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Research

U.S. beef producer perspectives on "sustainable beef" and implications for sustainability transitions

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Abstract
Beef production systems are at the center of ongoing discussion and debate on food systems sustainability. There is a growing interest among beef producers, consumers, and other beef supply chain stakeholders in achieving greater sustainability within the industry, but the relationship of this interest to general sustainability issues such as climate change, biodiversity loss, food security, livelihood risks, and animal welfare concerns is unclear. Specifically, there is very little research documenting how beef producers define and view the concept of sustainability and how to achieve it. Producer perspectives are critical to identifying constraints to sustainability transitions or to help build agreement with other producers about the shared values such transitions may support. Through a secondary analysis of survey data of U.S. beef producers (n = 911) conducted in 2021 by the Trust in Food division of Farm Journal, a corporation that provides content, data, and business insights to the agricultural community (e.g., producers, processors/distributors, and retailers), we investigated what "sustainable beef" means to U.S. beef producers, highlighting the key components and constraints they perceive to achieving desirable sustainability outcomes. Leveraging the three-pillar model of sustainability as a framework for analysis, we identified key themes producers use to define "sustainable beef." We found that producers collectively viewed sustainability as: (1) multidimensional and interconnected; (2) semi-closed and regenerative; (3) long-lasting; and (4) producer-centered, although an integrated perspective uniting these aspects was rare. We discuss how these perspectives may be the basis for sustainability efforts supported by producers and raise future research considerations toward a shared understanding of what sustainability is and what is needed for enduring sustainability solutions in the U.S. beef industry.

Keywords Sustainability · Beef production · Cattle industry · Three-pillar model

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1 Introduction

In recent decades, there has been increasing attention in both academic scholarship and popular media on the sustainability of meat, particularly of beef. Growing concerns about the contribution of the beef industry to climate change [1], the impact of grazing on ecosystem services [2–4], the health consequences of high levels of meat consumption [5, 6], pollution from intensive livestock production [7], and animal welfare issues [8] have put beef production and consumption in the spotlight. In the U.S., it is no surprise that beef has been foregrounded in food systems sustainability discussions given the industry's far-reaching environmental, social, and economic footprint.

In 2022, cattle production represented about 17% of the $462 billion in total cash receipts for agricultural commodities—the largest share of any agricultural sector [9]. Further, an estimated 654 million acres in the U.S. are used for pasture or open range grazing (as compared with 391.5 million acres of cropland), making livestock grazing the largest land-use type—and thus an important consideration for sustainability across public and private lands—in the contiguous 48 states [10]. Between pastures and cropland used to produce feed, 41% of land in the contiguous U.S. is used to support livestock, which is managed by an estimated 2.6 million farmers and ranchers [9, 10]. The industry is often described as being divided into two main production sectors, cow-calf producers and cattle feeding producers, the fed-cattle industry being the largest in the world [9]. At the same time, within and outside of these production systems, ranch and farm grazing operations can be diverse (e.g., cow-calf, stocker, grass-finishing) and use a wide range of different management systems and practices (e.g., continuous, multi-paddock, agrosilvopastoral grazing). In addition to the primary aspects of production in the U.S., secondary aspects of the beef supply chain (i.e., meatpacking, processing to retail operations) play important roles in achieving sustainability in the industry, along with consumers, who eat the most beef out of any country in the world [9].

Given the complexity of the beef supply chain, which operates at multiple scales across multiple regions, it is no surprise that there is no one definition of sustainability in the industry or consensus on the methods or indicators that should be used to measure it. While a number of papers have attempted to define and assess sustainability and beef production globally and in the U.S. [11–15], very little research examines producer perspectives on what sustainability means and how to achieve it. Yet, sustainability advocates (i.e. policy-makers, Extension agents, academics) would benefit from understanding producer needs, values, and perceptions garner support from producers for sustainability-oriented policy or market-driven initiatives. In this paper, we address this research gap by examining definitions of "sustainable beef" among U.S. beef producers, highlighting the variety of conceptualizations, connections, and values expressed.

2 Sustainability & beef production in the literature

One of the most widely used frameworks for conceptualizing sustainability in academic literature is the three-pillar model. This model is often depicted as a "three-legged stool" or shown as a Venn diagram where sustainability is the center of three overlapping circles that represent the economic, social, and environmental dimensions of sustainability [16]. In beef production systems, the interactions between the environmental, social, and economic "pillars" of sustainability are complex and multifaceted [17–19]. While numerous studies have attempted to examine and evaluate the different dimensions of sustainability in the beef industry, there is not a well-established definition for what it actually *is* or consensus around what methods or metrics should be used to achieve or evaluate it [11, 12]. Furthermore, a recent systematic mapping of the sustainability in beef and lamb production literature found a majority (60%) of studies focused on just one or two dimensions of sustainability, thus highlighting a need for research that adopts a more holistic approach where all three dimensions of sustainability are included and examined in concert with each other and within the same study [11].

Specifically, environmental sustainability in the beef industry is often discussed in reference to the land, water, and greenhouse gas burdens of production [13] and is most commonly evaluated using either life cycle assessment (LCA) or ecological footprint approaches [11]. For example, using life-cycle approach, beef supply chains are estimated to emit about 2.9 gigatons of CO_2-eq globally, about 40% of all livestock emissions [20]. Or, as Eshel et al. (2014) found, per consumed calorie, beef production requires 28, 11, 5, and 6 times more land, irrigation water, GHG and nitrogen, respectively, than the average of other livestock categories (i.e., dairy, poultry, pork and eggs) [13]. Studies using

these approaches have tended to show that beef production has uniquely high resource demands. At the same time, another body of research suggests that some cattle production systems can enable desirable environmental outcomes. For example, livestock grazing can be compatible with—and even beneficial to—managing noxious weeds and improving wildlife habitat [21–23]. Grazing lands can also play a role in mitigating climate change through soil carbon sequestration to the extent that they reduce bare ground and promote perennialization [24]. Further, some scholars have argued that despite decades of criticism from environmentalists, native rangeland ranching may be the most ecologically sustainable segment of the U.S. meat industry because it exemplifies numerous characteristics of diversified farming systems while providing other ecosystem services [21, 25–29].

The economic dimension of sustainability in the beef industry is similarly complex, and there is very little research that examines economic sustainability as it relates to the other dimensions, especially in light of the significant contribution of cattle production to economies globally and in the U.S. In the United States, cattle production consistently accounts for the largest share of total cash receipts for agricultural commodities at $72.9 billion (37%) in 2021 [30]. Yet, across the supply chain, the industry is challenged with preserving this market, adapting to consumer priorities, complying with regulatory changes, and overcoming the ongoing effects of COVID-19 disruptions to remain economically sustainable [31, 32]. Moreover, for producers to be financially stable, they must be resilient to market shocks as well as the impacts of corporate consolidation in the beef supply chain [33–35]. Recently, domestic demand for beef has also been an issue of growing concern for the industry with the increasing availability and marketing of plant-based protein alternatives (e.g., [36]).

Perhaps the least well defined and researched dimension of sustainability, particularly in the beef industry, is the social dimension [12, 37]. Gosnell et al. (2021) define social sustainability in the beef industry as "conditions of social well-being for all those impacted by it—ranchers, employees, consumers, and other stakeholders." They identify six themes that are critical to social sustainability in the beef industry: human health; learning/adaptation; community relations; equity and inclusion; land ownership, tenure, and succession; and industry structure [12]. While the research on these themes is sparse, a recent study by Sitienei et al. (2020) found that social sustainability goals, and specifically human health, was a leading reason U.S. grass-fed beef (GFB) producers chose to participate in the grass-fed enterprise, rather than economic or environmental [38]. Recently, social sustainability themes have also been covered in popular media, raising a new level of public awareness and concern. For example, the COVID-19 pandemic shed light on the issue of human health and equity as the pandemic disproportionately impacted meat packing plant workers, many of whom are members of marginalized and underserved racial minorities [12, 39]. Other scholarship has brought to light the value of cattle ranching for providing recreation and tourism opportunities, particularly in the U.S. West [21], for maintaining a way of life, promoting connections and "social fabric" for neighbors and communities [40], and for reducing the out-migration of residents in rural communities [17].

