirements and (subject to feasibility issues that may yet be raised by the platform builders) generate solutions they wanted. This aims to empower Australian grassfed beef producers to move from being reactive recipients of technology designed for them by others, to becoming proactive partners who anticipate market requirements and proactively design the digital tools needed for measuring, reporting and verifying their environmental performance.

Second, the technology we sought to develop was to improve information flow in the producer-market relationship (Ali and Kumar, 2011; Lezoche et al., 2020). The approach thus combined value chain and producer perspectives. Our decision was to research the value chain perspectives, then to feed that information into the co-design process while also incorporating value chain perspectives in that discussion process. Throughout the process, focus remained on the "value proposition" for users, meaning both producers and the value chains which seek verified sustainable produce, with the aim to include the users' perspective and requirements while considering their context (e.g., diversity in producers, their properties and production systems).

Third, the project supports new perspectives on use of co-design in the development of technology in agricultural settings. In Reflexive Interactive Design, co-design originally consisted of a series of three consultative, one off, workshops with different stakeholder groups (farmers, consumers, experts) in which the participants provided information, but it was up to the project team to decide how to incorporate that information into the design. Over time the Reflexive Interactive Design process has become more consultative (Elzen and Bos, 2019), but there is little reflection on the implications that this has for the roles of the project team (Blackmore et al., 2016). Building on those experiences, our co-design approach consisted of a series of interrelated working group meetings—with the same group of participants—that treated users as full collaborators. By considering our own roles reflexively, we have recognised this user-centered technology development process involved different levels of co-design, involving ourselves as a cross-sectoral collaboration of project partners, as well as the nested collaborative then consultative co-design with producers. Forming and consolidating three project partners as a consortium, then moving through processes to develop the platform (via co-design working groups and design briefs and informed by business research) has been a non-linear process. While the project had clear aims and a general "vision" of what the platform should ultimately offer, much deliberation was required at every stage, starting from quite an open view of what the platform could offer and be, and gradually "funneling" towards greater clarity but with some revisiting of options and ideas. In this process, the project team's views iterated with what we were learning from the co-design group iterations, and no doubt will continue to evolve in interaction with the platform builders and the testers of the technology.

Fourth, as we had expected, technology development to demonstrate sustainability using remote sensing posed several challenges (Bakker and Ritts, 2018; Marshall et al., 2020). While recognising advantages, the producers participating in the co-design process had valid concerns about the visibilities and invisibilities created by remote sensing. The integrity of remotely sensed data was questioned, as well as its varying ability to represent sustainable management practice. Depending on the theme, some argued the need for ground-truthing where possible, to strengthen confidence in the relationship between remote sensing and on-ground actualities (and hence, over time, improve remote sensing and its uses).[6] This is a separate matter to on-ground audits of performance on properties: it is about validating measures from remotely sensed data to use it within its limitations. The producers also emphasized circumstances in which remotely sensed data should be supplemented by other sources of data. This included carbon calculators, and user input to over-ride remotely sensed data where local knowledge was considered more accurate (but which may not be possible to include in the platform, at least at first). A related issue is how well remote sensing can represent the theme required. In some cases, digital tools and remote imagery can be true substitutes but for many issues—and biodiversity in particular—they should be seen as complementary, providing a way of streamlining and reducing on-ground costs, but not displacing the need for on-ground measurement. A further consideration is that remotely sensed data is geographically comprehensive. This brings in issues of privacy and confidentiality about property management, amidst concerns about information being used against producers by distant policy makers or market actors that may now be able to "read" the properties at a distance and impose control mechanisms in the form of environmental standards or policies.

Fifth, while a strong co-design process can identify and communicate users' requirements, correct interpretation of the design

6 This reflects a need for ancillary activity, especially as future research. It is not possible to make it a part of the platform design at this stage.

briefs is critical for translating the co-design process into a practical platform. This depends largely on the level of expertise of the technology developers (Howard and Melles, 2011; Durall et al., 2019) who are stepping up as new intermediaries and knowledge brokers (Bernards et al., 2020). This entails both technical expertise to build the different parts of the platform, and an ability to understand and empathise with what the users are saying, and why, through the design briefs. We note that in our case, three sub-teams of platform builders, each with different expertise, need to develop collaboration to create an integrated platform.