As the wide array of topics and themes covered in the literature demonstrates, sustainability in beef production systems depends not only on the elements of "how," "where," and "what" of production systems and practices used by producers, but also on the metrics that scientists use to evaluate it. A recent report released by the International Panel of Experts on Sustainable Food Systems (IPES-Food) highlights how the "hype" about the un/sustainability of meat is often a result of assessments that are narrowly focused on simplistic metrics such as CO2 emissions, ignoring the broader picture of sustainability, including how and where food is produced, the practices and production systems that provide ecosystem services and benefits, and the social and economic contributions of beef production systems to livelihoods of producers and those who benefit from beef end products [35]. At the same time, these often-overlooked dimensions of sustainability are emphasized as important by the industry itself, as evidenced by the National Cattlemen's Beef Association's commitment to "healthy animals, sustainable land and a safe product that helps ensure families—including our own—are nourished and strengthened by the beef they eat" [41].

Although the three-pillar model is ubiquitous in sustainability science, there is a lack of consensus on what each pillar means, how they interact, and how the concept can be operationalized [16]. Moreover, this model is often deployed as a normative concept which can impede the recognition of trade-offs among the three pillars (i.e., sustainability is not entirely made up of "win-wins") and can mask value- and power-laden decisions made under the guise of sustainability as a "common-sense" and widely agreed-upon ideal [42–44]. For example, for producers who have grazing operations, economic sustainability is directly connected to the condition of their range or pastureland as well as access to land considering rising land prices and the challenges related to retaining leases on public grazing land [31]. In this way, producers are sometimes faced with trade-offs between the economic sustainability of their operation and the environmental sustainability of the natural resources that support the operation [45]. These

trade-offs and linkages across multiple pillars of sustainability in the beef industry have not been well documented in the scientific literature, particularly from the perspective of producers.

In this paper, we address this by conducting a secondary analysis of U.S. beef producer perspectives on sustainability. We present the results of our analysis of responses to an open-ended question in a national survey (n = 911) of U.S. beef producers, highlighting how producers describe key components of and constraints to achieving the desirable outcomes (including public goods) that a more sustainable industry would support. Building on our results, we discuss how compatible (or not) these perspectives are with current scientific and policy debates. We propose future research directions that could expand shared understandings of what sustainability is and what is needed for enduring sustainability solutions in the U.S. beef industry.

3 Data & sampling

We collected data for this analysis via an open-ended question included in a national survey of beef producers developed and conducted in 2021 by the Trust in Food division of Farm Journal, a corporation that provides agriculture content, data, and business insights to the agricultural community (e.g., producers, processors/distributors, and retailers). Farm Journal regularly enters into formal agreements with academic teams and institutions for data collection and sharing. For this study, Farm Journal sought experts in the social and sustainability sciences and the first two authors were contracted to analyze data from the U.S. Beef Producers Perspectives on Sustainability 2021 survey. This survey was developed by Farm Journal to learn more about what the "American beef rancher thinks and feels about 'sustainable beef' and all things sustainability related" as part of an initiative to develop a collaborative program to empower beef producers to enact meaningful 'climate-smart' change. The survey included questions about beef producers' perceptions of sustainability, questions about producers' management plans and practices, and questions related to operation type and other demographic information. All authors were provided full access to the survey dataset; all research was conducted independently by the author team, which included one representative from Farm Journal. There was no direction or oversight by Farm Journal for the analysis, interpretation, or discussion for this study.

Producers were recruited via the Farm Journal email database of approximately 83,000 U.S. producers with any number of beef cattle who subscribed (or 'opted in') to Farm Journal platforms. Producers who had opted in to receive mail from Farm Journal were offered the option, within the normal course of operations, to additionally consent to receive research offers. Opt-outs were available at any time. No incentives were paid or offered. The sample included producers who had a wide range of different operation types, including cow-calf, stocker and fed beef cattle operations. The survey was sent iteratively via email seven times over the course of five weeks, excluding from subsequent mailings those individuals who had already completed the survey. Individuals who began but did not finish the survey were sent three additional reminders to complete the survey. A total of 1341 producers started the survey and 911 useable responses were collected. These methods and response rates are typical of market and industry research rather than traditional survey research [46], thus our goals here are to begin outlining the contours of producer perspectives on sustainable beef, rather than provide parameter estimates for the U.S. population of beef producers. This initial research from a large sample of U.S. beef producers helps advance our collective understanding and investigations of producer perspectives on sustainability currently lacking in the literature.

4 Methods

To understand how beef producers define sustainability in their own words, we analyzed verbatim responses (n = 911) to the open-ended question "In your own words, please tell us what does 'sustainable beef' mean to you?" Unlike closed-ended questions which limit responses to given options, the open-ended question format required respondents to answer the question based on their own knowledge and experience of sustainability. Thus, the open-ended question allowed us to gather valuable information from producers' perspectives that would have been constrained by other question formats, while embedding the question in a survey enabled a large sample size. Additionally, recruiting responses at the national scale was important because it allowed us to understand perspectives from the wide range of producers in the U.S. beef industry who differ across location, operation size, and operation type.

We developed a structured codebook and analyzed producer responses using a standardized iterative process [47] that we describe in the following six key steps. In Step 1, the sample of 911 responses were reviewed by a subset of the

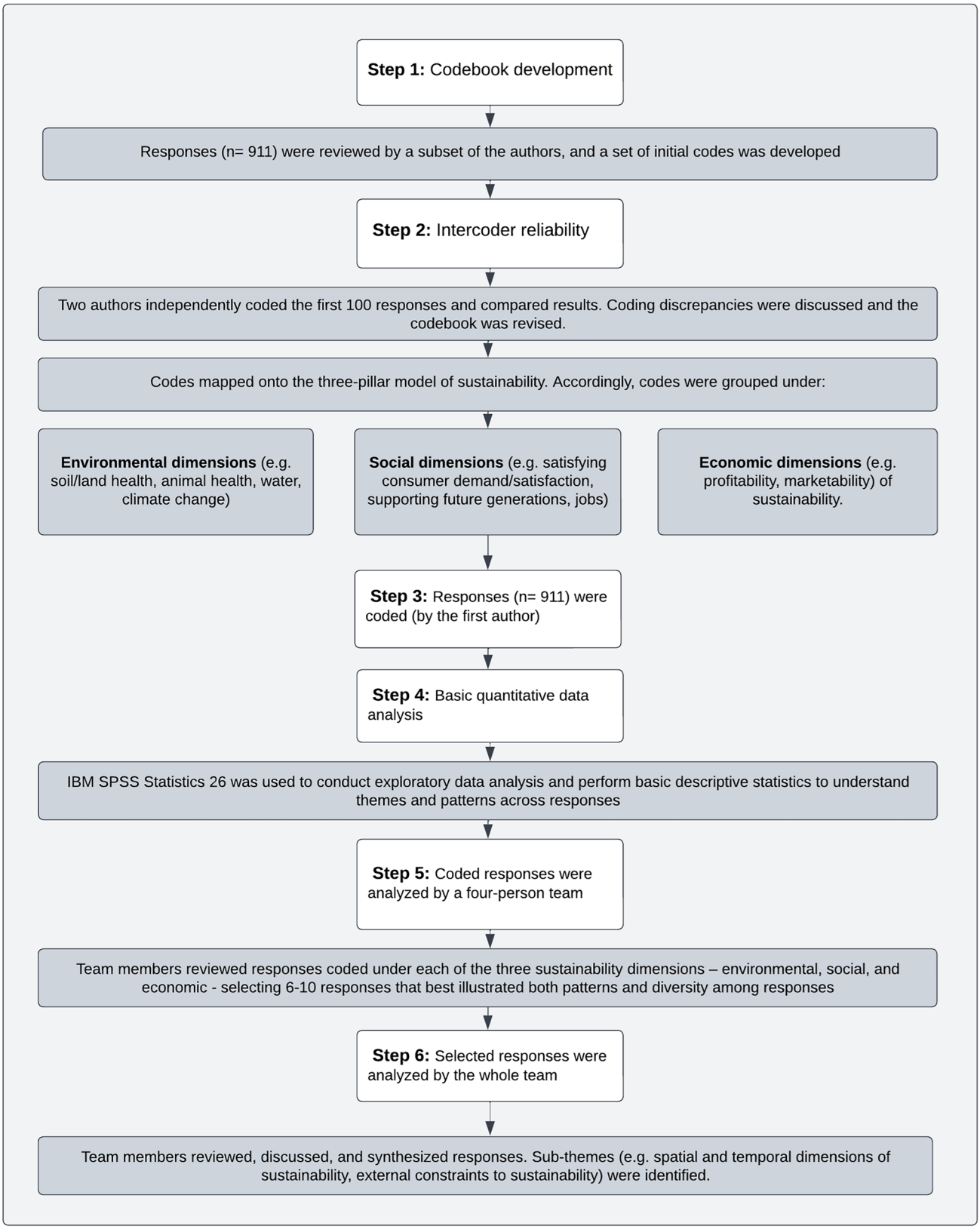

Fig. 1 A flowchart summary of the six-step process we used to develop a codebook and iteratively analyze producer responses (n = 911)

authors, and a set of initial codes was developed. In Step 2, to test the comprehensiveness and reliability of codes, two of the authors independently coded the first 100 responses and compared results. Coding discrepancies were discussed and the codebook was revised accordingly. This process was repeated until the two coders reached agreement on the final codebook. During this phase of analysis, we inductively found that codes mapped well onto the well-known three-pillar model of sustainability. Accordingly, codes were grouped under the environmental (e.g., soil/land health, animal health, water, climate change), social (e.g., satisfying consumer demand/satisfaction, supporting future generations, jobs), and economic (e.g., profitability, marketability) dimensions of sustainability. Responses that were relevant to two or more codes were double-coded, allowing us to identify co-occurrences of and linkages among codes. Thus, while we did not start by developing codes to fit within the three-pillar framework at the outset, the prominence of all three themes across responses made it a useful conceptual and organizational tool for coding and analysis. In Step 3, all responses (n = 911) were coded by the first author using the final codebook and following the aforementioned organizational scheme.

Following the initial round of coding, in Step 4 we used IBM SPSS Statistics 26 to filter responses according to code category (i.e., environmental, social, or economic) and topic/sub-code (e.g., soil/land health, consumer satisfaction, profitability). We conducted exploratory data analysis and performed basic descriptive statistics (used to create Figs. 2 and 3) to understand themes and patterns among responses. Next, in Step 5, the full dataset went through a second round of analysis with a four-person team where each member independently reviewed responses within each of the three dimensions—environmental, social, and economic—selecting 6–10 exemplar responses that best illustrated patterns and diversity within each dimension (see Tables 1, 2 and 3). In Step 6, the selected responses were reviewed, discussed, and synthesized by the team as a whole. During this process, additional themes were identified, including spatial and temporal dimensions of sustainability and 'external factors' described by producers as both enabling and constraining efforts to achieve sustainability in the beef industry. Figure 1 summarizes this process.

5 Results

5.1 Respondent characteristics

The majority of respondents were 55 years or older, with 31.8% (n = 291) of respondents between the ages of 55 and 64 and 31.1% (n = 284) of respondents between the ages of 65 and 74, which is in line with the national average age of 59 years (USDA NASS, 2017). In addition, the majority of respondents were from families with three or more generations in beef production (71%, n = 649 with three or more generations in beef production). Most respondents (90%, n = 823) indicated that they were a primary decision maker or a member of the decision-making group in their beef cattle operation.

Respondents represented a range of different types of beef cattle operations. Among respondents, 725 producers had cow-calf operations, 420 had stocker operations, and 226 had feeder operations (some respondents had more than one type of operation). Survey respondents had operations ranging in size from 50 to over 2500 cattle. Just over half of respondent producers (n = 475) reported an average herd size between 100 and 299 animals (at the largest size during the year), followed by producers with 50–99 animals (n = 230), producers with 300–499 animals (n = 182), and producers with 500–999 animals (n = 172). Fewer producers had large operations with between 1000 and 2499 animals (n = 67) and 2500+ animals (n = 70). Nearly half of all respondents (49.8%, n = 455) operated on 1000 acres or more (excluding public lands grazing). Some survey respondents grazed their cattle on public lands (13.5%, n = 123), however the majority of survey respondents indicated that they did not (86.3%, n = 789). All lower 48 U.S. states were represented among respondents; however many respondents were from states that dominate the U.S. beef industry (i.e., Texas, Oklahoma, Missouri, Nebraska, etc.). Importantly, while we were unable to conduct a nonresponse bias test on these data, and do not purport to infer generalizations to the entire population of U.S. beef producers, the responses we analyzed include the perspectives of beef producers whose operations range in size and location and represent the dominant sectors—cow-calf, stocker, and feeder operations—of U.S. beef industry.

5.2 Theme 1: The three pillars of sustainability & their interconnectedness

Producers consistently associated the term "sustainable beef" with environmental dimensions of sustainability. Key topics that were mentioned by producers included land health (i.e., terms such as land, grass, range, and soil), animal health, water resources, climate change (i.e., terms such as GHGs, methane, carbon), and general environmental sustainability or use of natural resources. Almost half (49%) of all responses mentioned one or more of these topics. More

specifically, 25% of the responses contained references to land health, 22% to general "environmental sustainability," 18% to animal health, 4% to water, and 2% to climate change. Producers associated "sustainable beef" with having a "low impact," a "small footprint" or "without a negative effect" on the environment or as "environmentally friendly." Producers also associated sustainability with the "wise use" of natural resources and with production that "conserves the natural resource base" more generally. A colloquialism used by numerous producers in defining "sustainable beef" was that it means to "leave land better than you found it." Many producers referenced "improving," "sustaining," or "taking care" of specific elements of the environment such as pastures, soil, and wildlife, while a smaller subset of producers mentioned specific modes of production such as regenerative agriculture, an alternative means of producing food that its advocates suggest may have lower or even positive environmental and/or social impacts [48, 49]. In contrast, producers who linked sustainable beef with animal health more often mentioned specific practices such as raising animals without hormones, antibiotics or "correctly administered meds," and/or achieving a "good quality of life" for animals. A small subset of producers discussed water and climate, including practices and/or an industry that protects or conserves water resources and is "carbon neutral," "carbon efficient," or has a low carbon footprint" (see Table A1 for additional data).

Over two-fifths of producers (43%) discussed the economic dimensions of sustainable beef. Producers frequently referenced profitability, marketability, cost, and efficiency. Producers indicated that sustainability in the industry was directly linked to being profitable, using phrases such as being able to produce beef "without going broke," for "top dollar," and while "making a living." Some producers linked profitability to fairness (e.g., "a fair profit to the producer and a fair price to the consumer") while others connected profitability with other conditions that needed to be met (e.g., "raised responsibly for a profit," and "profit which supports family"). Many producers focused on efficiency, productivity, and reducing the cost of production. Producers shared that sustainable beef is produced "without costly inputs," with "low inputs," and with a "low cost of production," or "continued positive margins for each additional input." Producers also associated sustainability with marketability, using a range of descriptors such as beef that is "locally marketed," beef that is produced in an "open market," being "able to market the product," or beef produced within a "fair and competitive market" (see Table A3 for additional data).

With regard to social dimensions, producers also suggested that sustainability in the beef industry has to do with two key themes related to supporting people: (1) satisfying consumers and (2) sustaining producers, their families, communities, and future generations. One or both social dimensions of sustainability were referenced in one quarter (25%) of producer responses (see Fig. 3). Producers used words such as "safe," "nutritious," "healthy," "high quality," and "affordable" to describe "sustainable beef" that meets the needs of consumers. Responses also associated sustainable beef with meeting consumer demand, using phrases such as "feeding America," "feed our ever-growing population," and "food supply for the world." Producers also emphasized family and generational aspects in their definitions of 'sustainable beef.' Producers expressed that sustainable beef "supports the family," "provides for me and my family," is "grown by family farms," and is "economically viable for my family." For many producers, sustainable beef supports "future generations" by providing "a living," and the opportunity to continue in the beef business and to maintain "lifestyle" that it provides (see Table A2 for additional data).