Returning to concerns about measurement raised in the literature, especially about the power differentials that verification practices (and by implication our technology) can create (Bakker and Ritts, 2018; Bernards et al., 2020; Gupta et al., 2020; Kloppenburg et al., 2022), we have sought to produce an alternative that puts producers in stronger positions of control than conventional auditing systems, while making use of potential efficiencies in technology that can be more affordable and hence inclusive. Grassfed beef producers do not actually do the "measuring" as remote sensing provides much of the data, and they need a type of independent verification of their actions and outcomes. Therefore, the producers and the members of value chains, working together in the co-design groups, have selected the indicators and measures that best suit their purposes. In this proposed platform the "how" of doing the measuring may be less accurate than on-ground audits, but is far more accessible, being more cost-effective and less subject to distance. While the project team originally envisaged the platform as providing information to markets to improve market access for producers, the producers decided that "for whom" included themselves: the platform can and should provide valuable management information for their own uses, irrespective of any decisions to share it with their markets. This process of platform development, coupled with producers having the control over what information to share with value chains seeking evidence of sustainability, arguably puts producers in a position of power. It could however introduce new inequalities (Kloppenburg et al., 2022), between those sharing their evidence for market access and those who cannot or choose not to, and so remain in markets which focus on price, or other non-sustainability factors. The growing technology intensiveness of verification of environmental performance may be easier to navigate for larger cattle producers who have the skills and resources to engage with this digital environment. Consequently, smaller and more family-based beef producers, and those with poor internet connections, may be left out, thereby potentially widening existing inequalities in access (Bernards et al., 2020).

5.1. Limitations

This is a unique case study of technology development, in which decisions were taken for specific reasons. As with any study or development process, some limitations are worth highlighting. As this paper presents work in progress, a limitation is that we are not certain that all design characteristics, indicators and measures sought by the co-design groups can necessarily be adopted in the prototype then platform. At this stage we can only say that the platform builders are committed to follow the co-designed specifications as far as is possible and affordable. For example, there is a reliance on remote-sensed data with no current mechanism for user-inputted data on the prototype platform, though such a capability is being pursued. They may well uncover practical difficulties as they proceed. Further, as experts in technology development and the development of learning materials, they have the right and opportunity to make further suggestions based on their knowledge and experience. The project team will work closely with them to refine the directions the platform build takes.

Another consideration, rather than necessarily a limitation, in the approach to conducting online co-design was that there was a necessary trade-off between the breadth and depth of participation, i.e., the number of people who could be included (with perceptions of having more participants being "more representative"), bandwidth and numbers online limiting the stability of online meetings, and the amount of time each person could contribute within each meeting. In our experience, large face-to-face workshops can appear to include more people, but offer less opportunity for each individual to say much, let alone have their views recorded reliably. A different issue with "representation", more important to us, is that the producers and value chain members needed to cover (between them) all of Australia's major beef producing regions, sizes, farming systems and types of property. Participants however needed to be willing and interested, not merely "sampled". The diversity sought was achieved by purposeful selection among those who responded to the open call for participants, so that they collectively met criteria of property location, size and type of operation, and gender of producers.

5.2. Further research

Further research could take several directions. There is potential to test, adapt, and improve upon the types of approach taken in this project in other agrifood industries, and in other sectors. There is a need to keep testing and refining approaches to co-design, both online (where there are few examples, though there is a growing body of literature on online focus groups) and face-to-face. There is much scope to test the reliability, and market acceptance, of online alternatives to on-ground assessments of sustainable production practices and outcomes, particularly those using remote sensing.

6. Conclusion

In this paper, we have presented a case in which an innovative approach to developing an online platform has involved drawing market analysis and three levels of co-design together to inform development of technology that meets the needs of beef producers seeking to demonstrate and improve their environmental performance. The platform, when built, will draw primarily on remote sensing data, combined with complementary information sources and user inputs where required. The online learning resources on the platform will provide opportunities towards continual improvement of the producers' sustainability performance. Overall, the platform should offer Australian grassfed beef producers an efficient and cost-effective alternative for demonstrating and informing improvement of their environmental performance. This will assist value chain participants in their purchasing decisions, and ultimately raise consumer confidence and enhance the Australian beef industry's environmental reputation.

We have shown the importance of taking a "demand-driven" rather than a "supply-driven" approach, for the best possible fit of new technology to its users. In doing so, we have tested the use and effectiveness of co-design, and in particular online co-design, which is particularly apt for development of an online technology. Our approach shows different approaches to co-design—collaborative and consultative—should be considered and can be combined. It further shows that online co-design, though largely forced by circumstances in this case, is possible.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by the University of Queensland Australia. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

All authors (and some of those acknowledged) contributed to the development of the platform reported here. SS and HR coordinated the drafting and editing of the manuscript. SS, HR, SB, SP, MW, and KL drafted substantial sections and assisted with editing. KB, TC, DB, and AM contributed shorter passages to this manuscript while having substantial roles in the conduct of the project. All authors contributed to the article and approved the submitted version.

Funding

The project was funded by the Australian Government under its National Landcare Smart Farming Partnerships Program, as project L.SFP.1000. In-kind support was provided by the three principal collaborators on the research grant: Meat & Livestock Australia, The University of Queensland and WWF-Australia; and by some project participants.

Acknowledgments

The authors would like to thank Leanne Sherriff and Joanna Jones of Pinion Advisory, Renelle Jeffrey, Doug McNicholl and Margaret Jewell and colleagues at MLA, and Leanne Sommer and Andrew Rouse at WWF-Australia, for their contributions to the project. Figure 1 is reprinted with permission from Nova Science Publishers, Inc. from Harper et al. (2019).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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