Some producers envisioned sustainable beef as the intersection of two or more of the social, economic, and environmental dimensions. Although the largest portion (48%) of responses associated sustainable beef with just one dimension of sustainability and 28% of responses mentioned two of the three dimensions, only 5% of responses mentioned all three. As such, Figs. 2 and 3 illustrate how, collectively, producers describe "sustainable beef" as emerging from a beef production system that has synergies across environmental, social, and economic elements. Table 1 includes selected responses from producers who describe the linkages between two or all three sustainability dimensions. For example, producers articulated how economic and environmental aspects of sustainability are inextricably connected—that, "the land, vegetation, air and water must be managed in such a way to sustain economically viable beef production." Another producer illustrated these linkages by describing sustainable beef as a combination of providing, "the highest quality beef…for human consumption" while simultaneously, "improving the land/environment for wildlife, water purification, grass species," resulting in an "overall better place to live." Many producers discussed the relationship between profit and maintaining a livelihood for generations to come, saying that sustainable beef, "…means considering our social commitment to our community and striving to profit so we can offer the next generation of our family the choice to produce beef on this ranch." Table 1 also includes selected responses from producers who referenced all three dimensions (5% of total responses), suggesting that sustainability is a "balance" among "economic, social, and environmental well-being."

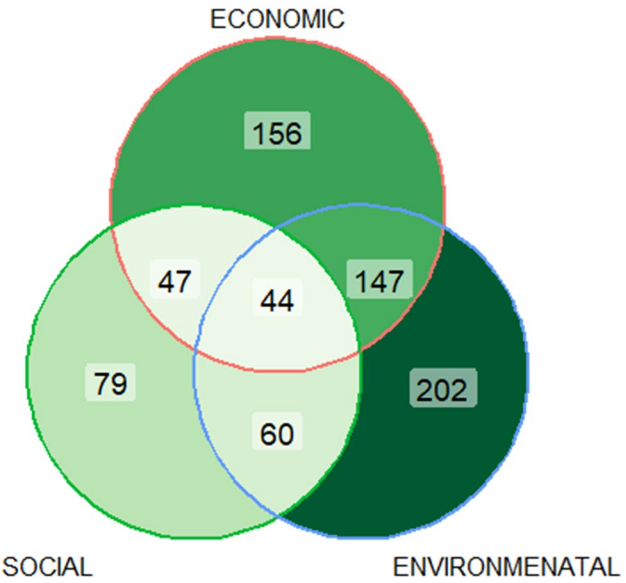

Fig. 2 Venn diagram showing the number of responses coded under one or more dimension of sustainability (i.e., environmental, social, and economic)

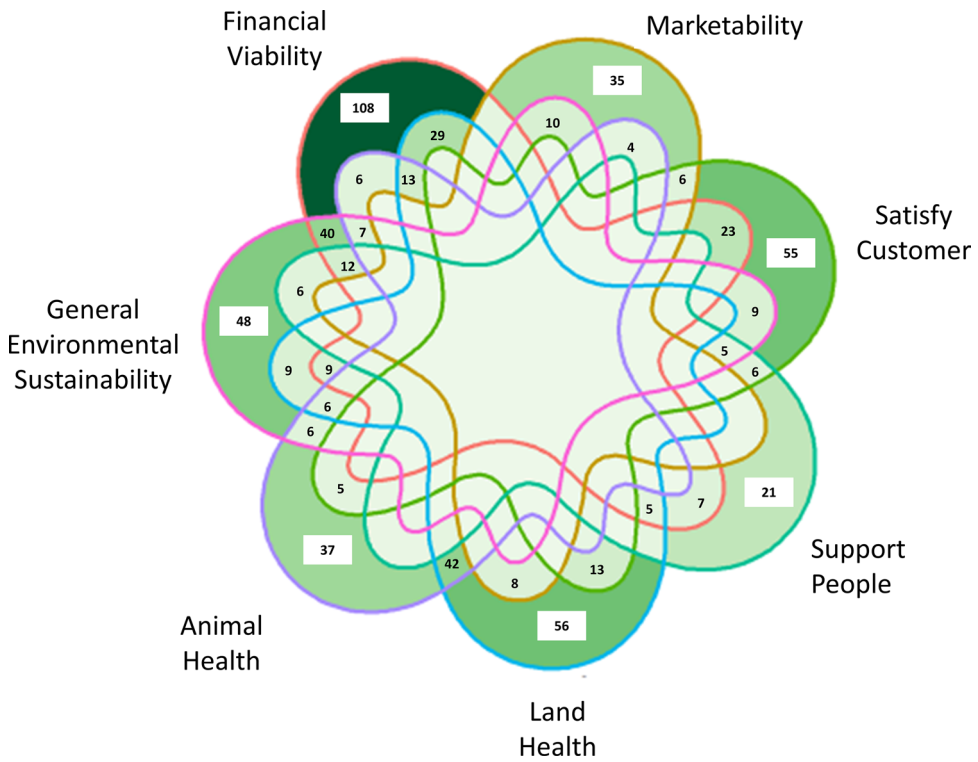

Fig. 3 This Venn diagram shows the number of responses coded under one or more subtheme of the environmental (general environmental sustainability, animal health, land health), social (support people, satisfy customer) and economic (financial viability, marketability) dimensions of sustainability. Each of the seven subthemes have a different color of curved *outer* boundary. Numbers inside the curved boundaries indicate the number or responses associated with each subtheme or combination of subthemes. For example, there were 108 responses coded solely under "financial viability," 40 responses coded with both "financial viability" and "general environmental sustainability," and 6 responses coded with both "financial viability" and "animal health." Figure A1 includes all areas where there were 0 responses coded

Table 1 Linkages between sustainability dimensions in producer responses

Sub-theme	Selected responses
Environmental ↔ Economic	The land, vegetation, air and water must be managed in such a way to sustain economically viable beef production
	Beef that can be produced economically without depleting the soil and water resources of the land
	Must be profitable and should leave land utilized better than it was before
	A product that was raised with a heightened consciousness of the needs for the environment while also being economically sound for those in the industry
	A beef operation that is both profitable and environmentally sound
Environment ↔ Social	Sustain the productivity of the land ability to sustain the family life style
	Raising cattle for meat production while balancing the health of the ecosystem, the animals, and our family in a manner that is renewable and plans for future generations
	Produce beef by taking care of the animals and being good stewards of the land giving the consumer a quality product and keeping a stable demand for beef
	To carry on from year to year as a producer with a positive influence on the environment and my family
	Raising the highest quality beef available for human consumption and at the same time improving the land/environment for wildlife, water purification, grass species, and overall better place to live
Social ↔ Economic	Staying in business to produce food for our growing population
	It also means the ranch and farm families receive equitable returns for the healthy food product they breed, calve, raise and market
	Raised by owners who depend on proceeds
	… it means considering our social commitment to our community and striving to profit so we can offer the next generation of our family the choice to produce beef on this ranch
	for an operation to continue into future generations with affordable beef for the consumer and the producer
	Sustainable beef is basically a baseline system to continue to produce the safest protein source to feed our ever growing population while also being fairly compensated by the end user to allow to continue doing business. I hope that we as a business unit can get back to square with our end user and customers to allow my children and future generations to continue this lifestyle of farming and feeding livestock to meet the protein needs of the human race
All three dimensions	A beef production system that balances economic, social and environmental well being
	3 things: (1) Economically viable cattle business; (2) optimal utilization of environmental resources, allowing for continual improvement; i.e., more pounds per acre grazed due to both healthier grazing lands and improved genetic performance of cattle; (3) socially/culturally acceptable practices such that strong demand for our beef exists
	Sustainable beef means beef that is produced by a cattleman, who pays attention to the environment, the community, and his or her bottom line. You need to be financially stable, environmentally careful and support your community. A healthy operation that passes to the next generation is sustainable
	We have to maintain a way of life…first financially (being profitable in whatever scheme or niche chosen), second environmentally-taking care of the land to stay in business, 3rd socially/ethically-getting along with neighbors, buyers, and end uses. I view this as a 3 leg stool, we can't keep doing what we are if one of these fail, but some legs might be stronger or longer than others […]
	For me, sustainable beef means animal welfare as a result of responsible stewardship of the land and water recourses in order to produce a safe food source at a viable rate. Ranchers are at the mercy of Mother Nature and must be able to sacrifice and adapt in order to stay in business. We must keep ranching profitable in order to keep next generations interested in continuing the operations
	(1) Profitable (2) My land/forages can support my operation wo outside food purchases (3) Practice good conservation (4) Take care of land and take care of the cattle and they take care of you

5.3 Theme 2: The spatial and temporal dimensions of sustainability

Producers not only described "what" defines "sustainable beef"—identifying elements of and synergies between environmental, social, and economic dimensions—but also that sustainability can involve both spatial and temporal considerations. While these themes were included in a smaller portion of responses than the three dimensions of sustainability (Theme 1), their reoccurrence across the data supports their inclusion as important aspects of sustainability for producers. Selected responses illustrating these themes are included in Tables 2 and 3.

Table 2 Spatial dimensions of sustainability

Sub-theme	Selected responses
Inputs	Producing beef in a way that improves the resources that are being used to raise them with a minimal amount of outside resources
	An operation that continually supports itself, financially, without outside input, while remaining economically viable
	Beef that is produced using a minimal amount of inputs with the smallest impact on the environment as possible (given your production system and geography)
	Being able to raise quality animals on a continuous basis with as little negative environmental impact as possible. Production of a product with as few inputs as possible
	Utilizing as many different forages available to produce healthy beef with minimal inputs while taking care of the land and available resources
	Economic stability, minimum inputs to achieve economic stability and caring for the land in a way that maintains productivity with minimum environmental impact
Locality, traceability	A closed loop natural system that promotes clean air and water using land that increases in wildlife diversity and fertility over time
	Operation is self sufficient
	Most of the inputs along the process have to regenerate themselves (renewable resource) or have to produce enough benefit to outweigh the cost. Ie the fossil fields used are offset by the increased plant production on well managed ground
	Cattle using feed and forage grown on our farm as nature intends it to be
	Being able to raise top quality animals for end consumers off the grain, grass and water from our land
	Cattle raised with only the bear minimum, by that I mean only approved inputs that can from the land and can be traced. Not using any type of pesticides or implants and limited antibiotics
	An operation that land, labor, and cattle numbers are in balance so little or no outside feed is needed. Raise all you can… Feed all you raise

The spatial aspect of sustainability was reflected in producer responses (10%) that described sustainability as having to do with minimizing "outside resources" or inputs, or conversely, production where producers use their "own" resources. Producers expressed that sustainable beef meant beef produced "without outside input," "without much in the way of external feed inputs," with a "minimal amount of inputs," or with "as few inputs as possible." It should be noted that specific "inputs" were not typically identified, but could include supplemental plant or grain-based feed, feed additives, mineral fertilizers, or antibiotics and other drugs for livestock. In addition, producers defined sustainable beef systems that were "self-sufficient," "closed-loop," and "self-contained." Producers also expressed that sustainable beef necessitates the use of "inputs along the process" that "regenerate themselves" or involves cattle produced "using feed and forage grown on our farm" or "off the grain, grass, and water from our land." One producer summed up this sentiment with the expression, "Raise all you can…feed all you raise." In this way, from producers' perspectives, sustainable beef should be semiclosed, or operate within the limits of a "local" resource base.

Across responses, 22.6% described the temporal dimensions of sustainability (i.e., the ability to continue producing, long lasting, long-term, continuation, future viability). Responses included references to the root word "sustain," or the temporal dimension of "sustain-ability," including descriptions of the long-lasting, ongoing, and generational attributes needed to achieve sustainability in their industry. For most producers, sustainable beef was not defined by *short term* gains and *quick* returns, but rather by an industry that is "able to move to the future," by operations that continue "year after year," "long term," or in a "continuous loop." Importantly, many producers emphasized the generational aspect of sustainability in the beef industry, expressing the significance of keeping "next generations interested" or allowing "my children and future generations to continue this lifestyle." In this way, numerous producers expressed the sentiment that sustainable beef goes beyond making a quick buck, but is rather about "longevity for resources, generations of people, and cattle." Some producers are explicit about the fact that a sustainable beef industry is one that requires, *and enables*, individuals to play a role in creating a viable future for generations to come. For one producer, sustainability signifies "the ability to be able to pass down my operation to the next generation through my stewardship." For another producer, sustainable beef is "profitable over generations by protecting family, animals, and the environment." Another producer expressed that, "for my operation, sustainability means being able to pass the farm, the land assets, the value of the health of the livestock on to the next generation and to leave it to them in better condition than I received it."

Table 3 Temporal dimensions of sustainability

Sub-theme	Selected responses
Social + economic + Temporal	Being able to keep raising beef year after year and being profitable
	Raising beef in such a way that the business can survive beyond the present generation
	Beef operation that will be able (viable) to operate for 5+ more generations and be profitable
	Continued improvement of beef production through the use of tools and technologies that enhance the quality, safety and productivity of our beef operations and resources that ensure the future of our business for generations
	Ability to up cycle protein for human consumption in an ongoing continuous loop
	Sustainable to us means operating our ranch with long term survival and improvement in mind
	An operation that endures the economic and political climate
Environmental + Temporal	Manage land and animal so that both improve in quality each year
	Beef that can continue to be raised on the same ground for years to come
	Land Management and livestock practices that you use that can be carried on over time without degradation of the land and water resources
	leave the land in better shape to future generation
	The ability to be able to pass down my operation to the next generation through my stewardship
All sustainability dimensions + Temporal	Producing beef in a manner that is financially and ecologically viable long term
	Sustainable beef means longevity for resources, generations of people, and cattle. The longevity of resources is more than sustainable, it is renewable! Longevity of people means they provide a living for multiple generations. And cattle are sustainable when they have longevity!
	Sustainability means many things. Financially sustainable, environmentally sustainable, ethically sustainable. I believe that for my operation, sustainability means being able to pass the farm, the land assets, the value of the health of the livestock on to the next generation and to leave it to them in better condition than I received it
	For me, sustainable beef means animal welfare as a result of responsible stewardship of the land and water recourses in order to produce a safe food source at a viable rate. Ranchers are at the mercy of Mother Nature and must be able to sacrifice and adapt in order to stay in business. We must keep ranching profitable in order to keep next generations interested in continuing the operations

5.4 Theme 3: External constraints to sustainability

The question "what does sustainable beef mean to you?" also prompted producers to discuss the external factors beyond the farm or ranch level that enable or constrain sustainability. This theme and its sub-themes were identified in Step 6 of analysis following initial coding (Fig. 1). Specifically, some producers referenced monopolization within the meat-packing industry, the distribution of power and money in the market or beef supply chain, and government regulations or policies as influencing their ability or the ability of the industry to be sustainable. In addition, some producers felt that sustainability in the industry was compromised by the monopolies that packers have over price-setting in the market. Sentiments expressed included that "packers make to[o] much money and control to[o] much of the market" and that sustainability would mean "having as much profit as the packer" or would entail "each level of producer (cow/calf, feeders, finishers, etc.) not being gouged by the packers and being able to continue their way of life at least a somewhat profitable manner." One producer suggested that sustainability means not being a "price-taker," or being pressured to accept or "take" low prices for their beef due to a lack of any other option. Some producers also described that sustainable beef requires a deconsolidation of the meat-packing industry and more local or regional processing facilities. One producer shared their vision of sustainability as "helping young families to invest in building and operating local processing plants to allow ranchers to move livestock through locally" so that they don't have to, "rely completely on the big, limited packing plants that are currently running the prices down to the ground in their monopoly." Another producer expressed that, as it is now, the beef industry has, "serious issues in providing enough regional processors to build resilience in the chain." (Table 4).

Producers also described unfairness and inequity in the distribution of power and profits in the beef supply chain. One producer said they are "real tired of all the blood sweat and tears to make enough money to barely get by" and that "these packers handle a carcass less than 24 hours and reap all the benefits of the farmers fruit they have worked for years

Table 4 External constraints to sustainability in the beef industry

Sub-theme	Selected responses
Meat-packing industry, market consolidation	I do believe the packers make to[o] much money and control to[o] much of the market
	trying to keep the 4 big packers from stealing cattle, so the producer can make a good product and stop sending in imported cattle
	This is relatively hard these day [SIC] mainly due to prices the packers are willing to pay for live cattle and the lack of local processing facilities in the area. We have the product but nowhere to process the products for consumer use. Our industry really needs to be investing in helping young families to invest in building and operating local processing plants to allow ranchers to move livestock through locally than having to rely completely on the big limited packing plants that are currently running the prices down to the ground in their monopoly
	[…] Being able to make a profit from the cattle without the packers controlling the industry
	Having a fair and competitive market, which we do not have right now with the packers. Being able to go back to negotiated trade rather that being told if you want to sell your cattle this is what you will do no negotiation. The current situation with the packers is not a sustainable practice and many feedyards will not last much longer, there are very few sets of cattle that you can even protect yourself by hedging anymore. I foresee here in the very near future the suicide rate for feedyard managers and owners skyrocketing not only because of the issues with the packers but because employees are so scarce it is such a depressing industry to be in
	Ability for cattle producers to be profitable & remain in business long term with packer manipulation of prices
	Being able to support our family in a comfortable way with just the income from our cattle ranch. I'm real tired of all the blood sweat and tears to make enough money to barley get by and these packers handle a carcass less than 24 hours and reap all the benefits of the farmers fruit they have worked for years to improve
	Each level of producer (cow/calf, feeders, finishers, etc.) not being gouged by the packers and being able to continue their way of life at least a somewhat profitable manner
	Getting a top quality product to the customer and having as much profit as the packer
Distribution of Power and Profit	Sustainable beef means being able to raise my cattle and make a LITTLE money. I have been doing it for 40 years and the picture is bleak. A small farmer like me is being shut out. The price gap between the producers and the packers must be addressed if I am going to survive. I have 2 children, who would love to carry on what is going on here, but with the price of everything, that will be hard
	Cow/calf folks and feedlots are being killed by the lack of packer capacity which in turn doesn't allow us to make any money. Unless something is done to eliminate the monopoly the big 3 packers have been allowed to put together the other parts of the industry will gradually dry up and fail. You cannot sustain a system in which packers are netting 1000 dollars per animal and we are losing money on every calf we sell. We as cow/calf folks have an obligation to be good stewards of the land and treat our animals well, but if we continue to lose money with no plan to address the packer concentration issue, the beef industry will fail
	Sustainable beef means being able to produce a superior product born raised and processed in the USA. Having a fair market for cow calf producers to make a profit while taking care of the land leaving it in better condition for the next generation. We need a fair market system to be able to pass on to future generation
	Currently the beef system has some serious issues in providing enough regional processors to build resilience in the chain. What has not been addressed enough is the value of feedyards and processors operating year-round. There is a significant amount of overhead in a processing plant and it needs to operate year-round. Feedyards make it happen where grass-finished beef would struggle to keep the processors full. This efficiency keeps beef prices lower for the consumer and more competitive with pork and poultry in the store
	When the cow calf producers get a fair market value for the product they produce, with the cost of feed, fuel and equipment keep rising the producers are going to stop working for little or no profit, then we will be left importing beef
	Each sector of the industry needs to be able to show a profit. We cannot survive without each other. Vertical integration will be the end of the beef industry as we know it and we must resist it at every opportunity

Table 4 (continued)

Sub-theme	Selected responses
	Making enough money to make it worth while, with every thing so costly fencing, feed, labor, trucks, land, it's getting to be not worth while! Packers making money, hogs selling at almost same as cattle, think I should just rent land to row crop farmers and just go fishing or ride my horses for pleasure. I've spent a lot of money for balers, cutters rakes, barns, etc., after all these years I feel like it's getting to be un sustainable !! I've always used the best bulls I could afford to have the best cattle, even though I get some premiums it doesn't pay enough for my time and investment
	An open market in which the producer isn't a price taker
Government involvement/regulation, subsidization of industry	economically viable for all participating partners without subsidization from government and or outside entities while maintaining and/or increasing resources including soil, water, and capital
	Able to raise beef for a profit without government interference
	On the cost side of the equation, they need to be free from being overburdened with illogical regulations that make it impossible to continue producing livestock year over year
	Means a United States beef herd that is sustainable. Including producers capable of sustaining their business without government intrusion and financially viable operations. Most ranchers are already land stewards we don't need that tamped down our necks. Let us be profitable and the land will be take care of better than ever [SIC]
	Governments need to learn about proper grazing management and make policy that encourages it

to improve." Some producers feel that the continued inequities may eventually run them out of business, constraining their ability to "survive" and for their business and livelihood to "pass on to future generation." One producer shared, "I have 2 children, who would love to carry on what is going on here, but with the price of everything, that will be hard."

Other producers expressed negative sentiments about government regulations, subsidies, and policy that they argued make it hard for the industry to achieve sustainable outcomes. Numerous producers expressed that sustainable beef means an industry where producers can have viable operations "without subsidization from government," can "profit without government interference," and are not "overburdened with illogical regulations." Other sentiments were framed more positively, suggesting that sustainability could be enabled by government learning more about aspects of the beef industry such as proper grazing management and "mak(ing) policy that encourages it."

6 Discussion

From the results presented above, four key themes emerged that help define sustainability in the beef industry from the perspectives of beef producers themselves. Collectively, producers described sustainability as: (1) multidimensional and interconnected; (2) semiclosed; (3) long-lasting; and (4) producer-centered. In this section, we describe these themes and attempt to put these perspectives in conversation with current scientific and policy discussions around sustainability in the livestock sector. By doing so, we hope to illuminate aspects of producer perspectives that are synergistic with broader understandings of sustainability and highlight how these shared perspectives may be the basis for action towards achieving sustainable beef that garners the support of producers within the industry.

6.1 Sustainability is multidimensional and interconnected

We found that U.S. beef producers understand sustainability in their industry as including environmental, social, and economic aspects. Collectively, producers described multiple dimensions of sustainability (Figs. 2 and 3) and the synergies of benefits across these three pillars along the supply chain from producer to consumer. As one example, for some producers, economic sustainability cannot be achieved without environmental sustainability addressed first: "The land, vegetation, air and water must be managed in such a way to sustain economically viable beef production." Another producer made clear linkages between the environmental and social dimensions, saying, "Sustain the productivity of the land […] to sustain the family life style." While producers as a whole identified linkages between all three dimensions, it was rare for all three dimensions to be on any one producer's mind. In other words, while none of the three pillars of

sustainability was ubiquitously omitted or opposed among producers collectively, the more holistic view of sustainability that includes all three pillars was largely not reflected in individual producers' responses. Although potentially an artifact of questionnaire design that might have encourage shorter, single-dimensional answers (i.e., one open-ended question), this finding may reflect an opportunity for producers to broaden their perspectives on sustainability. Encouragingly, because all aspects of sustainability were reflected across producer responses, it follows that peer-to-peer dialogue may be an effective means to build awareness of the multidimensionality of sustainability. This interaction could encourage a way of thinking about sustainability that is more holistic, or reflecting a systems perspective that few individual producers expressed. Peer-to-peer dialogue and social networks are well-established in the literature as a way of promoting, learning, and sharing information and ideas among agricultural producers, and livestock producers/managers specifically [50–52]. At the same time, researchers have also recognized systems thinking as a useful tool for improving capacity to deal with uncertainty and complexity in agriculture [53–56]. In the context of livestock production, research has shown that systems thinking could help producers contextualize problems and formulate management responses toward positive social and ecological outcomes [54, 57]. This approach is also a defining characteristic of regenerative ranching [24] often exhibited by producers who use Holistic Management, a framework promoted to help producers improve their decision making and outcomes for the environment and producer livelihoods [58, 59]. Thus, our results suggest peer-to-peer networking about sustainability may be an avenue to encourage a systems thinking approach for collectively defining sustainability, as well as developing ideas for practices, processes, and pathways to support all dimensions of sustainability in the beef industry.

In contrast to the multiple dimensions and interactions between them that producers collectively described (Theme 1, Table 1), sustainability in the beef industry is often evaluated in the scientific literature using a narrow set of metrics. A recent synthesis of ranch-level sustainability indicators by Ahlering et al. (2021), showed that across sustainability assessments, the focus tended to be on ecological indicators, highlighting the need for the further incorporation of, and agreement on, socioeconomic indicators of sustainability [60]. In another systematic review of literature on sustainability at farm-level in beef and lamb meat production globally, Segerkvist et al. (2021) found that only 40% of studies on beef cattle (and 27% of those dealing with sheep) had studied or evaluated all three sustainability dimensions. Moreover, studies predominately used a narrow set of indicators, such as GHG emissions and nutrient balance in the soil, when evaluating environmental sustainability in beef cattle production [11]. In contrast, producer's indicators for sustainability were described in more holistic terms, as the functioning of a complex social-ecological system. Accordingly, there is a need for sustainability assessments that move beyond common indicators (e.g., GHG emissions, soil health metrics, and production numbers) to also include indicators that are important from producer perspectives, particularly regarding the social dimensions of sustainability (e.g., the ability of the industry to support livelihoods, and market access/fairness, etc.).

The failure of current sustainability assessments of the beef industry to incorporate all three pillars and the linkages among them has led to misleading messages about the beef industry in popular media, agency reports and academic scholarship. As a recent IPES-Food report highlights, reductionist metrics for evaluating the sustainability of livestock production can lead to claims that all systems of production are extractive or unsustainable while "ignoring the diversity of production systems and their impacts (positive and negative) on other aspects of sustainability" [35, pg. 6]. For example, evaluating sustainability solely on GHG emissions does not account for the multiple roles that animals can play in communities (e.g., providing food, wool, cultural values) or for the ways livestock production makes use of marginal land in a way that supports livelihoods and regional food security. Consistent with the call in the IPES-Food report, our findings suggest that sustainability in the U.S. beef industry is understood by producers as much more complex than the indicators often used to measure it. Rather, sustainability was defined by producers as a much broader and more diverse concept that includes combinations of—and synergies between—all three dimensions, pointing to the need for assessments that more accurately reflect this. Moreover, context is often lost in assessments. For example, feedlot systems, pastoralist systems, and multi-paddock grazing systems are barely comparable yet regularly conflated. Thus, sustainability assessments would also benefit from metrics that reflect *how* and *where* beef is produced. We posit that more contextually-relevant research may help inform current debates that generalize blame and creates divisiveness. It is our hope that future research will promote dialogue based on shared understandings of how sustainability might be envisioned in specific places and systems, and by people within those systems.

6.2 Sustainability is semiclosed

A second theme that emerged from producer responses in this study was that sustainability in beef production systems necessitates minimizing inputs or "outside resources," or conversely, maximizing reliance on on-farm or on-ranch

resources. This alludes to a preference for closure in beef systems, specifically in terms of on-farm/ranch production, which was apparent in producer word choices including "self-sufficient," "closed-loop," and "regenerative" to describe perceptions of sustainable beef (see Table 2 for examples). While we only coded for the sub-theme describing "minimizing inputs" which accounted for roughly 10% of responses, during subsequent analysis, we discovered this broader, related theme that was reflected across a larger portion of producer responses. These descriptions are consistent with discussions in literature describing sustainable systems as "closed" (e.g., [61]). Although no agronomic system is truly closed as its purpose is to produce an output (e.g., beef) that is harvested and consumed outside the system, references equating sustainability to closure in beef production indicate a preference for operations that are as close to self-sustaining as possible, relying very little on off-farm/ranch inputs such as energy or nutrients. This aligns with Pearson's (2007) definition of a "semiclosed" system; using "regenerative" systems as a synonym, these are systems designed to minimize external inputs or external impacts of agronomy outside the farm. The idea of a closed or semiclosed farm/ranch operation, although not novel, is not the norm in U.S. and global conventional agriculture. Advancements in technology, and pressures of market-based competition including declining margins and profitability), have shifted beef production (and most global food products) toward a reliance on off-farm inputs such as fertilizer, fossil fuels, pesticides, fewer farm workers, and longer and more complex chains of production which has immense implications for sustainability [61, 62].

Producers also associated sustainability with minimizing inputs (see Table 2 for examples), which is a defining characteristic of regenerative agriculture [48, 49]. In a recent review of 229 journal articles that attempt to define regenerative agriculture, no or low external inputs and/or the use of on-farm inputs was one of the most commonly cited features of a regenerative system (26% of publications) [48]. In a study on the processes of transition to "climate-smart" regenerative agriculture, Gosnell et al. (2019) define regenerative farming as a system where farmers "reduce or eliminate the use of chemical inputs such as synthetic fertilizer, herbicides, and pesticides… and those with livestock typically use strategic (or holistic) planned grazing to increase soil biodiversity, soil moisture retention, soil fertility, and soil carbon, moving livestock frequently between habitats and across elevational gradients to follow optimal forage conditions as they shift during the growing season" [63]. Thus, there is evidence to suggest that there is recognition among both beef producers that a shift to more sustainable, or regenerative, beef production systems requires the adoption of management practices that minimize inputs or "leakiness" in the system [61].

Based on our findings, we see an opportunity for systematic research to directly investigate the relationship between how beef producers define and perceive sustainability and their willingness and ability to act or change behavior. For example, how and why do certain producers adopt regenerative agricultural practices or take other actions toward what they perceive to be more sustainable systems of beef production? What factors will catalyze a shift from conventional, open systems of beef production toward more closed, sustainable systems? Further, what do producers need to make these transitions? What barriers stand in their way? We suggest that as a starting place, researchers can build on recent work by Gosnell et al. (2019) and others exploring the "zones of friction and traction" in three different "spheres of transformation" for beef producers: the practical, political, and personal [63–65]. Gosnell et al.'s (2019) work found that friction and traction in the context of practical, political and personal decisions were predictors of producers' ability to undertake transitions. Although Gosnell et al. (2019)'s sample was made up self-identified "regenerative farmers" and/or "Holistic Management practitioners," we suggest this conceptual approach may be useful for understanding constraints and opportunities for sustainability transitions among a broader cross-section of U.S. beef producers (i.e., conventional cow-calf operators, feeder operations, and self-identified regenerative farmers).

In addition to asking questions about sustainability transitions in beef production at the individual or farm level, it is imperative to also ask questions about (1) structural or policy level influences that encourage the use of fewer inputs, (e.g., removing subsidies, "true cost" accounting, financial assistance), and (2) the trade-offs that exist in such a transition. For example, although regenerative systems require fewer chemical, fuel, and fertilizer inputs, these systems generally require higher on-farm labor than more open, conventional systems (e.g. [66]; a survey of 1144 farms in the UK). Addressing these research questions will provide critical information to support policy that effectively incentivizes transitions toward sustainability in beef production, specifically through better understanding links between perceptions of sustainability in the beef industry and actions toward achieving it.

6.3 Sustainability is long-lasting and enduring

A third theme that emerged from producer responses was that sustainability in the beef industry is characterized by ongoing or long-lasting operations that are able to "move to the future," reflecting producers ability to "sustain" resources, land, lifestyles, and livelihoods related to raising livestock from generation to generation (Table 3). While just under a

quarter of responses (22.6%), emphasized this temporal aspect of sustainability, long-range considerations of what sustainability means across all three dimensions is rarely reflected in scholarship or popular discourse on sustainability pathways or solutions in the beef industry. Rather, sustainability solutions promoted by agribusinesses, agricultural processors, global agri-development partnerships (e.g., the Gates Foundation, see [67]), and some livestock producer associations [35, 68] often center around rapid technological advances without consideration for their long-term social, ecological, and economic implications or trade-offs. As an example, the IPES-Food Report 2022 describes new "precision livestock" packages and new breeding approaches that have been promoted for their potential to increase productivity in the short-term. However, as the report describes, these potential "solutions" may also create "a treadmill of environmental and epidemiological risks" that could "spark problems further down the line (often with a time lag before they are visible)" [35]. Thus, technological advances that are often based on reinforcing the intensity and uniformity of industrial production systems, may deliver initial gains in productivity, but at the expense of long-lasting sustainability Similarly, recent claims about the benefits of producing and consuming alternative proteins, i.e., lab-grown meat to decrease beef consumption—and thus reduce inherent environmental impacts, increasing general environmental sustainability (e.g., [67, 69, 70])—ignore hidden costs or externalities of perpetuating a reliance on mass-produced, monocultured ingredients and energy-intensive processing [71, 72]. In sum, technological innovation pathways do not always equate to sustainability outcomes, especially if measured against a more holistic definition that includes the social/temporal dimensions producers view as essential to sustaining the industry.

Based on our results, we suggest that transformative pathways to sustainability in the beef industry will address the long-term needs expressed by producers. Future research directions might be to explore questions such as: How do dominant "solutions" (e.g., technology treadmill) promote or contradict producers' definitions of a sustainable beef production system that is ongoing, long-lasting, and generational? And; how can future research incorporate metrics for this temporal dimension of sustainability (e.g., through more longitudinal studies that capture the effects of practice adoption or sustainability 'solutions' over time)? Exploring these research ideas may expand our understanding of what 'solutions' are enduring and will help support sustainability in beef production systems long-term.

6.4 Sustainability in the beef industry is producer-centered

The consolidation of power and profit in the beef supply chain has resulted in numerous negative social, economic, and environmental impacts [73–75] that are well-documented in the literature and were also reflected in producer perspectives on sustainability in the beef industry. Over the last forty years, the beef supply chain in the U.S. has become concentrated in the hands of a shrinking number of multinational corporations [33–35]. Between 1977 and present, the largest four beef packing firms (JBS, Tyson, Cargill, and National Beef) increased their market share from around one quarter to around three quarters of the current market [76]. As a result, the price producers receive for their animals continues to fall while beef packers make record margins and the consumer price of beef continues to rise [77].

In our study, the economic impacts of consolidation were highlighted by producers. While this was not a dominant theme in our data, it emerged within our "external constraints" subtheme, and given its prominence in current policy debates, our data offers a window into producer perspectives on this important topic. Among responses, there were recurring sentiments that sustainability in the industry would require decentralization of industry ownership, power, and profits to individual farm/ranch workers and the rural communities in which beef production takes place. Some producers described how industry consolidation has come at personal expense and is antithetical to sustainability in the beef industry. Other producers expressed that sustainability involves their ability to, "make a profit without the packers controlling the industry" or, "having a fair and competitive market, which we do not have right now with the packers." One producer said:

> "This [sustainability] is relatively hard these days mainly due to prices the packers are willing to pay for live cattle and the lack of local processing facilities in the area. We have the product but no where to process the products for consumer use."

They went on to share their vision for the future of the industry, saying:

> "Our industry really needs to be investing in helping young families to invest in building and operating local processing plants to allow ranchers to move livestock through locally than having to rely completely on the big, limited packing plants that are currently running the prices down to the ground in their monopoly."

The disparities in power and profit that this producer described were amplified by disruptions in meat supply chains during the COVID-19 pandemic. During April and May of 2020, live cattle prices plummeted 18%, and meat processing and packing plants shut down across the U.S. due to COVID-19 outbreaks among workers [78]. At the same time, beef prices at U.S. grocery stores nearly doubled [79], and meat processors and packers, not producers, saw their profit margins reach historic highs. A USDA report looked at "price spread" in the beef industry which measures the difference between what processors pay for live cattle and what they charge wholesalers and retailers for beef products (i.e., a measure of the meatpackers' profits). The study found that while the average price spread between 2016 and 2018 was $21 per hundred pounds, by the second week of May 2020, price spread had spiked to $279 per hundred pounds, confirming a dominant market power held by processors. In 2020, two of the largest global meat companies' profits increased substantially: Tyson's revenue went up 2% to $43.2 billion, and Cargill's revenue increased 17% to $3 billion [80].

Recently, there have been several pieces of legislation that take steps to address consolidation in the meat industry and redistribute power to producers. For example, Senator Cory Booker's (D-NJ) "Food and Agribusiness Merger Moratorium and Antitrust Review Act" and Senator Mike Lee's (R-UT) bill "Opportunities for Fairness in Farming Act" are attempts to halt corporate concentration in the agricultural sector. Further, the Biden administration recently pledged to invest approximately $1 billion to expand independent meat processing capacity in the United States [81]. Yet, the industry has yet to see widespread shifts. The following two producer responses in this study underscore to the ongoing need to address this issue:

> Having a fair market for cow calf producers to make a profit while taking care of the land leaving it in better condition for the next generation. We need a fair market system to be able to pass on to future generation.

When the cow calf producers get a fair market value for the product they produce, with the cost of feed, fuel and equipment keep rising the producers are going to stop working for little or no profit, then we will be left importing beef.

Given the extent of consolidation in the beef industry in recent decades, it is no surprise that fairness and redistribution of market share and profit emerged as needed in order to achieve sustainability in the industry for some producers, albeit a relatively small fraction of our sample. Although there have been some efforts to define and measure aspects of "good," "clean," or "fair" food production broadly-speaking [82], research on these topics within the context of the beef industry is largely lacking. We suggest that understanding sustainability in the U.S. beef industry necessitates research that examines power imbalances and the political economy of beef supply chains from producer to consumer. We suggest that research emerging from the fields of political ecology, food sovereignty, and just transitions may be well positioned to further interrogate and understand these dynamics and pathways forward that center producer well-being. Using these research approaches could further expand our understanding of fairness, equity, and justice in the beef industry—elements perceived by many producers as essential for the further development of sustainability in the U.S. beef industry.

7 Conclusion

Beef production systems, globally and in the U.S., have been in the spotlight of discussion and debate on food systems sustainability. The so-called "future of food" is now rarely discussed without reference to what sustainability might look like in the livestock sector. As sustainability challenges continue to mount—from climate change and biodiversity loss to food security, livelihood risks, and animal welfare concerns—the attention on the livestock, and beef production in particular, is warranted. In this paper, we fill an important gap in our understanding of sustainability and beef production from producer perspectives. We found that, for U.S. beef producers, sustainability is described as: (1) multidimensional and interconnected; (2) semi-closed; (3) long-lasting and; (4) producer-centered. We describe how these themes emerged from producer responses to our open-ended survey question, and discuss the values and needs producers expressed as central toward achieving the environmental, social, and economic sustainability dimensions. By providing insight on sustainability from producers' perspectives, our findings highlight both the possibilities and constraints for transitions toward a more sustainable U.S. beef industry.

Author contributions The study was conceptualized and designed by Ada P. Smith, Alexander L. Metcalf, Elizabeth Covelli Metcalf, Laurie Yung, and Brenna Swinger. Material preparation, data collection and analysis were performed by Ada P. Smith, Alexander L. Metcalf, Elizabeth Covelli Metcalf, Laurie Yung, Brenna Swinger, Tina M. Cummins, and Drew Slattery. The first draft of the manuscript was written by Ada P. Smith and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability All data that support the findings of this study are included within the article (and supplementary files).

Code availability Not applicable.

Declarations

Ethics approval and consent to participate This study used anonymous, secondary data from a non-university partner (Farm Journal). The study did not include any interaction or intervention with human subjects or include any access to identifiable private information and thus did not require IRB review.

Competing interests The authors declare that although the data analyzed here was accessed through a contractual relationship with Farm Journal, a for-profit corporation, and co-author D.S. was a Farm Journal employee for a portion of our research timeline, we enjoyed full intellectual autonomy throughout the analysis, interpretation, and writing process and have no financial or competing interests.

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